Advanced brain injury detection and protection

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The U.S.-based PANTHER program is pioneering a physics-based approach to TBI for quantitatively and deterministically linking the physics of a head insult to the resulting biological injury response. Christian Franck and Alice Lux Fawzi discuss

Mild traumatic brain injuries (mTBI) persist as one of the most common injuries in both military and civilian populations worldwide, with one recent survey finding that 29% [1] of American adults had at least one mTBI with recognizable symptoms. The true incidence of mTBI is even higher as the vast majority are asymptomatic, occurring without any outward physical sign of injury. Yet, the damage from repetitive mild brain injury accumulates over time and is linked to long-term neurodegenerative diseases.

What is mTBI?

When the head is struck, the brain's soft tissue within the skull deforms, transmitting forces to networks of cells. A mild traumatic brain injury occurs when the rate and magnitude of brain deformation are severe enough to cause brain cells to die.

No imaging equipment in a standard emergency room (MRI or X-ray/CT) can detect brain injury at the cellular scale, and even if mTBI is identified, there is no course of treatment to heal injured brain cells. In the face of these challenges, a diverse portfolio of research projects uses the physical connection between cell-deformation and injury as the foundation for breakthroughs to predict and prevent mTBI.

Brain injury detection: A physics-based approach to predict and prevent TBI

A new program called PANTHER (Physics-bAsed Neutralization of Threats to Human tissuEs and oRgans) was founded in 2017 to understand, predict and prevent mTBI. Headed by the University of Wisconsin-Madison in partnership with the Office of Naval Research, PANTHER is pioneering a physics-based approach to TBI for quantitatively and deterministically linking the physics of a head insult to the resulting biological injury response.

PANTHER projects build upon the advanced understanding of the cellular response to impact and blast with wearable sensor systems and finite element model simulations to develop predictive injury models and a new generation of protective materials to prevent injury.

Defining the cellular injury threshold

Defining the cellular injury threshold, the foundation of PANTHER's approach to mTBI, has taken a tenacious investment. Animal brain cells are grown in a 3D transparent medium and then deformed at a carefully controlled rate and magnitude. Results have shown that depending on the experienced deformation rate, distinct pathologies (primary/secondary) can emerge with profound implications for injury classification and diagnosis. The threshold of injury is used in finite element models of the head.

Tissue and brain-scale measurements

The material properties of human brain tissue and the interface connecting the brain to the inside of the skull can both be measured in an MRI scanner if a head is rocked or jiggled during the scan using tagged MRI. The accuracy of PANTHER's finite element models relies on the accurate definition of material and interface properties.

Predicting injury with finite element models

Finite element head models link the motion of the head to the response of the brain's soft tissue and compare it to the cellular injury threshold to predict injury. PANTHER has several head models for different applications. During helmet testing, a generic head model of a 50th percentile male head is commonly used to simulate impacts to dummy headforms in the lab. Sophisticated individualized head models are generated from MRI scans and used to learn how the head and brain features of an individual influence susceptibility to injury. The final input to a finite element head model is an accurate measure of head motion.

Brain injury detection: Head sensing

Accurately recording head motion during an impact is deceptively challenging because the hair, scalp, and facial skin slip relative to the rigid skull. PANTHER has approached head sensing with noteworthy mathematical rigor, developing an externally worn research-grade sensor system that preserves the accuracy of accelerometer measurements to calculate head rotation without introducing extraneous noise. The sensor system outputs are ideally suited inputs for finite element modeling.

From benchtop breakthrough to consumer product

PANTHER's physics-based approach supports helmet innovation through collaboration with industry. Helmet designers aspire to make the most protective products possible. Still, without understanding which kinematic measures of head motion are linked to injury, designers cannot evaluate if design changes will make their helmets more protective. In response, PANTHER developed an easy-to-use tool to interpret helmet tests, showing that injury can be driven by angular acceleration, angular velocity, or both depending on the time duration of the impact. [(2)]

PANTHER's industry collaborations also revealed that helmet designers needed a better way to mathematically characterize the response of soft materials like foams because they have complex deformation over time. In a helmet designed for brain protection, foams should decelerate the head at a specific rate to attenuate an impact before the foam is totally compressed.

PANTHER has spearheaded rate- specific foam characterization testing so that helmet performance can be strategically optimized via digital engineering. [(3)] Helmet designer needs have guided PANTHER research, and in turn, PANTHER innovations are putting better physics-based brain protection into the hands of consumers.

PANTHER is poised to meet the urgent need for a breakthrough in understanding mTBI, providing the missing pieces for predicting and preventing injury. PANTHER's focus on injury at the cellular scale, defining cellular injury thresholds, can be used to cut through mTBI confusion in avoiding injury and diagnosis via body-worn sensors.

PANTHER's research is available now to direct improvements in helmet design and revise safety guidelines for hazards found in sports and military arenas, reducing the incidence of mTBI. As PANTHER research progresses, the physics-based understanding of mTBI may unlock diagnosis, intervention to disrupt disease progression, and even treatments that promote healing to the damaged neurons.

Acknowledgments

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References

1. J. Daugherty, L. DePadilla, K. Sarmiento, and M. J. Breiding, "Self-Reported Lifetime Concussion Among Adults: Comparison of 3 Different Survey Questions," J Head Trauma Rehabil, vol. 35, no. 2, pp. E136–E143, 2020, doi: 10.1097/HTR.0000000000000534.
2. R. W. Carlsen, A. L. Fawzi, Y. Wan, H. Kesari, and C. Franck, "A quantitative relationship between rotational head kinematics and brain tissue strain from a 2-D parametric finite element analysis," Brain Multiphysics, vol. 2, p. 100024, 2021, doi: 10.1016/j.brain.2021.100024.
3. X. Li, J. Tao, A. K. Landauer, C. Franck, and D. L. Henann, "Large-deformation constitutive modeling of viscoelastic foams: Application to a closed-cell foam material," Journal of the Mechanics and Physics of Solids, vol. 161, p. 104807, Apr. 2022, doi: 10.1016/j.jmps.2022.104807.