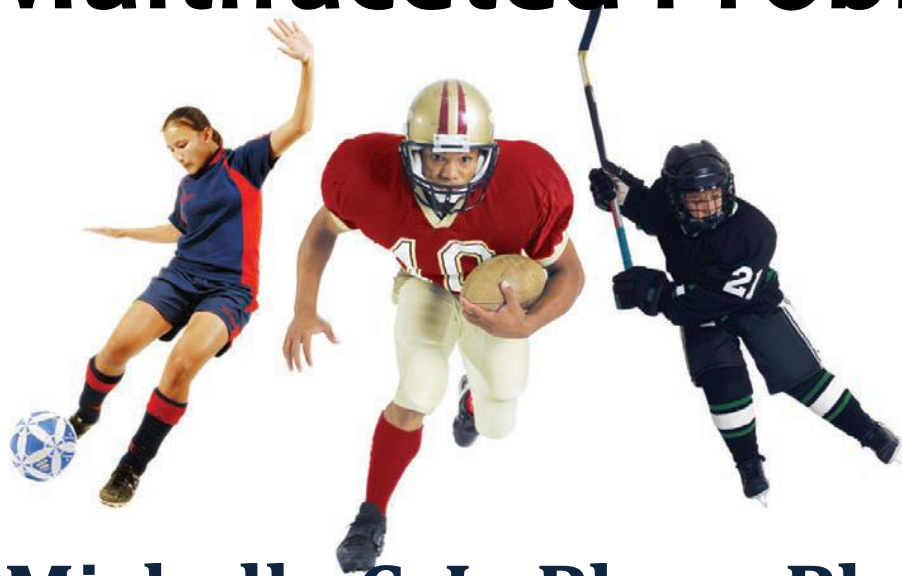


Concussion / mTBI: A Multifaceted Problem



Michelle C. LaPlaca, Ph.D.

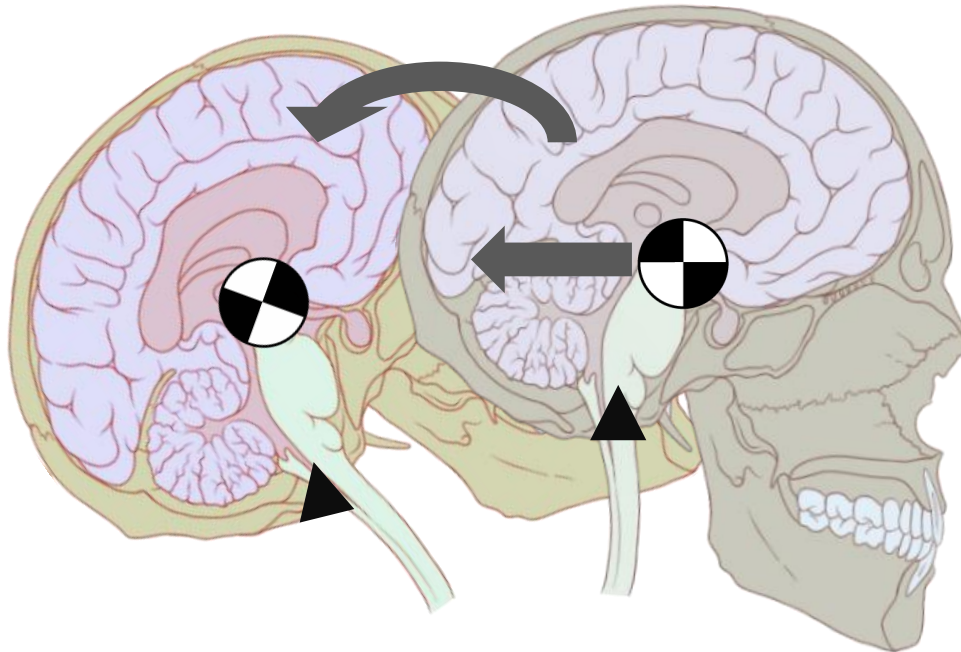
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What is a concussion?

“Concussion is a brain injury and is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces.” Zurich (2012) Concussion in Sport (CIS) Group Conferences



Concussion is induced by biomechanical forces



Concussion affects neurological function



“ No area of sports medicine involves more clinical uncertainty and controversy than the treatment of concussion.” Melvin Field, MD



Updated Definition of Concussion

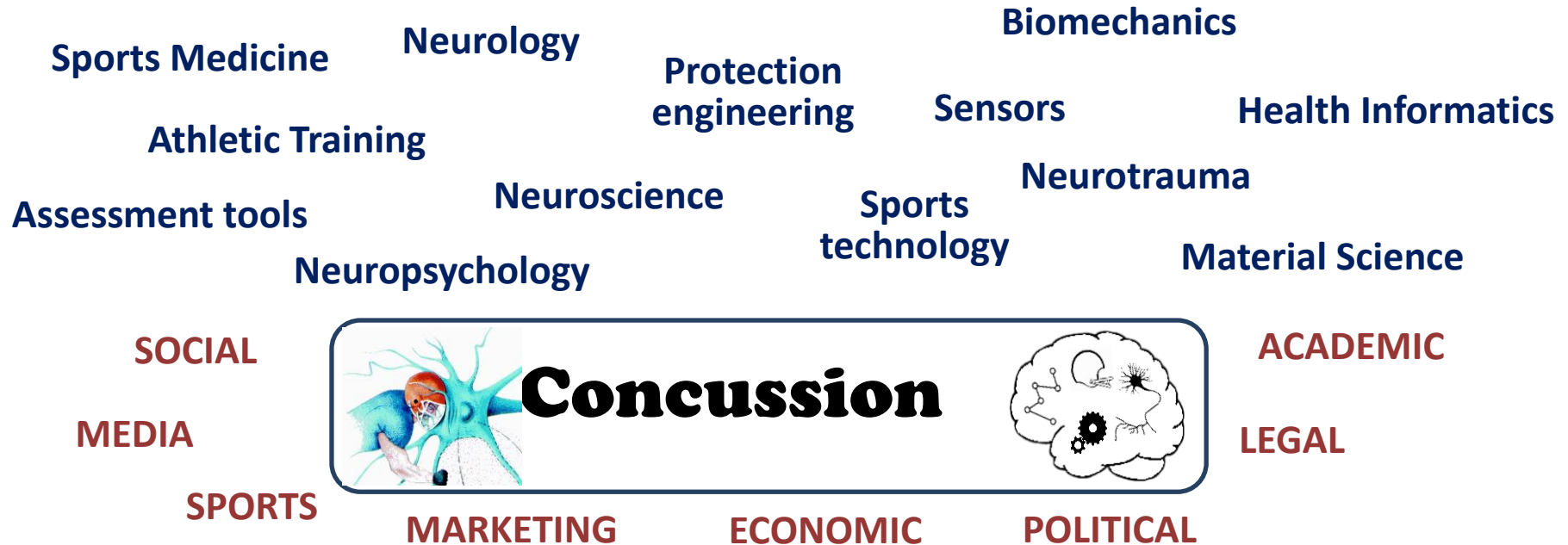
Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016.
McCorry P, et al. Br J Sports Med 2017;**51**:838–847.

