

# Project Notes:

## Project Title: Intelligent Impact-Sensing Liner for Youth Female Athlete Safety

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**Note Well: There** are NO SHORT-cuts to reading journal articles and taking notes from them. Comprehension is paramount. You will most likely need to read it several times, so set aside enough time in your schedule.

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## Knowledge Gaps:

This list provides a brief overview of the major knowledge gaps for this project, how they were resolved and where to find the information.

Knowledge Gaps	Resolved By	Information is Located	Date Resolved
What path do I want to take with my project?	Identified the need for a youth-focused intelligent helmet liner that combines impact mitigation with real-time sensing rather than diagnosis-only systems.	Articles #1, #5, #8, #14	Aug 18, 2025
What are problems with how concussions are identified?	Found that current methods rely heavily on self-reporting, delayed symptom	Articles #1, #8, #9, #10	Aug 25, 2025

	recognition, and poor correlation between symptoms and biomechanical data, especially in youth athletes.		
How do you make sensors?	Reviewed how MEMS accelerometers and gyroscopes are manufactured, packaged, and integrated into wearable concussion-monitoring systems.	Articles #9, #15; Patent #1	Sep 2, 2025
What measurable impact forces/accelerations correlate to concussions? Difference in adults vs. youth?	Determined that both linear and rotational acceleration contribute to concussion risk, and that youth athletes sustain concussions at lower thresholds than adults.	Articles #8, #10, #11, #12	Sep 10, 2025
What liner materials best absorb and dissipate impact energy without compromising comfort/weight?	Identified advanced foams, multilayer liners, honeycomb, and bio-inspired structures that improve energy absorption while remaining lightweight and comfortable.	Article #6	Sep 18, 2025
Which sensors provide accurate, real-time measurements inside a helmet?	Compared helmet-based sensors and instrumented mouthguards, identifying accuracy tradeoffs and real-time measurement capabilities.	Articles #7, #9, #10	Sep 26, 2025

<p>What is optimal placement within helmet?</p>	<p>Evaluated sensor placement strategies to minimize relative motion between the sensor and skull for improved measurement accuracy.</p>	<p>Articles #7, #10, #15, #19</p>	<p>Oct 3, 2025</p>
<p>How can I calibrate it?</p>	<p>Identified calibration techniques using controlled laboratory drop tests, known acceleration profiles, and validation against established systems.</p>	<p>Articles #9, #10, #15</p>	<p>Oct 10, 2025</p>
<p>How to translate raw sensor data into meaningful concussion risk alerts within a few moments?</p>	<p>Reviewed probability-based risk models and AI-based approaches that convert raw acceleration data into real-time concussion risk metrics.</p>	<p>Articles #7, #11, #12, #13</p>	<p>Oct 20, 2025</p>
<p>How to embed sensors/electronics without reducing protection or comfort?</p>	<p>Studied liner architectures and smart helmet designs that integrate electronics without compromising impact attenuation, fit, or comfort.</p>	<p>Articles #6, #17; Patent #2</p>	<p>Oct 30, 2025</p>
<p>How to prove that it has a protective performance and monitoring accuracy?</p>	<p>Used prospective youth studies, exposure metrics, and validation approaches to evaluate both sensing accuracy and protective performance.</p>	<p>Articles #8, #9, #20</p>	<p>Nov 7, 2025</p>

<p>What rules and certifications govern smart helmets?</p>	<p>Reviewed existing helmet evaluation systems and identified gaps in standards governing smart helmet sensors and data interpretation.</p>	<p>Articles #10, #17</p>	<p>Nov 14, 2025</p>
<p>What materials can be used to make sensors?</p>	<p>Identified MEMS-based silicon sensors, conductive materials, and protective encapsulation commonly used in wearable electronics.</p>	<p>Articles #9, #15; Patent #1</p>	<p>Nov 18, 2025</p>
<p>What products don't dissolve in water?</p>	<p>Determined that sealed housings, polymer encapsulation, and moisture-resistant materials are required to protect electronics from sweat and environmental exposure.</p>	<p>Patent #1, Patent #2</p>	<p>Nov 21, 2025</p>
<p>What can I learn from other products on the market?</p>	<p>Analyzed patented concussion-monitoring products to understand existing solutions, design limitations, and opportunities for improvement.</p>	<p>Patent #1, Patent #2</p>	<p>Nov 25, 2025</p>
<p>What do I need to order / what do I already own?</p>	<p>Identified required components such as sensors, microcontrollers, housings, and liner materials based on reviewed systems.</p>	<p>Articles #9, #15; Patent #1</p>	<p>Dec 1, 2025</p>

What structures work best to hold electronic firmware in place?	Found that multilayer liners, internal channels, and rigid-flex structures best stabilize electronics during impacts.	Articles #6, #17; Patent #2	Dec 4, 2025
How to program electronics?	Reviewed firmware and data-processing pipelines used in head-impact telemetry and AI-based concussion monitoring systems.	Articles #7, #9; Patent #1	Dec 6, 2025
What heights can mimic hits?	Identified laboratory drop-test heights commonly used to reproduce sports-related head impact accelerations.	Articles #10, #15, #19	Dec 8, 2025
What to do for field testing?	Used methodologies from prospective youth field studies to plan real-world validation and data collection.	Articles #8, #20	Dec 9, 2025



## Literature Search Parameters:

These searches were performed between (Start Date of reading) and XX/XX/2025.

List of keywords and databases used during this project.

Database/search engine	Keywords	Summary of search
Gordon library	Concussion athletes	I found the different forces that act on the head to create the concussion and how different types of people get affected by them
Gordon library	Concussion force measurement	I was able to find measurable forces for my sensors to look for and data to base my parameters on
Google Scholar	Concussion force measurement	Found the 7 and 8 articles
Google	Acceleration thresholds concussive	Found my ninth and tenth articles
Google Patents	Concussion monitor	Found my patents
Gordon Library	Second Impact Concussion	Based on previous article read, found quite a few more articles based on this topic
Gordon Library	Helmet Fit Concussion	Found two articles on this subject

Tags:

Tag Name	
#concussion	#brainstorming
#athletes	#forces
#helmet structure	#liner
#positions	#exact
#probability	#model
#second impact	#fit



## Article #0 Notes: Example

Article notes should be on separate sheets

**KEEP THIS BLANK AND USE AS A TEMPLATE**

<b>Source Title</b>	
<b>Source citation (APA Format)</b>	
<b>Original URL</b>	
<b>Source type</b>	
<b>Keywords</b>	
<b>#Tags</b>	
<b>Summary of key points + notes (include methodology)</b>	
<b>Research Question/Problem/ Need</b>	
<b>Important Figures</b>	
<b>VOCAB: (w/definition)</b>	
<b>Cited references to follow up on</b>	
<b>Follow up Questions</b>	

# Article #1 Notes: Current Issues in the Identification, Assessment, and Management of Concussions in Sports-Related Injuries

Article notes should be on separate sheets

<b>Source Title</b>	Current Issues in the Identification, Assessment, and Management of Concussions in Sports-Related Injuries
<b>Source citation (APA Format)</b>	McKeever, C., & Schatz, P. (2003). Current issues in the identification, assessment, and management of concussions in sports-related injuries. <i>Applied Neuropsychology</i> , 10(1), 4–11. <a href="https://doi.org/10.1207/S15324826AN1001_2_1_2">https://doi.org/10.1207/S15324826AN1001_2_1_2</a>
<b>Original URL</b>	<a href="#">Current Issues in the Identification, Assessment, and Management of Concussions in Sports-Related Injuries</a>
<b>Source type</b>	Journal
<b>Keywords</b>	concussion, sports-related injury, mild traumatic brain injury, neuropsychological assessment, athletes, computerized assessment, baseline assessment, sideline assessment
<b>#Tags</b>	#concussion #athletes
<b>Summary of key points + notes (include methodology)</b>	McKeever and Schatz review the growing concerns around identifying, assessing, and managing sports-related concussions, noting rising awareness but also major research gaps in youth and female athletes. They emphasize the importance of baseline and post-concussion neuropsychological testing for guiding safe return-to-play decisions, especially with computerized tools. The authors call for more research,

better education for families and physicians, and validation of assessment methods to improve concussion care.

**Research Question/Problem/Need**  
 How can sports-related concussions be more accurately identified, assessed, and managed, especially for youth and female athletes?

**Important Figures**

*Table 1. Comparison of Postconcussion Assessment Schedules*

Study	Schedule of Serial Postconcussion Assessments							Measures Used
	Hours		Days					
	1-2	24-48	3	5	7	10	30	
NCAA-Multiple sports (Echemendia et al., 2001)	2	24			7		30	PC, HVLT <sup>a</sup> , SDMT, Stroop Test, Trails <sup>b</sup> , VIGIL/W <sup>c</sup> , Digit Span, PSU, COWAT
NCAA-Football (Collins et al., 1999)	1		3	5	7			HVLT <sup>a</sup> , Trails <sup>b</sup> , Digit Span, SDMT, COWAT, Pegboard <sup>d</sup>
NCAA-Football (Barth et al., 1989)		24		5		10		SDMT, Trails <sup>b</sup> , PASAT
Prof. Hockey Players (Echemendia, 2001)		24		5 <sup>e</sup>	7 <sup>e</sup>			PC, HVLT <sup>a</sup> , SDMT, Trails <sup>b</sup> , PSU, COWAT, BVMT-R
Prof. Football Players (Lovell & Collins, 1998)		24		5				HVLT <sup>a</sup> , SDMT, Trails <sup>b</sup> , Digit Span, COWAT, Pegboard <sup>d</sup>
Prof. Rugby Players (McCrooy et al., 1997)	1			5				SDMT, Choice RT <sup>f</sup> , Memory <sup>g</sup> , Orientation <sup>h</sup>
Prof. Rugby Players (Himion-Bayre et al., 1999)			3 <sup>i</sup>		7 <sup>i</sup>		35 <sup>i</sup>	SDMT, Digit Symbol, Speed of Comprehension <sup>h</sup>

*Note:* PC = Postconcussion Checklist; SDMT = Symbol Digit Modalities Test; PSU = Penn State University Cancellation Task; COWAT = Controlled Oral Word Association Test; PASAT = Paced Auditory Serial Addition Test; BVMT-R = Brief Visuospatial Motor Test-Revised.  
<sup>a</sup>Postconcussion Checklist. <sup>b</sup>Trail Making Test A & B. <sup>c</sup>Continuous Performance Task. <sup>d</sup>Grooved Pegboard Test. <sup>e</sup>Athletes tested 5 to 7 days postconcussion. <sup>f</sup>Color Trail Making Test. <sup>g</sup>Symbol Digit Modalities Test (with incidental memory testing). <sup>h</sup>Unspecified. <sup>i</sup>Athletes tested 1 to 3 days, 1 to 2 weeks, 3 to 5 weeks postconcussion. <sup>j</sup>Digit Symbol subtest of the Wechsler Adult Intelligence Scale-Revised.

This table summarizes various studies assessing post-concussion protocols in athletes, focusing on timing and measures used. Studies are categorized by sport and the researchers involved. The schedule of serial post-concussion assessments is detailed in hours and then days post-injury. Different cognitive and motor function tests were employed to evaluate players' recovery.

**VOCAB: (w/definition)**

Cognitive: relating to the process of acquiring knowledge and understanding through thought, experience, and the senses

Myelination: Myelination is a process of creating the myelin sheath that surrounds the axons of the nerves, forming an electrically insulating layer

Psychomotor coding: development of organized patterns of muscular activities guided by signals from the environment

Cerebral: the cerebrum of the brain

**Cited references to follow up on**

Barth, J. T., Freeman, J. R., Broshek, D. K., & Varney, R. N. (2001). Acceleration-deceleration sport-related concussion: The gravity of it all. *Journal of Athletic Training*, 36, 253–256.

<b>Follow up Questions</b>	<ol style="list-style-type: none"><li>1. How do concussion symptoms and recovery trajectories differ between male and female athletes?</li><li>2. What role do genetic or biological factors play in susceptibility and recovery from concussions?</li><li>3. How accurate and reliable are computerized neuropsychological tests (ImPACT) in monitoring recovery?</li></ol>

## Article #2 Notes: Mind-reading brain implant converts thoughts to speech almost instantly: 'breakthrough'

Article notes should be on separate sheets

<b>Source Title</b>	Mind-reading brain implant converts thoughts to speech almost instantly: 'breakthrough'
<b>Source citation (APA Format)</b>	Pester, P. (2025, April 3). <i>Mind-reading brain implant converts thoughts to speech almost instantly: "Breakthrough."</i> <i>Live Science</i> . <a href="https://www.livescience.com/health/neuroscience/mind-reading-brain-implant-converts-thoughts-to-speech-almost-instantly-breakthrough">https://www.livescience.com/health/neuroscience/mind-reading-brain-implant-converts-thoughts-to-speech-almost-instantly-breakthrough</a>
<b>Original URL</b>	<a href="https://www.livescience.com/health/neuroscience/mind-reading-brain-implant-converts-thoughts-to-speech-almost-instantly-breakthrough">https://www.livescience.com/health/neuroscience/mind-reading-brain-implant-converts-thoughts-to-speech-almost-instantly-breakthrough</a>
<b>Source type</b>	Website
<b>Keywords</b>	mind-reading brain implant, brain-computer interface (BCI), thoughts to speech, almost instantaneously / near-synchronous voice streaming, neuroprosthesis, artificial intelligence (AI), speech decoding, motor cortex, neural signals / brain signals, synthetic voice, severe paralysis, streaming brain-to-voice
<b>#Tags</b>	#brainstorming
<b>Summary of key points + notes (include methodology)</b>	Scientists have discovered how to use AI with a brain implant to decode a person's thoughts and give them a voice, to give a synthetic voice to people who are unable to speak. They do this by putting electrodes onto the surface of the brain, specifically the motor cortex, which controls

	<p>speech, so that they can access speech signals. It works by intercepting signals where the thought is translated into articulation, so it would not repeat every thought within a person's head. The brain-computer interface (BCI) can decode the signals intended for speech in real time. This is significantly quicker, and the voice is less robotic than previous versions. It uses a similar algorithm to Siri to decode the brainwaves. The test has moved on to human trials, where it can detect words and convert them to speech in about three seconds because it processes individual words and not sentences. Research continues to enhance the algorithm's ability to generate speech more quickly and clearly. I think that I could do something similar with conductive hearing loss in order to convert sound waves into brain waves along the auditory nerve pathways to the brain. For sensorineural hearing loss, I believe that similar implants on the brain could produce gamma brainwaves or something similar.</p>
<b>Research Question/Problem/Need</b>	<p>Can brain activity be decoded and converted into speech in near real time, enabling people with severe paralysis to communicate more naturally and quickly?</p>
<b>Important Figures</b>	<p>No included figures</p>
<b>VOCAB: (w/definition)</b>	<p>Neuroprosthesis: a prosthetic that interfaces directly with the nervous system  Motor cortex: the part of the cerebral cortex in the brain where the nerve impulses originate that initiate voluntary muscular activity</p>
<b>Cited references to follow up on</b>	<p>Ellery, M. (2025, March 31). <i>Brain-to-voice neuroprosthesis restores naturalistic speech</i>. <b>Berkeley Engineering</b>. University of California, Berkeley. Retrieved August 24, 2025, from <a href="https://engineering.berkeley.edu/news/2025/03/brain-to-voice-neuroprosthesis-restores-naturalistic-speech/">https://engineering.berkeley.edu/news/2025/03/brain-to-voice-neuroprosthesis-restores-naturalistic-speech/</a></p>

## Follow up Questions

1. How accurately can the implant decode complex sentences or emotional tone in speech, beyond basic word reproduction?
2. What are the long-term safety and stability considerations of implanting such a brain–computer interface in patients with severe paralysis?
3. How might improvements in AI algorithms further reduce the delay to achieve truly real-time, natural-sounding communication?

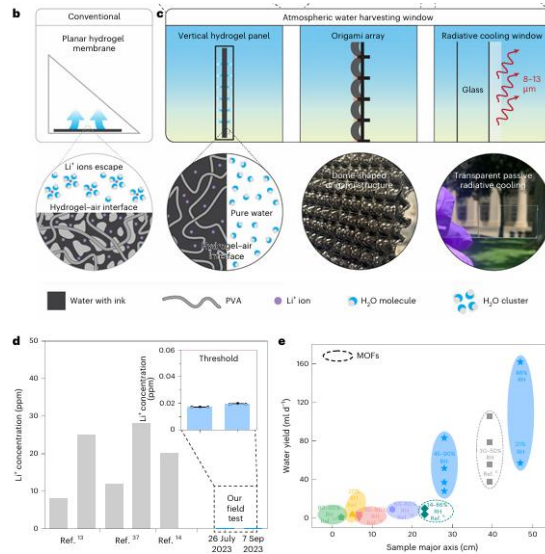
## Article #3 Notes: A metre-scale vertical origami hydrogel panel for atmospheric water harvesting in Death Valley

Article notes should be on separate sheets

<b>Source Title</b>	A metre-scale vertical origami hydrogel panel for atmospheric water harvesting in Death Valley
<b>Source citation (APA Format)</b>	Liu, C., Yan, X.-Y., Li, S., Zhang, H., Deng, B., Fang, N. X., Habibi, Y., Chen, S.-C., & Zhao, X. (2025, June 11). <i>A metre-scale vertical origami hydrogel panel for atmospheric water harvesting in Death Valley</i> . <i>Nature</i> . <a href="https://doi.org/10.1038/s44221-025-00447-2">https://doi.org/10.1038/s44221-025-00447-2</a>
<b>Original URL</b>	<a href="https://www.nature.com/articles/s44221-025-00447-2">https://www.nature.com/articles/s44221-025-00447-2</a>
<b>Source type</b>	Journal article
<b>Keywords</b>	Atmospheric water harvesting (AWH), Origami hydrogel panel, Passive water harvester, Vertical hydrophilic device, Water scarcity solution, Solar still / window-like chamber, Hygroscopic hydrogel, Safe drinking water (low lithium-ion contamination), Climate-adaptive water collection
<b>#Tags</b>	#brainstorming
<b>Summary of key points + notes (include methodology)</b>	This is a study meant to address water scarcity in places that are landlocked or off the grid. It presents the Atmospheric Water Harvesting Window (AWHW), which is a passive atmospheric water harvesting device that operates without electricity. It was tested in Death Valley for producing safe drinking water in extremely low humidity. While there are other water harvesting devices out there,

	<p>this one is more efficient for three reasons. It uses a hydrogel composition which is super stable, called PVA-LiCl-glycerol hydrogel, to avoid leakage and crystallization, as well as maintaining a low Li<sup>+</sup> ion concentration which makes it safe for drinking. The AWHW also has a unique origami structure. It is a dome-shaped, vertical origami panel which enhances water absorption by increasing surface area. Finally, it uses a solar still design to improve condensation and water collection. The AWHW produces anywhere from 57.0 to 161.5 ml/day and has gone through over 340 wet-dry cycles, a year of daily use, without performance loss. To meet WHO's daily water need of 5.3L, the window can be scaled to about 8 units, only covering about 16 m<sup>2</sup>. This is unique for being the first passive hydrogel system on a meter scale, which helps it outperform both active and passive sorbent-based systems. I would like to work with something like this on a larger scale, which can easily be incorporated into a dual-purpose solar panel and water harvester or a portable harvester for disaster relief with a built-in tube for drinking.</p>
<b>Research Question/Problem/Need</b>	Can a large-scale, origami-designed hydrogel panel efficiently harvest safe, drinkable water from the atmosphere under extreme arid conditions such as Death Valley?

