The Biomechanics of Concussion

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What is concussion?

"…a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces. "

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Linear Forces

- Linear and rotational acceleration/deceleration = primary cause of concussions (Meaney & Smith, 2011).
- Avg. peak linear accelerations of 65.1g and 88.5g = 50% and 75% chance, respectively (McIntosh et al., 2014).
- Linear acceleration caused by a radial force - more likely to lead to a skull fracture or hematoma-related injury (Kleiven, 2013).

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Rotational Forces

- Rotational accel due to the deformation shear strain of the brain (Guskiewicz & Mihalik, 2011; Meaney & Smith, 2011, Rowson et al., 2016).
- Rotational acceleration = higher incidence of the brain scraping the inside of the cranium & increases tissue alteration (Barth et al., 2001).
- Coronal plane rotational acceleration impacts = 50% chance of concussion with a ≤ than 1747 rad/sec^2 rotational accel and a 75% ≤ 2296 rad/sec^2 (McIntosh et al., 2014).
- No impact to the head? Twice the rotational accel is needed to generate a concussion (Rowson et al., 2016).

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Shear Forces

- Top of the head impacts generate lower rotational accel but high enough linear acceleration to produce concussive symptoms (Guskeiwicz and Mihalik, 2011).
- Rotational acceleration causes shear strain, which is linked to axonal injuries and blood-brain barrier damage (Kleiven, 2013).
- The brain is more resistant to compression than to shear strain, leading to shear being a primary cause of deformation to the brain (Kleiven, 2013).
- High levels of shear strain cause a gliding contusion, which damages the deeper areas of the brain without affecting the brain's surface (King, Yang, Zhang, Hardy, & Viano, 2003).
- Shear strain resulting from rotational acceleration is more likely to lead to a brain injury than linear acceleration, which leads to pressure developing that the brain resists (Kleiven, 2013).

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Linear Head Impact Frequency Among Collegiate Football Players

Biomechanics

Methods
An observational study was conducted using a convenient sample pool of college athletes from a NAIA football team during spring football.

Participants consisted of 20 male collegiate football players who wore CUE Sensor helmets for entire spring football season.

Findings/Conclusions
Offensive linemen received more impacts than any other position

Higher number of impacts to offensive lineman could lead to an increased number of concussions and more frequent and severe concussion symptoms.

More impacts occurred during games than during practices, which could be due to the spontaneous nature of games, or internal factors such as coaching philosophy.

Figure 1. Frequency and Means of Impact by Position Group

Note: N=20, (X) – number per group

Robertson L, Garrett Z, & **Konz SM.** (2019). Using Impact Sensors to Identify Individuals Susceptible to Concussions. National Athletic Trainer's Association 70th Clinical Symposium & Annual Meeting, Las Vegas, NV: National Athletic Trainer's Association.

Linear Head Impact Magnitude Among Collegiate Football Players

Biomechanics

Methods
The purpose of the study was to investigate linear acceleration forces to the head among football athletes in spring football and how the forces compare between position groups.

Participants consisted of 20 male collegiate football players who wore CUE Sensor helmets for entire spring football season.

Findings/Conclusions
Mean linear acceleration forces (62.95g ± 36.57, n=3921).

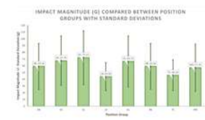
Defensive line (n=484) ↑ magnitude of linear impacts (72.11g ± 40.04).

Skill players ↑ risk for head injuries

Defensive linemen highest magnitude of linear acceleration

Offensive line position group sustained the highest frequency of impacts.

Position	Number of Players	Impact Magnitude (g)		
		Mean	SD	number of impacts
Defensive Back	3	59.19	34.12	580
Defensive End	1	67.74	36.49	319
Defensive Line	1	72.11	40.04	484
Linebacker	1	44.06	20.7	69
Offensive Line	3	66.53	37.98	1220
Running Back	3	59.36	33.87	500
Tight End	1	46.19	22.67	72
Wide Receiver	6	57.25	35.04	677
All Positions	19	60.25	36.57	3921



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Head Involvement - Tackle vs. Flag

Biomechanics

- Flag football fewer impact exposures
  - Tackle football→17.55 x more impacts in practice & 19.48 x more impacts in practice than flag (Sarmiento et al., 2021)
  - Flag football has fewer head impact exposures (TFB 14.67x↑) (Waltzman et al., 2021)

Head Involvement - Tackle vs. Flag

Biomechanics

- Tackle football greater magnitude of impact(Sarmiento et al., 2021)
  - (50^{th}) Tackle → 18.15g vs. Flag → 16.84 g
  - (95^{th}) Tackle → 52.55g vs. Flag → 33.51 g
- Youth flag football ↓ risk of impacts>20g (Lynall et al., 2019)
  - But ↑ risk of impacts between 2500.00–7499.99 rad/s2

A Comparison of Football and Rugby Tackling During Spring Ball

Biomechanics

Methods

The purpose of the project is to examine the effects tackling style has on forces translated to the brain in football and rugby.

