



Concussion Management: Current recommendations and interventions

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Disclosures

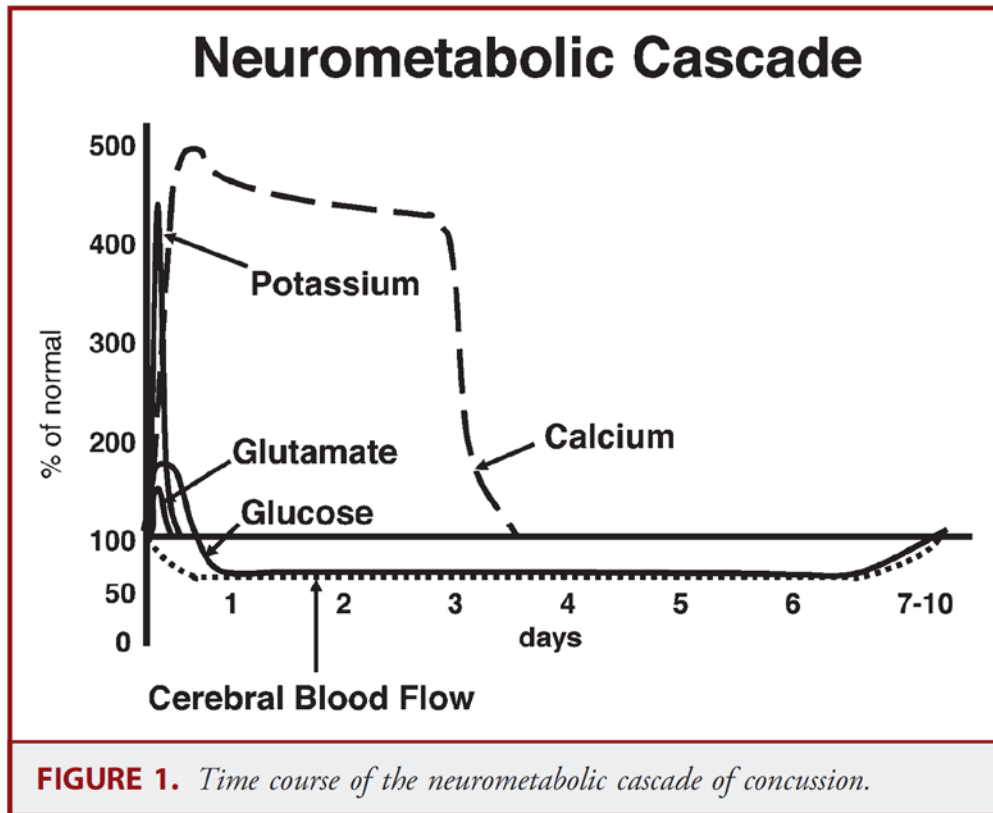
- No financial conflicts/disclosures

Overview

- Brief pathophysiology review
- Assessment/Diagnosis of Concussion
- Conceptual framework for concussion management
- Risk factors for protracted recovery from concussion
- Recent literature on aspects of management (rest, exercise, sleep etc.)

Pathophysiology of Concussion

Neurometabolic Cascade of Concussion



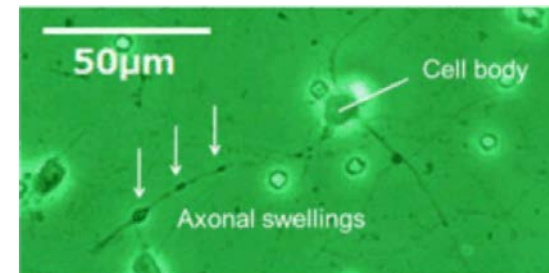
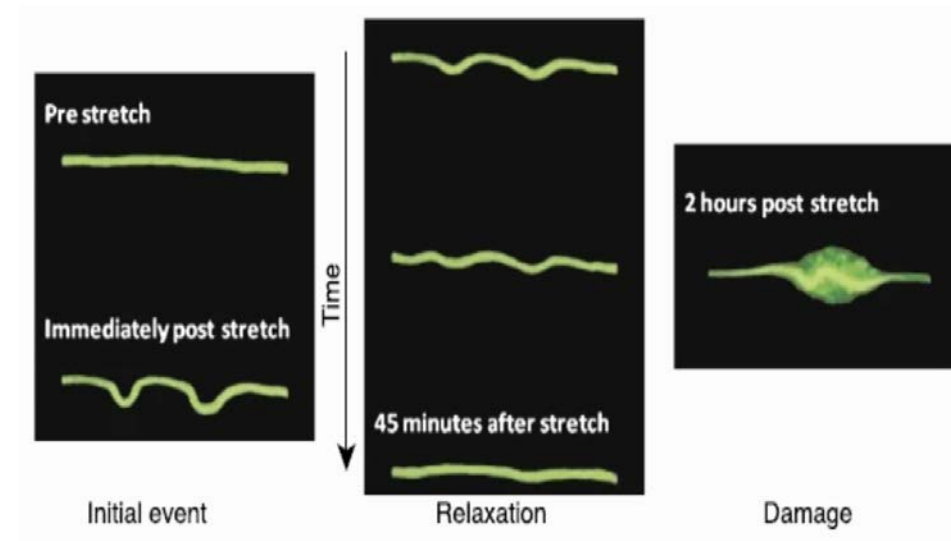
(Giza & Hovda, 2014)

- Biomechanical force to the brain resulting in neurological signs and symptoms without macroscopic neural damage.
- Referred to as the “neurometabolic cascade of concussion”
- Involves bioenergetic challenges, cytoskeletal and axonal alterations, and impairments in neurotransmission.

Acute pathophysiology of concussion

Axonal Dysfunction (traumatic axonal injury)

- Axons are particularly vulnerable to biomechanical stretching (mechanism behind DAI).
- Unmyelinated axons are more susceptible to damage.
- Evidence from animal models of more prominent axonal injury with repeated TBI.



Aomura et al., (2016) Stretch-induced functional disorder of axonal transport in the cultured rat cortex neuron

Acute pathophysiology of concussion

24 hours post vs controls

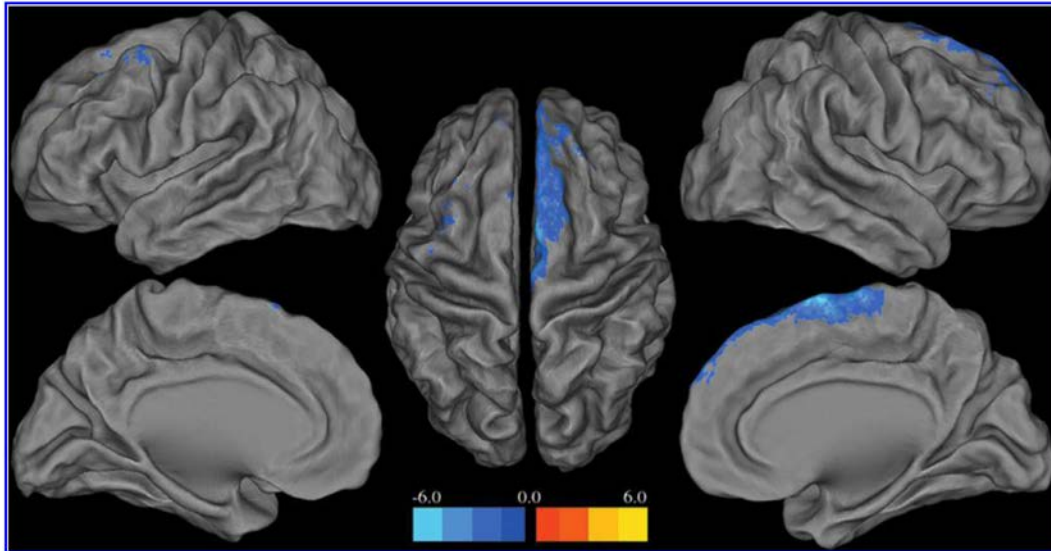


FIG. 1. Regions (in blue color) show significantly less cerebral blood flow (CBF) in concussion group at 24h after injury, compared with the control group. No region shows significantly more CBF in the concussion group compared to the control group. Images reflect family-wise error correction at $p < 0.05$. Color bar indicates the t score. Color image is available online at www.liebertpub.com/neu

From Wang et al., (2016) Cerebral blood flow alterations in acute sport-related concussion. *J Neurotrauma*

Energy Crisis

Changes in Cerebral Blood Flow

- Regulation of CBF achieved through changes in arteriolar vessel diameter, and cerebrovascular reactivity (CVR) is sensitive to all forms of TBI
- After initial hyperglycolysis and metabolic uncoupling, glucose metabolic rates enter state of impaired metabolism matching blood flow (50% of normal) around 24 hours post-injury.
- Calcium levels return to baseline ~3-4 days, glucose and CBF around 7-10 days.

Acute pathophysiology of concussion

8 days post vs controls

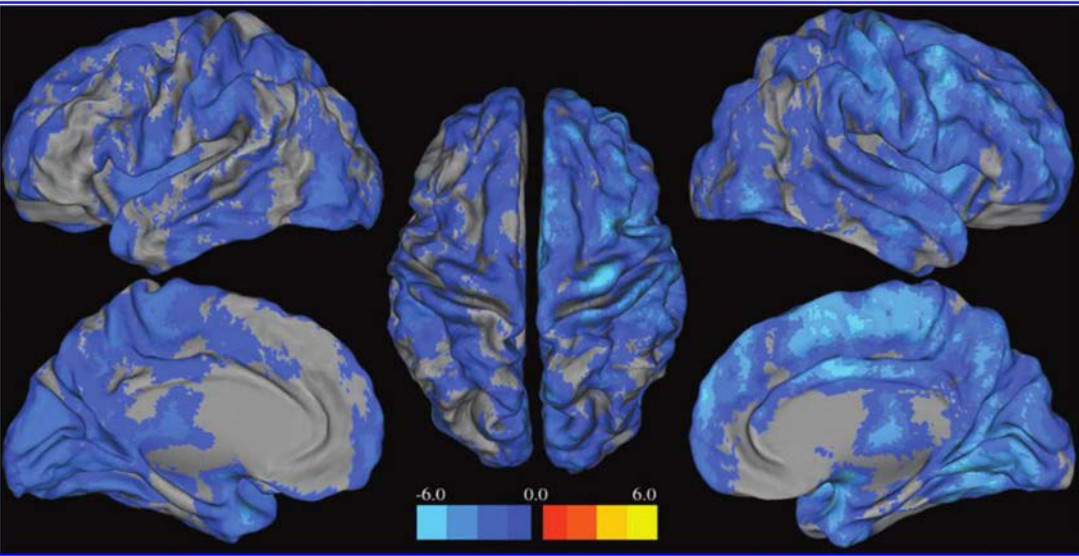


FIG. 2. Diffuse cortical and subcortical regions (in blue color) show significantly less cerebral blood flow (CBF) in concussion group at 8 days after injury, compared with the control group. No region shows significant more CBF in the concussion group compared to the control group. Images reflect family-wise error correction at $p < 0.05$. Color bar indicates the t scores. Color image is available online at www.liebertpub.com/neu

From Wang et al., (2016) Cerebral blood flow alterations in acute sport-related concussion. *J Neurotrauma*

Energy Crisis

Changes in Cerebral Blood Flow

- At 8 days, lower CBF diffusely across cortical grey matter, mainly bilateral prefrontal regions, temporal lobes, some parietal lobes, thalamus
- Autoregulation of cerebral blood flow has been found to be affected up to 14 days post-concussion

Evaluation and Management of Acute/Subacute Concussion

Concussion Definition

- “Concussion is defined as a traumatically induced transient disturbance of brain function that involves a complex pathophysiological process...
- The clinical signs and symptoms of concussion cannot be otherwise explained by drug, alcohol, medication use, or other injuries (such as cervical injuries or peripheral vestibular dysfunction) or other comorbidities (psychological or medical conditions)”