## Important Figures



This shows water harvesting technology using hydrogels and metal-organic frameworks. It shows different configurations of both planar and vertical hydrogel panels, as well as an array for atmospheric water harvesting. The graphs in the bottom present data on lithium-ion concentration and water yield relative to sample size, suggesting the performance metrics for technology.

## VOCAB: (w/definition)

Sorption-Based Atmospheric Water Harvesting (SAWH): A method of AWH where a sorbent material—like a hydrogel—absorbs water vapor from the air and then releases it as liquid water through desorption

Desorption: the release of an absorbed substance from a surface

Hydrogel: A three-dimensional polymer network capable of absorbing and retaining substantial quantities of water. Hydrogels can be either synthetic or natural and are commonly used in applications ranging from biomedical devices to water sustainability platforms.

## Cited references to follow up on

Lord, J. et al. Global potential for harvesting drinking water from air using solar energy. *Nature* 598, 611–617 (2021).

Progress on Household Drinking Water, Sanitation and Hygiene 2000–2017: Special Focus on Inequalities (World Health Organization, 2019)

C. Liu, et al. Broadband thermal management using smart cooling films. *Joule*

	<a href="https://doi.org/10.2139/ssrn.4315402">https://doi.org/10.2139/ssrn.4315402</a> (2023).
<b>Follow up Questions</b>	<p>How does the origami folding geometry affect absorption/desorption cycles?</p> <p>Can this shape be optimized for even greater yield? What contributes to the low lithium ion concentration, and how do collected water samples meet broader drinking-water safety standards? Are there risks of contamination from the hydrogels themselves or the enclosure materials over prolonged use? How can these systems be integrated with other structures to maximize impact?</p>

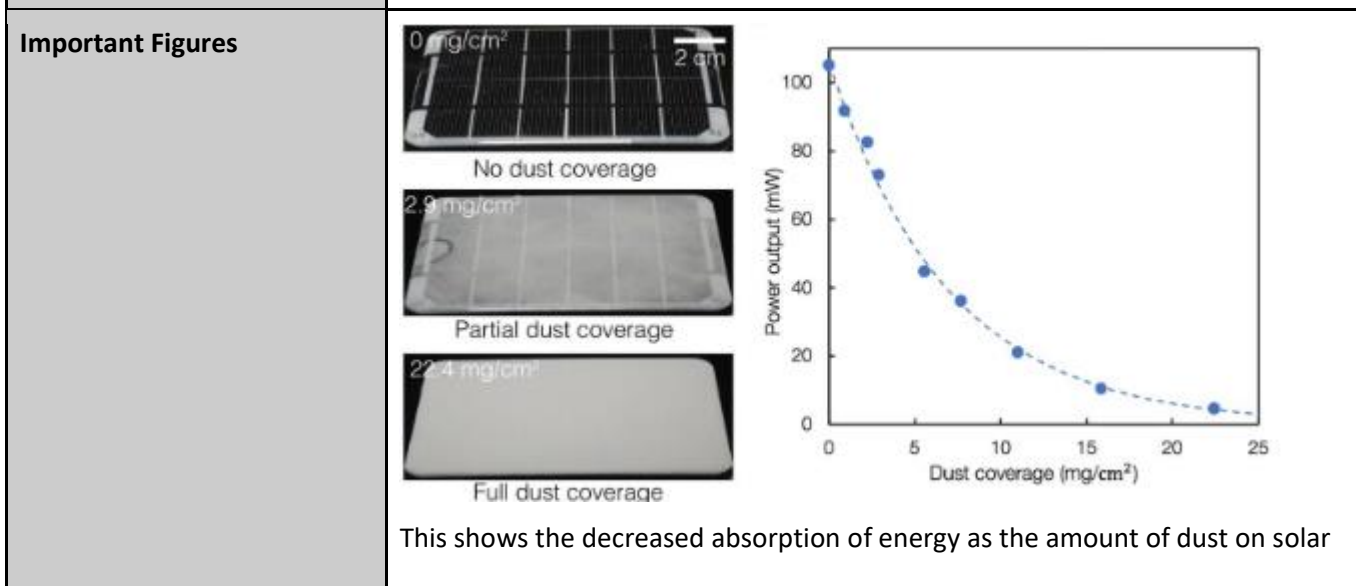
## Article #4 Notes: Electrostatic dust removal using adsorbed moisture–assisted charge induction for sustainable operation of solar panels

Article notes should be on separate sheets

<b>Source Title</b>	Electrostatic dust removal using adsorbed moisture–assisted charge induction for sustainable operation of solar panels
<b>Source citation (APA Format)</b>	Panat, S., & Varanasi, K. K. (2022). <i>Electrostatic dust removal using adsorbed moisture–assisted charge induction for sustainable operation of solar panels</i> . <i>Science Advances</i> , 8 (eabm0078). <a href="https://doi.org/10.1126/sciadv.abm0078">https://doi.org/10.1126/sciadv.abm0078</a>
<b>Original URL</b>	<a href="#">Electrostatic dust removal using adsorbed moisture–assisted charge induction for sustainable operation of solar panels   Science Advances</a>
<b>Source type</b>	Research Article
<b>Keywords</b>	Electrostatic dust removal, Charge induction, Adsorbed moisture, Solar panel cleaning, Waterless cleaning method, Desert/arid sustainability, Threshold electric potential, Dust particle charging, Relative humidity range, Power recovery of solar panels
<b>#Tags</b>	#brainstorming
<b>Summary of key points + notes (include methodology)</b>	Researchers from MIT addressed the persistent issue of dust accumulation on solar panels, which drastically reduces energy output and typically demands water-intensive cleaning. They have introduced a waterless technique based on electrostatic induction where a lightweight electrode scans above a transparent conductive coating on

the panel, charging dust particles via moisture-assisted induction so they repel away from the surface. The team quantified particle charge using Stokes experiments in an electric field and computed a threshold potential where electrostatic force overcomes adhesion, gravity, and van der Waals forces. They found the method works effectively across a wide humidity range—from about 30 % up to 95 %. In their laboratory prototype, it restored up to 95 % of power lost to dust (especially for particles larger than  $\sim 30 \mu\text{m}$ ) without any current flow between electrodes, meaning negligible energy consumption. This approach offers a sustainable, scalable, and cost-saving alternative to traditional water-based or mechanical cleaning methods for solar installations. I plan to use this information in combination with my ideas from the second STEM article in order to create a long-term disaster relief kit, which hopefully would be able to incorporate both water and energy collection.

**Research Question/Problem/ Need**  
 Can a dry, waterless electrostatic method—based on moisture-assisted charge induction—effectively remove dust from solar panels and restore their power output across a broad range of humidity conditions?



	panels increase.
<b>VOCAB: (w/definition)</b>	<p>Electrostatic Force: The attractive or repulsive force between electrically charged particles. In this context, it's used to lift and remove dust from solar panel surfaces.</p> <p>Charge Induction: A process by which an electric charge is redistributed on a material without direct contact, caused by the presence of an external electric field.</p> <p>Adsorbed Moisture: Thin layers of water molecules that cling to the surface of dust particles from the air. This moisture makes otherwise insulating dust more conductive, enabling effective charging and removal.</p> <p>Threshold Potential: The minimum applied voltage required to induce enough charge on dust particles to overcome adhesion forces and remove them from the solar panel.</p> <p>Waterless Cleaning: A method of cleaning solar panels without using water—critical for desert and arid regions where water scarcity is severe.</p>
<b>Cited references to follow up on</b>	<p>P. K. Nayak, S. Mahesh, H. J. Snaith, D. Cahen, Photovoltaic solar cell technologies: Analyzing the state of the art. <i>Nat. Rev. Mater.</i> <b>4</b>, 269–285 (2019).</p> <p>M. Mani, R. Pillai, Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations. <i>Renew. Sustain. Energy Rev.</i> <b>14</b>, 3124–3131 (2010).</p>
<b>Follow up Questions</b>	<p>How does repeated application of electrostatic cleaning affect the long-term performance and lifespan of solar panels, coatings, and electrodes?</p> <p>What engineering challenges need to be addressed to scale this technology for large solar farms in desert regions, and how does its cost compare with existing cleaning methods?</p>

	<p>How does the efficiency of electrostatic dust removal vary with different dust compositions, particle sizes, and humidity levels in real-world climates beyond controlled tests?</p>
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## Article #5 Notes: Biomechanics of Concussion

Article notes should be on separate sheets

<b>Source Title</b>	Biomechanics of Concussion
<b>Source citation (APA Format)</b>	<p>Meaney, D. F., &amp; Smith, D. H. (2011). Biomechanics of concussion. <i>Clinics in sports medicine</i>, 30(1), 19–vii.</p> <p><a href="https://doi.org/10.1016/j.csm.2010.08.009">https://doi.org/10.1016/j.csm.2010.08.009</a></p>
<b>Original URL</b>	<a href="#">Biomechanics of Concussion - PMC</a>
<b>Source type</b>	Journal Article
<b>Keywords</b>	Biomechanics, Tolerance, Mild traumatic Brain injury, Concussion
<b>#Tags</b>	#forces #concussions
<b>Summary of key points + notes (include methodology)</b>	<p>A concussion is a mild traumatic brain injury that happens more often than severe brain injuries but can still cause lasting neurological problems. Instead of being caused by a skull fracture, concussions usually come from sudden movements of the head that make the brain shift inside. The two main kinds of motion are linear acceleration, which moves the brain in a straight line and creates pressure, and rotational acceleration, which twists the brain and creates shear forces. Rotational acceleration is especially dangerous because it causes tissue deformation that disrupts brain function. On a microscopic level, these forces can change how neurons and astrocytes send signals, alter receptor activity, and even make cell membranes more permeable, all without obvious structural damage. Scientists use computational models and helmet sensors to study how these forces work in real life and to predict their effects on the brain. By connecting large-scale research with cell-level findings, experts hope to design better protective equipment and strategies to prevent concussions.</p>
<b>Research Question/Problem/Need</b>	How do different mechanical forces cause tissue-level and cellular-level changes in the brain that lead to concussion, and how can this understanding inform

	prevention and protective strategies?
<b>Important Figures</b>	No figures are included in the article.
<b>VOCAB: (w/definition)</b>	<p>Shear Forces: Forces that distort tissue by sliding layers against each other, critical in brain injury.</p> <p>Tolerance Curve (Wayne State Tolerance Curve): A standard linking mechanical input (e.g., acceleration) to the probability of head injury.</p> <p>Finite Element Models (FEM): Computational simulations used to predict brain deformation under impact.</p> <p>Microscale Injury: Cellular-level changes (astrocyte reactivity, receptor alterations, membrane permeability shifts) caused by mechanical stress.</p>
<b>Cited references to follow up on</b>	<p>Gurdjian ES, Lissner HR, Evans FG, et al. Intracranial pressure and acceleration accompanying head impacts in human cadavers. <i>Surg Gynecol Obstet</i> 1961; 113:185–90.</p> <p>Gurdjian ES, Webster JE, Lissner HR. Studies on skull fracture with particular reference to engineering factors. <i>Am J Surg</i> 1949;78(5):736–42 [Disc 749–51].</p> <p>Nahum AM, Smith R, Ward CC. Intracranial pressure dynamics during head impact. in 21st Annual Stapp Car Crash Conference. 1977: Society of Automotive Engineers</p>
<b>Follow up Questions</b>	<p>At what thresholds of acceleration do functional impairments occur, even without structural cell death?</p> <p>How can computational models be improved to predict individual differences in concussion risk?</p> <p>What role do repeated sub-concussive impacts play in long-term brain changes?</p> <p>What molecular pathways link mechanical forces to lasting neurological dysfunction?</p>

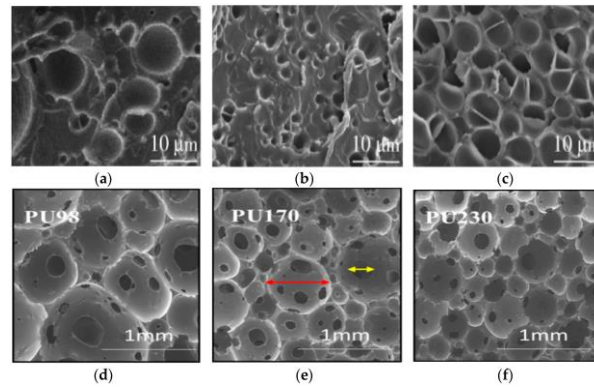


# Article #6 Notes: Research Progress on Helmet Liner Materials and Structural Applications

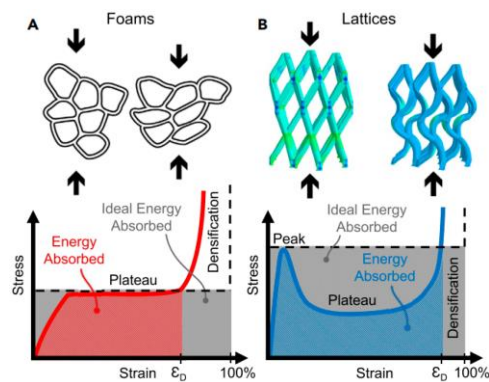
Article notes should be on separate sheets

<b>Source Title</b>	Research Progress on Helmet Liner Materials and Structural Applications
<b>Source citation (APA Format)</b>	Zhang, X., Yang, B., Wu, J., Li, X., & Zhou, R. (2024). Research Progress on Helmet Liner Materials and Structural Applications. <i>Materials</i> , 17(11), 2649. <a href="https://doi.org/10.3390/ma17112649">https://doi.org/10.3390/ma17112649</a>
<b>Original URL</b>	<a href="#">Research Progress on Helmet Liner Materials and Structural Applications - PMC</a>
<b>Source type</b>	Journal Article
<b>Keywords</b>	helmet liner, energy absorption performance, composite materials, bionic structure, additive manufacturing
<b>#Tags</b>	#helmet structure #liner
<b>Summary of key points + notes (include methodology)</b>	Recent research has focused on developing liner materials that are lighter, stronger, and more comfortable, while still reducing the risk of brain injury. Traditional liners use foams like expanded polystyrene, which can absorb energy but are not always good for repeated impacts. Newer materials include advanced polymers, nanomaterials, and even structures inspired by nature that improve shock absorption and flexibility. Scientists are also studying how different liner shapes and designs, such as honeycomb or layered structures, can reduce both linear and rotational acceleration during impacts. Computer simulations and real-world tests are being used together to better predict how liners perform. The goal is to combine new materials with smart structural designs to make helmets safer, lighter, and more effective in preventing injuries like concussions.
<b>Research Question/Problem/ Need</b>	How can advanced materials and innovative structural designs improve helmet liners to reduce impact forces and better prevent head injuries?

## Important Figures



This is a SEM photo comparison of PES foam and PU foam. A is PES foam at an immersion pressure of 10 MPa. B is PES foam at an immersion pressure of 12.5 MPa. C is PES at an immersion pressure of 15 MPa. D is PU at a density of 98 kg/m<sup>3</sup>. E is PU at a density of 170 kg/m<sup>3</sup>. F is PU at a density of 170 kg/m<sup>3</sup>. Cell apertures are shown by yellow arrows, while cell diameters are indicated by red arrows. This indicates how they compress at different densities and at different pressures and how they compare.



This diagram compares the mechanical behavior of foams and lattices under compression based on their ability to absorb energy. It illustrates their stress-strain relationship, highlighting the plateau region, indicating the materials ability to absorb energy at a relatively constant stress level. Foams are more consistent than lattices, leading to more area under the curve for energy absorbed.

## VOCAB: (w/definition)

**Impact Attenuation:** The ability of a material to reduce and spread-out force from an impact.

**Expanded Polystyrene (EPS):** A lightweight foam commonly used in helmet liners for absorbing energy.

	<p>Nanomaterials: Extremely small materials at the molecular or atomic scale with unique properties that can improve strength and flexibility.</p> <p>Honeycomb Structure: A design pattern that mimics natural structures and is effective for absorbing energy.</p> <p>Multilayered Liner: A helmet liner made of several layers of different materials to balance strength, comfort, and shock absorption.</p>
<b>Cited references to follow up on</b>	<p>Sone, J.Y.; Kondziolka, D.; Huang, J.H.; Samadani, U. Helmet efficacy against concussion and traumatic brain injury: A review. <i>J. Neurosurg.</i> 2017, 126, 768–781.</p> <p>Vanden Bosche, K.; Mosleh, Y.; Depreitere, B.; Vander Sloten, J.; Verpoest, I.; Ivens, J. Anisotropic polyether sulfone foam for bicycle helmet liners to reduce rotational acceleration during oblique impact. <i>Proc. Inst. Mech. Eng. Part H J. Eng. Med.</i> 2017, 231, 851–861.</p> <p>Chen, Z.; Li, J.; Wu, B.; Chen, X.; Ren, X.; Xie, Y.M. A novel bio-inspired helmet with auxetic lattice liners for mitigating traumatic brain injury. <i>Smart Mater. Struct.</i> 2023, 32, 105020.</p> <p>Zhang, W.; Yin, S.; Yu, T.X.; Xu, J. Crushing resistance and energy absorption of pomelo peel inspired hierarchical honeycomb. <i>Int. J. Impact Eng.</i> 2019, 125, 163–172.</p>
<b>Follow up Questions</b>	<p>What materials can replace traditional foams while still being affordable for helmet production?</p> <p>How do different liner structures, like honeycomb or layered designs, compare to prevent concussions?</p> <p>Can nanomaterials or smart materials be made safe and durable enough for everyday helmet use?</p> <p>How can helmets be designed to protect against both single strong impacts and repeated smaller impacts?</p>



# Article #7 Notes: AI-based identification of head impact locations, speeds, and force based on head kinematics simulations

Article notes should be on separate sheets

<b>Source Title</b>	AI-based identification of head impact locations, speeds, and force based on head kinematics simulations
<b>Source citation (APA Format)</b>	Zhan, X., Liu, Y., Cecchi, N. J., Towns, J., Callan, A. A., Gevaert, O., Zeineh, M. M., & Camarillo, D. B. (2025). <i>AI-based identification of head impact locations, speeds, and forces based on head kinematics simulations</i> . <i>IEEE Transactions on Biomedical Engineering</i> . <a href="https://doi.org/10.1109/TBME.2025.3581171">https://doi.org/10.1109/TBME.2025.3581171</a>
<b>Original URL</b>	<a href="#">AI-based identification of head impact locations, speeds, and force based on head kinematics simulations   IEEE Journals &amp; Magazine   IEEE Xplore</a>
<b>Source type</b>	Journal
<b>Keywords</b>	traumatic brain injury, head impact, impact direction, deep learning, recurrent neural network
<b>#Tags</b>	#concussion #forces
<b>Summary of key points + notes (include methodology)</b>	To figure out how to predict impact details from motion data, the researchers first made a giant dataset of 16,000 simulated helmet collisions using a Riddell helmet model. They tracked the head's accelerations and rotations during each simulated hit. Then, they trained a Long Short-Term Memory (LSTM) neural network to analyze those kinematic signals and predict the impact's location, direction, speed,

and force profile. When tested on the simulation data, the model was highly accurate, reaching over 70%  $R^2$  scores for most predictions, with force estimates coming within 0.2 kN of the true values. They also used transfer learning to adapt the system to a different helmet brand (Vicis) and found that it still performed reliably with less training data. For real-world validation, they studied 79 football impacts captured by instrumented mouthguards and matched game films. The AI correctly identified the hit location almost 80% of the time, which was a huge leap compared to traditional mechanical methods that scored below 50% accuracy. These results show that the model not only works in simulation but also has strong potential in the field.