Convenient sample of 30 male football and rugby participants from two universities participated in this observational study. 20 football participants had CUE™ Sports Sensor placed in the helmet, 10 rugby participants were fitted with VECTOR™

Left: CUE™ Sports Sensor
Right: VECTOR™ Sports Sensor Mouthguard

Garrett Z & **Konz SM.** (2019). A comparison of football and rugby tackling during spring ball. 2019 American Academy of Neurology Sports Concussion Conference, Indianapolis, IN: American Academy of Neurology Sports Concussion.

A Comparison of Football and Rugby Tackling During Spring Ball

Biomechanics

Findings/Conclusions

Football → 3921*** impacts over 12 practices or games,
Rugby → 1868 impacts over 9 practices

Football → at 62.95 ± 36.57g linear accel impacts.
Rugby → 20.59 ± 15.79g linear accel impacts.

Impact frequency and average impact force appears to be lower in rugby athletes than football athletes during spring ball.

The use of a rugby-style tackle generated lower impact forces in athletes when contact occurs.

Lower impact forces may be due to the position of the head to the side of the body.

Teams employing a rugby style tackle may see a lower incidence of concussion.

Figure 4. Impact magnitude of rugby vs football

***Welch's F (1, 5741.884) = 3780.385, p <.001

***(Welch's F (1, 4119.84) = 29.41, p <.001).

Garrett Z & **Konz SM.** (2019). A comparison of football and rugby tackling during spring ball. 2019 American Academy of Neurology Sports Concussion Conference, Indianapolis, IN: American Academy of Neurology Sports Concussion.

The Effects of Concussion on Quantity and Quality of Sleep

Findings/Conclusions

To investigate the changes in sleep quantity and sleep quality of concussed collegiate football players.

20 male (19.93±0.22 YO, 1.82±0.01M, 96.42±4.09kg) MU & NAIA football athletes wore a Readiband™

Total minutes in bed at the initial measurement (df = 11.839, p = .037) between the concussed (353.29 ± 110.48 minutes) and non-concussed (471.5 ± 125.09 minutes) groups.

Total minutes asleep at the initial measurement (df = 12.662, p = .032) between the concussed (286.43 ± 86.73) and non-concussed groups (383.7 ± 104.86)

Calculated minutes in bed at the initial measurement (df = 11.916, p= .023) between the concussed (326.4 3± 97.01) and non-concussed groups (441.60±110.55)

Table 1. Participant's means and standard deviations for non-concussed and concussed groups variables.

Variable	Non-concussed	Concussed
Total minutes in bed at the initial measurement	471.5 ± 125.09	353.29 ± 110.48
Total minutes asleep at the initial measurement	383.7 ± 104.86	286.43 ± 86.73
Quantity of sleep was the calculated minutes in bed at the initial measurement	441.60±110.55	326.4 3± 97.01

Notes: n= 27; 20 non-concussed and 7 concussed

Taren Bone, **Konz SM**, Garrett Z, & Gilliland A. (2021). The Effects of Concussion on Quantity and Quality of Sleep. National Athletic Trainer's Association Virtual Clinical Symposium & Annual Meeting: National Athletic Trainer's Association.

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Brain Slosh

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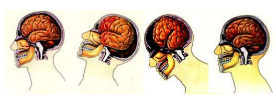
Brain slosh

- Brain "bouncing around" inside the skull.
  - Contre-coup injury
- Forces that cause movement of the brain inside the cranium



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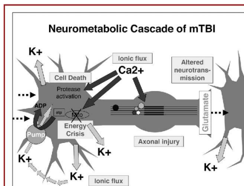
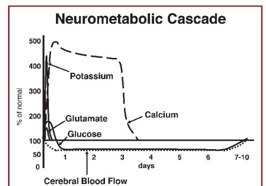


Diagram of the acute cellular biological processes occurring after



Time course of the neurometabolic cascade of concussion.

Giza, C. C., & Hovda, D. A. (2014). The new neurometabolic cascade of concussion. Neurosurgery, 75 Suppl 4, S24-33. doi:10.1227/NEU.0000000000000505

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Brain Slosh & Cavitation

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Head acceleration & cavitation

- Linear acceleration causes transient intracranial pressure gradients (Rowson et al., 2016).
- Rotational acceleration causes injury through shear strain (Rowson et al., 2016).
- The rotational and linear accel combination from a tangential force leads to shear strain resulting in cavitation (Kleiven, 2013).

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Cavitation

- Liquid acceleration causes small bubbles to form within low-pressure regions of liquid
- Bubbles expand the pressure is further reduced along with the flow
- Sudden bubble collapse when higher pressure returns.