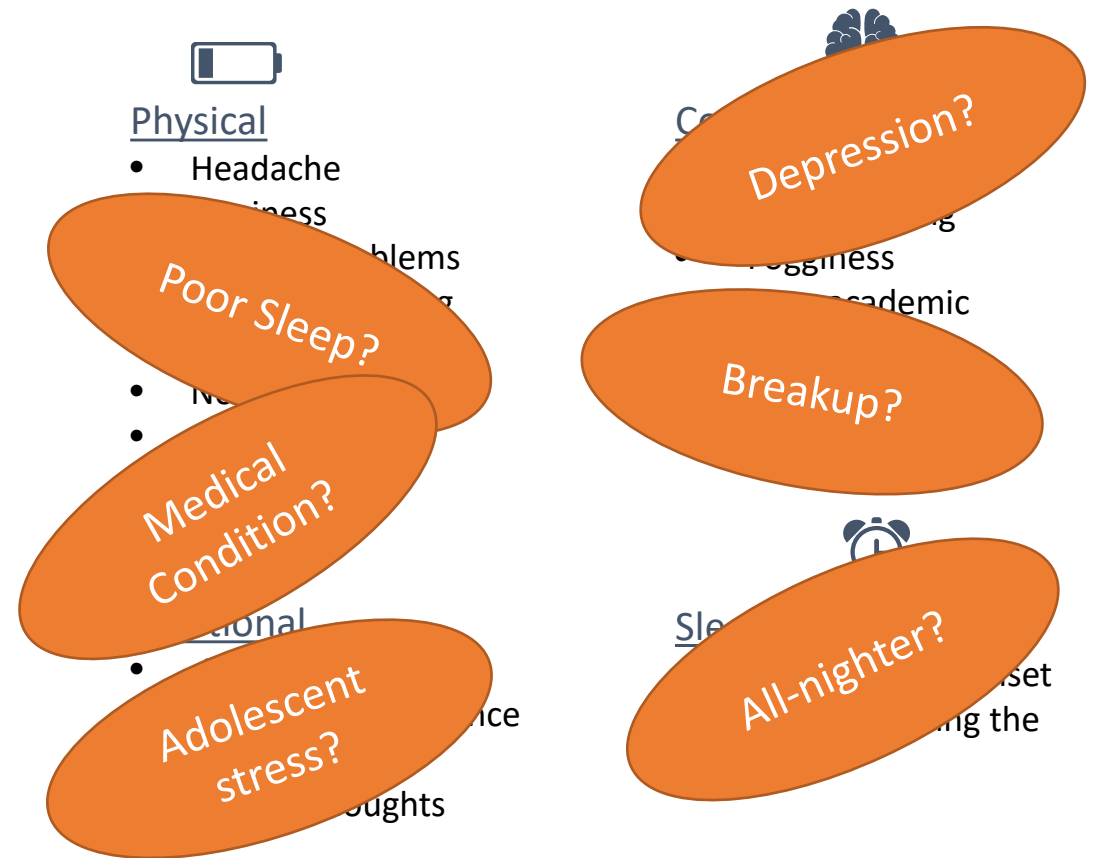
Consensus statement

American Medical Society for Sports Medicine position statement on concussion in sport

Kimberly G Harmon,¹ James R Clugston,² Katherine Dec,³ Brian Hainline,⁴
Stanley Herring,⁵ Shawn F Kane,⁶ Anthony P Kontos,⁷ John J Leddy,⁸ Michael McCrea,⁹
Sourav K Poddar,¹⁰ Margot Putukian,^{11,12} Julie C Wilson,¹³ William O Roberts¹⁴

Concussion Diagnosis

- Remains a predominately symptom-based diagnosis
- “Concussion remains a clinical diagnosis made by carefully synthesizing history and physical exam findings as the injury evolves” *AMSSM 2019 Position Statement*
- Individual symptoms of concussion in isolation are highly non-specific.
- Some available clinical tools to help identify concussion/concussion-like symptoms but a general lack of validated tools and reliance of self-report complicates evaluation.



Current CDC Guidelines for Pediatric Concussion (2018)

Must

- Imaging when certain criteria are met
- Clear follow up instructions

Children Between 2 and 18 Years Old	
Predictor	Risk of Clinically Significant TBI
GCS ≤ 14 Altered Mental Status Signs of basilar skull fracture	4.3%
LOC History of Vomiting Severe headache Severe Mechanism	0.8%
No predictors present	<0.05%

Should

- Screen for pre-risk factors for protracted recovery
- Counsel patients on typical recovery times, risk factors, and unique recovery
- Closely monitor patients at high risk of protracted recovery
- Refer to health care professionals when recovery does not occur in typical window.
- Brief period of rest (first 2-3 days) followed by active sub-symptom graded return to activity.
- Gradually increase the duration and intensity of schoolwork.
- Customized academic accommodations based on symptom severity, adjusted until student reaches pre-injury levels.
- Maintain academic workload without significant exacerbation of symptoms.
- OTC medication with counseling on rebound headaches (chronic post-concussive headaches to be treated by multi-disciplinary team).
- Guidance on sleep hygiene.
- Determine etiology of cognitive dysfunction
- Recommendation for treatment of cognitive dysfunction that reflects *presumed etiology*

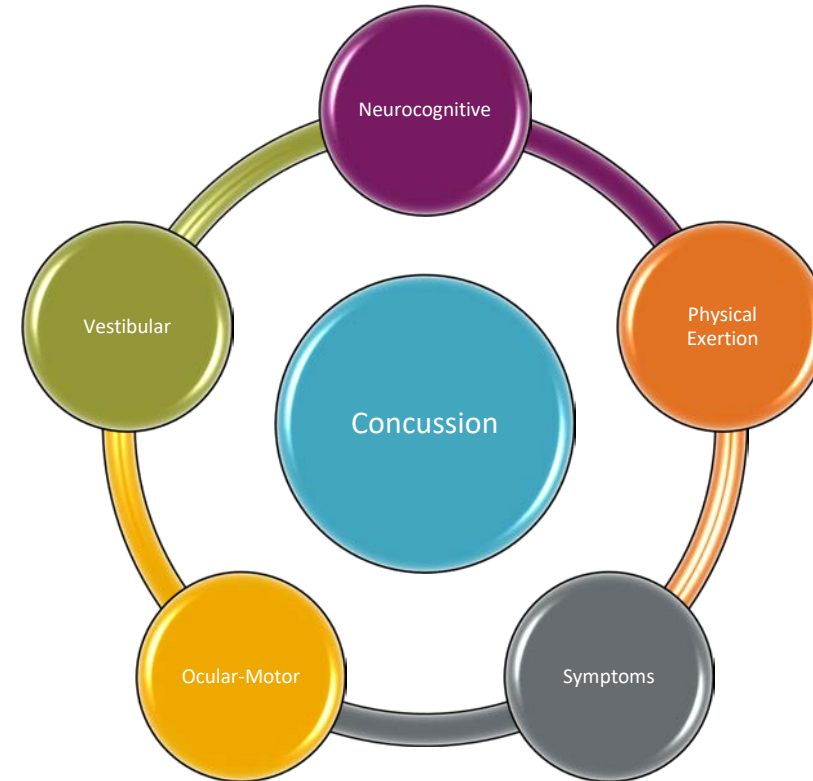
May

- Validated neurocognitive testing to assess recovery
- Balance testing
- Combine prediction rules with risk factors for better prognostication of recovery
- Assessment of social support
- Referral for vestibular rehabilitation
- Sleep specialist for protracted sleep issues.

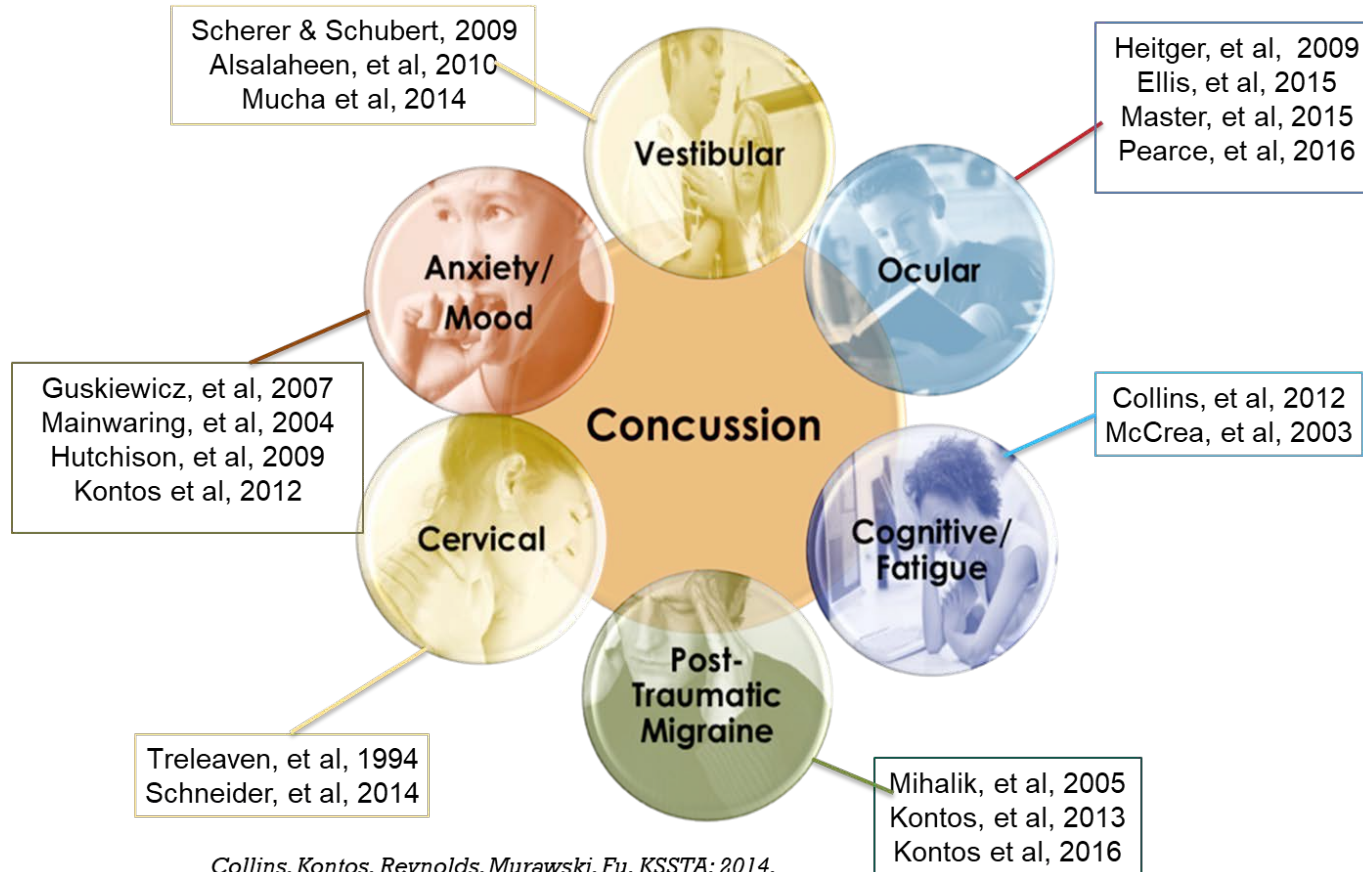
Acute/Subacute Concussion Management

Multi-Domain Assessment Approach

- **Clinical Evaluation and Assessment**
 - Detailed clinical interview (Risk Factors, Injury characteristics, early symptom profile)
 - Computerized neurocognitive testing
 - Vestibular-Ocular Screening (VOMS)
 - Ocular dysfunction (CISS)
 - Balance testing (BESS)
- **Goals of Evaluation**
 - Establish diagnosis and prognosis
 - Establish *clinical and treatment profiles*
 - Establish individualized treatment and rehabilitation plan
 - Plan for return to play/return to learn/return to work