**Research Question/Problem/  
Need**

Can a large learning model accurately predict head impact location, speed, and force from head kinematics, and outperform traditional mechanical estimation methods?

**Important Figures**

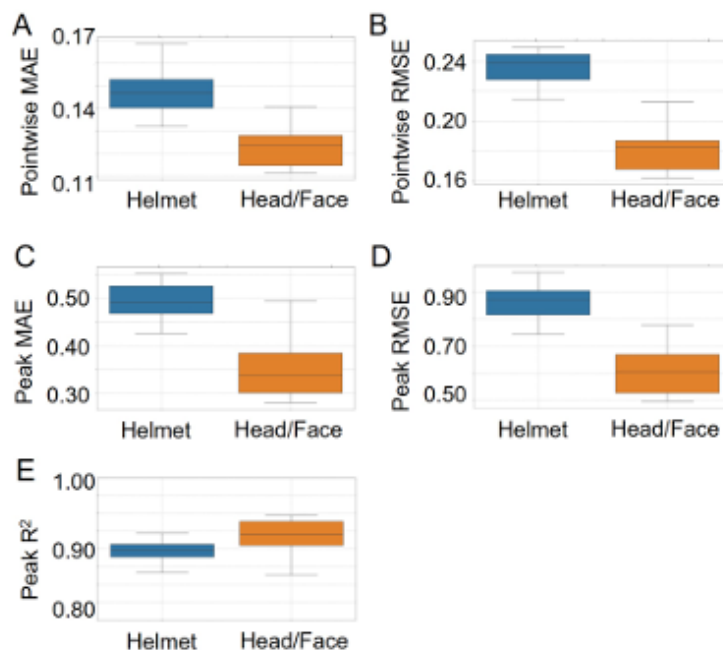


Fig. 4. The performance of predicting force profiles based on head kinematics based on the LSTM model on the simulated Riddell Helmet finite-element-simulation datasets. The distribution of the performance metrics on the test set over 20 experiments with random training/validation/test dataset partitions were reported: pointwise mean absolute error (MAE) (A), peak MAE (B), pointwise root mean squared error (RMSE) (C), peak RMSE (D), peak  $R^2$  (E).

The model displays how accurate the LSTM model is at predicting force profiles, where it is better on the helmet than the head and face, shown by lower MAE, RMSE, and Peak RMSE, and higher  $R^2$ .

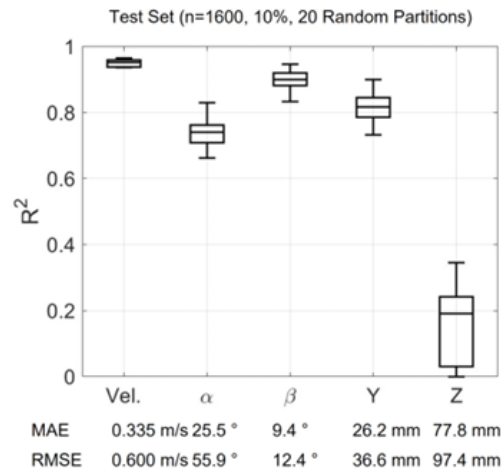


Fig. 3. The  $R^2$  of predicting impact speed and orientation based on head kinematics based on the LSTM model on the simulated Riddell Helmet finite-element-simulation datasets. The mean and standard deviation of mean absolute error (MAE) and root mean squared error (RMSE) on the test set (10% data used as the hold-out test samples) over 20 experiments with random training/validation/test dataset partitions were reported.

Explains how good the LSTM model is at predicting impact speed and orientation for multiple angles of concussion.

#### VOCAB: (w/definition)

Head Kinematics – the motion of the head during and after impact, usually tracked with accelerometers and gyroscopes.

Finite Element Model (FEM) – a computer simulation that divides a helmet and head form into tiny parts to calculate impact responses.

LSTM (Long Short-Term Memory) – a type of recurrent neural network that analyzes time-series data and learns long-term patterns.

Impact Force Profile – the changing amount of force over the short time span of an impact.

Transfer Learning – re-using a trained model on new but related data, like adapting from Riddell helmets to Vicis helmets.

<p><b>Cited references to follow up on</b></p>	<p>X. Zhan, Y. Li, Y. Liu, A. G. Domel, H. V. Alizadeh, S. J. Raymond, J. Ruan, S. Barbat, S. Tiernan, O. Gevaert et al., “The relationship between brain injury criteria and brain strain across different types of head impacts can be different,” <i>Journal of the Royal Society Interface</i>, vol. 18, no. 179, p. 20210260, 2021</p> <p>Y. Liu, A. G. Domel, N. J. Cecchi, E. Rice, A. A. Callan, S. J. Raymond, Z. Zhou, X. Zhan, Y. Li, M. M. Zeineh et al., “Time window of head impact kinematics measurement for calculation of brain strain and strain rate in American football,” <i>Annals of biomedical engineering</i>, vol. 49, no. 10, pp. 2791–2804, 2021.</p> <p>C. Kuo, M. Fanton, L. Wu, and D. Camarillo, “Spinal constraint modulates head instantaneous center of rotation and dictates head angular motion,” <i>Journal of biomechanics</i>, vol. 76, pp. 220–228, 2020.</p>
<p><b>Follow up Questions</b></p>	<p>How well would the model work across different sports with different helmet types?</p> <p>Could the system be miniaturized into real-time wearable tech for athletes?</p> <p>What are the ethical concerns of collecting large datasets of player impacts?</p> <p>Can the model be improved to better detect impacts at less common locations (like the top or back of the head)?</p> <p>How can this be adapted for my own project? Should I use AI for the analysis portion?</p>

# Article #8 Notes: Youth Australian Footballers Experience Similar Impact Forces to the Head as Junior- and Senior-League Players: A Prospective Study of Kinematic Measurements

Article notes should be on separate sheets

<b>Source Title</b>	Youth Australian Footballers Experience Similar Impact Forces to the Head as Junior- and Senior-League Players: A Prospective Study of Kinematic Measurements
<b>Source citation (APA Format)</b>	Woolley, L. M., Ekegren, C. L., Gabbe, B. J., Finch, C. F., & Donaldson, A. (2018). <i>Youth Australian footballers experience similar impact forces to the head as junior- and senior-league players: A prospective study of kinematic measurements. BMJ Open Sport &amp; Exercise Medicine, 4(1)</i> , e000398. <a href="https://doi.org/10.1136/bmjsem-2018-000398">https://doi.org/10.1136/bmjsem-2018-000398</a> Day).
<b>Original URL</b>	<a href="#">Youth Australian Footballers Experience Similar Impact Forces to the Head as Junior- and Senior-League Players: A Prospective Study of Kinematic Measurements - Worcester Polytechnic Institute</a>
<b>Source type</b>	Research article
<b>Keywords</b>	concussion, biomechanics, youth athletes, head impacts, rotational acceleration, sports medicine
<b>#Tags</b>	#forces, #concussion
<b>Summary of key points + notes</b>	This study examined head impacts among 19 male youth Australian football

**(include methodology)** players (ages 13–14) across 11 games in the 2017 season. Each player wore an XPatch sensor behind the ear to measure linear and rotational accelerations during impacts. Self-reported logbooks captured whether players recalled direct head contact and any symptoms (headache, dizziness, confusion, etc.). Results: players averaged 5 (±4) impacts per game, with median peak linear acceleration at 15.2g (95th percentile 45.8g) and rotational acceleration at 183,117 deg/s<sup>2</sup> (95th percentile 594,272 deg/s<sup>2</sup>). These forces are strikingly similar to those previously recorded in older junior- (17–19) and senior-league (20+) players. Notably, players who self-reported head impacts did not differ substantially in measured impact forces compared to those who did not, illustrating the difficulty of recognizing concussions in youth athletes. Limitations include reliance on self-reports, lack of medical staff or video verification, and potential XPatch measurement errors.

**Research Question/Problem/Need** Do youth Australian football players sustain head impact forces comparable to older players, and how do self-reported impacts align with measured forces?

**Important Figures**

**Table 2. Impacts to the head greater than 10g in youth Australian Football players by impact location for resultant peak linear and rotational accelerations, head impact telemetry severity profile and risk weighted exposure combined (linear and rotational) probability for number of impacts recorded, impact duration and impact magnitude. Data are presented as mean (± standard deviation) and median [25<sup>th</sup> to 75<sup>th</sup> interquartile range].**

Impact Location	Impact to the head				Peak Linear Acceleration (PLA(g))			Peak Rotational Acceleration (PRA(deg/s <sup>2</sup> ))			Head Impact Telemetry severity profile (HIT <sub>50</sub> )			Risk Weighted Exposure combined probability (RWE <sub>c</sub> )			
	N (%)	Mean ±SD	Median [IQR]	95%	Median [IQR]	95%	95%	Median [IQR]	95%	Median [IQR]	95%	Median [IQR]	95%				
<b>Total</b>																	
Front	112 (24.7)	11.0 ±7.5 <sup>abd</sup>	17.9 [13.6-25.9] <sup>abd</sup>	46.3	220,635 [141,624-360,729]	664,929	17.2 [13.6-23.3] <sup>c</sup>	48.7	.0003 [0.0006-0.0180] <sup>bc</sup>	.82							
Back	117 (25.8)	8.5 ±6.2 <sup>abd</sup>	14.6 [11.4-24.9] <sup>abd</sup>	48.6	192,909 [77,229-313,877.7]	889,294	14.1 [11.4-22.2] <sup>c</sup>	46.5	.0014 [0.0002-0.0166] <sup>a</sup>	.93							
Side	201 (44.4)	10.2 ±8.4 <sup>a</sup>	14.2 [11.6-22.6] <sup>abd</sup>	44.1	155,650 [86,557-242,642]	514,356	14.2 [12.3-20.1] <sup>ab</sup>	49.8	.0007 [0.0002-0.0038] <sup>a</sup>	.31							
Top	23 (5.1)	11.5 ±9.1 <sup>ab</sup>	14.1 [13.1-19.1] <sup>abc</sup>	40.8	206,053 [122,017-315,648]	600,477	14.3 [13.3-19.7]	46.4	.0015 [0.0005-0.0112]	.53							
<b>Injured</b>																	
Front	8 (30.8)	11.1 ±9.7	15.3 [11.1-18.4]	-	151,926 [131,924-201,292]	-	14.5 [11.3-16.4]	-	.0006 [0.0006-0.016]	-							
Back	6 (23.1)	4.8 ±3.1	12.4 [12.1-13.4]	-	222,606 [211,341-272,682]	-	12.6 [11.3-13.9]	-	.0019 [0.014-0.046]	-							
Side	10 (38.5)	10.3 ±5.3	15.4 [12.3-25.1]	-	166,261 [82,552-346,628]	-	13.8 [12.1-23.7]	-	.0009 [0.0003-0.0097]	-							
Top	2 (7.7)	9.0 ±5.7	15.0 [14.2-15.9]	-	350,198 [278,125-422,270]	-	17.5 [15.9-19.1]	-	.0565 [0.0290-0.840]	-							
<b>Non-Injured</b>																	
Front	104 (24.4)	11.0 ±7.3 <sup>abd</sup>	18.4 [13.7-26.9] <sup>abd</sup>	45.9	226,846 [144,723-368,859]	669,186	17.5 [13.7-25.1] <sup>bc</sup>	49.8	.0032 [0.0006-0.0224] <sup>bc</sup>	.83							
Back	111 (26.0)	8.7 ±6.2 <sup>abd</sup>	15.1 [11.3-26.0] <sup>abd</sup>	49.2	184,664 [76,152-328,884]	739,763	14.6 [11.4-22.3] <sup>bc</sup>	47.9	.0012 [0.0002-0.0168] <sup>a</sup>	.92							
Side	191 (44.7)	10.2 ±8.5 <sup>abd</sup>	14.2 [11.6-22.1] <sup>abd</sup>	43.3	155,174 [87,496-242,132]	500,502	14.2 [12.3-20.0] <sup>ab</sup>	47.6	.0007 [0.0002-0.0037] <sup>bd</sup>	.44							
Top	21 (4.9)	11.7 ±9.4 <sup>abc</sup>	14.1 [13.0-19.9] <sup>abc</sup>	41.5	201,171 [118,608-303,324]	621,762	14.3 [13.3-18.7]	47.9	.0014 [0.0005-0.0082] <sup>a</sup>	.55							

SD = Standard Deviation; ms = milliseconds; IQR = interquartile (25<sup>th</sup>-75<sup>th</sup>) percentile; 95% = 95<sup>th</sup> percentile; Significant difference (p < 0.05) than (a) = Front, (b) = Back; (c) = Side; (d) = Top

Location for impacts on the head, their linear and rotational acceleration, and a risk of exposure to concussion based on that data. Similar process that I will be creating.

**VOCAB: (w/definition)** Sports-related concussion (SRC): A mild traumatic brain injury caused by biomechanical forces, with symptoms such as dizziness, headache, and confusion.  
Peak linear acceleration (PLA): The maximum straight-line acceleration of the head

	<p>from impact, measured in g-forces.</p> <p>Peak rotational acceleration (PRA): The maximum angular acceleration of the head from impact, measured in degrees per second<sup>2</sup>.</p> <p>HITSP (Head Impact Telemetry Severity Profile): Composite metric including linear/rotational acceleration, impact duration, and location to estimate concussion risk.</p> <p>RWECP (Risk Weighted Exposure Combined Probability): A probability model combining impact metrics to estimate injury risk.</p>
<p><b>Cited references to follow up on</b></p>	<p>Hecimovich, M., King, D., Dempsey, A., &amp; Murphy, M. (2018). Head impact exposure in junior and adult Australian football players. <i>Journal of Sports Medicine</i>, 2018, 8376030.</p> <p>Rowson, S., &amp; Duma, S. (2011). Development of the STAR evaluation system for football helmets: Integrating player head impact exposure and risk of concussion. <i>Annals of Biomedical Engineering</i>, 39(8), 2130–2140.</p> <p>Greenwald, R. M., Gwin, J. T., Chu, J. J., &amp; Crisco, J. J. (2008). Head impact severity measures for evaluating mild traumatic brain injury risk exposure. <i>Neurosurgery</i>, 62(4), 789–798.</p> <p>Broglio, S. P., Schnebel, B., Sosnoff, J. J., Shin, S., Fend, X., He, X., &amp; Zimmerman, J. (2010). Biomechanical properties of concussions in high school football. <i>Medicine &amp; Science in Sports &amp; Exercise</i>, 42(11), 2064–2071.</p>
<p><b>Follow up Questions</b></p>	<ul style="list-style-type: none"> <li>• How do different wearable sensor technologies (mouthguards, helmet-based, ear patches) compare in accuracy for measuring youth head impacts?</li> <li>• How can concussion recognition be improved when biomechanical data</li> </ul>

and symptom reports do not align?

- Should medical staff coverage at youth games match that of senior-level matches given similar impact forces?
- What threshold values (PLA, PRA) are most predictive of concussion risk in children vs. adults?

