Balance after mild traumatic brain injury (mTBI); trends and new directions

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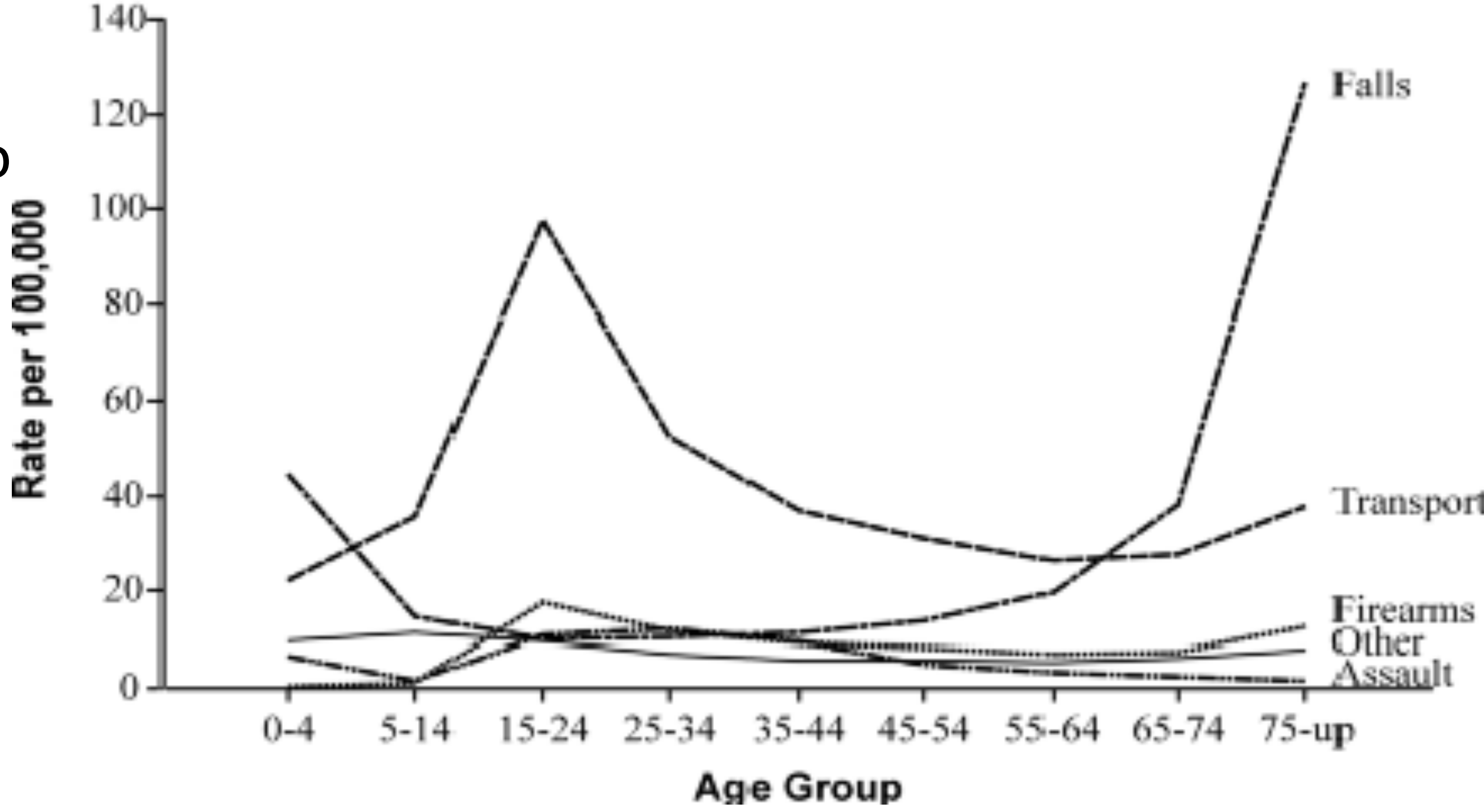
Overview for today

- Incidence and overview of mTBI
- How is balance impaired after mTBI and how do we measure?
    - Objective measures
    - Home monitoring
    - Turning
    - CSMI- motor activation
- Rehabilitation
    - Early rehabilitation?
    - Concussion subtypes
    - Biofeedback to target motor activation?