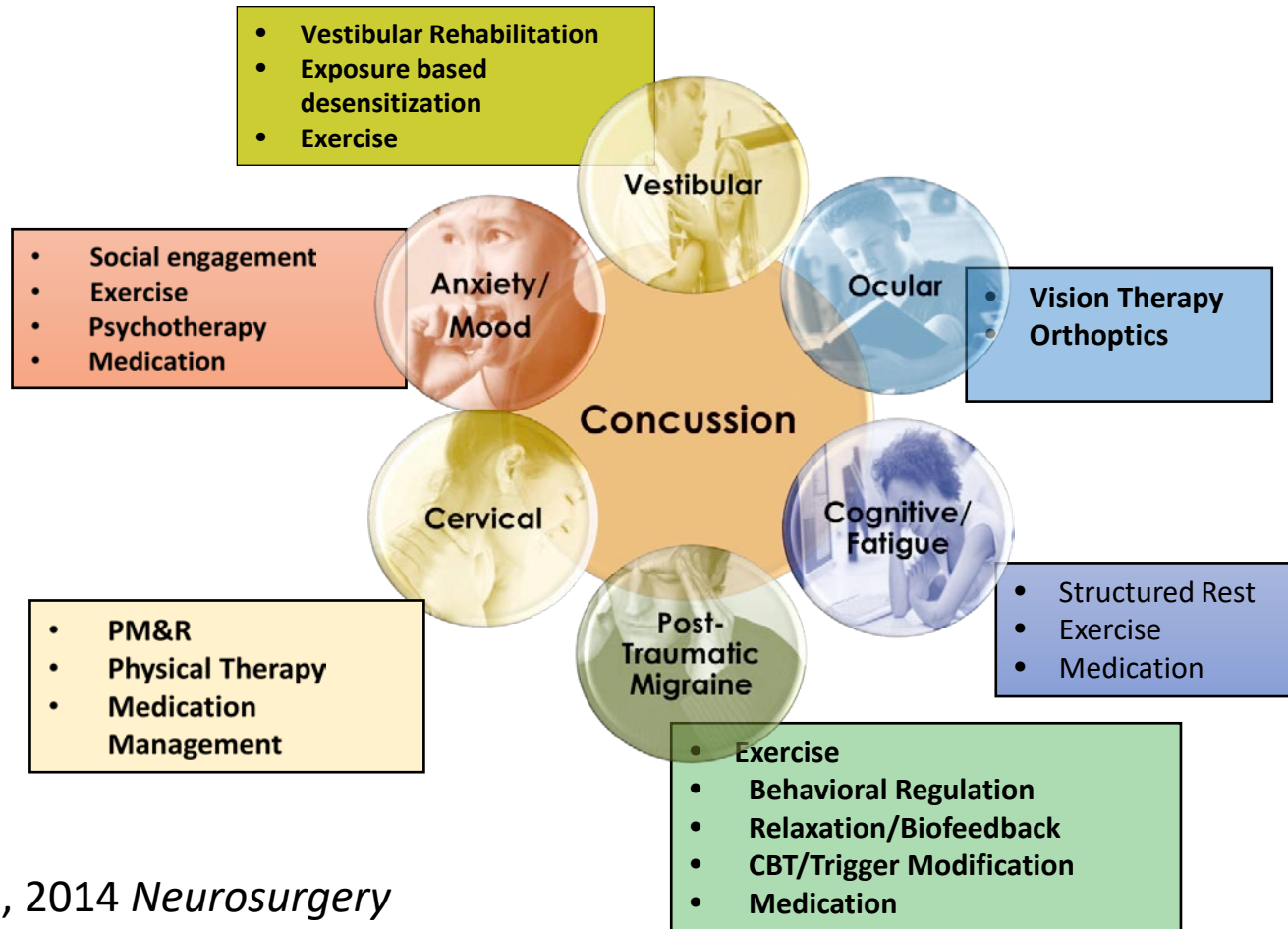


Outpatient Concussion Management

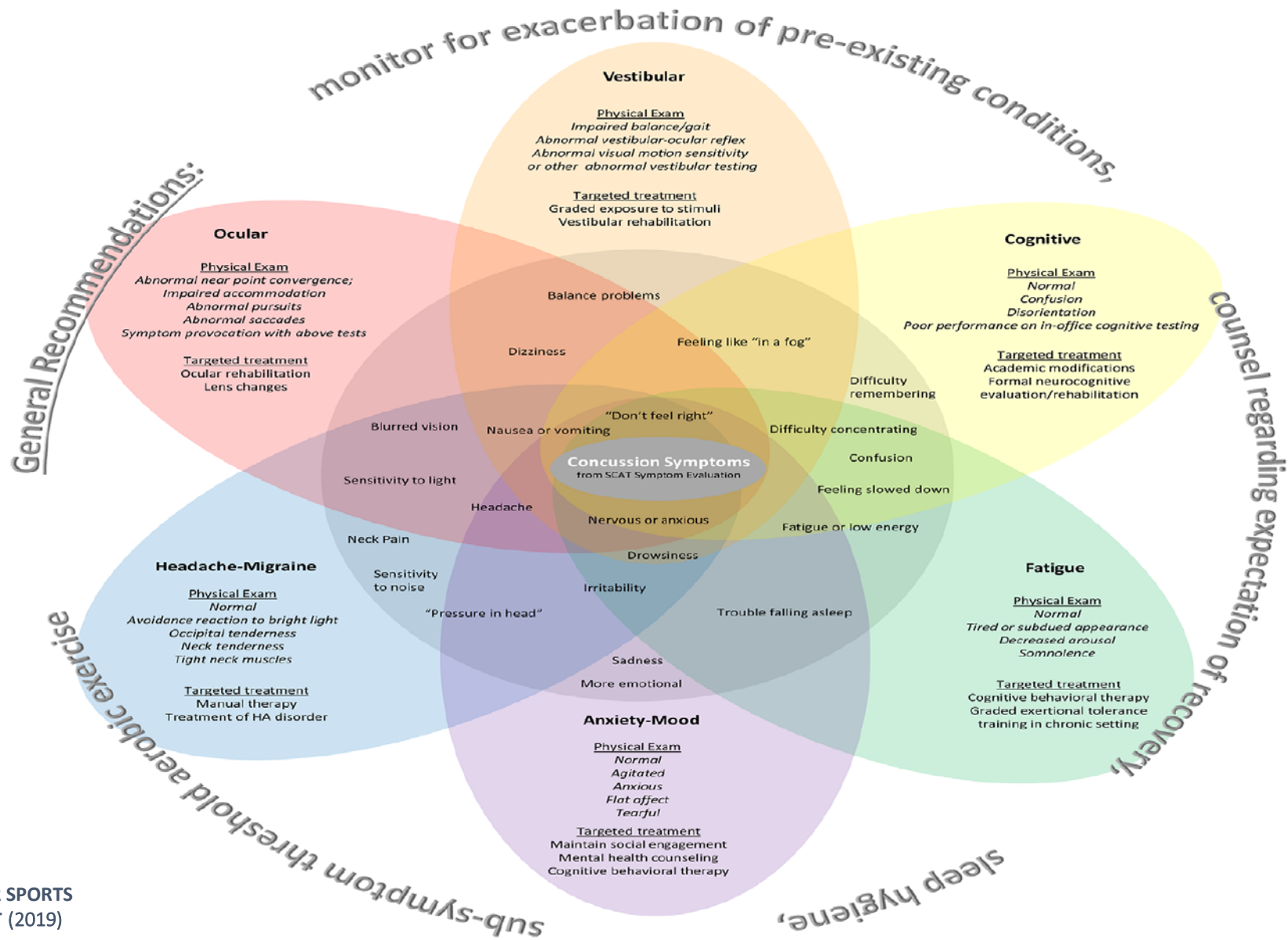


*Collins, Kontos, Reynolds, Murawski, Fu. KSSTA; 2014.
Collins, Kontos, Okonkwo et al., Neurosurg; 2016*

Outpatient Concussion Management

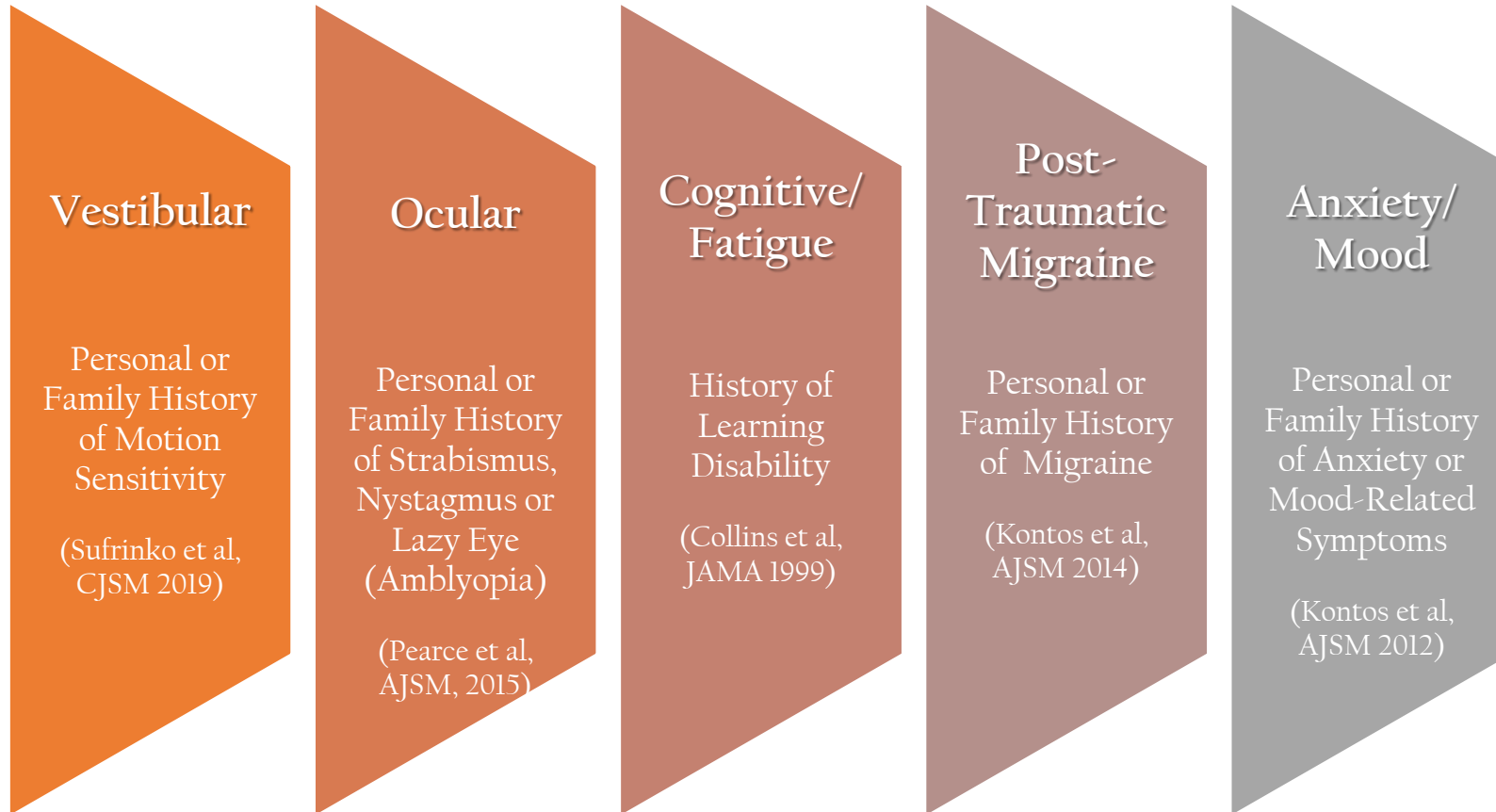


Collins et al., 2014 *Neurosurgery*



AMERICAN MEDICAL SOCIETY FOR SPORTS
 MEDICINE POSITION STATEMENT (2019)

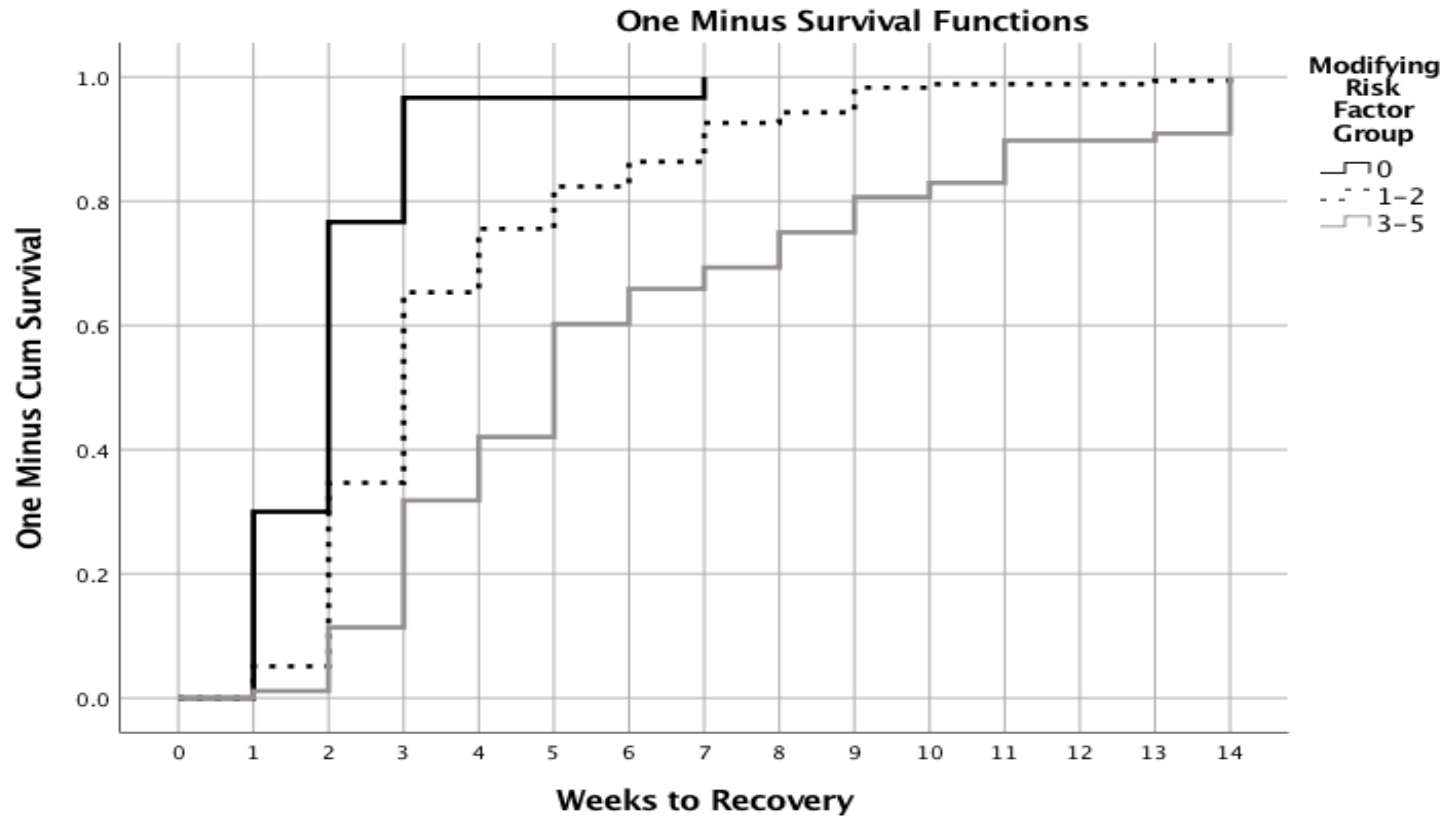
PRE-EXISTING RISK FACTORS FOR EACH CLINICAL PROFILE