# Article #9 Notes: Accelerometers for the Assessment of Concussion in Male Athletes: A Systematic Review and Meta-Analysis

Article notes should be on separate sheets

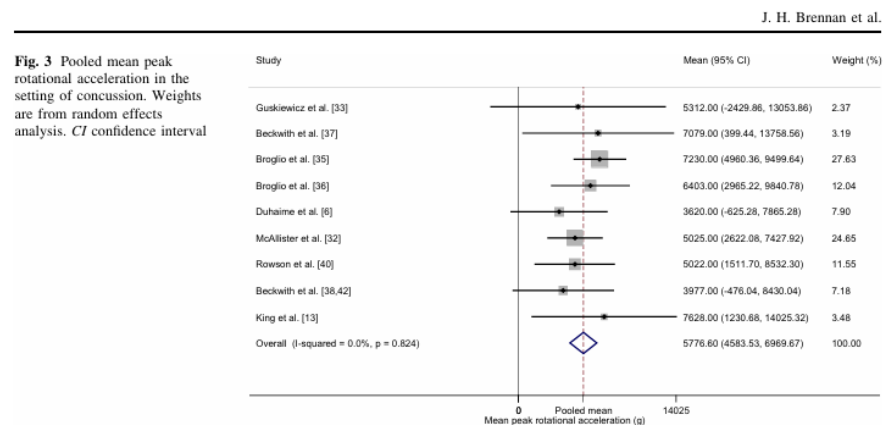
<b>Source Title</b>	Accelerometers for the Assessment of Concussion in Male Athletes: A Systematic Review and Meta-Analysis
<b>Source citation (APA Format)</b>	Brennan, J.H., Mitra, B., Synnot, A. <i>et al.</i> Accelerometers for the Assessment of Concussion in Male Athletes: A Systematic Review and Meta-Analysis. <i>Sports Med</i> 47, 469–478 (2017). <a href="https://doi.org/10.1007/s40279-016-0582-1">https://doi.org/10.1007/s40279-016-0582-1</a>
<b>Original URL</b>	<a href="#">Accelerometers for the Assessment of Concussion in Male Athletes: A Systematic Review and Meta-Analysis - PubMed</a>
<b>Source type</b>	Systematic Review
<b>Keywords</b>	Concussion, accelerometer, head impact telemetry, sports biomechanics, athlete monitoring, wearable technology
<b>#Tags</b>	#concussion, #forces
<b>Summary of key points + notes (include methodology)</b>	This systematic review and meta-analysis evaluated the use of wearable accelerometers for assessing concussive and sub-concussive head impacts in male athletes across contact sports. The authors conducted a structured search across multiple databases, which were PubMed, Scopus, and Web of Science, up to 2019, including only peer-reviewed studies that used accelerometers to measure head kinematics in sport settings. A total of 39 studies met inclusion criteria, encompassing over 2,500 athletes and 60,000+ head impacts. Data extracted

included device type (helmet, mouthguard, or skin-mounted patch), linear and rotational acceleration thresholds, sampling frequency, and validation methods. Results indicated significant variability in both device accuracy and impact detection algorithms, leading to inconsistent concussion risk estimations. The analysis showed a wide range of recorded linear accelerations (10–120 g) and rotational accelerations (1,000–10,000 rad/s<sup>2</sup>), with poor correlation between sensor data and clinical concussion diagnoses. The review highlighted methodological issues such as false positives, false negatives, and device calibration challenges. The authors emphasized that accelerometers are valuable tools for monitoring head impact exposure but are not sufficient as standalone diagnostic instruments for concussion. They called for standardized calibration procedures, improved sensor placement validation, and integration with clinical and neurocognitive assessments to strengthen concussion management protocols.

**Research Question/Problem/Need**

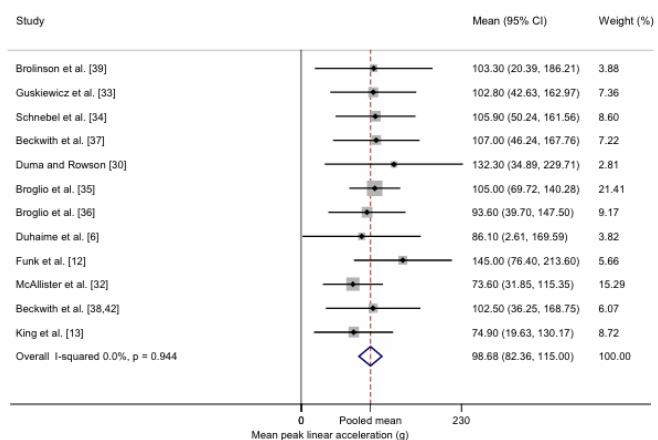
How valid and reliable are wearable accelerometers for assessing head impact exposure and concussion risk in male athletes across contact sports?

**Important Figures**



This is the mean rotational acceleration at the peak of impact when the hit results in a concussion.

**Fig. 2** Pooled mean peak linear acceleration in the setting of concussion. Weights are from random effects analysis. *CI* confidence interval



This is the mean linear acceleration at the peak of impact when the hit results in a concussion.

**VOCAB: (w/definition)**

Head Impact Telemetry (HIT): Technology embedded in helmets or patches to record linear and angular accelerations.

False positive/negative: Sensor readings that incorrectly detect or miss an actual head impact, affecting data reliability.

**Cited references to follow up on**

Wu, L. C., Nangia, V., Bui, K., & Camarillo, D. (2016). In vivo evaluation of wearable head impact sensors. *Annals of Biomedical Engineering*, 44(4), 1234–1245.

Siegmund, G. P., et al. (2015). Laboratory validation of head impact sensors in sports applications. *Journal of Biomechanics*, 48(12), 3339–3345. \*

**Follow up Questions**

- How can calibration standards for accelerometers be unified across manufacturers?
- What combination of biomechanical and neurocognitive measures best predicts concussion severity?
- How does sensor placement (helmet vs. mouthguard vs. skin) affect data accuracy in youth vs. adult athletes?

- Can real-time accelerometer feedback be integrated into coaching or medical protocols to improve concussion prevention?
- What minimum acceleration thresholds should define a potentially concussive event in youth sports?

# Article #10 Notes: Concussion biomechanics, head acceleration exposure and brain injury criteria in sport: a review

Article notes should be on separate sheets

<b>Source Title</b>	Concussion biomechanics, head acceleration exposure and brain injury criteria in sport: a review
<b>Source citation (APA Format)</b>	Gregory Tierney (2024) Concussion biomechanics, head acceleration exposure and brain injury criteria in sport: a review, <i>Sports Biomechanics</i> , 23:11, 1888-1916, DOI: 10.1080/14763141.2021.2016929
<b>Original URL</b>	<a href="#">Concussion biomechanics, head acceleration exposure and brain injury criteria in sport: a review</a>
<b>Source type</b>	Review article
<b>Keywords</b>	Concussion biomechanics, head acceleration exposure (HAE), rotational motion, finite element models, wearable sensors, instrumented mouthguards, brain injury criteria
<b>#Tags</b>	#concussion, #forces, #exact
<b>Summary of key points + notes (include methodology)</b>	This review synthesizes research on the biomechanics of concussion, head acceleration exposure, and the development of brain injury criteria in sports. Tierney discusses how rotational motion, rather than linear acceleration, is the primary biomechanical driver of concussive brain injury, due to the brain's viscoelastic and shear-sensitive properties. The paper reviews three main areas as a part of its methodology. The first was the biomechanical Injury mechanisms where concussions can occur from (1) a single high-load

head acceleration, (2) cumulative exposure reducing brain tolerance, or (3) both. The review links repetitive head acceleration exposure (HAE) to long-term neurodegenerative risks. The second was biomechanical measurement methods. Tierney critically evaluates techniques like quantitative video analysis, multibody simulations, anthropomorphic test devices (ATDs), wearable sensors (helmets, patches, mouthguards), and finite element (FE) brain models. Instrumented mouthguards are deemed the most accurate for in vivo head kinematics due to rigid coupling with the skull. FE models, which simulate tissue-level strain, show promise for understanding brain deformation but remain limited by variability in material properties and model validation. The third was its findings across sports. Mean concussive impacts across male team sports (e.g., football, rugby, hockey) range from ~74–105 g (linear acceleration) and 4,000–7,000 rad/s<sup>2</sup> (rotational acceleration). However, data are highly variable and depends on measurement tools and thresholds. Tierney concluded that improving concussion management requires validated biomechanical tools, consensus on HAE thresholds, and standardized sensor calibration and reporting protocols.

**Research Question/Problem/Need**

How do biomechanical forces (linear and rotational acceleration) contribute to concussion risk, and what validated methods can accurately quantify head acceleration exposure and brain injury criteria in sports?

**Important Figures**

Table 2. The mean and standard deviation (SD) peak resultant linear and rotational acceleration from studies reporting specifically on clinically diagnosed concussions in male team-based collision sports.

Study	Sport	Level	Method	No. of concussive impacts	Linear acceleration, g (SD)	Rotational acceleration, rad/s <sup>2</sup> (SD)
(Brolinson et al., 2006)	American Football	Collegiate	Instrumented Helmet	3	103.3 (42.3)	-
(Guskiewicz et al., 2007)	American Football	Collegiate	Instrumented Helmet	13	102.6 (30.7)	5312 (3950)
(Schoebel et al., 2007)	American Football	Collegiate & High School	Instrumented Helmet	3	105.9 (28.4)	-
(Beckwith et al., 2009)	American Football	Collegiate & High School	Instrumented Helmet	55	107 (31)	7079 (3408)
(Duma & Rowson, 2009)	American Football	Collegiate	Instrumented Helmet	6	122.3 (49.7)	-
(Broglio et al., 2010)	American Football	High School	Instrumented Helmet	13	105 (18)	7230 (1158)
(Broglio et al., 2011)	American Football	High School	Instrumented Helmet	20	93.6 (27.5)	6403 (1754)
(Funk et al., 2012)	American Football	Collegiate	Instrumented Helmet	4	145 (33)	-
(Rowson et al., 2012)	American Football	Collegiate	Instrumented Helmet	57	102.5 (33.8)	5022 (1791)
(Beckwith et al., 2013b)	American Football	Collegiate & High School	Instrumented Helmet	105	102.5 (33.8)	3977 (2272)
(Beckwith et al., 2013a)	American Football	Collegiate	Instrumented Helmet	50	71 (30)	3379 (1775)
(Rowson et al., 2018)	American Football	Collegiate	Instrumented Helmet	22	74 (26)	3742 (1653)
(Sanchez et al., 2019)	American Football	Professional	Anthropomorphic Test Dummy	20	94.3 (27.3)	6788 (1860)
(Funk et al., 2020)	American Football	Professional	Anthropomorphic Test Dummy	18	80 (31)	5857 (2345)
(Duhaime et al., 2012)	American Football	Collegiate	Instrumented Helmet	48	86.1 (42.6)	3620 (2166)
(McAllister et al., 2012)	Ice Hockey	Collegiate & High School	Instrumented Helmet	10	73.6 (21.3)	5025(1226)
(King et al., 2015)	Rugby Union	Amateur	Instrumented Mouthguard	2	74.9 (28.2)	7628 (3264)
(Rieffer et al., 2020b)	Rugby Union	Collegiate	Instrumented Mouthguard	2	78.2 (4.8)	-
(McIntosh et al., 2014)	Rugby League; Australian Rules Football	Professional	Multibody Modelling	27	103.4 (29.5)	7951 (3562)

This is a table depicting different studies tests for concussive impacts and the

	<p>forces that created those impacts, as well as how many that happened and by what method. This would allow me to refine and create a baseline idea for my parameters for a concussive possibility.</p>
<p><b>VOCAB: (w/definition)</b></p>	<p>Head Acceleration Exposure (HAE): The number and magnitude of head accelerations experienced by an athlete, including direct and indirect impacts.</p> <p>Finite Element (FE) Brain Model: A computational simulation that predicts tissue strain and deformation in the brain during impact.</p> <p>Instrumented Mouthguard: A mouthguard fitted with accelerometers and gyroscopes to record 6-degree-of-freedom head kinematics during play.</p> <p>Anthropomorphic Test Device (ATD): A crash test dummy designed to measure biomechanical responses under controlled impacts.</p> <p>Viscoelastic: viscous and elastic properties measurement combined</p>
<p><b>Cited references to follow up on</b></p>	<p>Bailes, J. E., Petraglia, A. L., Omalu, B. I., Nauman, E., &amp; Talavage, T. (2013). Role of sub concussion in repetitive mild traumatic brain injury. <i>Neurosurgery</i>, 75(4), S129–S137.*</p> <p>Rowson, S., &amp; Duma, S. M. (2013). Brain injury prediction: Assessing the combined probability of concussion using linear and rotational head acceleration. <i>Annals of Biomedical Engineering</i>, 41(5), 873–882.*</p> <p>Wu, L. C., Nangia, V., Bui, K., &amp; Camarillo, D. B. (2016). In vivo evaluation of wearable head impact sensors. <i>Annals of Biomedical Engineering</i>, 44(4), 1234–1245.*</p> <p>Kuo, C., Wu, L. C., Hammor, B. T., Luck, J. F., Cutcliffe, H. C., Lynall, R. C., ... &amp; Camarillo, D. B. (2016). Effect of the mandible on mouthguard measurements of head kinematics. <i>Journal of Biomechanics</i>, 49(9), 1845–1853.*</p>

	<p>Ghajari, M., Hellyer, P. J., &amp; Sharp, D. J. (2017). Computational modelling of traumatic brain injury predicts the location of chronic traumatic encephalopathy pathology. <i>Brain</i>, 140(2), 333–343.*</p>
<b>Follow up Questions</b>	<ul style="list-style-type: none"><li>• How can standardization be achieved for head impact measurement protocols across devices and sports?</li><li>• What are the most reliable thresholds of rotational acceleration that indicate risk of concussion?</li><li>• Can FE brain models be individualized using athlete-specific MRI data to improve predictive power?</li></ul>

# Article #11 Notes: Development of a Concussion Risk Function for a Youth Population Using Head Linear and Rotational Acceleration

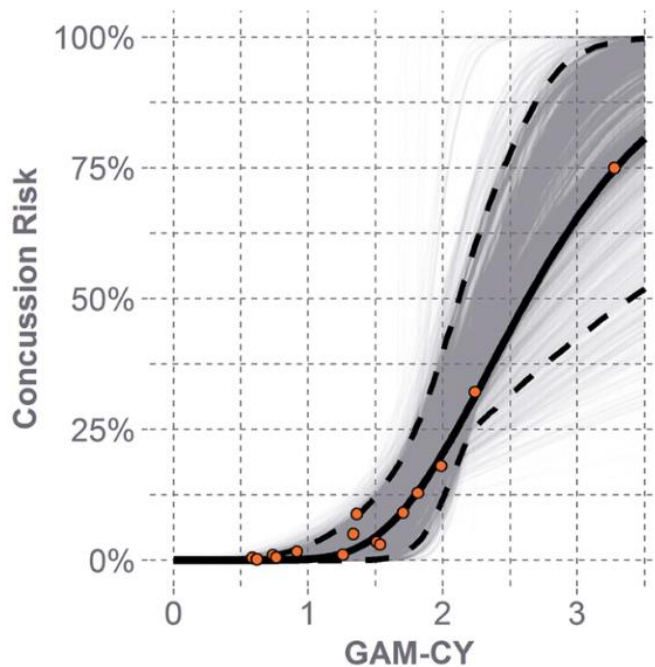
Article notes should be on separate sheets

<b>Source Title</b>	Development of a Concussion Risk Function for a Youth Population Using Head Linear and Rotational Acceleration
<b>Source citation (APA Format)</b>	Campolettano, E. T., Gellner, R. A., Smith, E. P., Bellamkonda, S., Tierney, C. T., Crisco, J. J., . . . Rowson, S. (2020). Development of a concussion risk function for a youth population using head linear and rotational acceleration. <i>Annals of Biomedical Engineering</i> , 48(1), 92-103. doi: <a href="https://doi.org/10.1007/s10439-019-02382-2">https://doi.org/10.1007/s10439-019-02382-2</a>
<b>Original URL</b>	<a href="https://doi.org/10.1007/s10439-019-02382-2">https://doi.org/10.1007/s10439-019-02382-2</a>
<b>Source type</b>	Scientific Journal Article
<b>Keywords</b>	Youth concussion, biomechanics, head acceleration, rotational acceleration, linear acceleration, football, brain injury, risk modeling, GAM-CY, survival analysis
<b>#Tags</b>	#forces #concussion #probability
<b>Summary of key points + notes (include methodology)</b>	<p>This study aimed to develop a concussion risk function tailored to youth athletes (ages 9–14) by combining head linear and rotational acceleration data. The researchers adapted the adult-focused Generalized Acceleration Model for Brain Injury Threshold (GAMBIT) into a youth-specific version called GAM-CY (Generalized Acceleration Model for Concussion in Youth).</p> <p>Using survival analysis and Kaplan–Meier estimators, data from 15 youth football players who sustained medically diagnosed concussions were compared to non-concussive impacts from a broader cohort (n = 124). The Head Impact Telemetry System (HIT System) captured linear and rotational acceleration values from over</p>

	<p>4,000 total player-seasons of data. Receiver Operating Characteristic (ROC) curves assessed predictive accuracy, with GAM-CY achieving an area under the curve (AUC) of 0.89, indicating strong predictive power. The study found that youth concussions occur at lower biomechanical thresholds—approximately 62.4 g linear acceleration and 2609 rad/s<sup>2</sup> rotational acceleration—compared to adult concussions (102.5 g and 4412 rad/s<sup>2</sup>, respectively).</p> <p>The findings suggest youth athletes are more vulnerable to concussions and that equipment testing standards should reflect these age-specific tolerances. The authors emphasize that helmet design and safety evaluation must consider these lower thresholds to effectively protect younger athletes.</p>
<b>Research Question/Problem/ Need</b>	How can a concussion risk function be developed specifically for youth athletes that accurately models concussion likelihood using both linear and rotational head accelerations?

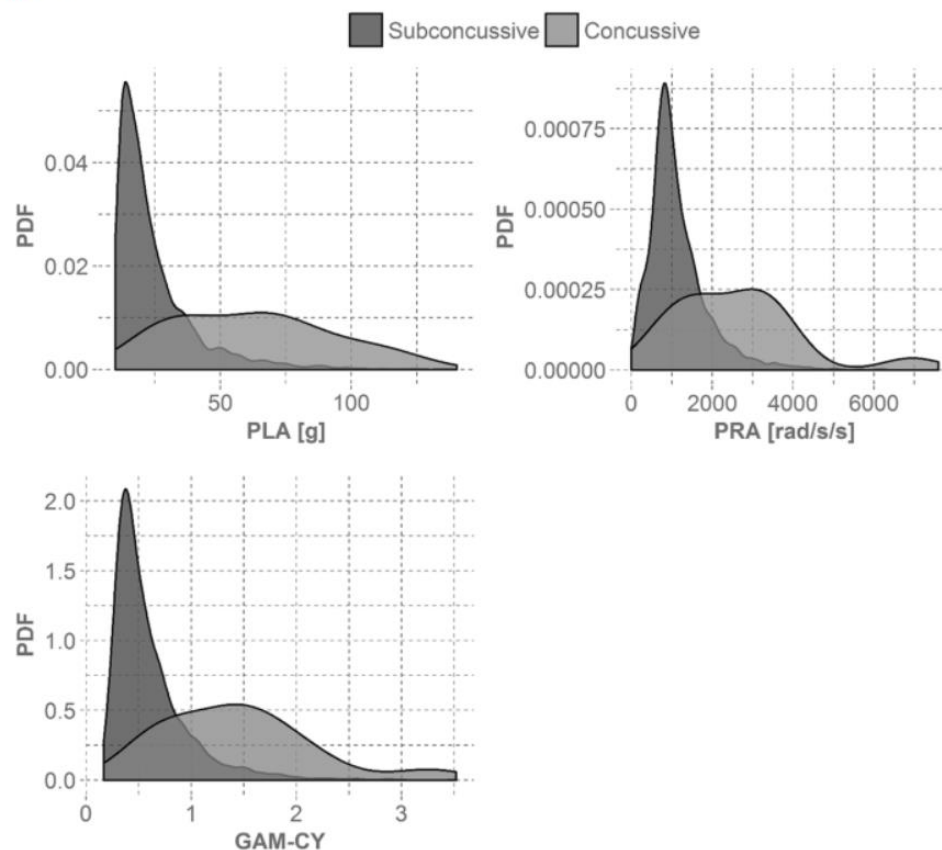
## Important Figures

Figure 3



Log-normal distribution fit to concussion data (solid line) with 95% confidence bounds (dashed lines). Most concussive head impacts were associated with lower values of GAM-CY. Fewer concussive head impacts were observed for higher values of GAM-CY ( $> 2$ ), so the 95% confidence bounds are much wider at these values. Gray lines represent log-normal distributions fit from the bootstrap samples for the concussion data.