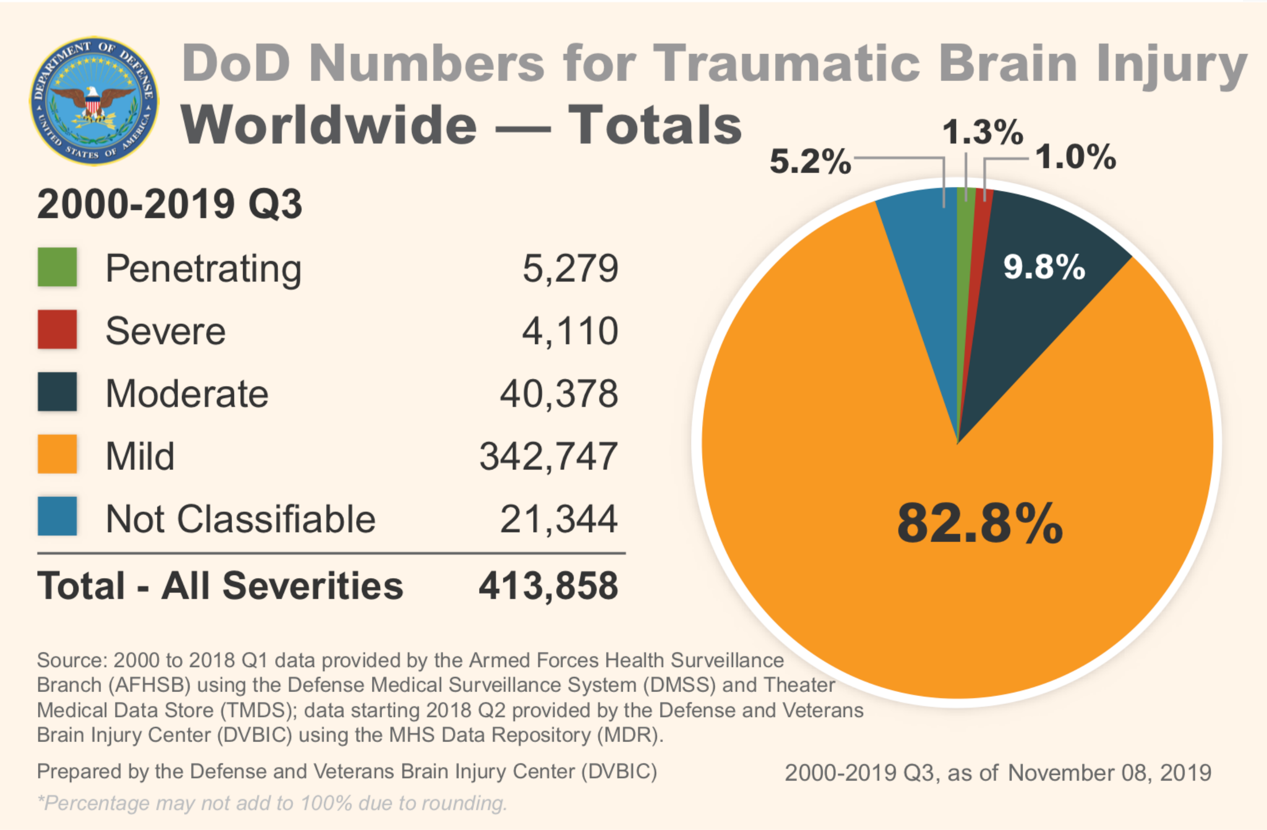
TBI incidence

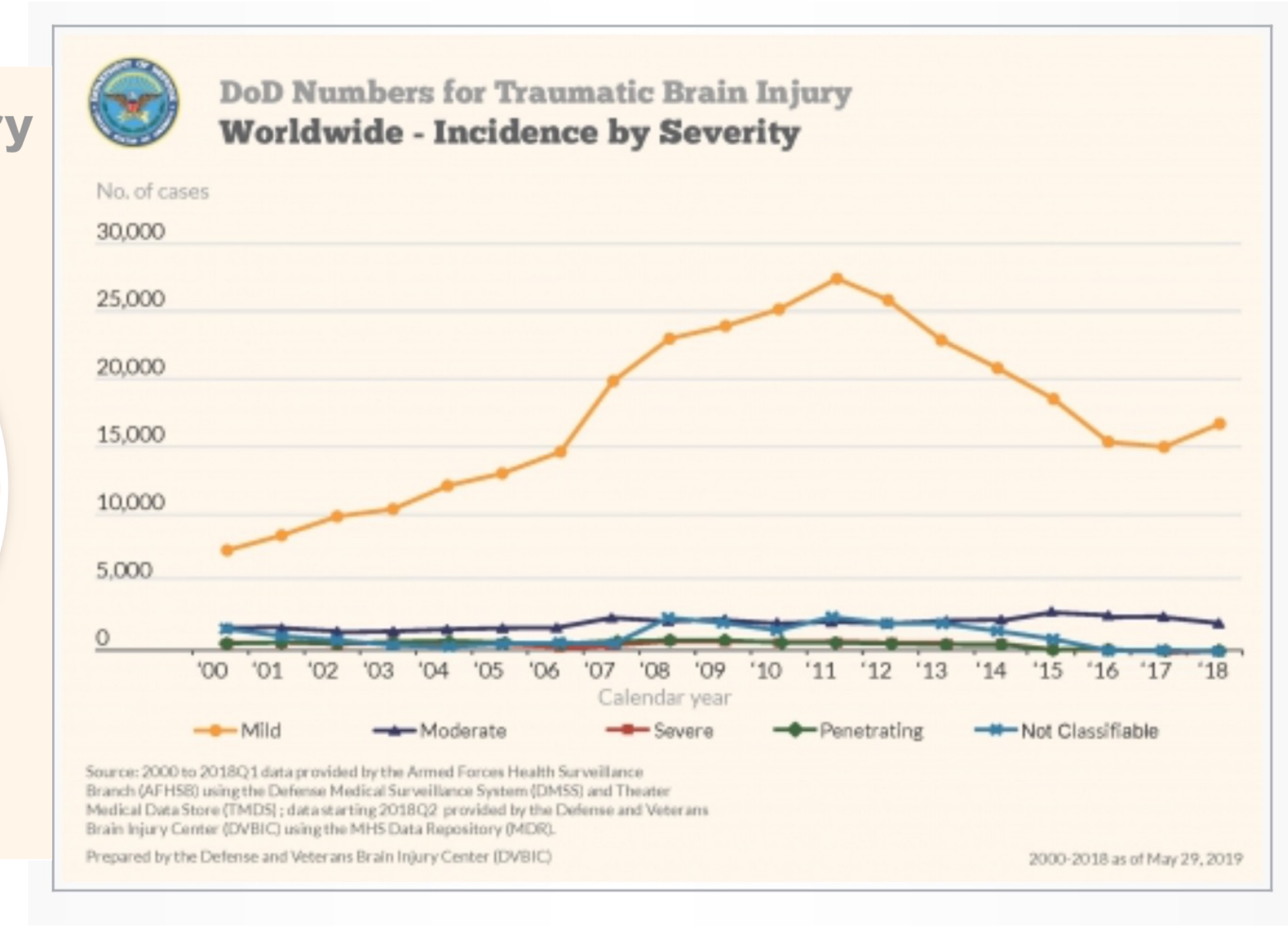
- **Worldwide:** 2016, there were approximately 27 million new cases of TBI
- TBI more common in men 2:1 Ratio
- 5.3 million people living with a TBI-related disability in the United States (2% of the U.S. population (CDC, 2015)).
- Older adolescents (ages 15 to 21 years) and older adults (ages 65 years and older) among the most likely to sustain a TBI.



Frost, Farrer, Primosch, & Hedges, 2012 Bezarian 2007, Selassie AW et al., 2013
CDC data 2015, (Faul, Xu, Wald, & Coronado, 2010); CDC-Report to Congress: Traumatic Brain Injury in the United States.