RISK FACTORS FOR PROTRACTED RECOVERY IN ATHLETES

Younger Age	<ul style="list-style-type: none"> Field, Lovell, Collins et al. <u>J of Pediatrics</u>, 2003 Pellman, Lovell et al. <u>Neurosurgery</u>, 2006
Migraine History & Symptoms*	<ul style="list-style-type: none"> Mihalik, Collins, Lovell et al, <u>J Neurosurgery</u>, 2006 Kontos, Collins, Elbin, French, Simenski, <u>AJSM</u>, 2013. Sufrinko, McAllister-Deitrick, Elbin, et al., <u>J Head Trauma Rehab</u>, 2017
Female Gender	<ul style="list-style-type: none"> Colvin, Lovell, Pardini, Mullin, Collins, <u>AJSM</u>, 2009 Covassin et al, <u>CJSM</u>, 2009 Mucha, Collins et al, <u>AJSM</u> 2014
Motion Sickness, Ocular Dysfunction	<ul style="list-style-type: none"> Sufrinko, Kegel, Mucha, Collins, Kontos, <u>Clin J Sport Med</u>, 2017 Pearce et al., 2015
On-field Dizziness, Sub-acute Fogginess	<ul style="list-style-type: none"> Lau, Collins, Lovell et al, <u>CJSM</u>, 2009 Lau, Collins et al, <u>AJSM</u>, 2011 Lau, Collins, Kontos et al, <u>AJSM</u> 2011
Playing through Injury	<ul style="list-style-type: none"> Elbin et al, <u>Pediatrics</u>, 2016
Low Psychological Resilience	<ul style="list-style-type: none"> Ernst et al, <u>Applied Neuropsychology</u>, 2021
Post-injury sleep disturbance	<ul style="list-style-type: none"> Bramley et al., <u>Clinical Pediatrics</u>, 2017
Prior concussions	<ul style="list-style-type: none"> Scopaz et al., <u>AOSSM</u>, 2013

Dose-Response for Risk Factors



- N=316 SRC ages 12-23
- Followed < 1 week through medical clearance

Kontos AP, Elbin RJ, Sufrinko A, Marchetti G, Hollan CL, Collins MW. J Head Trauma & Rehab, 2019.

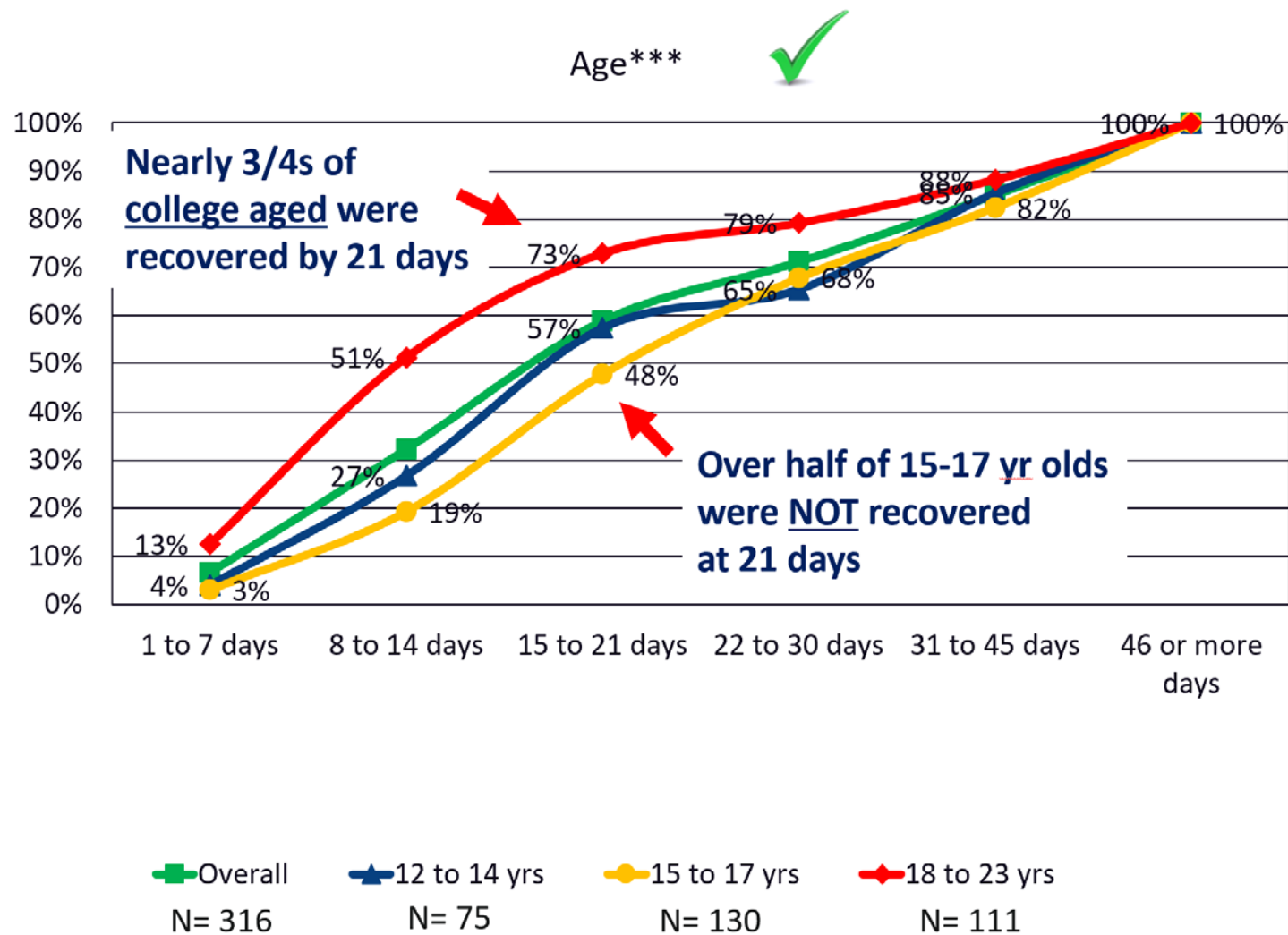
Pre-injury Factors:

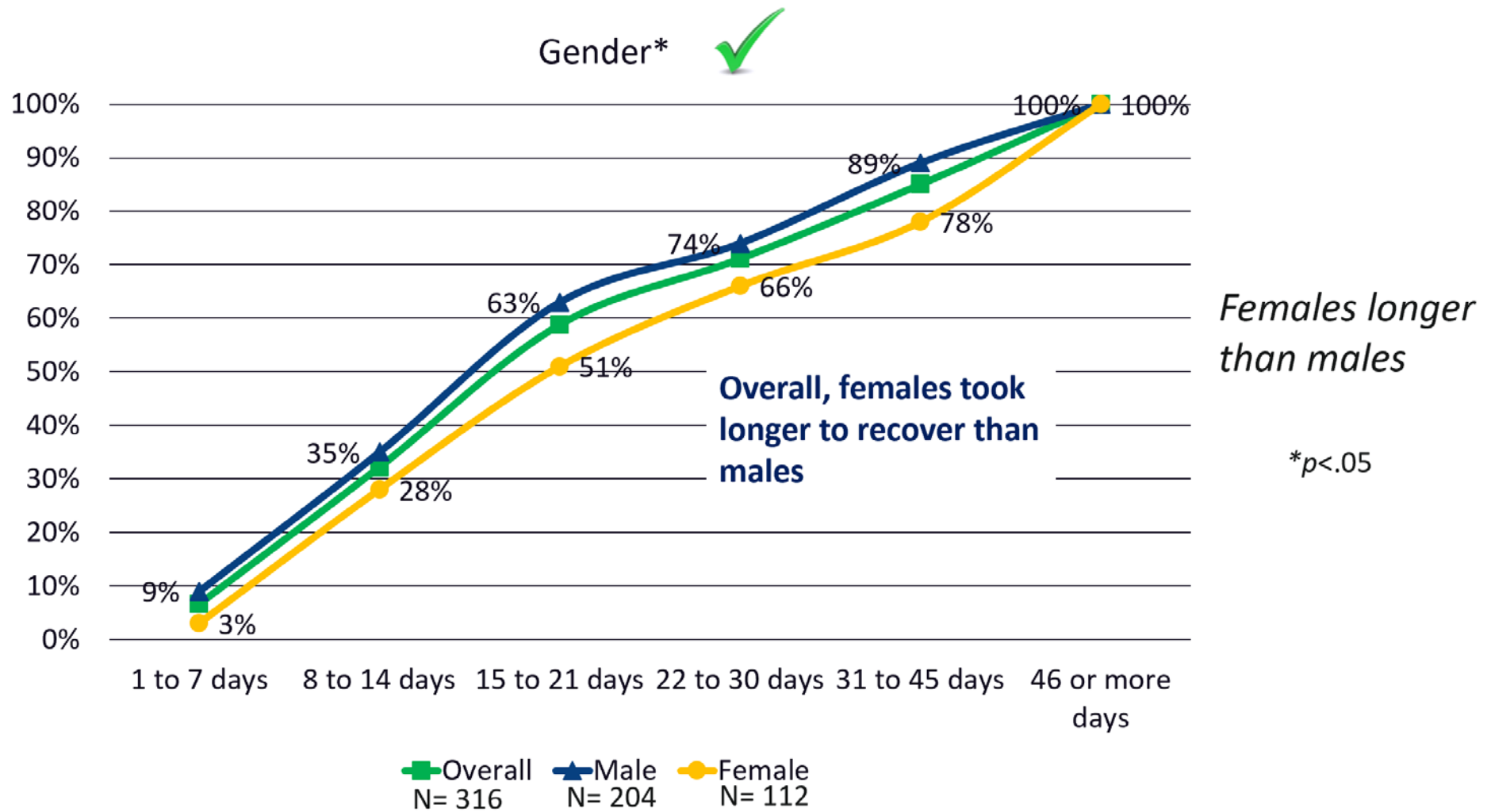
Age

Gender

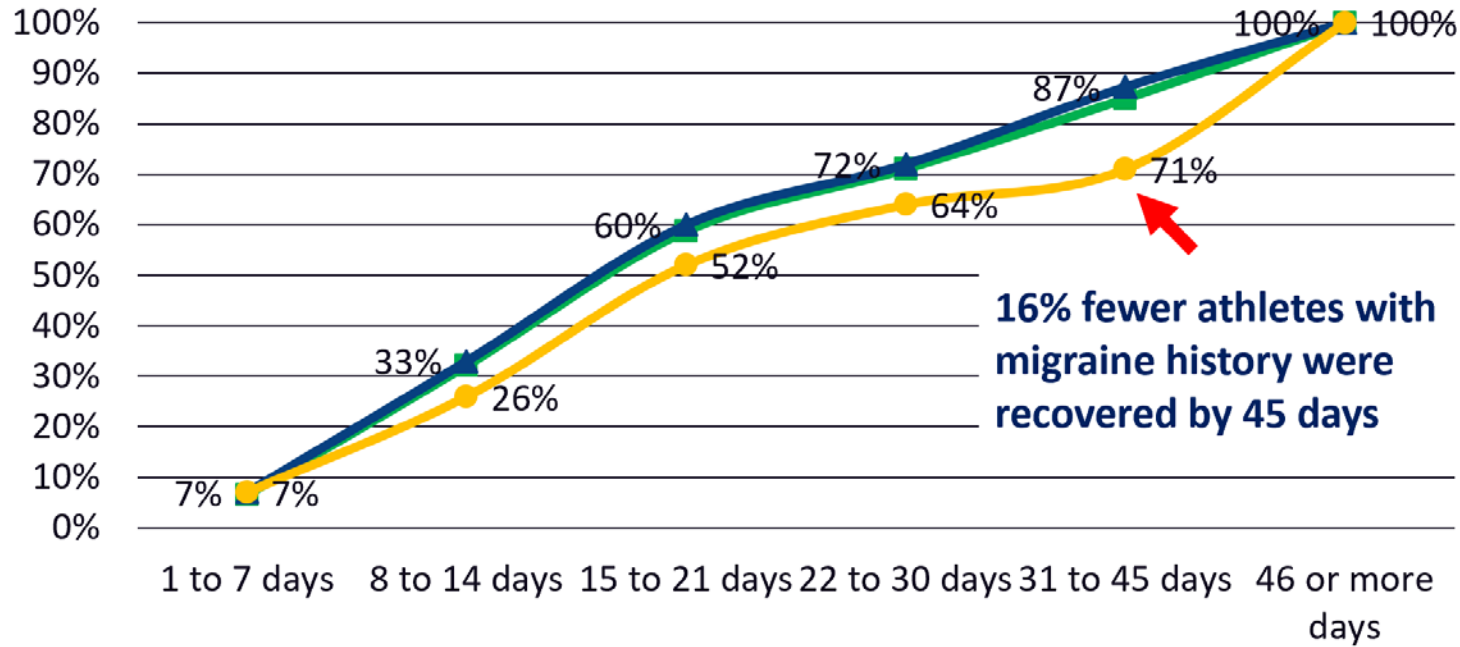
Personal Migraine History







Migraine History*



16% fewer athletes with migraine history were recovered by 45 days

Migraine Hx longer than NO Hx

* $p < .05$

Overall N= 301 No History N= 259 History of Migraine N= 42

Post-injury Factors:

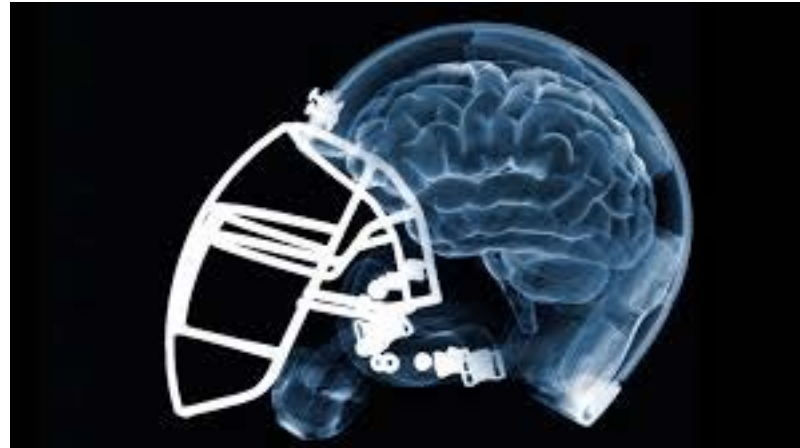
Post-traumatic Migraine Symptoms (HA, Nausea, Photo/Phono- Sensitivity)

Symptom Burden (≥21+ PCSS)

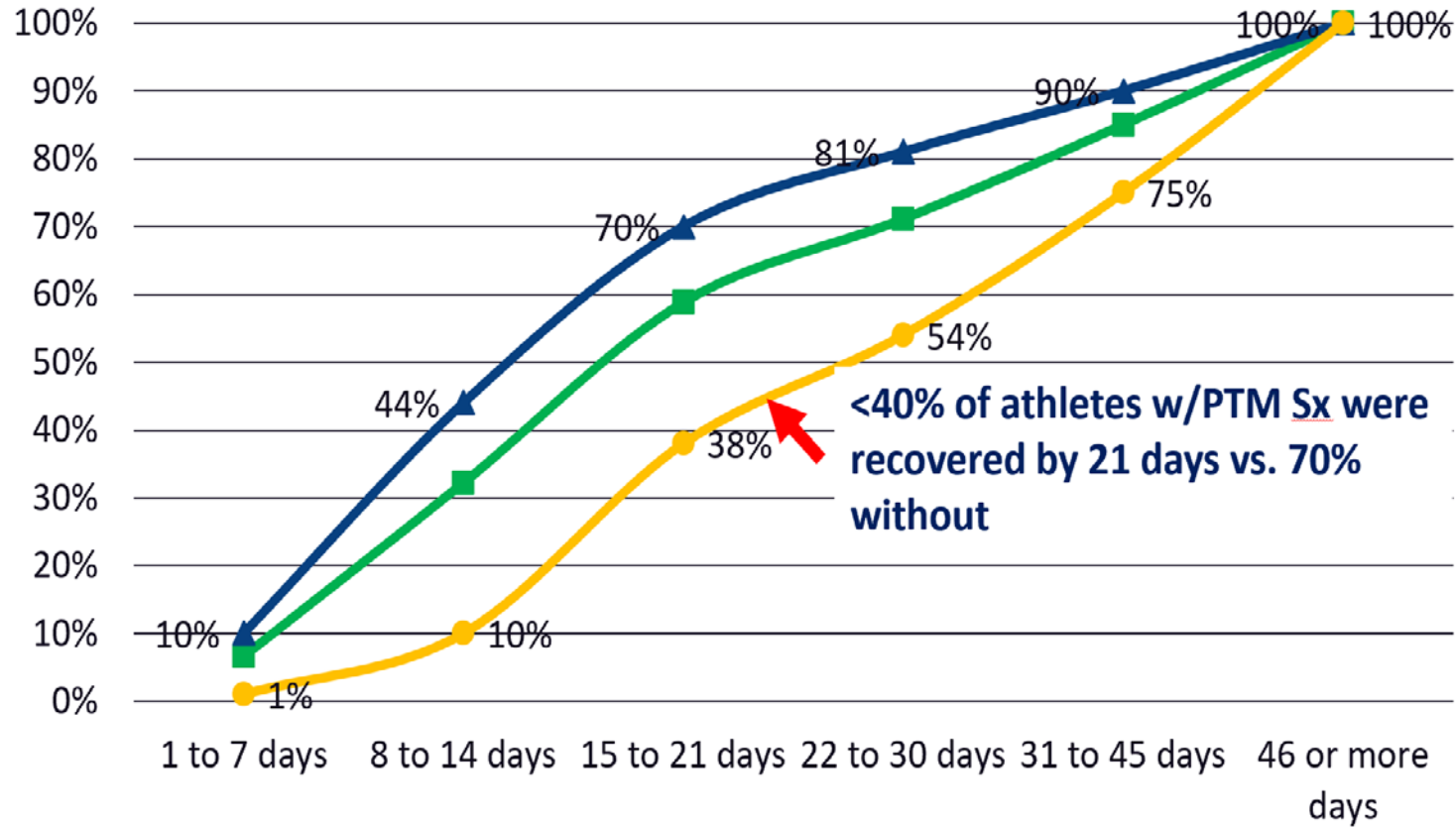
Dizziness at Time of Injury

Brief Loss of Consciousness (<1 min)