Figure 1

**VOCAB: (w/definition)**

- Concussion risk function – Mathematical model predicting concussion likelihood.
- GAM-CY – Youth-specific concussion risk metric combining linear and rotational accelerations.
- Survival analysis – Statistical method for analyzing time-to-event data, adapted here for impact risk.
- Kaplan–Meier estimator – Nonparametric estimator used to calculate probability of concussion.
- ROC curve (Receiver Operator Characteristic) – Graphical tool assessing predictive accuracy.
- AUC (Area Under the Curve) – Quantifies the overall performance of a predictive model.

	<ul style="list-style-type: none"> <li>• Subconcussive impacts – Head impacts not resulting in diagnosed concussion.</li> <li>• Risk-weighted exposure – Aggregate measure combining impact frequency and magnitude.</li> </ul>
<b>Cited references to follow up on</b>	<ul style="list-style-type: none"> <li>• Rowson, S., &amp; Duma, S. M. (2013). <i>Brain injury prediction: Assessing the combined probability of concussion using linear and rotational head acceleration</i>. <i>Annals of Biomedical Engineering</i>, 41, 873–882.</li> <li>• Pellman, E. J., Viano, D. C., Tucker, A. M., Casson, I. R., &amp; Waeckerle, J. F. (2003). <i>Concussion in professional football: Reconstruction of game impacts and injuries</i>. <i>Neurosurgery</i>, 53, 799–812.</li> <li>• Rowson, S., &amp; Duma, S. M. (2011). <i>Development of the STAR evaluation system for football helmets: Integrating player head impact exposure and risk of concussion</i>. <i>Annals of Biomedical Engineering</i>, 39, 2130–2140.</li> </ul>
<b>Follow up Questions</b>	<ul style="list-style-type: none"> <li>• How could future studies expand the sample size beyond 15 concussed players to improve statistical confidence?</li> <li>• Can my helmets adapt to data given?</li> <li>• What potential biases might result from using the HIT System, and how could newer sensor technologies address them?</li> <li>• How does the Kaplan–Meier survival analysis approach compare to other statistical methods (e.g., logistic regression) for modeling concussion risk?</li> <li>• How might adding other biomechanical factors—like impact duration or location—alter the GAM-CY concussion predictions?</li> <li>• What explains the difference between youth and adult concussion tolerance besides head-body ratio and neck strength?</li> </ul>

## Article #12 Notes: Brain injury prediction: assessing the combined probability of concussion using linear and rotational head acceleration

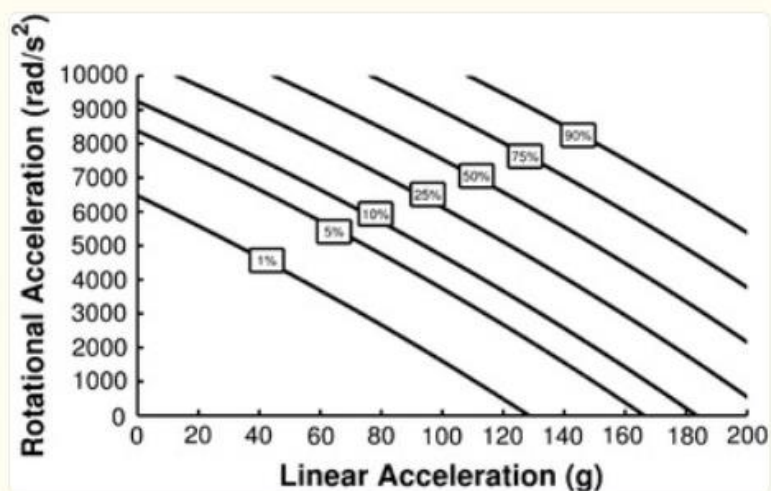
Article notes should be on separate sheets

<b>Source Title</b>	Brain injury prediction: assessing the combined probability of concussion using linear and rotational head acceleration
<b>Source citation (APA Format)</b>	Rowson S, Duma SM. Brain injury prediction: assessing the combined probability of concussion using linear and rotational head acceleration. <i>Ann Biomed Eng.</i> 2013 May;41(5):873-82. doi: 10.1007/s10439-012-0731-0. Epub 2013 Jan 9. PMID: 23299827; PMCID: PMC3624001.
<b>Original URL</b>	<a href="https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3624001/">https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3624001/</a>
<b>Source type</b>	Research Article (Journal)
<b>Keywords</b>	concussion risk, head acceleration, linear acceleration, rotational acceleration, combined probability, logistic regression, biomechanics, football, helmet instrumentation, head impact telemetry
<b>#Tags</b>	#concussion #forces #probability
<b>Summary of key points + notes (include methodology)</b>	This study by Rowson & Duma (2013) presents a novel injury risk metric — the <i>Combined Probability (CP) of Concussion</i> — which integrates both peak linear head acceleration (PLA) and peak rotational head acceleration (PRA) to estimate the likelihood that a single head impact will result in a concussion. To develop the CP metric, the authors compiled a large dataset from the HIT System (Head Impact Telemetry System) of instrumented football players (63,011 impacts

	<p>including 37 diagnosed concussions) and a secondary dataset from the NFL (impact reconstructions with dummy heads). They adjusted the dataset to account for under-reporting of concussions (estimating up to a 10× under-reporting rate) and used a multivariate logistic regression model (<math>CP = 1/(1 + e^{-(\beta_0 + \beta_1 \cdot a + \beta_2 \cdot \alpha + \beta_3 \cdot a \cdot \alpha)})</math>) to relate PLA (a) and PRA (<math>\alpha</math>) to concussion probability. They then compared the predictive performance (via ROC curves and area under the curve, AUC) of PLA alone, PRA alone, and CP across the two datasets. Results indicated that CP had the highest AUCs (0.982 in HITS; 0.892 in NFL) and significantly out-performed PRA, though in some cases PLA alone did similarly well. The authors conclude that combining linear and rotational acceleration improves concussion-risk estimation and suggest this metric has application in helmet design and safety testing. They also discuss limitations such as the focus on football, reliance on peak kinematics only, and the need for further work for rotational-dominant impacts.</p>
<p><b>Research Question/Problem/ Need</b></p>	<p>How effectively can a multivariate injury metric combining peak linear and rotational head accelerations predict the probability of concussion from a single head impact in football players, compared to metrics that consider only one kinematic parameter?</p>

## Important Figures

Figure 2.



[Open in a new tab](#)

Combined probability of concussion contours relating overall concussion risk to linear and rotational head acceleration

## VOCAB: (w/definition)

- Combined Probability (CP) of Concussion – The logistic regression-based metric introduced in this paper that estimates concussion risk for a given impact using PLA and PRA.
- Logistic regression – A statistical method modeling the probability of a binary outcome (here, concussion vs. no concussion) based on predictor variables.
- Receiver Operating Characteristic (ROC) curve – A plot of the true-positive rate vs. false-positive rate for a predictive model, across thresholds.
- Area Under the Curve (AUC) – The area under the ROC curve; a summary metric of model discriminative ability (1.0 = perfect, 0.5 =

	<p>chance).</p> <ul style="list-style-type: none"> <li>• Under-reporting (of concussion) – The phenomenon in which concussions occur but are not diagnosed or reported; this requires adjustment in datasets.</li> <li>• Head Impact Telemetry System (HITS) – Instrumentation system used in football helmets to measure head accelerations in real games/practices.</li> <li>• Risk contour – A graphical map (figure) showing constant levels (contours) of concussion probability in the space of PLA vs. PRA.</li> <li>• False positive rate / specificity – Metrics in predictive modeling: false positive rate is the proportion of non-concussion impacts incorrectly predicted as concussions; specificity is <math>1 - \text{false positive rate}</math>.</li> </ul>
<p><b>Cited references to follow up on</b></p>	<ul style="list-style-type: none"> <li>• Pellman, E. J., Viano, D. C., Tucker, A. M., Casson, I. R., &amp; Waeckerle, J. F. (2003). Concussion in professional football: reconstruction of game impacts and injuries. <i>Neurosurgery</i>, 53, 799–812.</li> <li>• Newman, J. A., Shewchenko, N., Welbourne, E., &amp; Brolinson, P. G. (2000). A proposed new biomechanical head injury assessment function—The maximum power index. <i>Stapp Car Crash Journal</i>, 44, 215–229.</li> <li>• Beckwith, J. G., Chu, J. J., &amp; Greenwald, R. M. (2007). Validation of a noninvasive system for measuring head acceleration for use during boxing competition. <i>Journal of Applied Biomechanics</i>, 23(3), 238–244.</li> <li>• Young, C., et al. (2014). Predicting mild traumatic brain injury with injury risk functions and finite element head models. <i>Annals of Biomedical Engineering</i>, 42(2), 338–350.</li> </ul>
<p><b>Follow up Questions</b></p>	<ul style="list-style-type: none"> <li>• How does the assumption of a 10× under-reporting rate of concussions affect the CP metric’s estimates, and how sensitive are the results to different under-reporting assumptions?</li> </ul>

- Given that PLA alone performed nearly as well as CP in some datasets, what is the added value of including PRA in predicting concussion, and in what contexts might it matter more?
- How might the CP model extend (or fail to extend) to other sports (e.g., soccer, hockey) or to impacts with different kinematic profiles (e.g., rotational-dominant impacts)?
- What role do other factors (impact location, duration, neck strength, prior concussion history) play in concussion risk, and how could they be integrated into risk-prediction models beyond PLA and PRA?
- For helmet design and certification, how might this CP metric be operationalized (e.g., selecting test conditions, setting threshold levels) and what practical challenges remain in its adoption?

## Article #13 Notes: Head Impact Density: A Model To Explain the Elusive Concussion Threshold

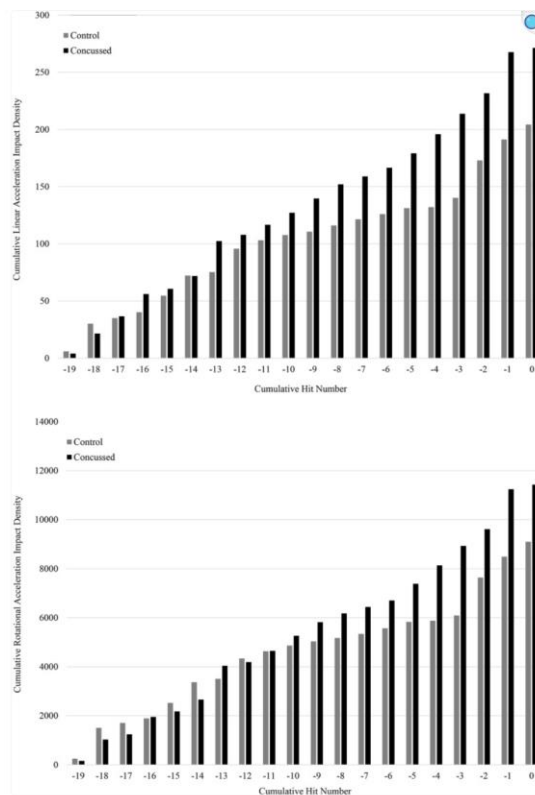
Article notes should be on separate sheets

<b>Source Title</b>	Head Impact Density: A Model To Explain the Elusive Concussion Threshold
<b>Source citation (APA Format)</b>	Broglio, S. P., Lapointe, A., O'Connor, K. L., & McCrea, M. (2017). <i>Head Impact Density: A Model To Explain the Elusive Concussion Threshold</i> . <i>Journal of Neurotrauma</i> , 34(19), 2713-2720. <a href="https://doi.org/10.1089/neu.2016.4767">https://doi.org/10.1089/neu.2016.4767</a>
<b>Original URL</b>	<a href="https://pmc.ncbi.nlm.nih.gov/articles/PMC5647505/">https://pmc.ncbi.nlm.nih.gov/articles/PMC5647505/</a>
<b>Source type</b>	Research article
<b>Keywords</b>	concussion risk; head impacts; linear acceleration; rotational acceleration; impact density; repeated head impacts; biomechanics; youth/ high-school football
<b>#Tags</b>	#model #concussion
<b>Summary of key points + notes (include methodology)</b>	This study by Broglio et al. (2017) proposes a novel metric called Impact Density to better explain why concussions may occur at seemingly lower or variable head-impact magnitudes. Recognizing that concussion thresholds are elusive and that individual impacts alone often fail to distinguish concussive from non-concussive events, the authors gathered head-impact kinematic data from high school football athletes across seven seasons using the HIT System (Head Impact Telemetry System) instrumentation. They included 29 diagnosed concussions, matched each concussed athlete with a control athlete based on impact magnitude of the final injurious impact, and then analyzed the preceding 20 impacts leading up to the injury (or matched time for the control). They computed Impact Density by summing

	<p>acceleration magnitudes (linear and rotational) of those prior impacts and dividing by the time interval from the previous impact to account for both magnitude and frequency/time between impacts. The key findings were that while the individual impact magnitudes of the final (or preceding) impacts did <i>not</i> significantly differ between concussed and control athletes, the Impact Density (both linear and rotational) was significantly higher in the concussed group. For example, linear Impact Density for concussed athletes was ~255.4 g/s vs ~145.4 g/s for controls (<math>p = 0.016</math>). Rotational Impact Density showed similar differences (<math>p = 0.029</math>). The authors interpret this as evidence that not just a single high-magnitude impact but the cumulative burden, frequency and short inter-impact rest times (i.e., higher impact density) reduce concussion tolerance. They suggest that the biomechanical threshold for concussion is dynamic and may fluctuate downward with increased load and reduced recovery time. They propose that practitioners and equipment standards should consider temporal accumulation of head impacts, not only peak magnitudes.</p>
<b>Research Question/Problem/Need</b>	<p>Can a metric that combines head-impact magnitude and the time interval between impacts (Impact Density) better discriminate athletes who sustain concussion from matched controls than magnitude-only metrics of individual impacts?</p>

## Important Figures

FIG. 4.



Cumulative linear (top) and rotational (bottom) acceleration Impact Density displayed for the final impact and the 19 preceding impacts. Impact Density for the final impact (i.e., impact 0) represents the sum of all previous impacts for linear or rotational acceleration sum divided by the time from the previous impact. Impact Density was higher among the Concussed athletes for both linear and rotational acceleration.

## VOCAB: (w/definition)

- Impact Density – A novel metric summing acceleration magnitude divided by the time from the previous impact; reflects magnitude + temporal proximity of impacts.
- Head Impact Telemetry (HIT) System – A helmet-based sensor system used to record head acceleration events during sport.
- Biomechanical tolerance – The threshold or capacity of head/brain system to endure an impact without resulting in injury (e.g., concussion).
- Concussive event – A head impact or sequence of impacts culminating in a diagnosed concussion.
- Matched control – In this context, a non-concussed athlete selected to match the concussed athlete's magnitude of final impact for

	<p>comparison.</p> <ul style="list-style-type: none"> <li>• Cumulative burden – The total load (number × magnitude) of head impacts over a period of time.</li> <li>• Inter-impact interval – The time between successive head impacts; shorter intervals may limit recovery and raise risk.</li> <li>• Temporal accumulation – Concept that repeated impacts in close time sequence reduce recovery and thus tolerance, shifting injury threshold downward.</li> </ul>
<p><b>Cited references to follow up on</b></p>	<ul style="list-style-type: none"> <li>• Beckwith, J. G., Greenwald, R. M., &amp; Chu, J. J. (2013). Timing of concussion diagnosis is related to head impact exposure prior to injury. <i>Medicine &amp; Science in Sports &amp; Exercise</i>, 45(4), 747-754.</li> <li>• Urban, J. E., Davenport, E. M., Golman, A. J., Maldjian, J. A., Whitlow, C. T., Powers, A. K., &amp; Stitzel, J. D. (2013). Head impact exposure in youth football: high school ages 14 to 18 years and cumulative impact analysis. <i>Annals of Biomedical Engineering</i>, 41(12), 2474-2487.</li> <li>• McAllister, T. W., Ford, J. C., Ji, S., Beckwith, J. G., Flashman, L. A., Paulsen, K., &amp; Greenwald, R. M. (2012). Maximum principal strain and strain rate associated with concussion diagnosis correlates with changes in corpus callosum white matter indices. <i>Annals of Biomedical Engineering</i>, 40(1), 127-140.</li> </ul>
<p><b>Follow up Questions</b></p>	<ul style="list-style-type: none"> <li>• Does the Impact Density concept apply equally across different age groups, sexes, or sports (e.g., youth vs collegiate, football vs hockey vs soccer)?</li> <li>• How does the inter-impact interval (time between impacts) specifically modulate concussion risk, and what recovery windows might be optimal for reducing risk?</li> </ul>

- Could monitoring of Impact Density in real time (e.g., via helmets or mouthguards) enable proactive interventions (e.g., removing a player) before concussion onset?