Sport related concussion is a traumatic brain injury induced by biomechanical forces. Several common features that may be utilised in clinically defining the nature of a concussive head injury include:

- ▶ *SRC may be caused either by a **direct blow to the head**, face, neck or elsewhere on the body with an **impulsive force transmitted to the head**.*
- ▶ *SRC typically results in the **rapid onset of short-lived impairment** of neurological function that resolves spontaneously. However, in some cases, signs and symptoms evolve over a number of minutes to hours.*
- ▶ *SRC may result in neuropathological changes, but the acute clinical signs and symptoms largely reflect a **functional disturbance rather than a structural injury** and, as such, no abnormality is seen on standard structural neuroimaging studies.*
- ▶ *SRC results in a **range of clinical signs and symptoms** that may or may not involve loss of consciousness. Resolution of the clinical and cognitive features typically follows a sequential course. However, **in some cases symptoms may be prolonged**.*

The clinical signs and symptoms cannot be explained by drug, alcohol, or medication use, other injuries (such as cervical injuries, peripheral vestibular dysfunction, etc) or other comorbidities (eg, psychological factors or coexisting medical conditions).

A Multidisciplinary Problem



“ No area of sports medicine involves more clinical uncertainty and controversy than the treatment of concussion.” Melvin Field, MD

Concussion / Mild Traumatic Brain Injury

“Concussion is a brain injury and is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces.” -Zurich (2012) Concussion in Sport (CIS) Group

Consensus Statement

- Epidemiology
- Signs & symptoms
- Assessment
- Biomechanics of concussion
- Prevention & protection

Concussion / Mild Traumatic Brain Injury

“Sports related concussion is a traumatic brain injury induced by biomechanical forces. Several common features....”

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Mild Traumatic Brain Injury (mTBI)

80% of TBIs are mild, 1.6M may be up to 3.8M

Faul, CDC/NCIPC, 2010; *MMWR*, 60(5), 2011

Collision sports-related concussion incidence:

20% of high school athletes & 10% of college athletes

O'Connor, JAT, 2017; 52(3); Zuckerman, Am J Sports Med. 2015;43(11)

Females have higher concussion rates than males.

Concussion outcome worse in females than males.

Dick, Br J Sports Med, 2009; 43(S1); Veliz, JAMA. 2017;318(12)

Sports Related Concussion (SRC)

20-50% of mTBIs are Sports Related

- ✓ Variety of signs and symptoms
- ✓ Signs can be subtle
- ✓ Athletes reluctant to report
- ✓ Awareness & education still need improvement
- ✓ No “Gold Standard” diagnostic tool

<https://www.nap.edu/catalog/18377/sports-related-concussions-in-youth-improving-the-science-changing-the-culture>
(2014)



Sports Related Concussion (SRC)

Concussion Rate per 10,000 Athlete-Exposures

Sport	High School	Collegiate
Men's Football	9.21	6.71
Men's Lacrosse	6.65	3.18
Women's Soccer	6.11	6.31
Men's Wrestling	5.76	10.92
Women's Lacrosse	5.54	5.21
Women's Basketball	4.44	5.95
Women's Field Hockey	4.42	4.02
Men's Soccer	3.98	3.44
Women's Softball	3.57	3.28
Women's Gymnastics	2.65	2.65
Men's Basketball	2.52	3.89
Women's Volleyball	2.50	3.57
Men's Ice Hockey		7.91
Women's Ice Hockey		7.5
Men's Baseball	1.67	0.90
Overall	3.89	4.47

O'Connor et al. Epidemiology of Sport-Related Concussions in High School Athletes: National Athletic Treatment, Injury and Outcomes Network (NATION), 2011–2012 Through 2013–2014 *Journal of Athletic Training* (2017) 52(3):175.

Zuckerman et al. Epidemiology of Sports-Related Concussion in NCAA Athletes From 2009-2010 to 2013-2014 Incidence, Recurrence, and Mechanisms *The American Journal of Sports Medicine* (2015) 43(11):2654.

Concussion / Mild Traumatic Brain Injury

“Sports related concussion is a traumatic brain injury induced by biomechanical forces. Several common features....”

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Clinical Assessment of Concussion

History

Previous concussion
Migraine
ADHD/ LD
Family Hx

Symptoms

Headache
Dizziness
Light sensitivity...

Self-reported vs.
observation

Physical Exam

Balance
Oculomotor function
Recall

Neuropsychological function

Processing
Working memory
Delayed recall
Reaction time

Concussion Symptom Domains

Behavioral / Mood

Irritability
Feeling sad
Feeling more emotional
Anxiety / nervousness

Somatic & Vestibular

Headache
Dizziness
Balance problems
Nausea
Vomiting
Neck pain
Pressure in head

Mental

Attention
Alertness
Orientation
Memory

Sleep / Arousal

Difficulty falling asleep
Fragmented sleep
Sleeping more than usual
Sleeping less than usual
Drowsiness
Fatigue / low energy
Feeling slowed down

Sensory

Sensitivity to light
Sensitivity to noise
Blurred vision
Visual problems

Cognitive

Fogginess
Difficulty concentrating
Difficulty remembering
“Don’t feel right”

“if you’ve seen one concussion, you’ve seen one concussion”

Concussion / Mild Traumatic Brain Injury

“Sports related concussion is a traumatic brain injury induced by biomechanical forces. Several common features....”