Post-Traumatic Amnesia



Post-traumatic Migraine (PTM) Symptoms***

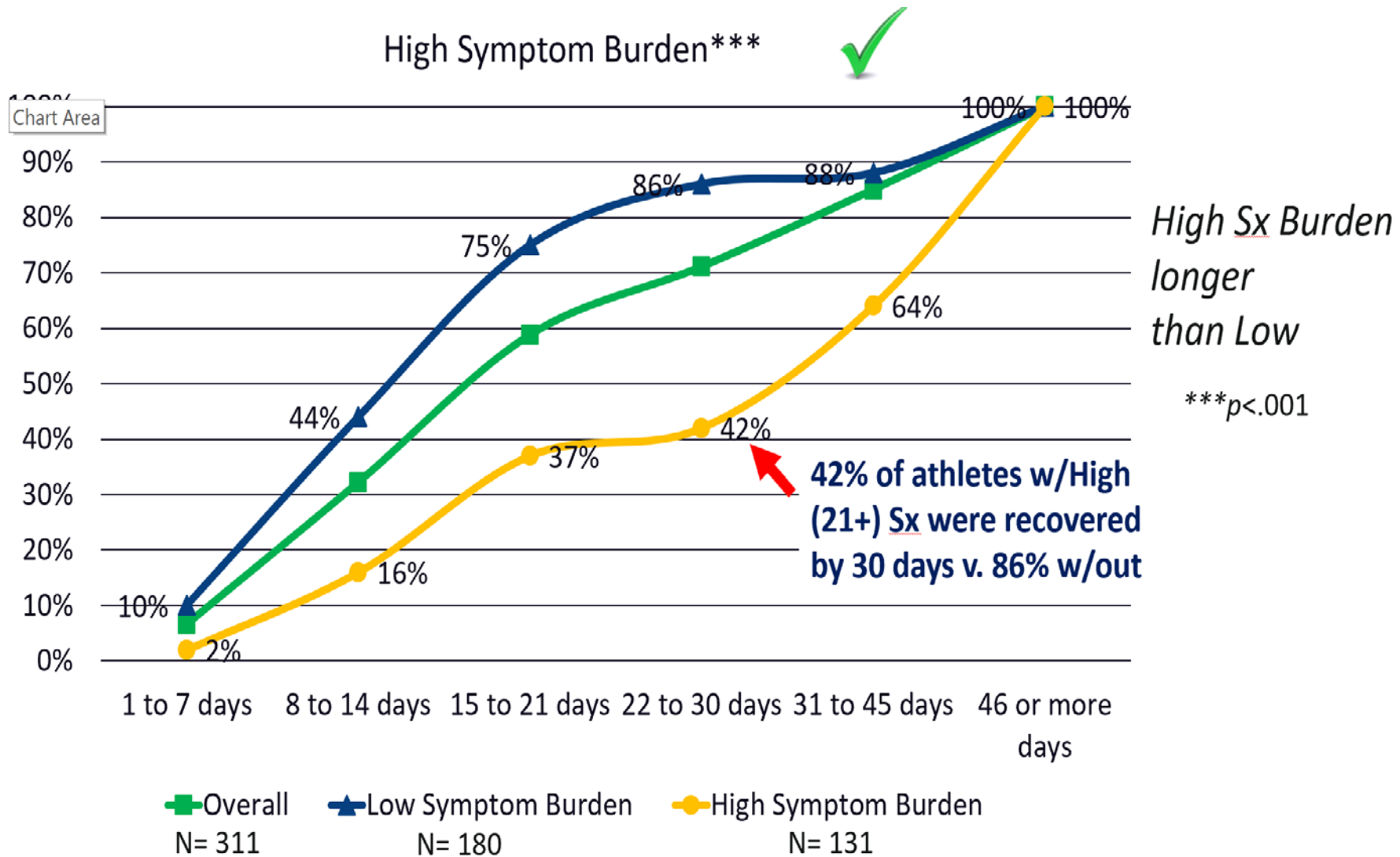


PTM longer than NO PTM

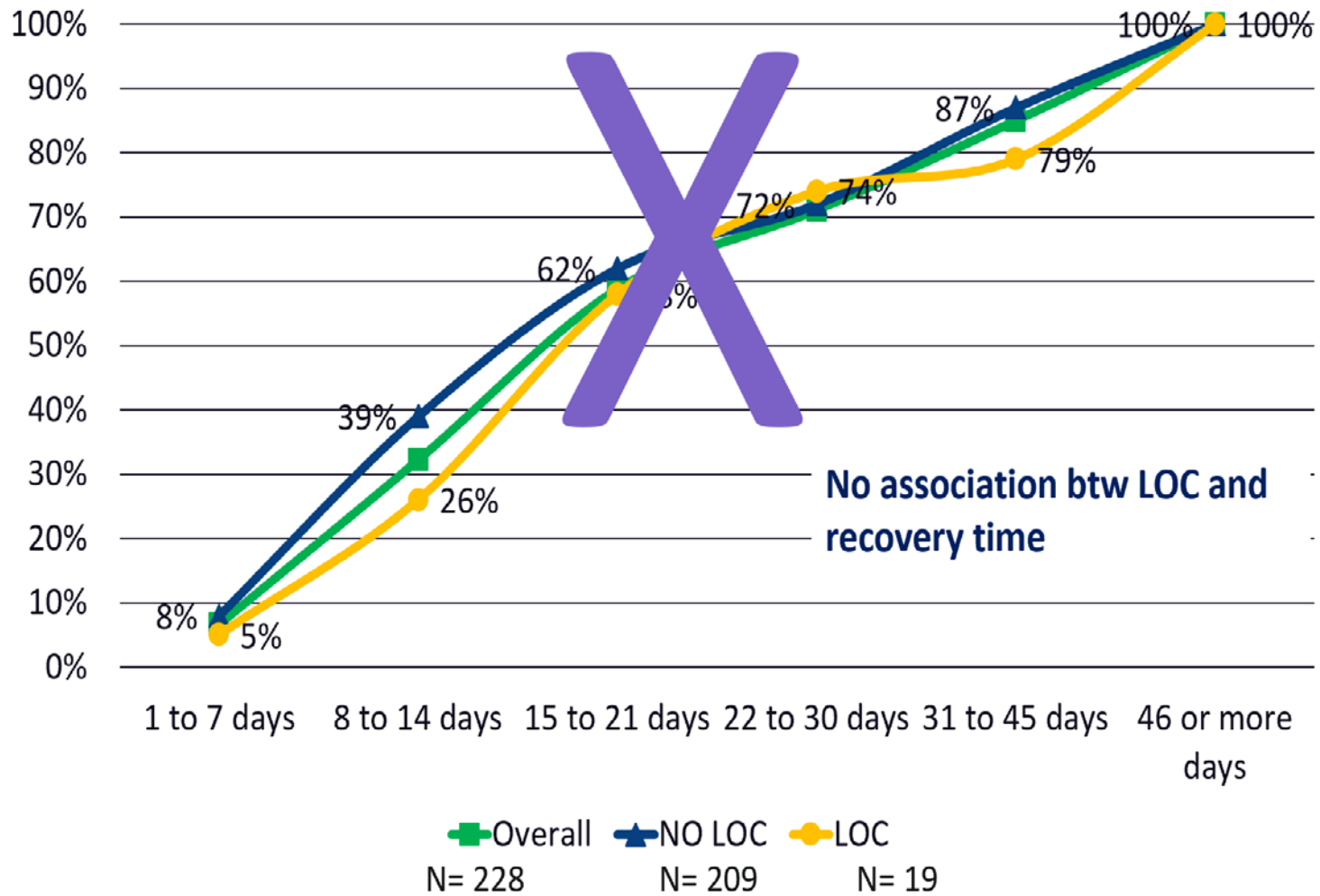
*** $p < .001$

<40% of athletes w/PTM Sx were recovered by 21 days vs. 70% without

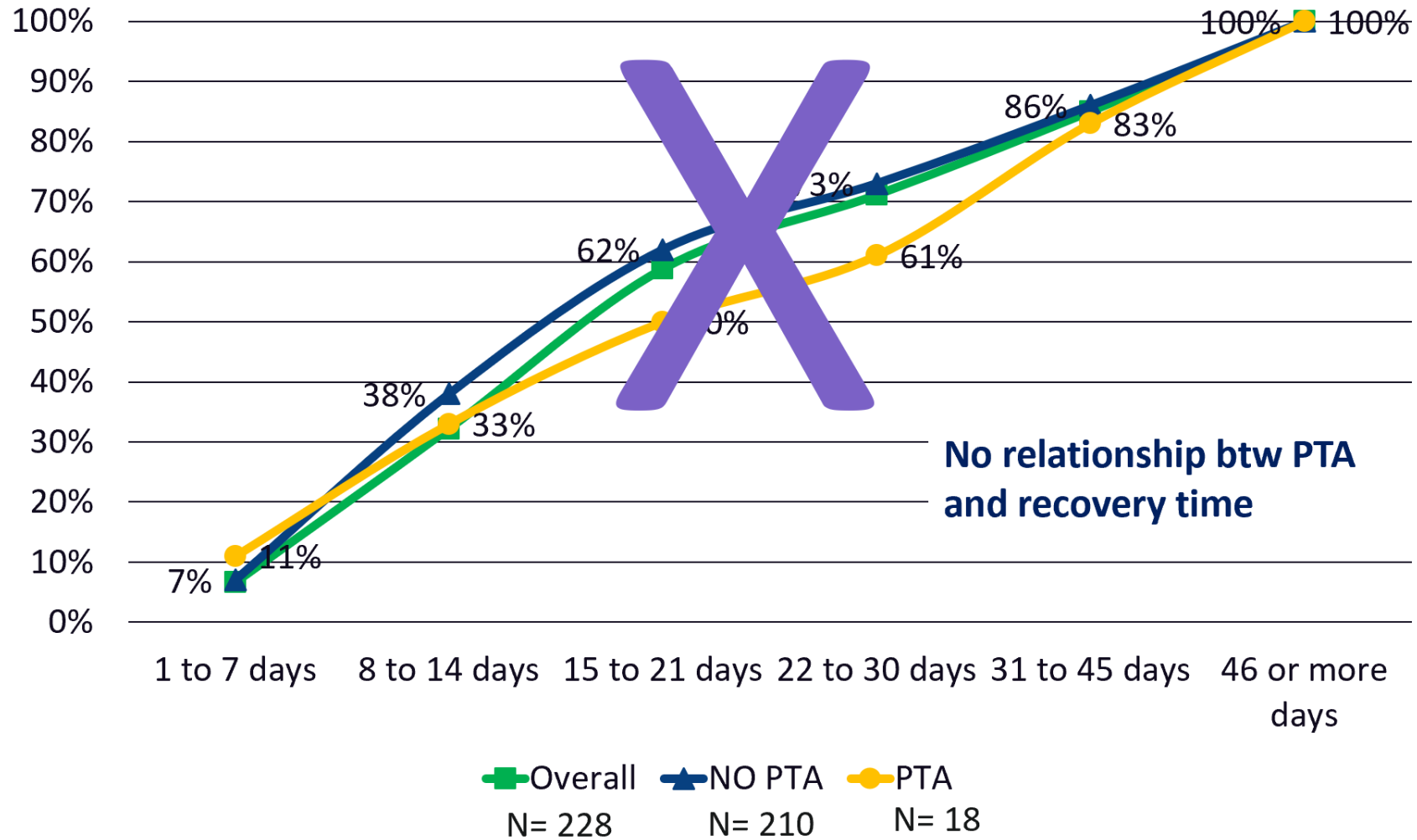
Overall N= 311 No PTM N= 205 PTM N= 106



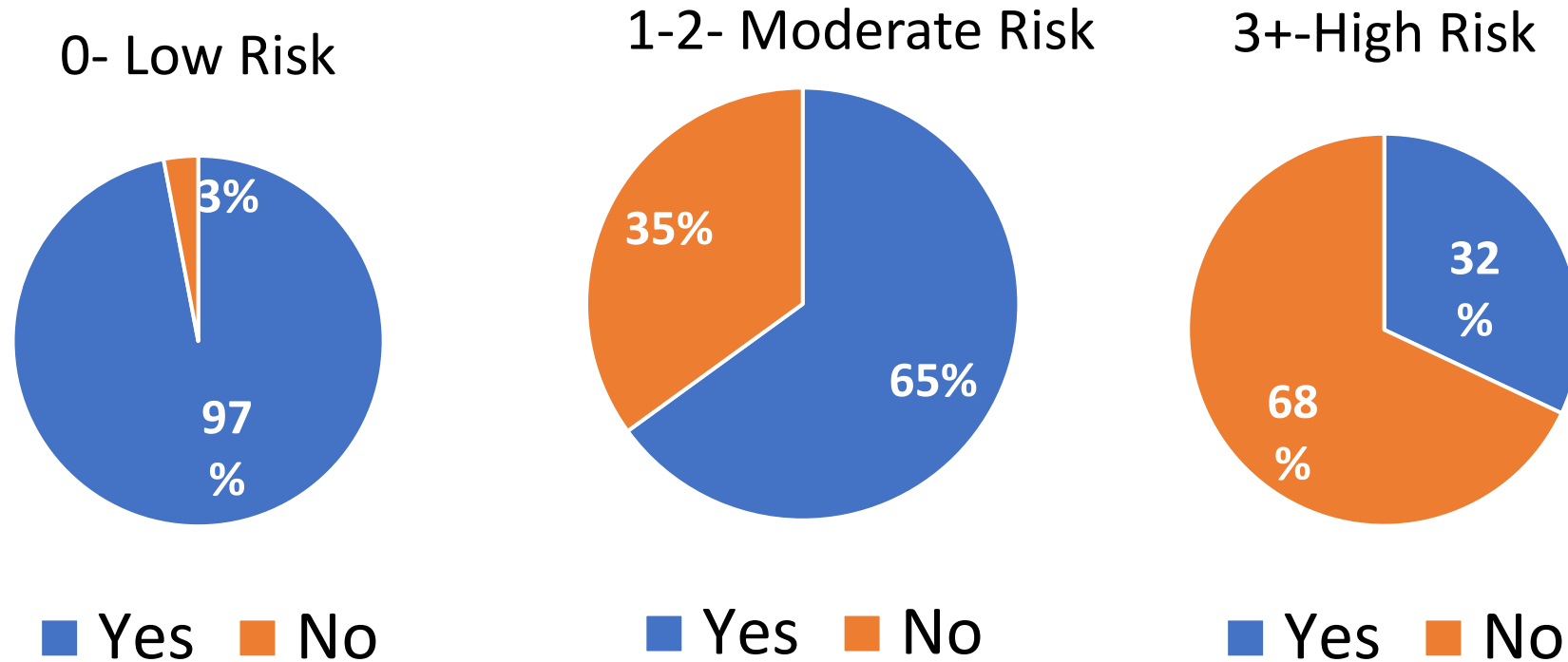
Brief Loss of Consciousness (LOC)



Post-traumatic Amnesia (PTA)



Dose-Response for Risk Factors (21 days)



*Less than half of high risk group were recovered at 1 month

Kontos AP, Elbin RJ, Sufrinko A, Marchetti G, Hollan CL, Collins MW. J Head Traum & Rehab, 2019.

Assessment of Risk Factors

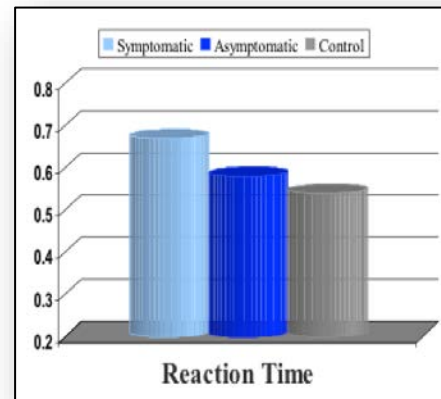
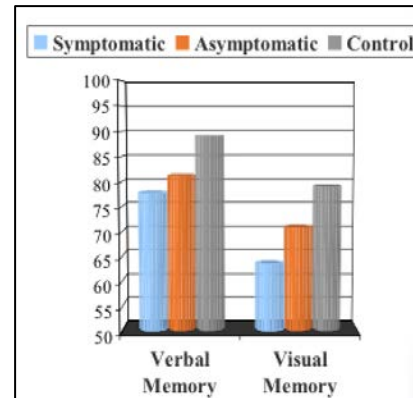
Acute Concussion Evaluation (ACE)

- Short intake form, includes assessment of some (but not all) risk factors)
- Some emerging questionnaires but more research needed
- Generally covered via intake form + clinical interview

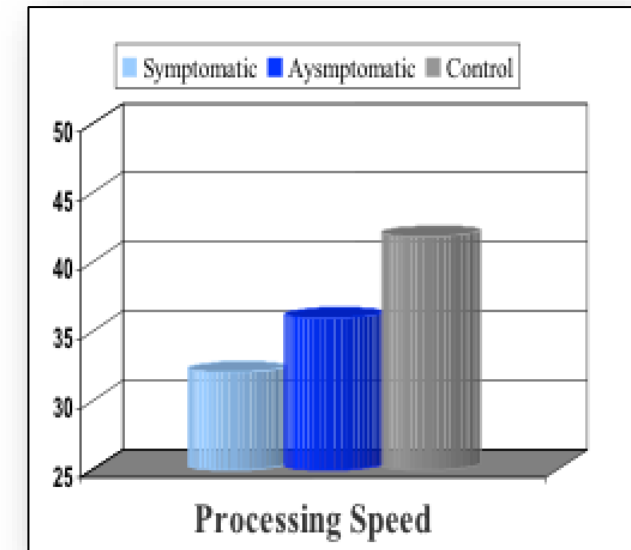
C. Risk Factors for Protracted Recovery (check all that apply)						
Concussion History? Y ___ N ___	√	Headache History? Y ___ N ___	√	Developmental History	√	Psychiatric History
Previous # 1 2 3 4 5		Prior treatment for headache		Learning disabilities		Anxiety
Longest symptom duration Days ___ Weeks ___ Months ___ Years ___		History of migraine headache ___ Personal ___ Family _____		Attention-Deficit/ Hyperactivity Disorder		Depression
If multiple concussions, less force caused reinjury? Yes ___ No ___				Other developmental disorder _____		Other psychiatric disorder _____
List other comorbid medical disorders or medication usage (e.g., hypothyroid, seizures) _____						

NEUROCOGNITIVE TESTING FOLLOWING CONCUSSION

- Considered to be a cornerstone of concussion evaluation (McCrory et al., 2017; Czernaik et al., 2021; Jennings et al., 2021)
- Computerized neurocognitive testing considered more sensitive to concussion (Broglio et al, 2007; Kontos et al 2016)
- Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) most widely used and researched computerized test (Meehan, 2012), but others exist (CNS Vital Signs; CogState Sport)