## Article #14 Notes: Concussive Head Impact Biomechanics in Women's Lacrosse and Soccer Athletes: A Case Series

Article notes should be on separate sheets

<b>Source Title</b>	Concussive Head Impact Biomechanics in Women's Lacrosse and Soccer Athletes: A Case Series
<b>Source citation (APA Format)</b>	Sayre, H. D., Bradney, D. A., Breedlove, K. M., & Bowman, T. G. (2019). <i>Concussive head impact biomechanics in women's lacrosse and soccer athletes: A case series</i> . <i>Athletic Training &amp; Sports Health Care</i> , 11(3), 143-146.  <a href="https://doi.org/10.3928/19425864-20190228-01">https://doi.org/10.3928/19425864-20190228-01</a>
<b>Original URL</b>	<a href="https://journals.healio.com/doi/10.3928/19425864-20190228-01">https://journals.healio.com/doi/10.3928/19425864-20190228-01</a>
<b>Source type</b>	Journal Article
<b>Keywords</b>	concussion biomechanics; women's lacrosse; women's soccer; head impact kinematics; peak linear acceleration; peak rotational acceleration; unhelmeted sport; case series; instrumented sensor; sport injury prevention
<b>#Tags</b>	#concussion #forces #exact
<b>Summary of key points + notes (include methodology)</b>	This study by Sayre et al. (2019) presents a case series of four female collegiate athletes (two from lacrosse, two from soccer) who sustained clinically diagnosed concussions. The authors report on the biomechanics of the head impact events associated with their injuries, including measured peak linear and rotational accelerations from in-field instrumentation. They found that the recorded kinematics in these female unhelmeted sports were <i>much lower</i> in magnitude than typical thresholds reported in male helmeted sports. For example, one lacrosse athlete had a stick-to-head impact of 15.8 g linear and 2,693 rad/s <sup>2</sup> rotational acceleration; another had 76.5 g linear and 11,976 rad/s <sup>2</sup> . The

	<p>methodology involves identifying the concussion event, matching the impact with sensor data (or video verification), and reporting the metrics of that impact. The authors discuss how the low magnitudes challenge the notion of universal concussion thresholds and highlight the potential need for sex- and sport-specific biomechanical criteria. They propose that female athletes in unhelmeted sports may incur concussion at lower kinematic magnitudes and that equipment, rules, and prevention strategies should reflect this.</p>																																																																
<p><b>Research Question/Problem/ Need</b></p>	<p>In female athletes participating in unhelmeted contact/collision sports (specifically lacrosse and soccer), what are the measured head-impact kinematics (linear and rotational acceleration) associated with a clinically diagnosed concussion, and how do these values compare to published thresholds in other populations?</p>																																																																
<p><b>Important Figures</b></p>	<p style="text-align: center;"><b>TABLE 1</b> <b>Biomechanical Data of Concussive Impacts</b></p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th rowspan="2">Characteristic</th> <th colspan="2">Women's Soccer</th> <th colspan="2">Women's Lacrosse</th> </tr> <tr> <th>Participant 1</th> <th>Participant 2</th> <th>Participant 3</th> <th>Participant 4</th> </tr> </thead> <tbody> <tr> <td>Position</td> <td>Defender</td> <td>Forward</td> <td>Attacker</td> <td>Attacker</td> </tr> <tr> <td>Age (y)</td> <td>19</td> <td>18</td> <td>22</td> <td>20</td> </tr> <tr> <td>Peak LA (g)</td> <td>55.86</td> <td>19.08</td> <td>15.78</td> <td>76.52</td> </tr> <tr> <td>Peak RA (rad/s<sup>2</sup>)</td> <td>5,614.11</td> <td>5,426.72</td> <td>2,693.18</td> <td>11,976.06</td> </tr> <tr> <td>Impact location</td> <td>Front</td> <td>Side</td> <td>Front</td> <td>Side</td> </tr> <tr> <td>Duration (ms)</td> <td>12</td> <td>9</td> <td>10</td> <td>17</td> </tr> <tr> <td>Impacts<sup>a</sup></td> <td>9</td> <td>7</td> <td>1</td> <td>5</td> </tr> <tr> <td>Cumulative LA (g)<sup>b</sup></td> <td>220.02</td> <td>108.61</td> <td>15.78</td> <td>167.53</td> </tr> <tr> <td>Cumulative RA (rad/s<sup>2</sup>)<sup>c</sup></td> <td>50,091.25</td> <td>14,732.30</td> <td>2,693.19</td> <td>246,971.30</td> </tr> <tr> <td>Mechanism of impact</td> <td>Head-to-head</td> <td>Head-to-ground</td> <td>Stick-to-head</td> <td>Stick-to-head</td> </tr> <tr> <td>Event</td> <td>Game (legal impact)</td> <td>Practice</td> <td>Practice</td> <td>Game (penalized illegal impact)</td> </tr> </tbody> </table> <p><small>LA = linear acceleration; RA = rotational acceleration  <sup>a</sup>Number of impacts on the day of concussion.  <sup>b</sup>Cumulative LA on the day of concussion.  <sup>c</sup>Cumulative RA on the day of concussion.</small></p>	Characteristic	Women's Soccer		Women's Lacrosse		Participant 1	Participant 2	Participant 3	Participant 4	Position	Defender	Forward	Attacker	Attacker	Age (y)	19	18	22	20	Peak LA (g)	55.86	19.08	15.78	76.52	Peak RA (rad/s <sup>2</sup> )	5,614.11	5,426.72	2,693.18	11,976.06	Impact location	Front	Side	Front	Side	Duration (ms)	12	9	10	17	Impacts <sup>a</sup>	9	7	1	5	Cumulative LA (g) <sup>b</sup>	220.02	108.61	15.78	167.53	Cumulative RA (rad/s <sup>2</sup> ) <sup>c</sup>	50,091.25	14,732.30	2,693.19	246,971.30	Mechanism of impact	Head-to-head	Head-to-ground	Stick-to-head	Stick-to-head	Event	Game (legal impact)	Practice	Practice	Game (penalized illegal impact)
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<p><b>VOCAB: (w/definition)</b></p>	<ul style="list-style-type: none"> <li>• Unhelmeted sport – A sport in which athletes do not wear helmets (e.g., women’s lacrosse, soccer) and thus biomechanics may differ.</li> <li>• Case series – A descriptive research design reporting on a small number of cases (here, four athletes) without a control group.</li> <li>• Kinematic threshold – The magnitude of head kinematics above which injury (e.g., concussion) is expected to occur; here questioned for women’s sports.</li> </ul>																																																																

	<ul style="list-style-type: none"> <li>• Stick-to-head impact – A mechanism of contact in lacrosse where a stick strikes the head of a player, causing an impact.</li> <li>• Instrumented sensor – A device (accelerometer/gyroscope) embedded or attached to record head movement during impacts in the field.</li> <li>• Biomechanical criterion – A measurable mechanical variable (like acceleration) used to predict injury risk.</li> <li>• Helmeted vs unhelmeted athlete – Refers to whether athletes wear protective helmets; this affects impact dynamics and thresholds.</li> <li>• Sex-specific biomechanics – The concept that biomechanical responses (e.g., head acceleration tolerance) may differ between male and female athletes.</li> </ul>
<p><b>Cited references to follow up on</b></p>	<ul style="list-style-type: none"> <li>• Lynall, R. C., Clark, M. D., Grand, E. E., Stucker, J. C., Littleton, A. C., &amp; Mihalik, J. P. (2016). Head impact biomechanics in women’s college soccer. <i>Medicine &amp; Science in Sports &amp; Exercise</i>, 48(9), 1772-1778. <a href="#">PubMed+1</a></li> <li>• Rowson, S., &amp; Duma, S. M. (2013). Brain injury prediction: assessing the combined probability of concussion using linear and rotational head acceleration. <i>Annals of Biomedical Engineering</i>, 41(5), 873-882. <a href="https://doi.org/10.1007/s10439-012-0731-0">https://doi.org/10.1007/s10439-012-0731-0</a></li> <li>• Patton, D. A., Huber, C. M., Arbogast, K. B., Fedonni, D., Margulies, S. S. (2022). Quantifying head impact exposure, mechanisms and kinematics using an instrumented mouthguard in female high school lacrosse. <i>Frontiers in Neurology</i>. <a href="#">PMC</a></li> <li>• Caswell, S. V., Breedlove, K. M., et al. (2020). Video-confirmed head impacts in female high school lacrosse: initial magnitudes and mechanisms. <i>Journal of Neurotrauma</i>. (Exact citation to be confirmed.)</li> </ul>

**Follow up Questions**

- Given the small sample size ( $n=4$ ), what study design and sample size would be needed to establish a statistically robust concussion threshold for female unhelmeted athletes?
- How do factors such as neck strength, head-size, impact location, or mechanism (stick vs ball vs player contact) contribute to concussion risk in these sports, beyond just PLA and PRA?

# Article #15 Notes: Six Degree-of-Freedom Measurements of Human Mild Traumatic Brain Injury

Article notes should be on separate sheets

<b>Source Title</b>	Six Degree-of-Freedom Measurements of Human Mild Traumatic Brain Injury
<b>Source citation (APA Format)</b>	Hernandez, F., Wu, L. C., Yip, M. C., Laksari, K., Hoffman, A. R., Lopez, J. R., Grant, G. A., Kleiven, S., & Camarillo, D. B. (2015). <i>Six degree-of-freedom measurements of human mild traumatic brain injury</i> . <i>Annals of Biomedical Engineering</i> , 43(8), 1918-1934. <a href="https://doi.org/10.1007/s10439-014-1212-4">https://doi.org/10.1007/s10439-014-1212-4</a>
<b>Original URL</b>	<a href="https://link.springer.com/article/10.1007/s10439-014-1212-4">https://link.springer.com/article/10.1007/s10439-014-1212-4</a>
<b>Source type</b>	Peer Reviewed Journal Article
<b>Keywords</b>	mild traumatic brain injury (mTBI); six-degree-of-freedom kinematics; head impact sensors; linear and rotational acceleration; angular velocity; angular acceleration; human head biomechanics; concussion prediction; head impact telemetry; brain injury thresholds
<b>#Tags</b>	#concussion #forces #position
<b>Summary of key points + notes (include methodology)</b>	Hernandez et al. (2015) present a study that takes advantage of six-degree-of-freedom (6DOF) head-kinematic measurements in human subjects who sustained mild traumatic brain injury (mTBI) to better understand how head motion in all axes (translations + rotations) relates to brain injury. The methodology involves instrumenting athletes with advanced sensors capable of capturing full 6DOF kinematics (linear accelerations, angular velocities, angular accelerations) during head impacts, and then matching those measurements with clinically diagnosed mTBI events. The authors compare these measured kinematics to non-injury impacts to explore differences and attempt to refine injury prediction. Key findings

include that many head impacts leading to mTBI involve substantial rotational components (angular velocity / acceleration) and that kinematic predictors focusing only on linear acceleration are insufficient. They also show that rotational kinematics in multiple axes improved the predictive power for brain injury when combined appropriately. The study argues for the inclusion of full 6DOF head motion data in injury risk modelling, helmet design, and monitoring of athletes. It also discusses limitations such as sample size, sensor placement, and variability in impact conditions.

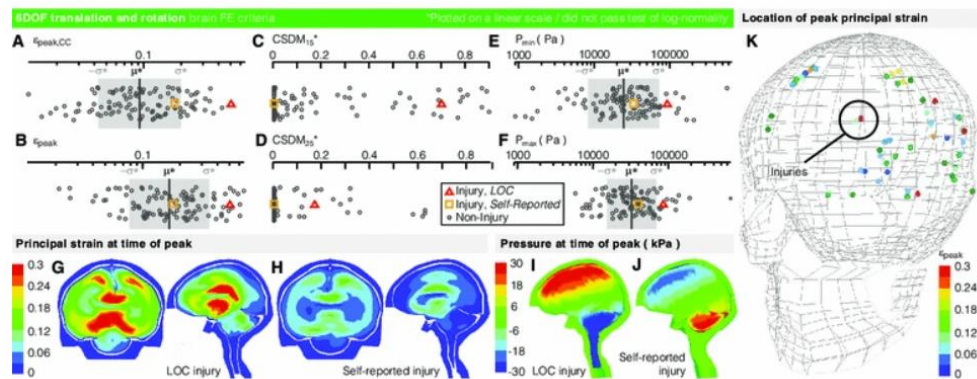
**Research Question/Problem/ Need**

Can six-degree-of-freedom head kinematic measurements (including translational and rotational movements in all axes) in human head impacts improve the prediction of mild traumatic brain injury compared to more limited kinematic measures?

**Important Figures**

## Figure 5

### From: Six Degree-of-Freedom Measurements of Human Mild Traumatic Brain Injury



Brain deformation injury criteria. Injury and non-injury values for each (a-f) brain deformation criteria are given for the subset of 110 impacts. Multiplicative standard deviation,  $\sigma^*$ , and log-normal median,  $\mu^*$ , are indicated (all criteria except CSDM passed a test of log-normality). Fringe plots of (g-h) principal strain and (i-j) pressure indicate regions of greatest brain deformation. (K) Peak principal strain in both injuries uniquely occurred in the corpus callosum

*Head Injury Criterion* (HIC<sub>15</sub> and HIC<sub>36</sub>)[21,45,51,63,78](#) is the most widely used injury criteria and was calculated as,

$$HIC = \max_{t_1, t_2} \left\{ \left[ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \|\vec{\mathbf{a}}(t)\| dt \right]^{2.5} (t_2 - t_1) \right\}$$

(2)

where  $\|\vec{\mathbf{a}}(t)\|$  is the magnitude of translational acceleration and the times  $t_1$  and  $t_2$  are chosen to maximize the value of HIC, bounded by  $t_2 - t_1 < 15$  ms for HIC<sub>15</sub> or  $t_2 - t_1 < 36$  ms for HIC<sub>36</sub>.

*Severity Index* (SI)[7,8,23,51,63](#) also known as Gadd Severity Index (GSI), is given by,

$$SI = \int \|\vec{\mathbf{a}}(t)\|^{2.5} dt$$

#### VOCAB: (w/definition)

- Six-degree-of-freedom (6DOF) – Movement in three translational axes (X, Y, Z) and three rotational axes (pitch, yaw, roll).
- Angular velocity – The rate of rotation of the head (often in rad/s) about an axis.
- Angular acceleration – The rate of change of angular velocity (rad/s<sup>2</sup>) during impact.
- Translational acceleration (linear acceleration) – Straight-line movement acceleration of the head (in g's) during impact.
- Head impact telemetry – Use of sensors to record head motion during impacts in sports/activities.
- mild traumatic brain injury (mTBI) – A concussion or brain injury of mild severity, often characterized by brief loss or alteration of consciousness/neurological symptoms.
- Biomechanical threshold – A level of kinematic input (acceleration, velocity, etc.) above which injury is likely to occur.
- Predictive modelling (injury risk metric) – Mathematical/statistical models that estimate the probability of injury based on input variables (e.g.,

	<p>kinematics).</p> <ul style="list-style-type: none"> <li>• Wearable sensor validation – The process of assessing the accuracy and reliability of sensors worn by subjects to measure head kinematics.</li> <li>• Vector resultant – The combined magnitude of a vector composed of multiple components (e.g., resultant angular velocity combining pitch, yaw, roll).</li> </ul>
<p><b>Cited references to follow up on</b></p>	<ul style="list-style-type: none"> <li>• Rowson, S., &amp; Duma, S. M. (2013). <i>Brain injury prediction: assessing the combined probability of concussion using linear and rotational head acceleration</i>. <i>Annals of Biomedical Engineering</i>, 41(5), 873-882. <a href="https://doi.org/10.1007/s10439-012-0731-0">https://doi.org/10.1007/s10439-012-0731-0</a></li> <li>• Ji, S., Zhao, W., Camarillo, D. B., Beckwith, J. G., Greenwald, R. M., &amp; Zhang, L. / (2014). Evaluation of brain strain as a predictor for injury using finite element modeling of head impacts. (Exact citation needs confirmation)</li> <li>• Kleiven, S. (2007). Predictors for traumatic brain injuries evaluated through accident reconstructions. <i>Stapp Car Crash Journal</i>, 51, 81-114.</li> <li>• Gabler, L. F., Crandall, J. R., &amp; Panzer, M. B. (2016). Assessment of kinematic brain injury metrics for predicting strain responses in diverse automotive impact conditions. <i>Annals of Biomedical Engineering</i>, 44(12), 3705-3718. <a href="https://doi.org/10.1007/s10439-016-1697-0">https://doi.org/10.1007/s10439-016-1697-0</a></li> </ul>
<p><b>Follow up Questions</b></p>	<ul style="list-style-type: none"> <li>• How would the inclusion of head impact location (impact vector/direction) further refine the predictive models based on 6DOF kinematics?</li> <li>• Given sensor placement and orientation errors in wearable systems, how reliable are the rotational measurements in real-world athlete impacts compared to lab settings?</li> <li>• How might the predictive models developed in this study vary across populations (e.g., age groups, sexes, sports) and what recalibrations would</li> </ul>

	be needed?
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# Article #16 Notes: The Controversial Second Impact Syndrome: A Review of the Literature

Article notes should be on separate sheets

<b>Source Title</b>	The Controversial Second Impact Syndrome: A Review of the Literature
<b>Source citation (APA Format)</b>	Giza, C. C., & Hovda, D. A. (2016). <i>The controversial second impact syndrome: A review of the evidence</i> . <i>Pediatric Neurology</i> , 64, 29–35.  <a href="https://doi.org/10.1016/j.pediatrneurol.2016.03.009">https://doi.org/10.1016/j.pediatrneurol.2016.03.009</a>
<b>Original URL</b>	<a href="#">The Controversial Second Impact Syndrome: A Review of the Literature - ScienceDirect</a>
<b>Source type</b>	Peer-reviewed journal article
<b>Keywords</b>	Second impact syndrome, Concussion, traumatic brain injury, pediatric neurology, sports injury
<b>#Tags</b>	#forces #concussion #second impact
<b>Summary of key points + notes (include methodology)</b>	This review article critically examines the evidence surrounding second impact syndrome (SIS) — a hypothesized condition in which an athlete sustains a second concussion while still recovering from an initial brain injury, leading to rapid neurological deterioration and potentially fatal cerebrovascular swelling. The authors synthesize clinical case reports, biomechanical theories of concussion, and existing epidemiological data to evaluate whether SIS represents a distinct pathological phenomenon or reflects mischaracterized severe traumatic brain injury. The methodology of the review consists of

	<p>systematic analysis of published cases, evaluation of diagnostic criteria used in SIS reports, and comparison with standard concussion pathophysiology. The authors emphasize inconsistencies in reported case definitions, lack of clear diagnostic biomarkers, and the difficulty in distinguishing true SIS from atypically severe single injuries. They also discuss biomechanical and physiological mechanisms that have been proposed (e.g., impaired cerebral autoregulation following an initial concussion) and critique the quality of evidence supporting them, calling for more rigorous research designs to clarify the existence and mechanisms of SIS.</p>
<b>Research Question/Problem/Need</b>	<p>What is the clinical and scientific evidence that second impact syndrome is a valid and distinct neurological condition, and how reliably can it be diagnosed and distinguished from other forms of traumatic brain injury?</p>
<b>Important Figures</b>	<p>None provided</p>
<b>VOCAB: (w/definition)</b>	<p><b>Second Impact Syndrome (SIS)</b> – A hypothesized scenario where a second head impact occurs before recovery from a first concussion, allegedly causing rapid and severe brain swelling.</p> <p><b>Cerebral autoregulation</b> – The brain’s ability to maintain stable blood flow despite changes in blood pressure.</p> <p><b>Neurological deterioration</b> – Worsening of brain function, such as loss of consciousness, vomiting, or pupillary changes, potentially linked to increased intracranial pressure.</p>
<b>Cited references to follow up on</b>	<p>Guskiewicz, K. M. et al. (2003). <i>Epidemiology of concussion in collegiate and high school football players. American Journal of Sports Medicine.</i></p> <p>McCrory, P. et al. (2017). <i>Consensus statement on concussion in sport — 5th International Conference on Concussion in Sport. British Journal of Sports</i></p>