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Post-Concussion Symptom Scale

Please indicate if you are experiencing any of the following symptoms today, regardless if you have had a concussion or not.

POST-CONCUSSION SYMPTOM SCALE							
Symptom	Severity Rating (0=not having; 6=severe) Circle.						
Headache	0	1	2	3	4	5	6
Nausea	0	1	2	3	4	5	6
Vomiting	0	1	2	3	4	5	6
Balance Problems	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Fatigue	0	1	2	3	4	5	6
Trouble Falling Asleep	0	1	2	3	4	5	6
Sleeping More than Usual	0	1	2	3	4	5	6
Sleeping Less than Usual	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Sensitivity to Light	0	1	2	3	4	5	6
Sensitivity to Noise	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous/ Anxious	0	1	2	3	4	5	6
Feeling More Emotional	0	1	2	3	4	5	6
Numbness or Tingling	0	1	2	3	4	5	6
Feeling Slowed Down	0	1	2	3	4	5	6
Feeling like "In a Fog"	0	1	2	3	4	5	6
Difficulty Concentrating	0	1	2	3	4	5	6
Difficulty Remembering	0	1	2	3	4	5	6
Visual Problems	0	1	2	3	4	5	6
Other	0	1	2	3	4	5	6

*****BELOW FOR OFFICE USE ONLY*****BELOW FOR OFFICE USE ONLY*****BELOW FOR OFFICE USE ONLY*****

Subtotal								TOTAL
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Heterogeneity of mTBI / Concussion

Heterogeneity stems from variation in the inherent nature of a system and the response to a changing state.

- Clinical manifestation can be transient or persistent
- Deficits include headache, nausea, dizziness, imbalance, sleep problems, concentration and memory difficulty, ...
- Assessment should consider multimodal outcome measures

Concussion Assessment Tools



3

How do you feel?

"You should score yourself on the following symptoms, based on how often you experience them."

	none		mild		mod		severe
Headache	0	1	2	3			
"Pressure in head"	0	1	2	3			
Neck Pain	0	1	2	3			
Nausea or vomiting	0	1	2	3			
Dizziness	0	1	2	3			
Blurred vision	0	1	2	3			
Balance problems	0	1	2	3			
Sensitivity to light	0	1	2	3			
Sensitivity to noise	0	1	2	3			
Feeling slowed down	0	1	2	3			
Feeling like "in a fog"	0	1	2	3			
"Don't feel right"	0	1	2	3			
Difficulty concentrating	0	1	2	3			
Difficulty remembering	0	1	2	3			
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6





Symptom checklists

Neurological symptoms

Neurocognitive testing

Balance testing

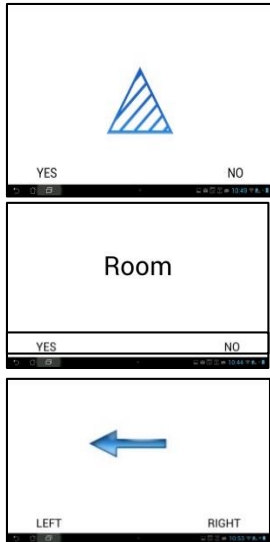
Vestibulo-ocular integrity

Sensory integration tasks



Multimodal Concussion Assessment

Neuropsychological Tests

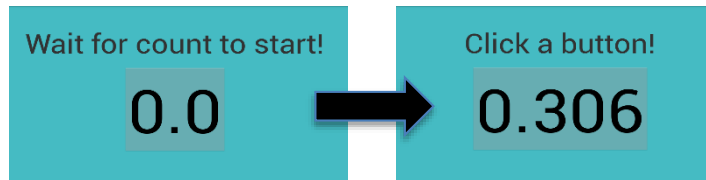


SHAPES: Complex
Choice Reaction Time
processing speed and
divided attention

WORD RECALL: Selective
Reminding Working
Memory (learning and
recall)

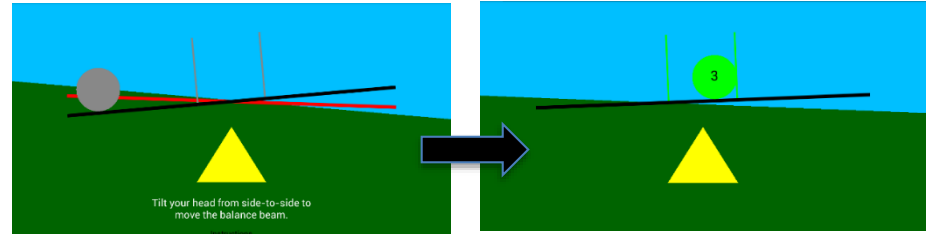
ARROWS: Conditional Choice
Reaction Time processing
speed and divided attention

Reaction Time Test



The user must maintain vigilance and wait for the timer to press the button

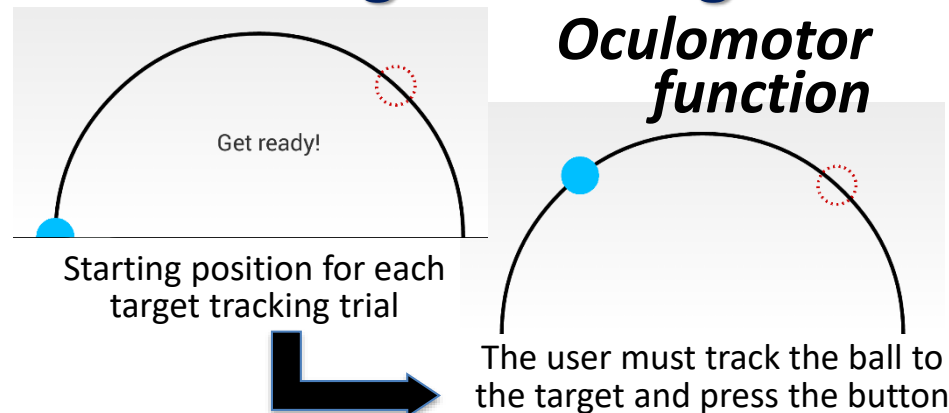
Non-Postural Balance Test



The user is instructed to tilt their head from side to side to balance the ball on the beam