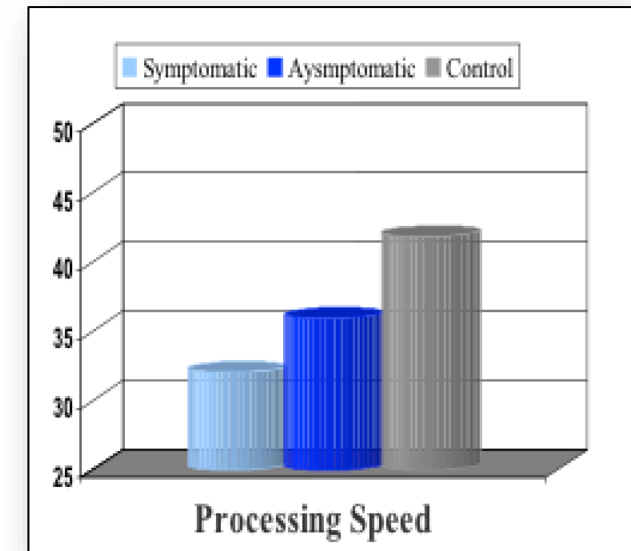
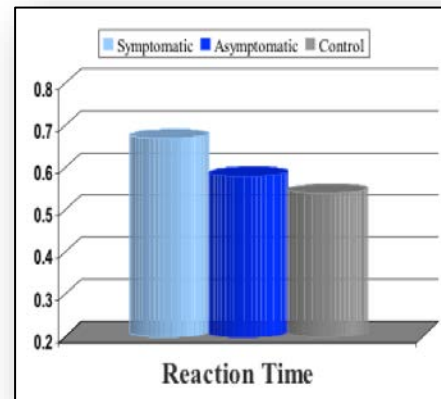
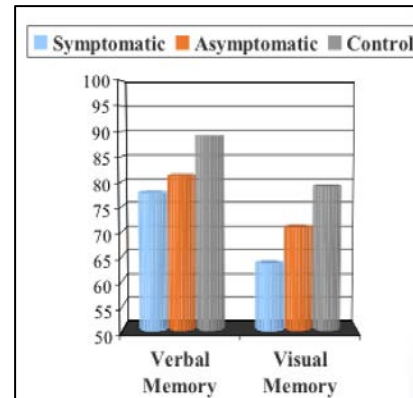


(Fazio et al., 2007)



NEUROCOGNITIVE TESTING FOLLOWING CONCUSSION

- Useful for determining level of academic accommodations (Iverson et al 2014)
- Must be interpreted within the context of mood factors, sleep, pain, and medications (Covassin, 2014, Blaney, 2020)
- As a sideline tool, SCAT-5 remains the gold-standard sideline tool, despite introduction of new and potentially innovative instruments e.g. blood based biomarkers, head impact sensors, vestibular-ocular eye tracking, mobile applications (Yue et al, 2020)



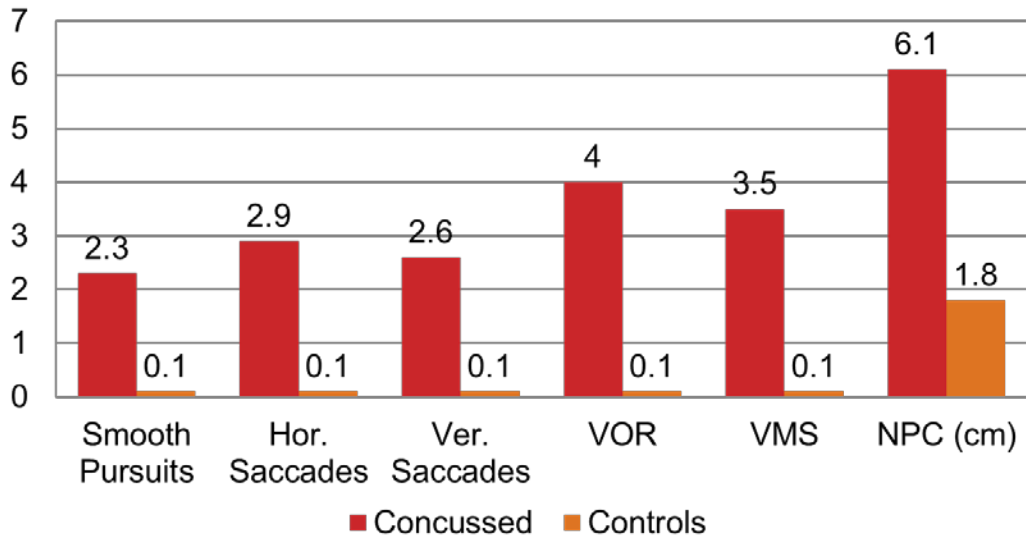
VESTIBULAR/OCULAR-MOTOR SCREENING FOLLOWING CONCUSSION

- VOMS most used vestibular/ocular screening tool.
 - Symptom provocation test
 - 2-3 minute to administer
 - Developed by vestibular PTs specializing in concussion for clinical screening by non-PTs (Mucha et al, 2014; Kontos & Collins 2018)
 - Significant number of validation studies finding it sensitive and specific to concussion, low false positive rate at baseline, and good incremental validity (Kontos et al., 2016; Moran et al., 2018; Elbin et al., 2019; Wallace et al., 2020)

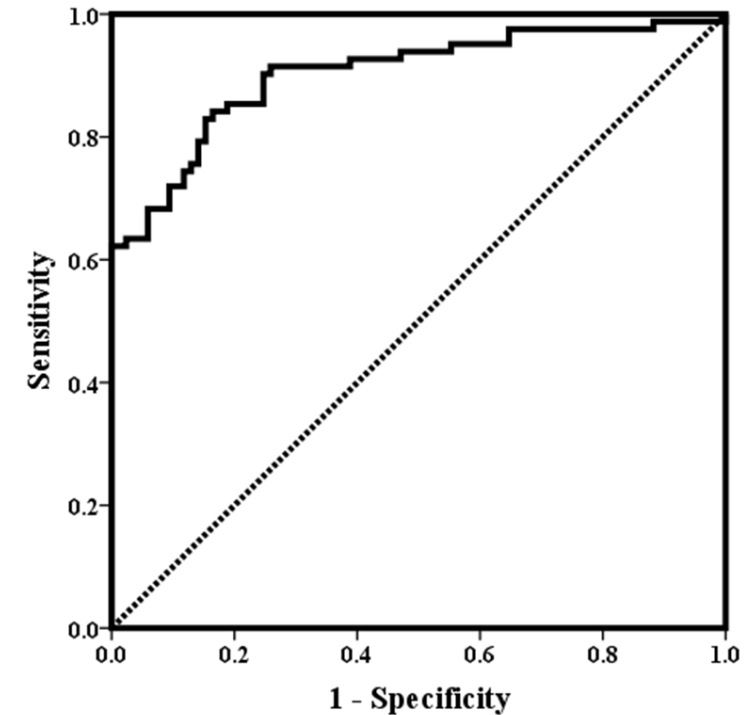


VESTIBULAR/OCULAR-MOTOR SCREENING FOLLOWING CONCUSSION

- ≥ 2 symptom score and/or NPC >5 cm abnormal
- Very few individuals report baseline symptoms or provocation on exam (Mucha 2014)



3 items:
VOR,
VMS,
NPC (cm)
= .89



VESTIBULAR THERAPY FOLLOWING CONCUSSION

Vestibular therapy following concussion needs to be^{1,2}:

- Targeted to specific deficits
- Follow the “expose-recover” model
- Performed by physical therapists with specialty training in vestibular rehabilitation.

Prior studies have found vestibular therapy following concussion improves self-report of dizziness/gait/balance complaints with protracted concussion recovery.^{3, 4, 5}

RCTs have found VT to be useful in treating patients with protracted recovery/PCS^{6, 7}

First double blind RCT of vestibular therapy started on average 6.1 days post-injury found those who received the treatment arm reported quicker resolution of vestibular symptoms and shorter total recovery time.

Dose, frequency, and intensity still needs to be studied

VISION CHANGES AND CONCUSSION

- Vision changes are very common following concussion (Master et al., 2019).
 - 69% had one or more of the following vision diagnoses
 - Accommodative disorders (51%)
 - Convergence insufficiency (49)
 - Saccadic dysfunction (29%)
 - Convergence Insufficiency Symptom Survey (CISS)
 - Commonly used screening tool
 - Highly sensitive, poor specificity (i.e. high false positive rate)
 - When identified, oculomotor exercises, pencil pushup or brock string exercises usually first intervention provided via vestibular PT.
- 2017: Vision Therapy for Post-Concussion Vision Disorders (Gallaway et al.)
- Case series indicated vision therapy improved most vision symptoms when outside normal recovery window
 - No current consensus on timeline, limited high-quality research on efficacy.

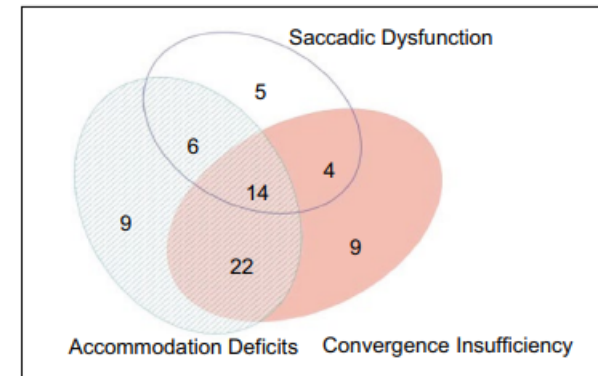


Figure 1. Vision diagnoses after concussion.

Storey et al 2016

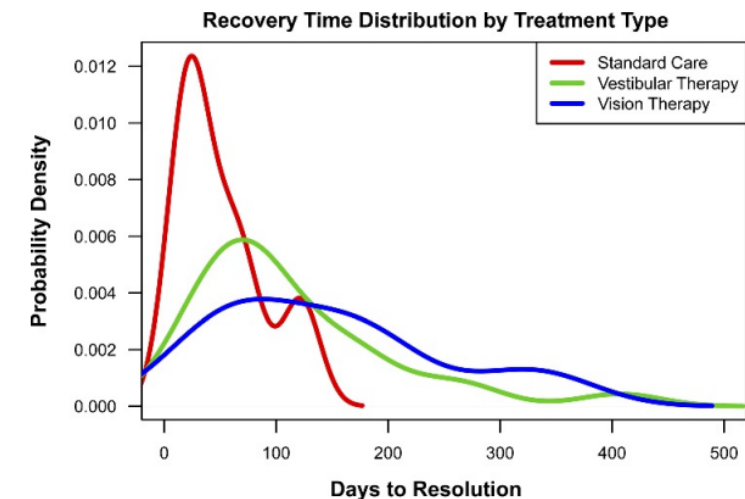


FIGURE 1.

Abnormal NPC recovery trajectory by treatment intervention. Probability density plot of number of study subjects recovering over time with standard clinical care (red), vestibular therapy with convergence exercises (green), or formal vision therapy (blue).

SLEEP CHANGES FOLLOWING CONCUSSION

- Sleep changes are very common after concussion
 - Pre-existing insomnia and daytime sleepiness have been found to increase the risk of concussion in at least one study of D-1 athletes (Raikes et al., 2019)
- Associated with greater symptom burden and longer recovery time
 - mild, moderate, or severe trouble falling asleep were 3.0, 4.6, and 6.7 times more likely to have persisting symptoms (DuPrey et al., 2022)
- Has significant negative effect on neurocognitive performance, particularly in male athletes (Cassimatis et al 2022)
- Contribute to post-traumatic headaches in acute and chronic phase (Murdaugh et al, 2018)
- First line intervention should be sleep hygiene (Register-Mihalik et al, 2018)
 - limiting evening caffeine
 - Reducing evening screen time
 - exercising daily
 - reducing nighttime stress using mindfulness activities
 - going to bed and waking at the same time each day
 - limiting naps to less than 30 min
 - reducing noise in the sleeping environment
- Limited evidence for medication intervention (mixed result for melatonin, amitriptyline and sleep aids can produce side effects that mimic concussion symptoms).

PHYSICAL REST VS EXERCISE

PHYSICAL REST VS EXERTION

2015: Programmed Physical Exertion in Recovery From Sports-Related Concussion: A Randomized Pilot Study (Maerlender et al)

- 28 college athletes assigned to begin mild to moderate intensity exertion via stationary bike at sub symptom threshold level (i.e. didn't worsen pre-existing symptoms)
- Vigorous exertion deleterious to recovery, mild to moderate deemed safe

2016: Association between early participation in physical activity following acute concussion and persistent postconcussive symptoms in children and adolescents (Groot et al)

- N=2143
- Pediatric patients who participated in light aerobic activity, moderate aerobic activity and contact (not advised) within 7 days of injury had faster recovery than those who did no exercise.