	<p><i>Medicine.</i></p> <p>Cantu, R. C. (1998). <i>Second-impact syndrome. Clinical Sports Medicine.</i></p> <p>Aubry, M. et al. (2002). <i>Summary and agreement statement of the First International Conference on Concussion in Sport. British Journal of Sports Medicine.</i></p> <p>Giza, C. C., &amp; Hovda, D. A. (2001). <i>The neurometabolic cascade of concussion. Journal of Athletic Training.</i></p>
<b>Follow up Questions</b>	<ul style="list-style-type: none"><li>• What are the key methodological challenges in differentiating second impact syndrome from atypically severe single-incident concussions?</li><li>• How do current imaging technologies (e.g., functional MRI, diffusion tensor imaging) contribute to or limit our understanding of concussion recovery timelines?</li><li>• In what ways do consensus concussion protocols (e.g., SCAT5) address or fail to address the concept of SIS in athletic settings?</li></ul>

## Article #17 Notes: The Helmet Fit Index – An intelligent tool for fit assessment and design customisation

Article notes should be on separate sheets

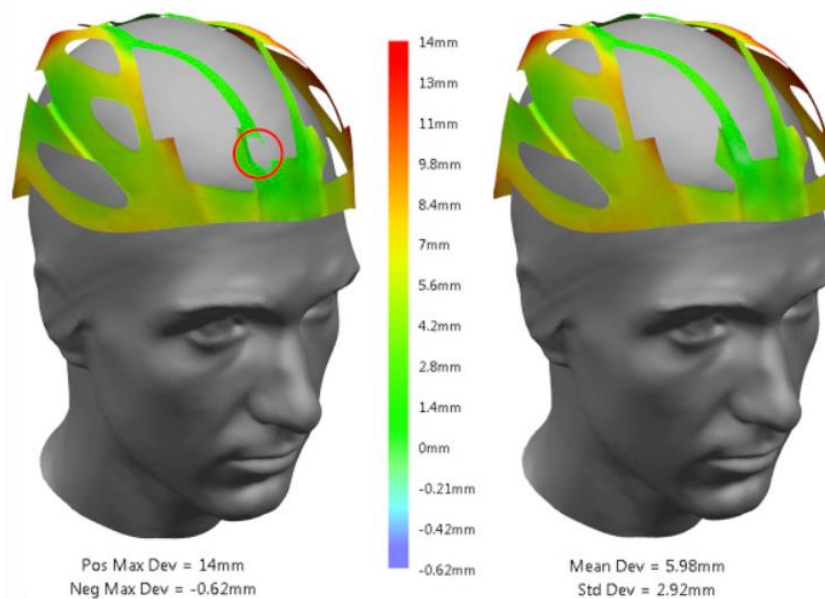
<b>Source Title</b>	The Helmet Fit Index – An intelligent tool for fit assessment and design customisation
<b>Source citation (APA Format)</b>	Ellena, T., Subic, A., Mustafa, H., & Pang, T. Y. (2016). The helmet fit index — an intelligent tool for fit assessment and design customisation. <i>Applied Ergonomics</i> , 55, 194–207. <a href="https://doi.org/10.1016/j.apergo.2016.02.008">https://doi.org/10.1016/j.apergo.2016.02.008</a>
<b>Original URL</b>	<a href="#">The Helmet Fit Index – An intelligent tool for fit assessment and design customisation - ScienceDirect</a>
<b>Source type</b>	Peer-reviewed journal article
<b>Keywords</b>	Helmet fit index; helmet fit; 3D anthropometry; reverse engineering; computational analysis; design customisation; protective equipment; ergonomics; cycling helmet fit
<b>#Tags</b>	#fit, #concussion
<b>Summary of key points + notes (include methodology)</b>	This article introduces the Helmet Fit Index (HFI), a novel quantitative metric for assessing how well a protective helmet conforms to an individual wearer’s head. The authors address the lack of objective fit standards by combining 3D anthropometric scanning, reverse engineering, and computational analysis to develop an index that produces a fit score from 0 (poor fit) to 100 (ideal fit). The methodology involved capturing detailed three-dimensional head and helmet liner

surface geometry, computing spatial distances across the head-liner interface, and synthesizing this data into a single fit index score. The authors then compared these quantitative HFI scores against subjective fit perceptions reported by a sample of cyclists wearing three commercially available helmets. Statistical analysis (e.g., correlation between HFI and subjective assessments) was used to validate whether the HFI reflects user experience. The results indicate that HFI scores correlate with cyclists' perceived fit and reveal demographic differences, with females and Asian participants tending to score lower on average compared to male and Caucasian participants. The study demonstrates the utility of quantitative assessment for helmet ergonomic design and suggests that HFI could inform helmet development for improved safety and comfort.

**Research  
Question/Problem/ Need**

How can helmet fit be objectively quantified across diverse head shapes to improve protective performance and user comfort in helmet design, addressing the shortcomings of subjective or one-dimensional fit measures?

**Important Figures**



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[Download: Download full-size image](#)

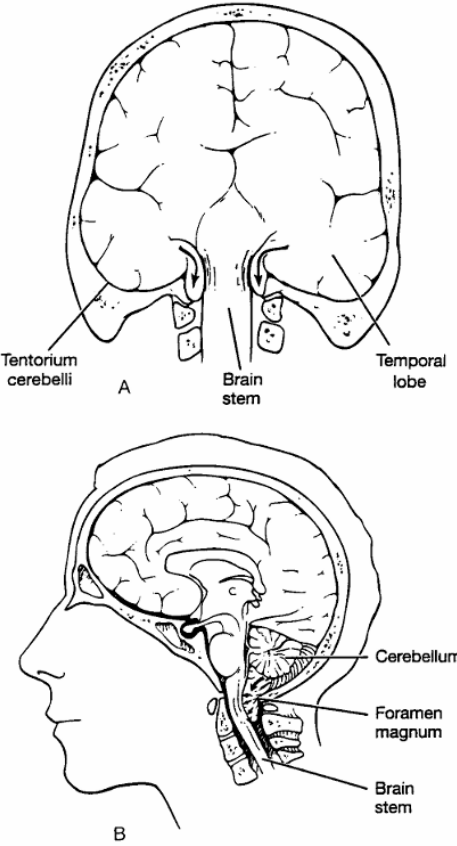
Fig.9. Gap analysis texture maps before (interferences marked in the red circle) and after offset. Hair thickness was 0.62mm, and SOD and GU were 5.98mm and 2.92mm, respectively.(For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

<b>VOCAB: (w/definition)</b>	<p>Helmet Fit Index (HFI) – A computed score (0–100) that quantifies the quality of fit between a wearer’s head and a helmet liner based on 3D spatial measurements.</p> <p>3D anthropometry – The measurement of human body dimensions using three-dimensional scanning technologies to capture accurate shape and size</p>
<b>Cited references to follow up on</b>	<p>Rowson, S., &amp; Duma, S. M. (2013). Brain injury prediction: Assessing the combined probability of concussion using linear and rotational head acceleration. <i>Annals of Biomedical Engineering</i>. <a href="#">PubMed</a></p> <p>McCrory, P., et al. (2017). Consensus statement on concussion in sport — 5th International Conference on Concussion in Sport. <i>British Journal of Sports Medicine</i>.</p> <p>Guskiewicz, K. M., et al. (2003). Epidemiology of concussion in collegiate and high school football players. <i>American Journal of Sports Medicine</i>.</p>
<b>Follow up Questions</b>	<p>What are the limitations of using distance-based fit metrics like HFI when evaluating helmet performance under dynamic impact conditions?</p> <p>How could the Helmet Fit Index be extended to account for tissue compression and soft-tissue deformation during impact?</p>

## Article #18 Notes: Second-impact syndrome

Article notes should be on separate sheets

<b>Source Title</b>	Second-impact syndrome
<b>Source citation (APA Format)</b>	Cantu, R. C. (1998). Second-impact syndrome. <i>Clinics in Sports Medicine</i> , 17(1), 37–44.
<b>Original URL</b>	<a href="#">Second-impact syndrome - PubMed</a>
<b>Source type</b>	Peer-reviewed review article
<b>Keywords</b>	Second-impact syndrome; concussion; cerebral edema; intracranial pressure; brain autoregulation; head trauma; contact sports; catastrophic injury; biomechanics of injury
<b>#Tags</b>	#second impact #concussion
<b>Summary of key points + notes (include methodology)</b>	<p>This article provides a clinical and pathophysiological review of second-impact syndrome (SIS), a rare but often fatal condition that occurs when an athlete sustains a second head injury before symptoms from an initial concussion have resolved. The author synthesizes epidemiological data, historical literature, and detailed clinical case studies—primarily from boxing and contact sports—to characterize SIS. Methodologically, the paper relies on retrospective case analysis, review of autopsy and surgical findings, neuroimaging evidence (CT and MRI), and comparisons with animal research on cerebral autoregulation. The key finding is that SIS is driven not by large hematomas but by rapid loss of cerebral blood flow autoregulation, leading to vascular engorgement, massive cerebral edema, elevated intracranial pressure, and brain herniation within minutes. The paper emphasizes that even minor secondary impacts can trigger catastrophic outcomes if the brain is still metabolically vulnerable. Prevention through strict return-to-play</p>

	<p>guidelines is identified as the most effective intervention, as treatment after onset is largely ineffective.</p>
<p><b>Research Question/Problem/Need</b></p>	<p>What mechanisms cause catastrophic brain swelling and death following a second head injury sustained before recovery from an initial concussion, and how can such outcomes be prevented in athletes?</p>
<p><b>Important Figures</b></p>	 <p><b>Figure 1.</b> In second-impact syndrome, vascular engorgement within the cranium increases intracranial pressure, leading to herniation of the uncus of the temporal lobe (<i>arrows</i>) below the tentorium in this frontal section (<i>A</i>), or to herniation of the cerebellar tonsils (<i>arrows</i>) through the foramen magnum in this midsagittal section (<i>B</i>). These changes compromise the brainstem, and coma and respiratory failure rapidly develop. The shaded areas of the brainstem represent the areas of compression.</p>
<p><b>VOCAB: (w/definition)</b></p>	<p>Second-impact syndrome (SIS): A catastrophic neurological condition in which a second head injury occurs before recovery from an initial concussion, leading to rapid cerebral edema, brain herniation, and often death.</p> <p>Cerebral autoregulation: The brain's ability to maintain constant blood flow despite changes in blood pressure; loss of this function is central to SIS pathophysiology.</p>

	<p>Intracranial pressure (ICP): The pressure within the skull caused by brain tissue, blood, and cerebrospinal fluid; critically elevated ICP leads to brain herniation.</p> <p>Cerebral edema: Swelling of brain tissue due to excess fluid accumulation, often resulting from vascular engorgement rather than direct tissue damage in SIS.</p> <p>Uncal herniation: Downward displacement of the temporal lobe beneath the tentorium due to increased intracranial pressure, compressing the brainstem.</p>
<p><b>Cited references to follow up on</b></p>	<p>Saunders, R. L., &amp; Harbaugh, R. E. (1984). Second impact in catastrophic contact-sports head trauma. <i>JAMA</i>, 252, 538.</p> <p>Cantu, R. C. (1986). Guidelines for return to contact sports after a cerebral concussion. <i>Physician and Sportsmedicine</i>, 14(10).</p> <p>Langfitt, T. W., Kassell, N. F., &amp; Tannenbaum, H. M. (1966). The etiology of acute brain swelling following experimental head injury. <i>Journal of Neurosurgery</i>, 24, 47.</p> <p>Kelly, J. P., Nichols, J. S., Filley, C. M., et al. (1991). Concussion in sports: Guidelines for the prevention of catastrophic outcome. <i>JAMA</i>, 226, 2867.</p> <p>McQuillen, J. B., McQuillen, E. N., &amp; Morrow, P. (1988). Trauma, sports, and malignant cerebral edema. <i>American Journal of Forensic Medicine and Pathology</i>, 9, 12.</p>
<p><b>Follow up Questions</b></p>	<p>How does the loss of cerebral autoregulation after concussion compare to material fatigue failure in engineered systems subjected to repeated subcritical loads?</p> <p>What biomechanical thresholds of acceleration or strain might trigger vascular dysregulation rather than structural tissue rupture?</p> <p>How could helmet materials and energy-dissipation designs be optimized to reduce rotational acceleration linked to SIS?</p>



# Article #19 Notes: Measurement and Assessment of Head-to-Helmet Contact Forces

Article notes should be on separate sheets

<b>Source Title</b>	Measurement and Assessment of Head-to-Helmet Contact Forces
<b>Source citation (APA Format)</b>	Jennings, T., Tillman, A., Mukasa, D., Marchev, M., Müftü, S., & Amini, R. (2025). Measurement and assessment of head-to-helmet contact forces. <i>Annals of Biomedical Engineering</i> , 53, 946–955. <a href="https://doi.org/10.1007/s10439-025-03677-3">https://doi.org/10.1007/s10439-025-03677-3</a>
<b>Original URL</b>	<a href="#">Measurement and Assessment of Head-to-Helmet Contact Forces   Annals of Biomedical Engineering</a>
<b>Source type</b>	Peer-reviewed journal article
<b>Keywords</b>	Helmet fit; Ergonomics; Sensors; Sex differences; Head shape; Kevlar composite
<b>#Tags</b>	#forces #exact #concussions
<b>Summary of key points + notes (include methodology)</b>	This study provides a quantitative, population-level assessment of head-to-helmet contact forces in Kevlar composite helmets commonly used by military and law enforcement personnel. Using an instrumented helmet system with force-sensitive resistors embedded in seven interior padding locations and custom chinstrap tension gauges, the authors measured contact forces across 89 human volunteers of varying sex and experience levels. Participants wore helmets in three configurations: unbuckled, user-preferred chinstrap tightness, and fixed-tension chinstrap. The methodology emphasized human-subject testing rather than surrogate headforms, with careful calibration of sensors and nonparametric statistical analysis (e.g., Mann–Whitney U and Kruskal–Wallis tests) due to skewed

force distributions. Results showed that contact forces were highly non-uniform, with the highest forces consistently concentrated at the front and rear pads, forming a triangular support pattern. Inter-individual variability far exceeded configuration-based variability, indicating that head shape—not chinstrap tension or basic head dimensions—is the dominant determinant of helmet fit. Significant differences were observed between male and female participants under user-controlled conditions and between experience levels in unbuckled configurations, suggesting preference- and experience-related effects. The authors conclude that current helmet sizing metrics based on head length, width, and circumference are insufficient to predict true fit, underscoring the need for revised ergonomic and biomechanical criteria.

**Research Question/Problem/ Need**

How do head-to-helmet contact forces vary across individuals, helmet configurations, biological sex, and experience level, and are current helmet sizing criteria sufficient to predict proper fit in Kevlar composite helmet systems?

**Important Figures**

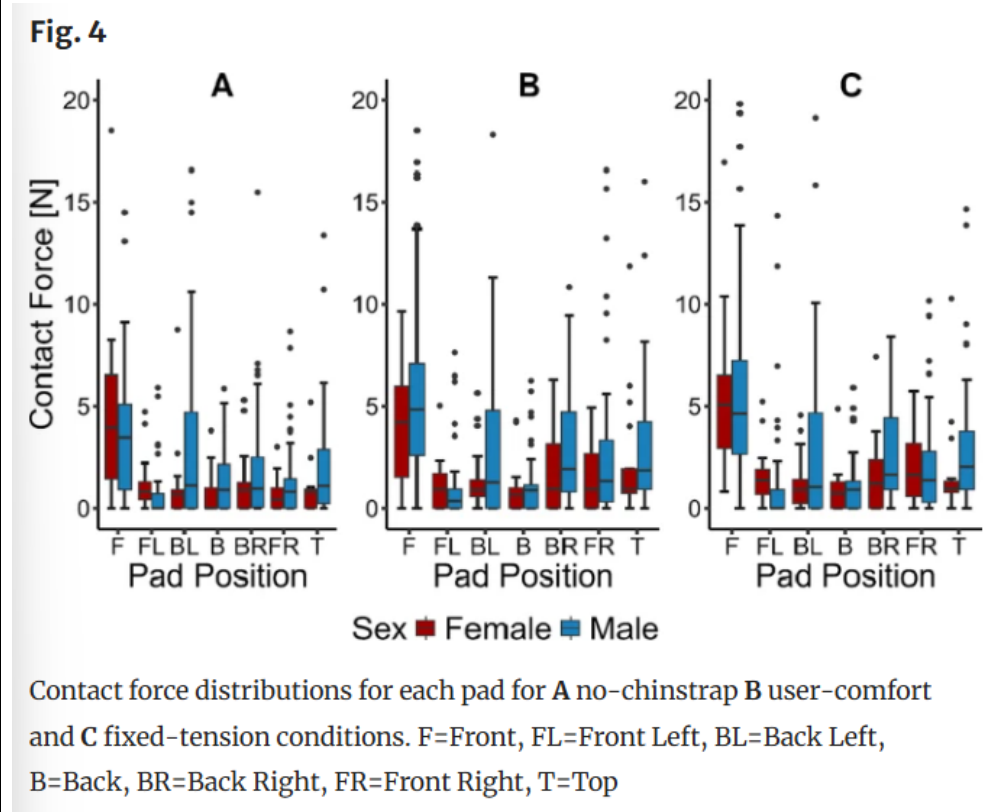
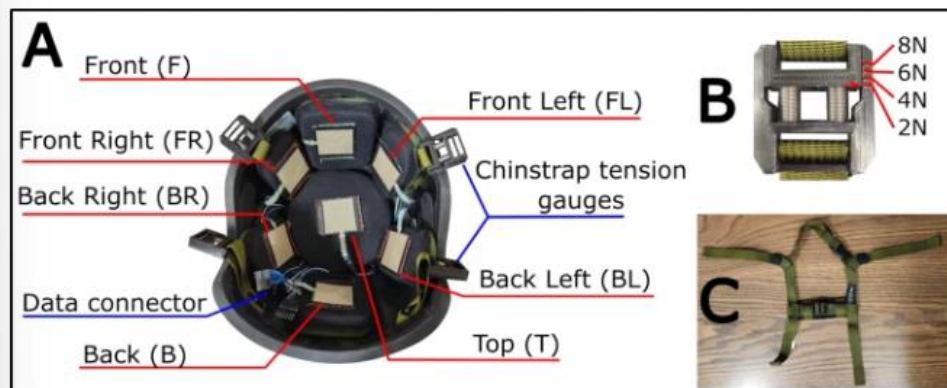


Fig. 1



Measurement system diagram. **A:** Helmet with force sensitive resistor notation marked in red, other key features marked in blue. **B:** Detail of the chinstrap tension gauges. **C:** Detail of the helmet chinstrap system, aligned to correspond to the helmet shown in **A**

**VOCAB: (w/definition)**

Head-to-helmet contact force: The normal force transmitted between the interior padding of a helmet and the wearer's head, reflecting helmet fit and pressure distribution.