The user must balance to place the ball in the target area and hold each trial for 3 seconds

Target Tracking Test



Concussion / Mild Traumatic Brain Injury

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Impact Biomechanics

Force is applied to head during impact



Acceleration is the movement of the head



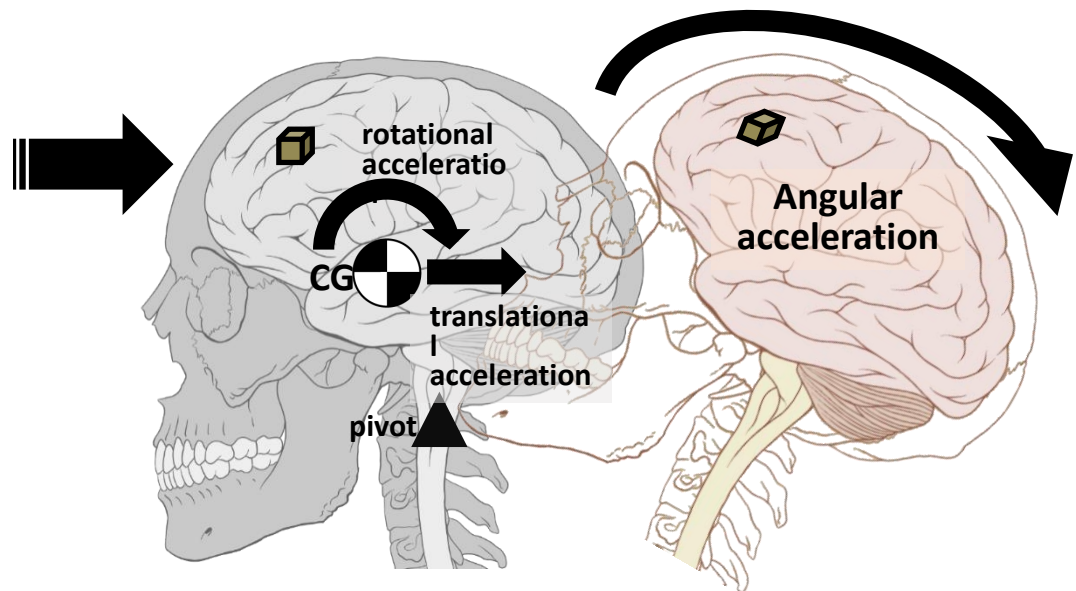
Stress and strain manifest in the tissue

- **Impact Biomechanics**

- Location of impact to head
- Surface of impact
- Velocity, duration
- Direction, Trajectory (kinematics)
- Acceleration (Linear & Rotational)

- **Head response depends on:**

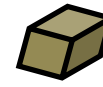
- Trajectory / constraints
- Neck strength
- Anticipation



*Volume Element
of brain tissue*



Undeformed



Deformed

Measuring Head Impact

- **Laboratory Testing:**

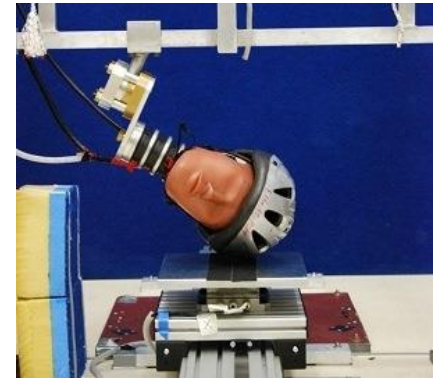


- Requires mechanical testing equipment
- Anthropomorphic head/neck
- Sensored equipment



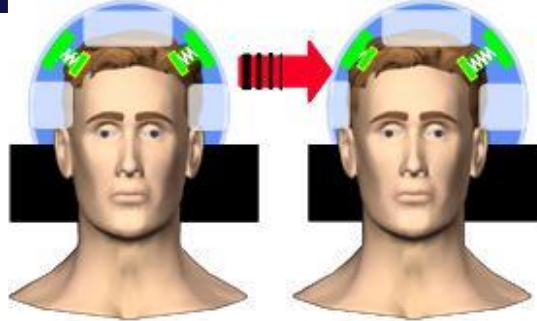
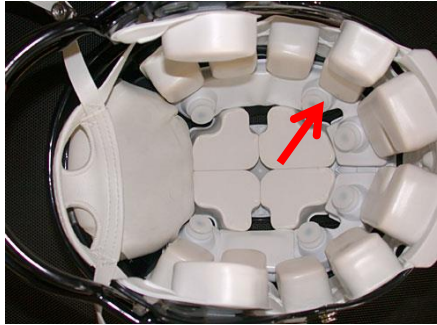
- **Field Testing:**

- Instrumented helmets (sensors)
- Mouthguard sensors
- Patch sensors
- Video analysis



Measuring Head Impact

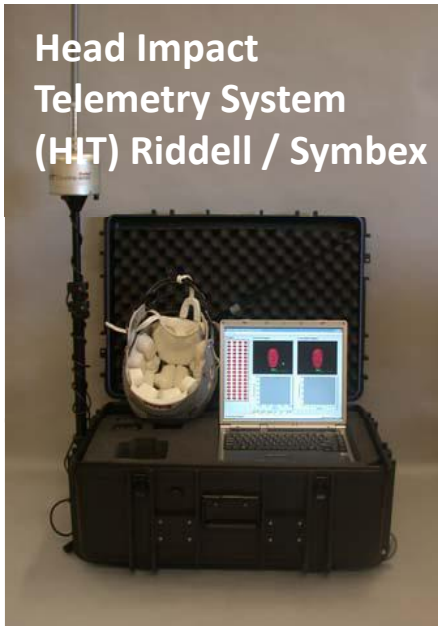
Field Testing:



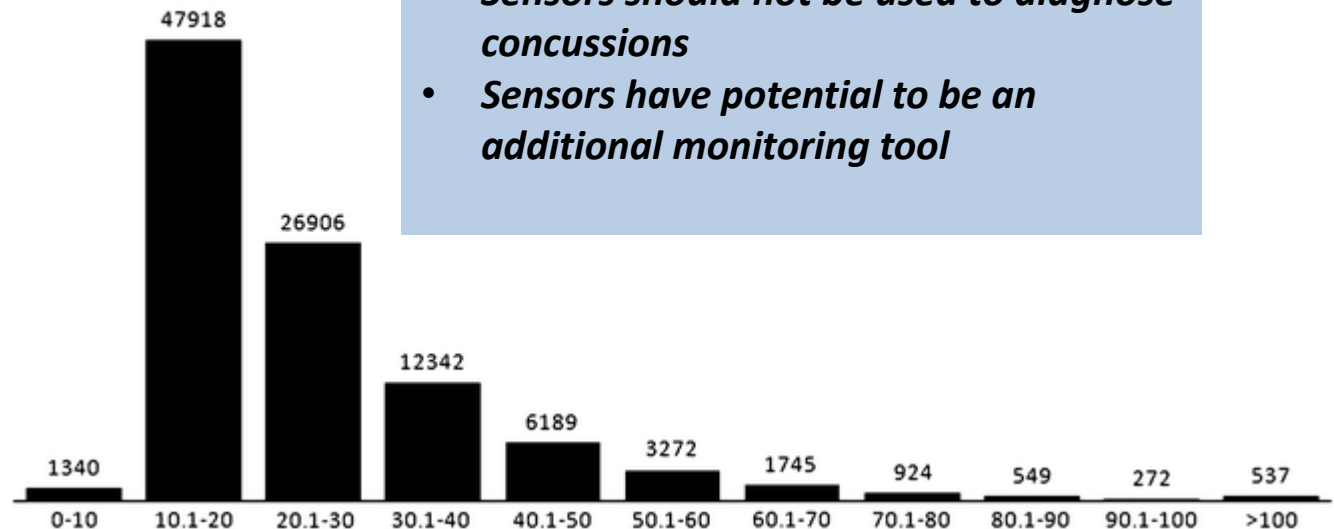
Average # impacts / football season = 1000

6 single axis accelerometers
1 kHz sampling, 40 ms bins
Wirelessly transmitted to base

Head Impact
Telemetry System
(HIT) Riddell / Symbex



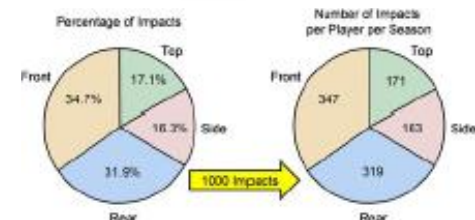
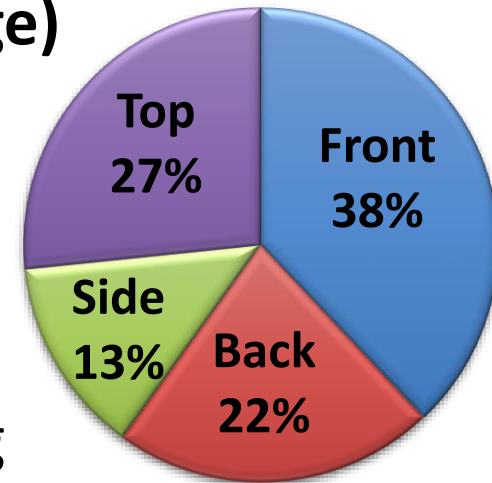
- Requires good helmet-head coupling
- Sensors error reported to be 10-30% (Jadischke et al, 2014; Allision et al, 2014)
- ***Sensors should not be used to diagnose concussions***
- ***Sensors have potential to be an additional monitoring tool***