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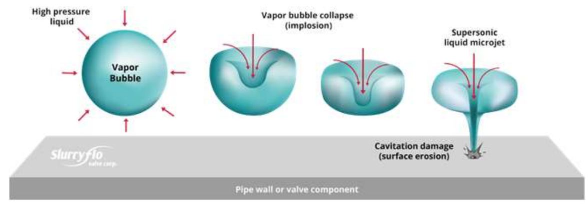
Cavitation



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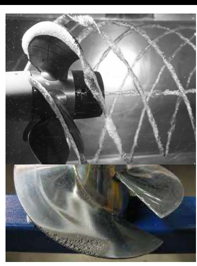
Cavitation damage



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Pistol Shrimp

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Brain Slosh & Cavitation

- Brain “bouncing around” inside the skull creates the environment for cavitation
- Closed fluid environment
- Slosh mitigation to increase fluid volume to limit brain movement
  - Q-collar

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Recoil & Recoil Energy

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Recoil

- Recoil backward → movement of the gun-shooter system
- Due to the momentum of gases created while shooting a firearm
- Conservation of momentum occurring within the system

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Recoil energy

- Recoil energy (free recoil) → propulsive force byproduct
  - Occurs when the powder charge is detonated within a firearm
  - Depends on the caliber of the gun
- Conversion of chemical energy to thermodynamic energy
- Kinetic energy transferred from the gun to the shooter

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- Recoil energy is an obtainable value.
- Recoil energy had yet to be determined.
  - Would be difficult standardized – variances in shooting style, restraints of movement, and physiological aspects
- Technology available was limited.

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Military Recoil Exposure

- Military personnel require regular contact with firearms
- To reduce the injury exposure risk due to excessive recoil loads:
  - Military outlines firearm use protocols
  - Military establishes recoil limits rounds per level of recoil energy
  - Allowable limit of rounds ↓
  - Ability to shoot multiple caliber guns ↓ as recoil energy increases
- Initiative is to reduce shoulder injury NOT head injury
- **BUT** → Acceleration and deceleration forces acting on the shoulder also act on the brain.

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Military Recoil Limits

- Above 60 ft-lbs. of recoil energy = NO firing of shoulder-mounted weapons (Burns, 2012)
- 25 rounds per day per person for weapons between 45-60 ft-lbs. of recoil energy (Burns, 2012).
- Unlimited rounds per day can be fired under 15 ft-lbs. (Burns, 2012).
  - Military service rifle
  - M16 = 57.8-58.9 ft-lbs.
  - 12 GA shot gun = 17.3-54.0 ft-lbs.
  - 16 GA shot gun = 21.5-27.6 ft-lbs.

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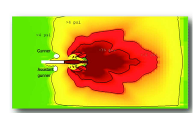
Military and shoulder fired weapons

- Soldiers experiencing blast wave overpressure are more prone to developing TBI.



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TBI and Recoil in the Military

- Chronic exposure to firing weaponry is suggested to contribute to the development of TBI (Belding et al., 2019).
- The power from gunshot recoil is generated via acceleration forces
  - small amounts of strain exist therefore the possibility of brain injury exists as well.
- Repetitive recoil exposing the shooter to symptoms of brain injury
- However, the long-term injury from gunshot recoil has yet to be determined despite possible connections of TBI to military weaponry

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Trap & Skeet Shooting

- Trap and skeet participants detail experiencing the concussion-like symptoms due to gunshot recoil:
  - Headache
  - ringing in the ears
  - blurred vision
  - memory loss
  - Nausea
- Brain tissue deforms at a rate of 2-5% from strain during mild, yet rapid deceleration at 20–30 m/sec^2 peak, lasting 40 msec duration (Bayly et al., 2005).

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Overpressure Exposure From .50-Caliber Rifle Training

- Serum GFAP decreased on D1 and D3 but not D2 after OP exposure.
- Nf-L was suppressed on D3 alone.
- amyloid beta peptides - Aβ-40 was elevated on D2 alone while Aβ-42 was elevated each day after OP exposure.
- Suppression of GFAP and elevation of Aβ-42 correlated to OP-mediated impulse levels measured on D3.
- Fluctuation of GFAP, Nf-L, and particularly Aβ peptide levels may have utility after sub-concussive exposure in the absence of extreme operational deficits or clinically defined concussion

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So,

what does all this mean?

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- CTE and brain disorder development is more complicated
- Athletic activities/significant TBI events absolutely impacts health and quality of life
- Chronic head acceleration exposure does impact brain health
  - Work-environment
  - Activities of a Lifetime
-

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More questions

- How does chronic exposure to low level head acceleration affect health and quality of life?
- Can we develop better diagnostics with these low-threshold outcomes?
- Do employers need to limit chronic exposure to vibration and head acceleration?

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Thank you for your time!

Questions?

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