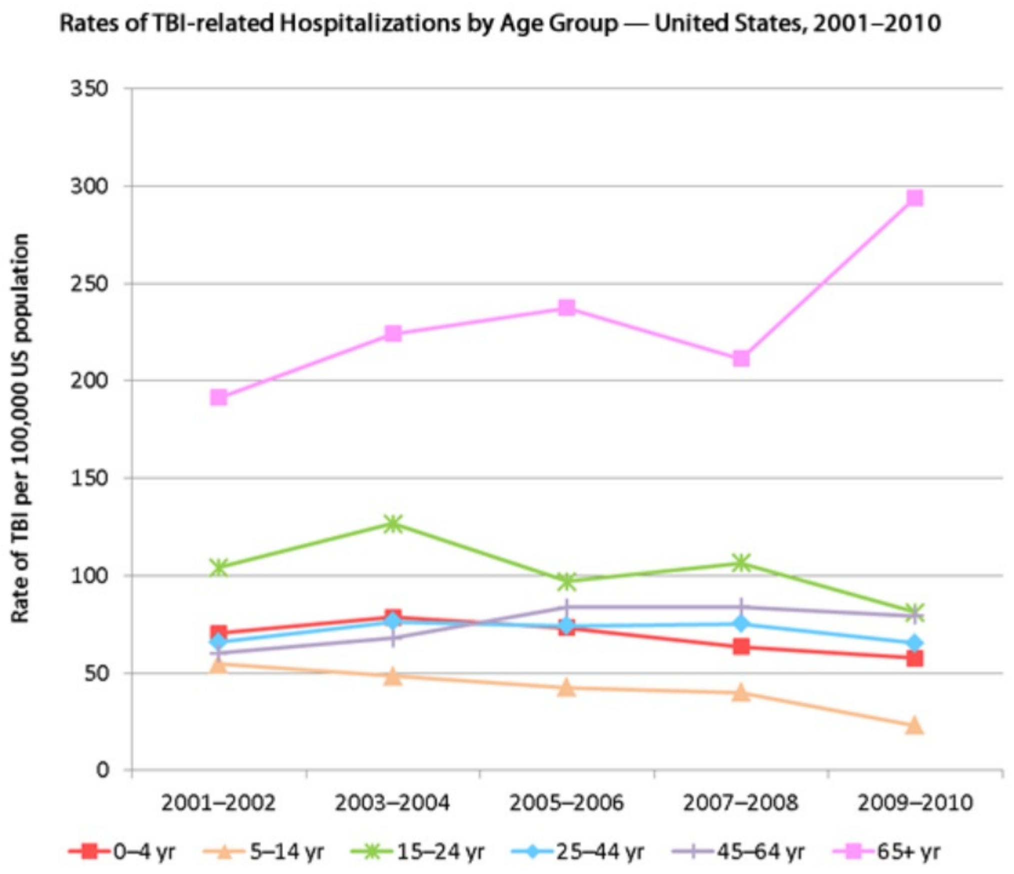
Mild TBI accounts for most of the TBI cases