Impact Event Characteristics

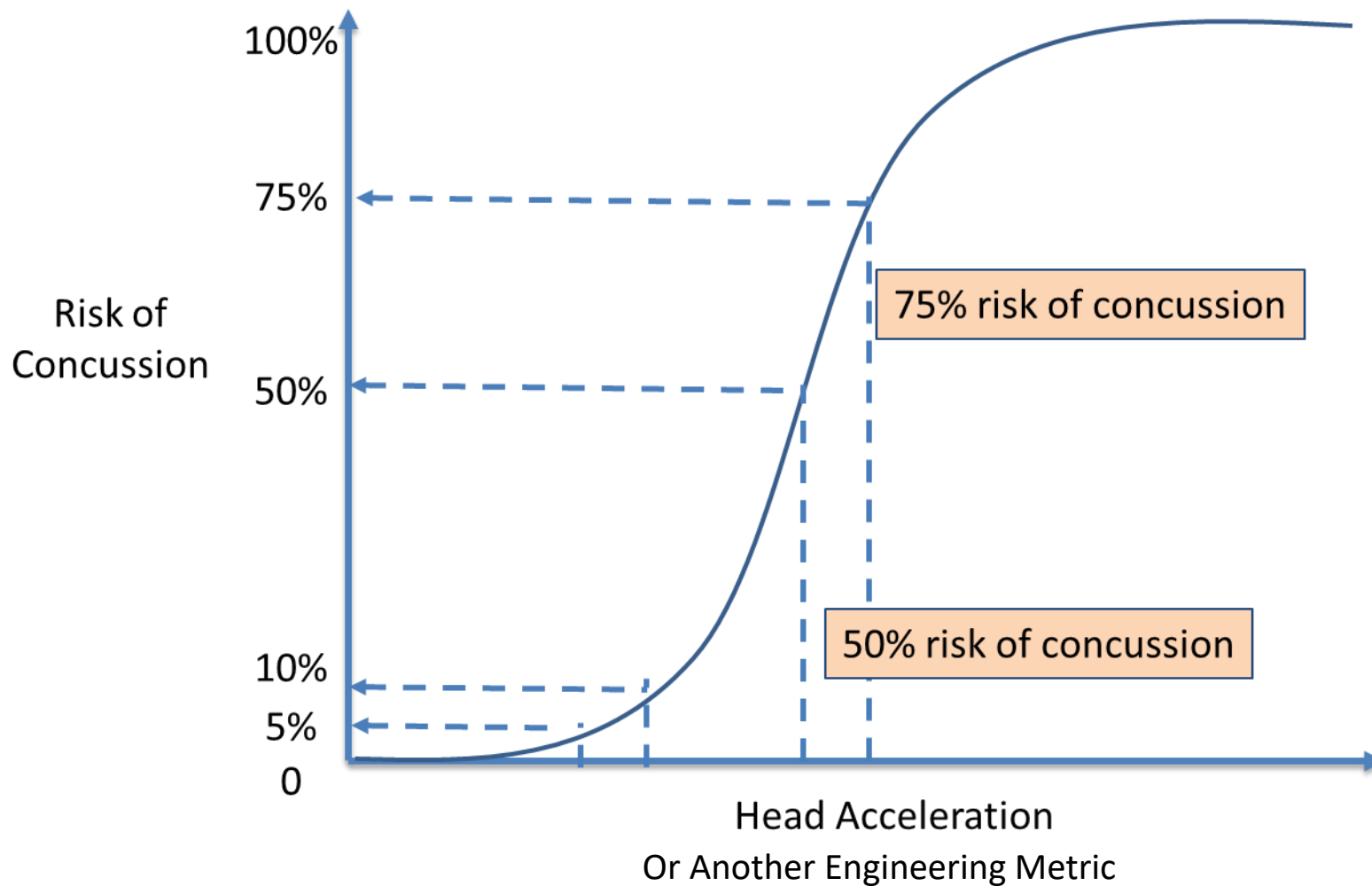
HIT Impact Sensor study (2 HS, 2 college)

- 34,679 Total impacts (1 season)
 - 12,091 HS, 22,589 College
- 60% impacts in sagittal plane
- 35% competition; 65% practice
- Linear acceleration range: 30 to 192g
- Rotational acceleration range: 602 to 12,115 rad/s²



<i>No difference between game & practice averages</i>	Average Linear Acceleration (g)	Average Rotational Acceleration (rad/s²)
Competition (12,167)	39.1 ± 22.6	2367 ± 1633
Practice (22,512)	38.9 ± 21.3	2154 ± 1425

Injury Risk



Concussion / Mild Traumatic Brain Injury

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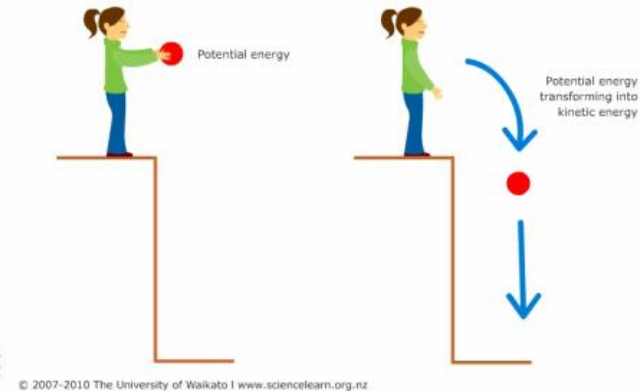
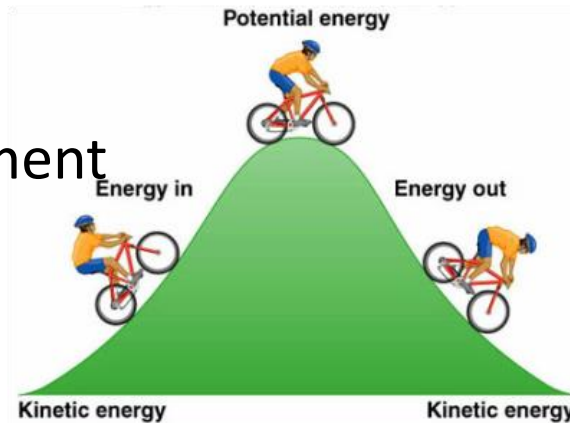
Injury Prevention

- **Education and Awareness Campaigns**
 - CDC Head's Up program (<https://www.cdc.gov/headsup/>)
 - E.g., Coaches Concussion Toolkit: Video, posters, fact sheets, research articles
- **Legislation**
 - All 50 states, youth sports
- **Equipment**
 - Proper fit
 - Safety standards
 - Playing surfaces
- **Rules**
 - Regulating certain activities (e.g., checking in hockey, frequency of impact practices)
 - Role of officials
 - Evidence based rules changes

Back to Physics: Energy

- Impact Energy

- Released to environment
- Stored & dissipated
- Transfer to brain



- Non-conservative energy
 - Absorbed, non-recoverable
 - Minimize (e.g., reduce drag); athlete loses less energy
 - **Maximize (e.g., protective gear)**
- Kinetic energy dissipation
- Kinetic energy transfer

Dissipate force

Helmet Design: Protection

- Helmet design preceded an understanding of injury mechanisms
 - Hard shell **distributes force** → reduce skull fracture
 - Padding **absorbs and dissipates force** → reduce inertial load



Riddell Flex

Vicis Zero1



The Guardian Cap

Impact Event Characteristics

- Helmets are designed to protect against skull fracture.
- Modern helmets have features to distribute force and dissipate energy.