Kevlar composite helmet: A ballistic helmet constructed from layered aramid fibers designed to provide impact and penetration resistance for military or law enforcement use.

Force-sensitive resistor (FSR): A sensor whose electrical resistance changes in response to applied force, used here to measure local contact forces between the head and helmet pads.

Chinstrap tension: The tensile force applied by the helmet's retention system, influencing helmet stability and perceived tightness.

Non-parametric statistical tests: Statistical methods that do not assume normal data distributions, suitable for skewed or non-Gaussian experimental data.

**Cited references to follow up on**

Maas, A. I., et al. (2022). Traumatic brain injury: Progress and challenges in prevention, clinical care, and research. *The Lancet Neurology*.

Cantu, R. C. (1998). Second-impact syndrome. *Clinical Sports Medicine*.

Guskiewicz, K. M., et al. (2003). Epidemiology of concussion in collegiate and high

	<p>school football players. <i>American Journal of Sports Medicine</i>.</p> <p>Chang, L.-T., Chang, C.-H., &amp; Chang, G.-L. (2001). Fit effect of motorcycle helmet: A finite element modeling. <i>JSME International Journal Series A</i>.</p> <p>Ellena, T., Subic, A., Mustafa, H., &amp; Pang, T. Y. (2016). The helmet fit index: An intelligent tool for fit assessment and design customisation. <i>Applied Ergonomics</i>.</p>
<b>Follow up Questions</b>	<p>How might three-dimensional head shape measurements improve predictive models of helmet fit compared to traditional linear dimensions?</p> <p>What are the potential biomechanical consequences of non-uniform contact force distributions during impact events?</p> <p>How could helmet designers integrate subject-specific fit data into scalable manufacturing processes?</p> <p>Why are non-parametric statistical methods particularly appropriate for analyzing biomechanical fit data in this study?</p> <p>In what ways might sex-based differences in helmet fit influence injury risk and equipment standards in military and law enforcement populations?</p>

## Article #20 Notes: REPIMPACT - a prospective longitudinal multisite study on the effects of repetitive head impacts in youth soccer

Article notes should be on separate sheets

<b>Source Title</b>	REPIMPACT - a prospective longitudinal multisite study on the effects of repetitive head impacts in youth soccer
<b>Source citation (APA Format)</b>	Lempke, L. B., Schmidt, J. D., Lynall, R. C., & Mihalik, J. P. (2021). Incidence of concussion in youth ice hockey players. <i>Neurotrauma Reports</i> , 2(1), 186–194. <a href="https://doi.org/10.1089/neur.2021.00484">https://doi.org/10.1089/neur.2021.00484</a>
<b>Original URL</b>	<a href="#">REPIMPACT - a prospective longitudinal multisite study on the effects of repetitive head impacts in youth soccer   Brain Imaging and Behavior</a>
<b>Source type</b>	Peer-reviewed journal article
<b>Keywords</b>	Ice hockey; Youth sports; Injury surveillance; Epidemiology; Sport-related concussion
<b>#Tags</b>	#forces #probability #positions #concussion
<b>Summary of key points + notes (include methodology)</b>	This study investigates the incidence and characteristics of sport-related concussion among youth ice hockey players, addressing a gap in injury surveillance data for younger age groups. Using a prospective cohort design, the authors analyzed concussion data collected through an organized injury surveillance system over multiple seasons of youth ice hockey competition. Certified athletic trainers or designated medical personnel recorded concussion diagnoses using

	<p>standardized clinical criteria consistent with contemporary concussion definitions. Athlete-exposure (AE) data were collected to calculate incidence rates per 1,000 AEs, allowing comparison across age divisions and competition settings. The methodology emphasizes real-world clinical diagnosis rather than self-report alone, increasing the reliability of injury identification. Results indicate that concussion incidence increases with age level and competitive intensity, with games presenting a higher risk than practices. Mechanisms of injury most commonly involved player-to-player contact, particularly body checking. The authors discuss how rule differences, physical maturation, and style of play may contribute to observed injury patterns and highlight the importance of targeted prevention strategies in youth hockey.</p>
<b>Research Question/Problem/ Need</b>	What is the incidence of sport-related concussion in youth ice hockey players, and how does concussion risk vary by age group, exposure type (practice vs. game), and injury mechanism?

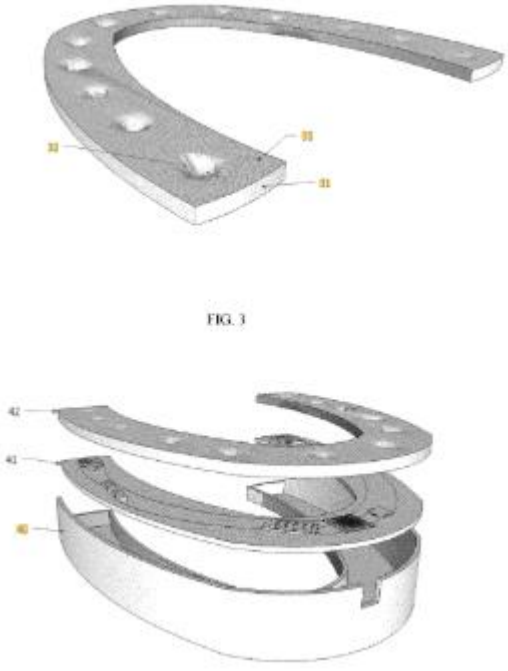
<p><b>Important Figures</b></p>	<p><b>Fig. 1</b></p> <pre> graph TD     BS[Brain Structure] --&gt; RHI[Repetitive Head Impacts]     BC[Brain Connectivity] --&gt; RHI     BB[Brain Biochemistry] --&gt; RHI     MP[Molecular Processes] --&gt; RHI     CS[Clinical Sequelae] --&gt; RHI     B[Behavior] --&gt; RHI     BS --&gt; BC     BC --&gt; BB     BB --&gt; MP     MP --&gt; CS     CS --&gt; B     B --&gt; BS     </pre> <p>REPIIMPACT aims to characterize between-group differences in behavior, clinical sequelae, molecular processes, as well as neuroimaging measures of brain biochemistry, brain connectivity, and brain structure</p>
<p><b>VOCAB: (w/definition)</b></p>	<p>Athlete-exposure (AE): One athlete participating in one practice or game in which they are at risk of injury; used as the denominator in injury incidence calculations.</p> <p>Prospective cohort study: A research design that follows a defined group over time to observe the occurrence of outcomes such as injuries.</p> <p>Injury surveillance system: A structured method for systematically collecting, analyzing, and interpreting injury data within a defined population.</p> <p>Body checking: A defensive maneuver in ice hockey involving intentional physical contact to separate an opponent from the puck.</p>
<p><b>Cited references to follow up on</b></p>	<p>Guskiewicz, K. M., et al. (2003). Epidemiology of concussion in collegiate and high school football players. <i>American Journal of Sports Medicine</i>.</p> <p>Emery, C. A., et al. (2010). Risk of injury associated with body checking among youth ice hockey players. <i>JAMA</i>.</p>

	<p>McCrary, P., et al. (2017). Consensus statement on concussion in sport—the 5th International Conference on Concussion in Sport. <i>British Journal of Sports Medicine</i>.</p> <p>Cantu, R. C. (1998). Second-impact syndrome. <i>Clinical Sports Medicine</i>.</p> <p>Halstead, M. E., &amp; Walter, K. D. (2010). Sport-related concussion in children and adolescents. <i>Pediatrics</i>.</p>
<b>Follow up Questions</b>	<p>How do age-related differences in physical development influence concussion risk in youth ice hockey?</p> <p>What are the strengths and limitations of using athlete-exposures as a denominator in concussion epidemiology?</p> <p>How might rule changes regarding body checking alter concussion incidence in youth leagues?</p> <p>In what ways does concussion surveillance in youth sports differ from collegiate or professional settings?</p> <p>How could longitudinal tracking of youth athletes improve understanding of cumulative concussion risk?</p>

# Article #21 Notes: Patent 1: Concussive Impact Sensing Mouthguard

Article notes should be on separate sheets

<b>Source Title</b>	Concussive Impact Sensing Mouthguard
<b>Source citation (APA Format)</b>	Fraylick, K. M. (2018). <i>Concussive impact sensing mouthguard</i> (U.S. Patent Application No. US 2018/0035952 A1). United States Patent and Trademark Office.  <a href="https://patents.google.com/patent/US20180035952A1">https://patents.google.com/patent/US20180035952A1</a>
<b>Original URL</b>	<a href="https://patents.google.com/patent/US20180035952A1">US20180035952A1 - Concussive Impact Sensing Mouthguard - Google Patents</a>
<b>Source type</b>	U.S. patent application
<b>Keywords</b>	Concussion; Mouthguard; Linear acceleration; Rotational acceleration; Gyroscope; Accelerometer; Traumatic brain injury; Impact force; Bluetooth transmission; Biometric data; Sports injury prevention; Second impact syndrome
<b>#Tags</b>	#forces #model
<b>Summary of key points + notes (include methodology)</b>	This patent describes a wearable mouthguard system designed to detect and assess concussive-risk impacts in athletic and recreational activities by measuring both linear and rotational head accelerations. The invention integrates a three-axis accelerometer and a gyroscope embedded within a layered mouthguard structure, positioned near the second molars to improve alignment with the skull and the head's center of gravity. Impact data are processed by an onboard central processing unit, logged in memory for short-term storage, and transmitted wirelessly via low-energy Bluetooth to external

	<p>software platforms accessible by coaches, parents, or medical personnel. The system incorporates user-specific biometric data—such as age, height, weight, and sex—to establish individualized concussion risk thresholds, which are used to flag impacts that may warrant clinical evaluation. The methodological approach is engineering- and design-based rather than experimental: the patent outlines sensor placement rationale, data acquisition logic, processing architecture, and intended use scenarios rather than validating performance through human-subject trials. The invention is positioned as an improvement over helmet-based systems by enabling applicability across sports that may lack headgear, emphasizing versatility, cost efficiency, and early injury detection to reduce the risk of undiagnosed concussion and second impact syndrome.</p>
<p><b>Research Question/Problem/Need</b></p>	<p>How can concussive-risk impacts be reliably detected across a wide range of contact sports using a non-intrusive, wearable device that accounts for both linear and rotational head motion and individual biometric differences?</p>
<p><b>Important Figures</b></p>	 <p>FIG. 3</p>
<p><b>VOCAB: (w/definition)</b></p>	<p>Three-axis accelerometer: A sensor capable of measuring acceleration along</p>

	<p>three orthogonal axes, allowing full characterization of linear head motion.</p> <p>Biometric data: Individual physical characteristics (e.g., age, height, weight, sex) used to personalize concussion risk thresholds.</p>
<p><b>Cited references to follow up on</b></p>	<p>Guskiewicz, K. M., et al. (2003). Epidemiology of concussion in collegiate and high school football players. <i>American Journal of Sports Medicine</i>.</p> <p>McCroory, P., et al. (2017). Consensus statement on concussion in sport—5th International Conference on Concussion in Sport. <i>British Journal of Sports Medicine</i>.</p> <p>Rowson, S., &amp; Duma, S. M. (2013). Brain injury prediction: Assessing the combined probability of concussion using linear and rotational head acceleration. <i>Annals of Biomedical Engineering</i>.</p> <p>Broglio, S. P., et al. (2011). Head impact density: A model to explain the elusive concussion threshold. <i>Journal of Neurotrauma</i>.</p>
<p><b>Follow up Questions</b></p>	<p>What are the biomechanical advantages and limitations of measuring head kinematics from a mouthguard compared to helmet-mounted sensors?</p> <p>How might individualized biometric thresholds improve or complicate concussion detection compared to universal acceleration thresholds?</p> <p>What validation studies would be necessary to clinically justify the concussion risk thresholds proposed in this patent?</p> <p>How do rotational acceleration measurements contribute to concussion risk prediction beyond linear acceleration alone?</p> <p>What ethical and privacy considerations arise when transmitting athlete impact data to third parties such as coaches or parents?</p>

## Article #22 Notes: Patent 2: Protective liner for helmets and other articles

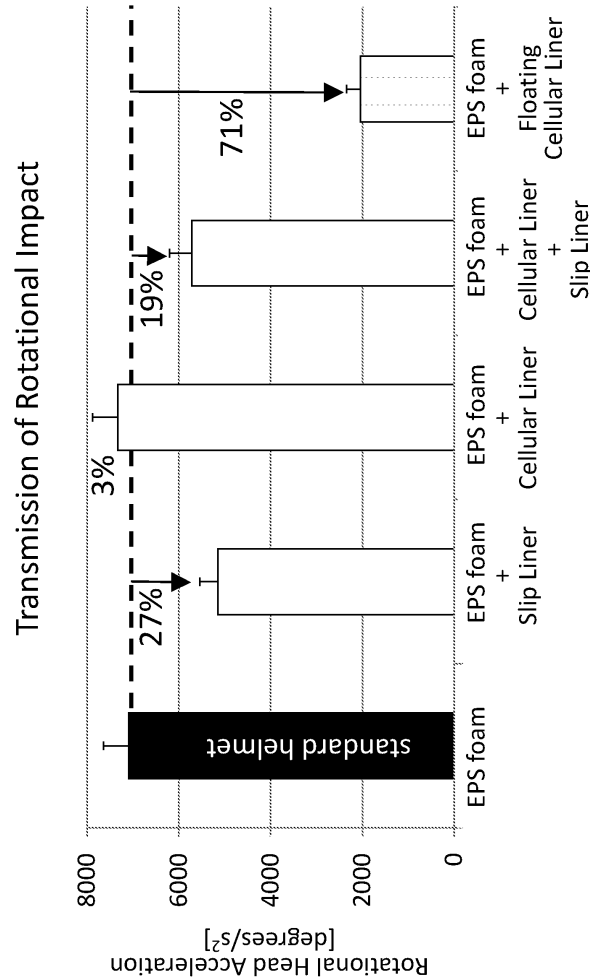
Article notes should be on separate sheets

<b>Source Title</b>	Protective liner for helmets and other articles
<b>Source citation (APA Format)</b>	Bottlang, M., Madey, S., Tsai, S., Bennett, J., & Knowles, D. (2020). <i>Protective liner for helmets and other articles</i> (U.S. Patent No. 10,834,987 B1). United States Patent and Trademark Office. <a href="https://patents.google.com/patent/US10834987B1">https://patents.google.com/patent/US10834987B1</a>
<b>Original URL</b>	<a href="https://patents.google.com/patent/US10834987B1">US10834987B1 - Protective liner for helmets and other articles - Google Patents</a>
<b>Source type</b>	Granted U.S. patent
<b>Keywords</b>	Protective helmet; Rotational acceleration; Torsional suspension; Anisotropic cellular liner; Oblique impact; Traumatic brain injury; Expanded polymer foam; Auxetic materials; Helmet liner; Impact mitigation
<b>#Tags</b>	#helmet structure #forces
<b>Summary of key points + notes (include methodology)</b>	This patent discloses a helmet liner system designed to substantially reduce rotational head acceleration during oblique impacts, a biomechanical factor strongly associated with traumatic brain injury. The core innovation is a “floating” anisotropic cellular liner that functions as a torsional suspension system. The liner is partially recessed within a rigid expanded polymer foam shell and separated by a low-friction barrier layer, allowing controlled translation and in-plane compression relative to the shell. During an oblique

	<p>impact, tangential forces are absorbed through simultaneous sliding and in-plane compression of the cellular structure, while normal forces are absorbed through out-of-plane compression and localized shear. The patent emphasizes that this combined deformation mechanism dissipates rotational energy more effectively than conventional foam liners, slip liners (e.g., MIPS), or honeycomb inserts used independently. Methodologically, the patent is design- and engineering-focused: it details structural configurations, material properties (including anisotropic stiffness and optional auxetic cell geometries), and comparative helmet impact test results demonstrating large reductions in rotational head acceleration—reported as up to 71% relative to standard EPS helmets. While the testing data are illustrative rather than peer-reviewed clinical trials, they are used to support the functional claims of improved rotational impact mitigation across a wide range of helmet and protective gear applications.</p>
<b>Research Question/Problem/Need</b>	How can helmet and protective equipment be engineered to more effectively mitigate rotational head acceleration from oblique impacts, beyond the capabilities of traditional foam liners or sliding-layer technologies, in order to reduce the risk and severity of traumatic brain injury?

**Important Figures**

**Figure 6**



**VOCAB: (w/definition)**

Rotational head acceleration: Angular acceleration of the head caused by oblique impacts, strongly linked to brain shear strain and concussion risk.

Oblique impact: An impact where force is applied at an angle rather than directly normal to the surface, generating both linear and rotational motion.

Anisotropic material: A material whose mechanical properties differ depending on direction; here, the liner is softer in-plane than out-of-plane.

Torsional suspension system: A mechanical system that absorbs rotational energy through controlled deformation and relative motion between components.

Auxetic material: A material with a negative Poisson's ratio that expands laterally when stretched, allowing improved conformity to curved surfaces.

Expanded polymer foam (EPS): A lightweight, energy-absorbing foam

	commonly used in helmet liners to reduce linear acceleration.
<b>Cited references to follow up on</b>	<p>Rowson, S., &amp; Duma, S. M. (2013). Brain injury prediction: Assessing the combined probability of concussion using linear and rotational head acceleration. <i>Annals of Biomedical Engineering</i>.</p> <p>Halldin, P., Gilchrist, A., &amp; Mills, N. J. (2001). A new oblique impact test for motorcycle helmets. <i>International Journal of Crashworthiness</i>.</p> <p>Depreitere, B., et al. (2006). Mechanics of acute subdural hematomas. <i>Journal of Neurotrauma</i>.</p>
<b>Follow up Questions</b>	<p>What are the limitations of using rotational head acceleration as a surrogate measure for brain injury risk?</p> <p>How might auxetic cellular geometries improve helmet fit and performance across diverse head shapes?</p>