2017: Aerobic exercise for adolescents with prolonged symptoms after mild traumatic brain injury: An exploratory randomized clinical trial (Kurowski et al)

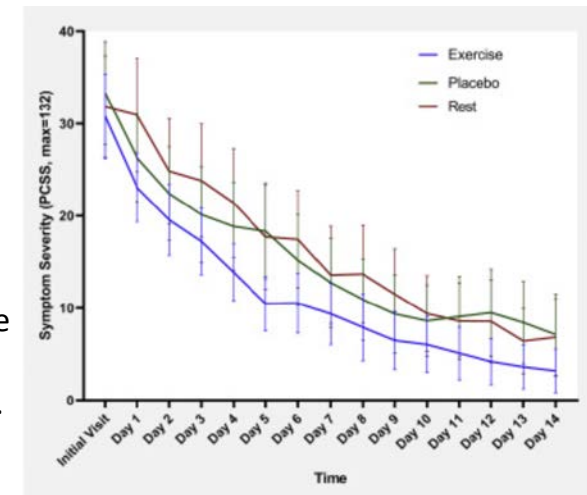
- Trial RCT with protracted recovery in adolescent patients (4-16 weeks post-injury)
- Symptom improvement in sub symptom exercise arm

2018: Exercise is medicine for concussion (Leddy et al)

- Preliminary guidelines for safe levels of acute/subacute exercise following concussion

2019: Comparison of Rest to Aerobic Exercise and Placebo-like Treatment of Acute Sport-Related Concussion in Male and Female Adolescents (Willer et al)

- Participants randomized to Rest, Placebo Stretching, or Exercise based on above protocol around 10 days post.
- Rest and Stretching performed equivalent, Exercise arm showed faster recovery.
- Female athletes more susceptible to negative effects of rest

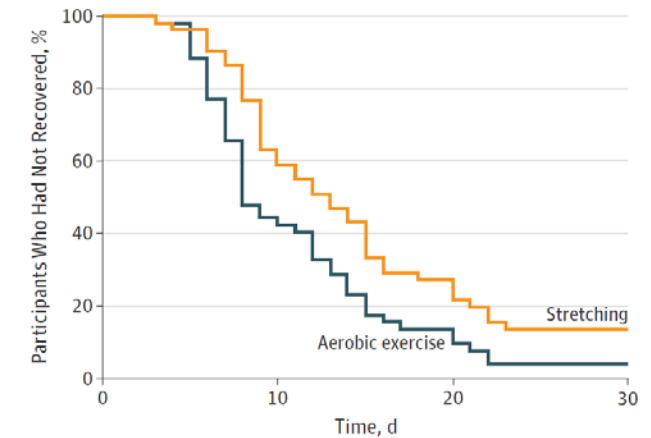


PHYSICAL REST VS EXERTION

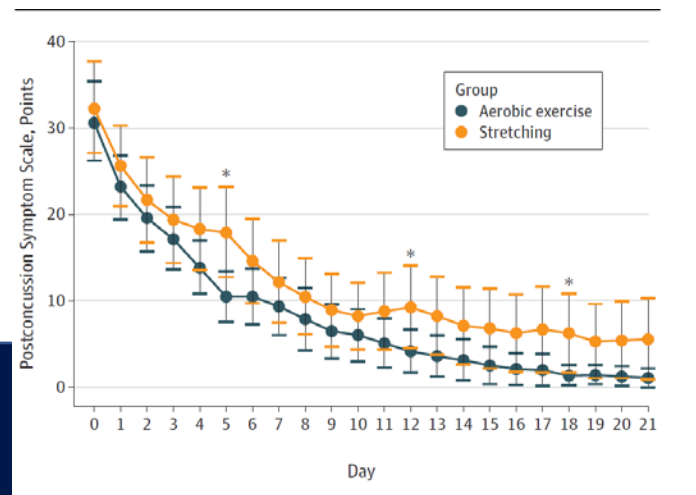
2019: Early Subthreshold Aerobic Exercise for Sport-Related Concussion: A Randomized Clinical Trial (Leddy et al)

- Pediatric athletes assigned a mean of 4 days post-injury to subsymptom threshold exercise arm or stretching
- Target heart rate of 80% of symptom exacerbation
- Tolerated a 2/10 severity increase in symptoms before stopping the assigned 20-minute exertion protocol
- Significant difference in both symptom report and recovery time

Figure 2. Kaplan-Meier Estimates of Time to Recovery



No. at risk	0	10	20	30
Aerobic exercise	52	23	7	2
Stretching	51	32	14	7



PHYSICAL REST VS EXERTION

2021: Early targeted heart rate aerobic exercise versus placebo stretching for sport-related concussion in adolescents: a randomized controlled trial (Leddy et al)

- Replication of 2019 study.
- Consistent findings of decreased recovery time in exercise arm of RCT

2022: Early aerobic exercise among adolescents at moderate/high risk for persistent post-concussion symptoms: A pilot randomized clinical trial (Howell et al)

- RCT specifically targeting at-risk adolescents based on risk factors
- Started a mean of 5 days post-injury
- A smaller proportion of the early aerobic exercise group developed PPCS when compared to the standard-of-care/rest group (44% vs. 86%)

2022: Adolescents with Sport-Related Concussion Who Adhere to Aerobic Exercise Prescriptions Recover Faster (Chizuk et al)

- n=61 adolescent athletes
- Assigned an exercise protocol based on 80% of target heart rate
- Initial increase in overall symptoms but faster recovery time for exercise group

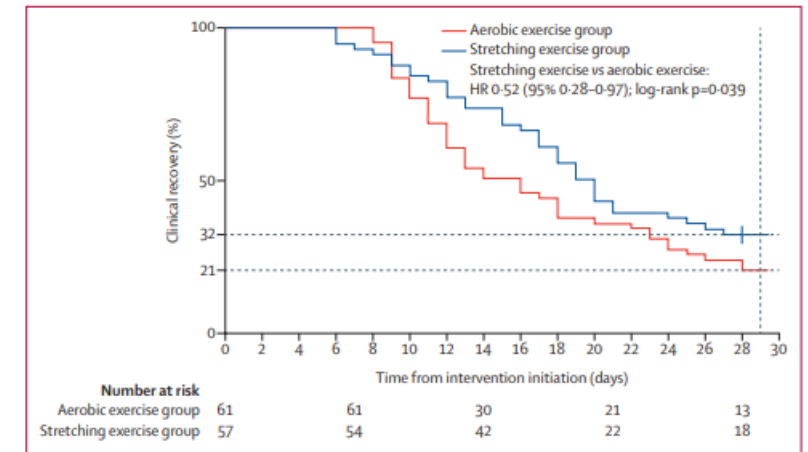


Figure 2: Kaplan-Meier survival curves stratified by intervention group. Dashed lines represent percentage of sample not recovered by day 29 for each intervention. HR=hazard ratio.

COGNITIVE ACTIVITY VS COGNITIVE REST

COGNITIVE ACTIVITY FOLLOWING CONCUSSION

“Brain rest” remains a frequent recommendation following concussion

- Some early uncontrolled case studies suggested brain rest might be helpful for recovery

2015: Benefits of strict rest after acute concussion: a randomized controlled trial (Thomas et al)

- Patients aged 11-22 assigned either 2 days of rest of 5 days of rest at ED visit, then return to school with graded return to learn
- Extra rest arm was slower to recover and reported more mood symptoms.
- No difference in neurocognitive scores at follow up

2017: Acute Cognitive and Physical Rest May Not Improve Concussion Recovery Time (Buckley et al)

- College policy change my sports medicine clinic to add 48 hours of rest before return to activity
- Comparison of 25 concussions pre-change and 25 post change
- Rest group was symptomatic LONGER than No Rest group
- No Rest and worse acute neurocognitive performance on ImpACT

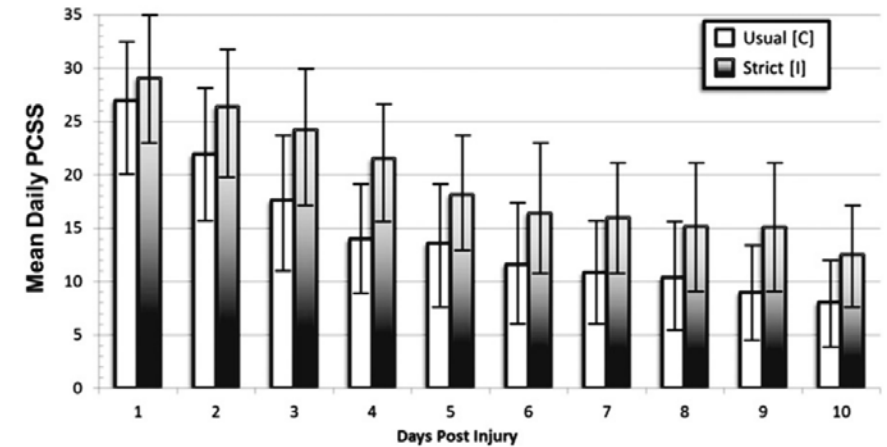


FIGURE 5

Mean PCSS with 95% confidence interval over time. Patients in the intervention group experienced higher total symptoms over the course of follow-up with the greatest difference in mean symptoms on day 4 (13.95 [C] vs 21.51 [I], $P < .03$).

COGNITIVE ACTIVITY FOLLOWING CONCUSSION

2017: The Effectiveness of Prescribed Rest Depends on Initial Presentation After Concussion (Sufrinko et al)

- Prescribed rest increased likelihood of longer symptomatic recovery
- Patients with signs of concussion (e.g. LOC/PTA) performed better on neurocognitive testing with acute rest.

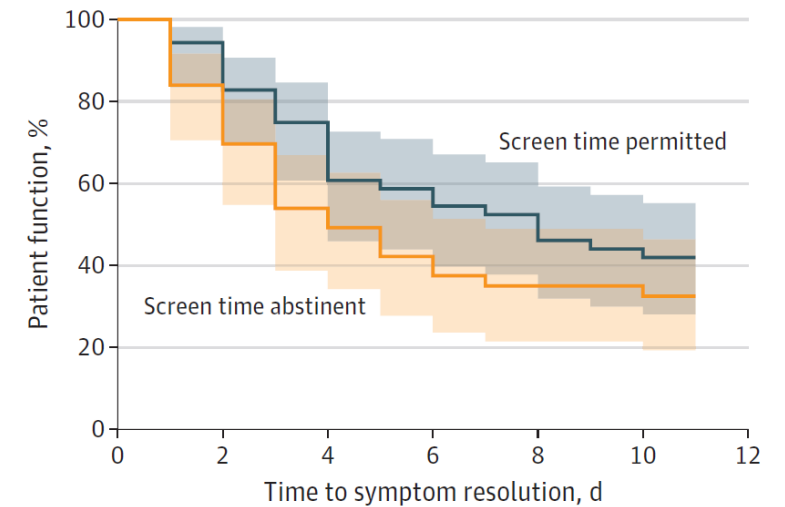
2021: Progression through return-to-sport and return-to academics guidelines for concussion management and recovery in collegiate student athletes: findings from the Ivy League–Big Ten Epidemiology of Concussion Study (Wiebe et al)

- N=1715 college athletes with concussion
- 67.9% had 24-48 hours of rest (compared to no rest)
- Rest group endorsed more symptoms and had longer recovery time

2021: Effect of Screen Time on Recovery From Concussion
A Randomized Clinical Trial (Macnow et al)

- First ever study to examine screen time use following concussion
- RCT in ED of normal screen time vs 48 hours of restricted screen time
- 48 hours of restricted screen time had quicker recovery time

Figure 2. Kaplan-Meier Survival Curve Comparing Days Until Concussion Recovery of Screen Time Abstinent vs Screen Time Permitted Groups



No. at risk	0	2	4	6	8	10	12
Screen time permitted	53	49	37	28	25	21	
Screen time abstinent	50	41	23	18	14	14	

EARLY TARGETED INTERVENTION FOLLOWING CONCUSSION

2020: Association of Time Since Injury to the First Clinic Visit With Recovery Following Concussion (Kontos et al)

- 162 athletes aged 12-22
- Grouped by those seen <7 days post injury vs >7 days
- Late group was 5.6x more likely to recover >30 days

2021: Timing Is Everything: The Role of Time Since Injury in Concussion Clinical Presentation and Recovery (Eagle et al)

- Follow up study with a mixed pediatric population
- 218 pediatric patients (sport + non-sport)
- Strongest predictor of recovery time was time to first visit
- >7 days to first visit 9.8x more likely to have >30 day recovery than those seen 8-20 days post-injury

2021: Examining how time from sport-related concussion to initial assessment predicts return-to-play clearance

- Large sample (n=1213) pediatric Canadian athletes seen in specialty clinics
- Initial evaluation <10 days predicted for faster recovery from injury.

2021: Early injury evaluation following concussion is associated with improved recovery time in children and adolescents (Cassimatis et al)

- 341 pediatric athletes referred to specialty concussion clinic
- Time to initial visit significant predictor of recovery time