Distribute force

NOCSEA CERTIFICATION

- National Operating Committee on Standards for Athletic Equipment (NOCSAE)
- Drop tests using head forms
- Certifies and re-certifies helmets
- Standards testing is for linear acceleration only

Real (field) impacts are a combination of linear and rotational acceleration

Preliminary evidence-based recommendations for return to learn: a novel pilot study tracking concussed college students

Zachary W Bevilacqua¹, Mary E Kerby², David Fletcher³, Zhongxue Chen⁴, Becca Merritt¹, Megan E Huibregtse¹ & Keisuke Kawata^{*,1,5}

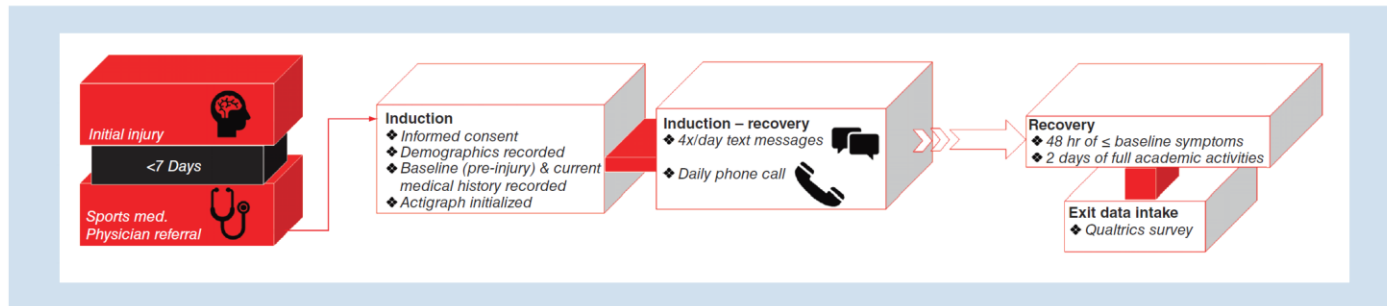


Figure 1. Study procedure timeline.

Behavior-symptom associations

- Listening to music was associated with increased headache, difficulty concentrating and fatigue.
- Absence of physical activity was associated with increased difficulty concentrating and fatigue.
- Greater water intake was associated with decreased anxiety.
- Greater amounts of sleep were associated with decreased dizziness.
- Time postinjury was associated with a decrease in all symptoms, with the exception of difficulty concentrating.

Student perceptions

- Math and computer-oriented courses were reported as the most difficult courses.
- Additional time on assignments/exams and reducing screen brightness were reported as the most beneficial accommodations.

RTL: College Students

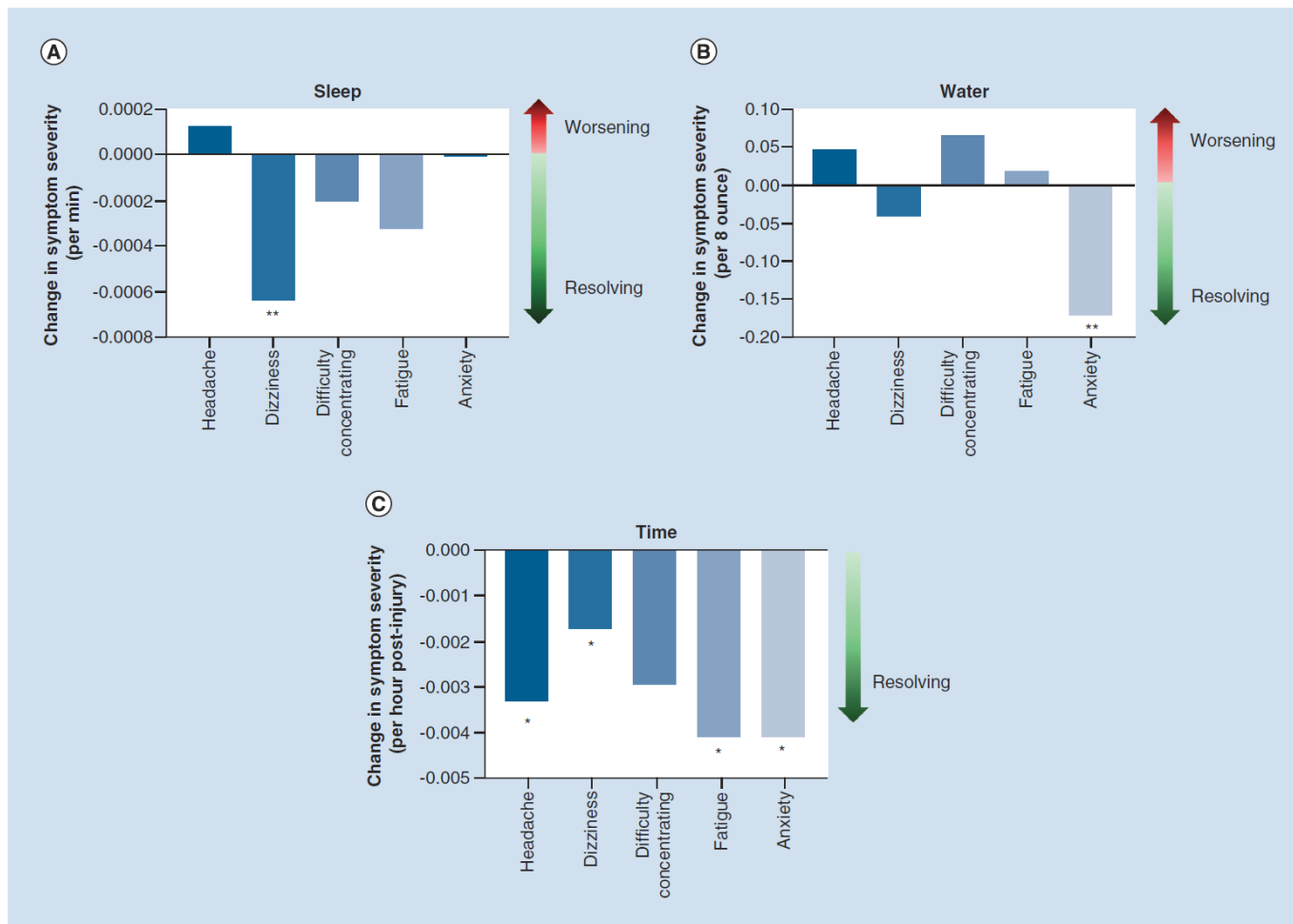


Figure 4. Adverse factors for concussion recovery. Behavioral variables vs symptom severity. Sleep vs symptoms (A), water vs symptoms (B), and time vs symptoms (C) are shown, respectively. Our five text message symptoms are listed along the x-axis, with symptom severity change along the left-sided y-axis, and effect of the behavior listed along the right-sided y-axis.

