BIOMECHANICS

PROGRAM SYLLABUS
BIOMECHANICS OF CONCUSSION: CONSIDERATIONS ON THE MECHANISMS OF INJURY AND REDUCTION OF RISK

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**Acceleration-Based Brain Injury**

When the head sustains an impact, the brain is subjected to inertial loading.

Head acceleration is a metric used to characterize risk because it is indicative of the inertial response of the brain to impact loading. It is important to keep in mind that it is not the acceleration of the skull that results in injury, but rather the pressure and strain response within the brain tissue.

Linear acceleration of the head is associated with transient intracranial pressure gradients. Rotation acceleration of the head is associated with a strain response. Both contribute to risk of injury.

Furthermore, duration for which accelerations are sustained affects risk of concussion. High accelerations are tolerable for shorter durations, while low accelerations are tolerable for longer durations.

Hardy et al. (2007) quantified brain motion during head impact\(^1\)
- High speed x-ray used to film cadaver head impacts at concussive severities
- Brain is not "flopping around" inside the skull. Only 5-7 mm of movement in a looping pattern.
- Kinematics of the head correlated to brain injury mechanisms: pressure and strain

**On-Field Head Impact Measurements**

High incidence of concussion in football provides scientists with an opportunity to collect biomechanical data to characterize concussion. The idea of this research is to instrument and observe a population that is at high risk for concussion. This allows data at potentially injurious severities to be collected from human volunteers in an ethical and natural manner. At Virginia Tech, we’ve been collecting head acceleration data from football players since 2003.

We have used two different systems to measure head accelerations experienced by football players: the commercially available HIT System and a custom 6 degree of freedom measurement device.\(^2\) Both systems consist of helmet-mounted accelerometers that remain in contact with the head. This ensures that head acceleration, not helmet acceleration, is measured from instrumented players.

Every head impact that instrumented players experienced during games and practices was recorded and paired with clinical data regarding concussion diagnosis.

The average concussion was associated with a linear acceleration of 105 g and a rotational acceleration of 5022 rad/s\(^2\). The average sub-concussive head impact was associated with a linear acceleration of 26 g and a rotational acceleration of 1137 rad/s\(^2\). Impact duration for all impacts were generally between 8 and 12 ms.

Risk of concussion for linear and rotational acceleration were quantified based on these data.\(^3\)-\(^5\)

**Role of Helmets in Reducing Concussion Risk**

There are two primary components of a helmet to protect from injury:
1. The helmet shell functions to deflect force over a larger area
2. The helmet liner functions to modulate the energy transferred to the head
These components can be optimized to reduce concussion risk by lowering head acceleration.
Are there differences concussion risk between helmets?
Yes, not all helmets are created equal. While all football helmets being sold pass the NOCSAE standard, there are differences in the ability of helmet to manage impact energy.

We created the Virginia Tech Helmet Ratings™ to provide consumers with objective and independent data characterizing which helmets were better than others. There are two fundamental concepts to the helmet ratings:
1. Tests are weighted based on how often they occur on the field
2. Helmets that lower head acceleration reduce concussion risk

Ratings and data are made public on the Virginia Tech Biomedical Engineering website: www.sbes.vt.edu/helmet. These ratings have created a paradigm shift in the way consumers purchase helmets and in the way manufacturers design helmets.

Do the ratings translate to the field?
Yes, the laboratory data closely match on-field data. We recently published an article in the Journal of Neurosurgery quantifying how concussion rates differ by helmet type. Over 1800 players at 8 universities were studied over a 5 year period. When comparing concussion rate by helmet type, the number of head impacts each player experienced in each helmet type was controlled for, which is critical for accurately quantifying differences. Comparing a 4 star helmet to a 1 star helmet, our laboratory ratings predict a 53.9% reduction in risk and our on-field data predict a 54.2% reduction in risk.

Can all concussions be prevented?
No, any player in any sport can sustain a head injury, even with the very best head protection. A specific person’s risk varies. Differences between individual tolerances, genetic predispositions, and extrinsic factors likely dominate this variation.

There are three strategies to reduce the incidence of concussion:
1. Rule changes
2. Teach proper technique
3. Better equipment

Together, these strategies can minimize concussion incidence. Rule changes and improved technique limit the number of head impacts that player sustain. This is perhaps most important in reducing the incidence of concussion. For the remaining head impact that do occur, having the very best head protection will further reduce risk.

Reducing Concussion Incidence through Rule Changes
Youth football players (6 to 14 years old) comprise of ~70% of all football players in the US. We have studied head impacts in youth football players for the last 3 years. Through analysis of head impact data and video of games and practices, we identified that the overwhelming majority of high-risk head impacts occur during practices and were generally associated with specific drills. Furthermore, these impacts were not representative of game impacts. Based on these data, Pop Warner and other youth football leagues changed their rules to limit contact in practice and eliminate the high-risk drills. The following year, we observed nearly a 50% reduction in head impact exposure in teams that adopted the new rules.

References