* $p < 0.05$; ** $p < 0.001$.

RTL: College Students

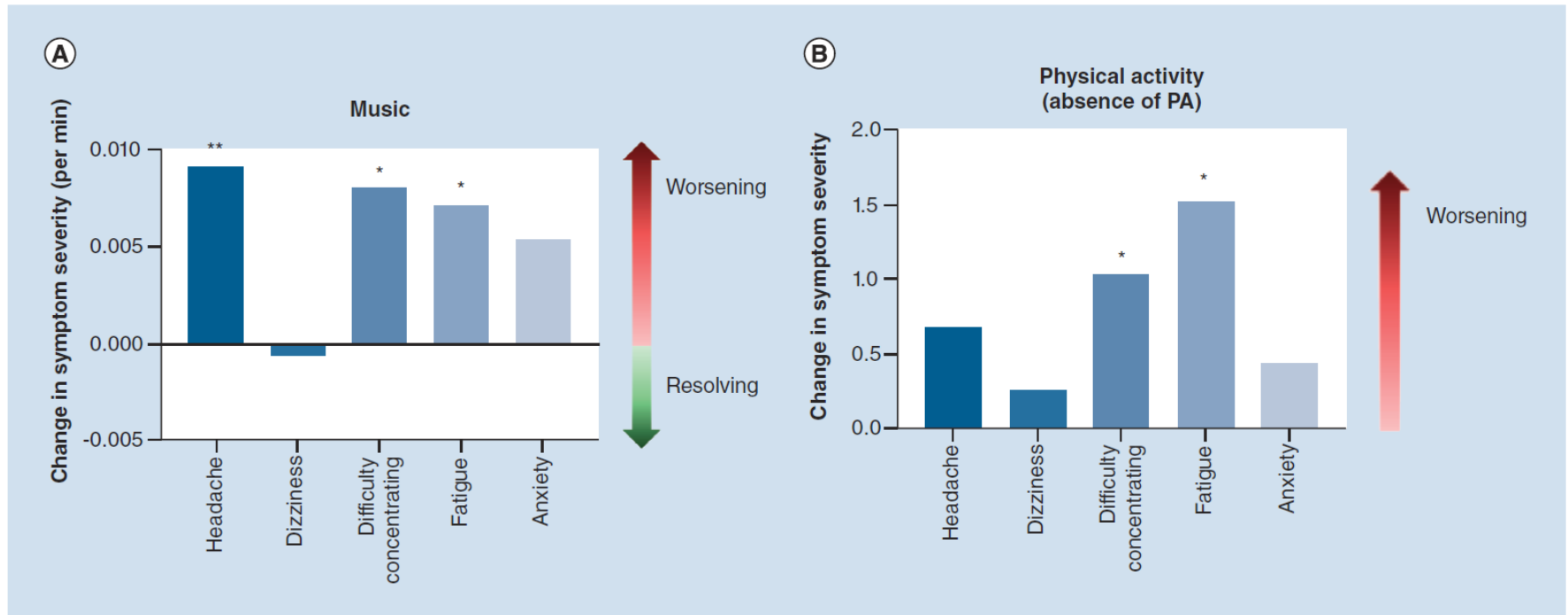


Figure 3. Beneficial factors for concussion recovery. Behavioral variables vs symptom severity. Music vs symptoms (A), and physical activity vs symptoms (B) are shown respectively. Our five text message symptoms are listed along the x-axis, with symptom severity change along the left-sided y-axis, and effect of the behavior listed along the right-sided y-axis. Significance was set at $p < 0.05$.

* $p < 0.05$; ** $p < 0.001$.

Concussion Knowledge (T/F)

- **Loss of consciousness is required for a diagnosis of concussion.**
- **A concussion is a brain injury.**
- **Children show better recovery from concussion than older individuals.**
- **Recovery from a concussion is complete when the individual is asymptomatic.**
- **The signs and symptoms of concussion can overlap with symptoms of other disorders such as depression, anxiety, and attention-deficit disorder.**

Concussion Knowledge (T/F)

- It is common for it to take up to a month for students to recover from concussion.
- Best care following concussion is for the student to be “cocooned” in their room with limited stimulation until all symptoms resolve.
- Students who return to moderate levels of physical and cognitive activity within the first week after their injury tend to have the quickest recovery.
- It is typical for a single concussion to result in long-term cognitive deficits.
- Physical effects of concussion, like headaches or light sensitivity, can impact academics as much as cognitive effects.

Gaps in Concussion Awareness and Care in College Students

- **Concussion awareness on college campuses outside of athletics departments is poor**
 - Low level of knowledge / high levels of misconceptions among students, staff, and faculty
 - Concussion diagnostic and return-to-learn/activities protocols lacking, not standardized
- **College students are uniquely vulnerable**
 - Student health center use sparse; pediatric primary providers not convenient, avoided
 - Student lack of awareness about appropriate campus resources and accommodations
 - Students, on average, have poor health hygiene (lack of sleep, high stress, suboptimal nutrition, and higher than average risk taking)
 - Poor resource seeking skills (judgment clouded by concussion effects, reliance on peer and internet advice, poor self-advocacy skills)
 - No legislation coverage (state laws cover athletics through secondary school systems, Americans with Disabilities act does not cover “temporary” conditions)
- **Campus services not designed for optimal concussion care**
 - Student health centers appointment delays
 - No standard protocol or guidance for return-to-learn/activities / lack of up-to-date resources
 - Disability services response time not compatible with optimal concussion care
 - Poor coordination of care across campus

Optimal concussion recovery relies on early access to resources and up-to-date concussion management

Questions

“If our brains were simple enough for us to understand them, we'd be so simple that we couldn't.” — Ian Stewart, *The Collapse of Chaos: Discovering Simplicity in a Complex World*