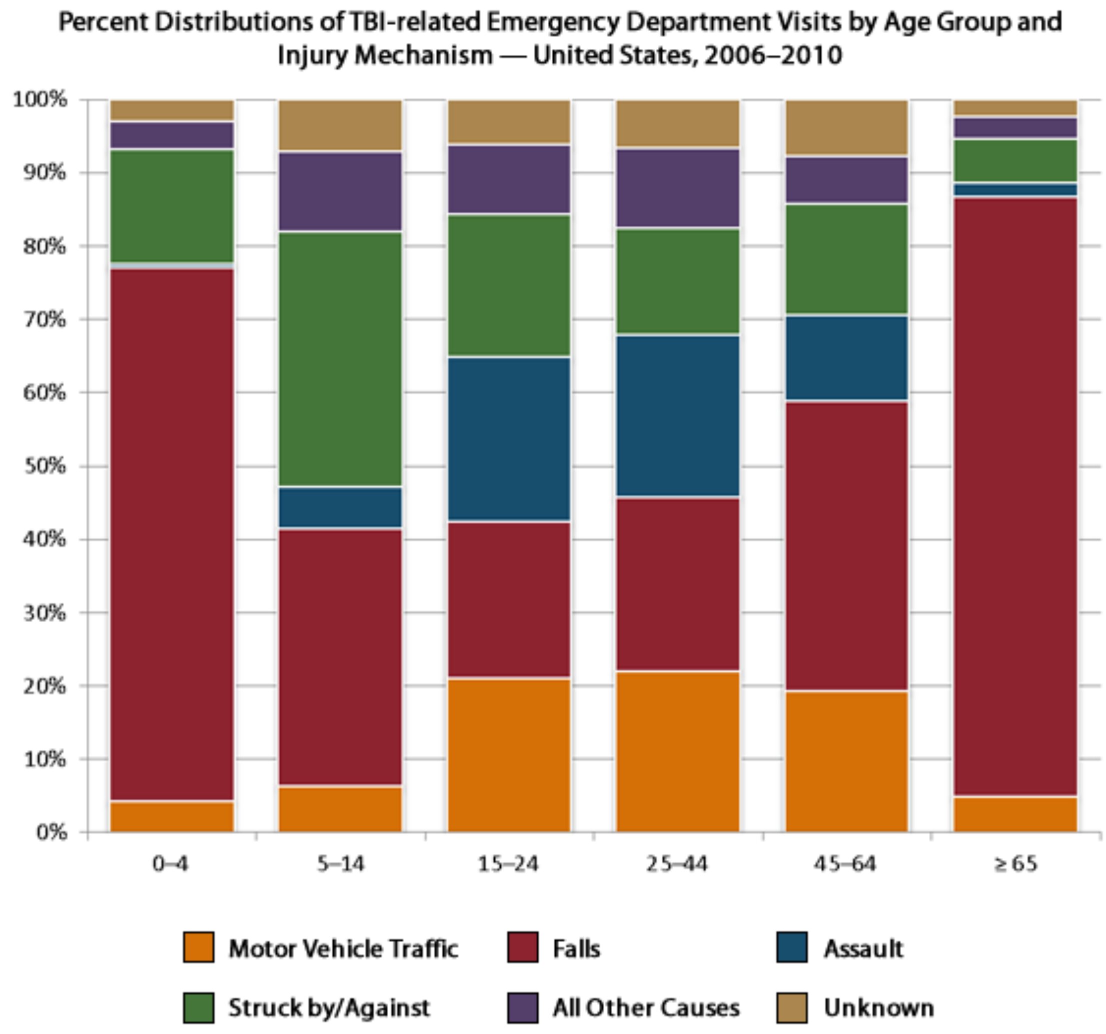




Dewan et al., J Estimating the global incidence of traumatic brain injury Neurosurg 130:1080–1097, 2019, Cassidy 2004, DVBIC

TBIs occur across the lifespan





CDC Traumatic Brain Injury and Concussion, 2016
https://www.cdc.gov/traumaticbraininjury/data/rates_hosp_byage.html
https://www.cdc.gov/traumaticbraininjury/data/dist_ed.html

High risk groups for mTBI

- **Contact athletes** Between 1.6-3.8 million per year (CDC)
  - (many don't seek treatment so hard to know)
- **Military** Veterans: an estimated 320,000 service members deployed between 2001-2007 screened positive for TBI (blast most common)
  - A survey of deployed troops in Operation Iraqi Freedom and Operation Enduring Freedom found that 17% reported MTBI during deployment, and of these, 59% reported more than one MTBI (Wilk et al., 2012).

- **Victims of domestic abuse**
  - At least 5 million acts of domestic violence occur annually
  - 87% of patients in the study reported more than one brain injury from abuse
  - TBI from domestic violence may affect 6% of population
  - Underreporting

Langlois et al., 2006n, D.C.: Congressional Budget Office 2007. Zieman et al; JNT 2017, Matthew S. Goldberg, Deputy Assistant Director for National Security: Projecting the costs to care for veterans of U.S. military operations in Iraq and Afghanistan. Washingto, Jeltsen M

Concussion crosses many domains of practice reflected in multiple Position Statements and Consensus Statements

- American Academy Neurology
- American Academy PMR
- American Medical Society Sports Medicine
- National Athletic Training Association
- Concussion in Sports Group
  international consensus

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 Roberts[14]

2014;49(2):245–265
7
iners' Association, Inc

National Athletic Trainers' Association Position Statement: ...gement of Sport ...ussion

P. Broglio, PhD, ATC*; Robert C. ... MD†; Gerard A. Gioia, PhD‡; Kevin M. ...wicz, PhD, ATC, FNATA, FACSM§; Kutcher, MD*; Michael Palm, MBA, Tamara C. Valovich McLeod, PhD, ATC, ¶

of Michigan, Ann Arbor; †Department of Surgery, Hospital, Concord, MA; ‡Division of Pediatric

POSITION STATEMENT ON CONCUSSION IN YOUTH SPORTS

The American Academy of Physical Medicine and Rehabilitation (AAPM&R) is the national medical society representing more than 8,000 physiatrists - physicians who are specialists in the field of physical medicine and rehabilitation. With a focus on restoring function, physiatrists treat children and adults. Physiatrists treat persons with acute and chronic pain, acute sports injuries including concussion as well as chronic injury, persons who have experienced catastrophic events resulting in paraplegia, quadriplegia, or traumatic brain injury, musculoskeletal injuries, and individuals with neurologic disorders such as stroke, multiple sclerosis, or any other disease process that results in impairment and/or disability. PM&R physicians treat any disability resulting from disease, sports-related activities or injury involving any organ system and their goal is to decrease pain and enhance performance without surgery. AAPM&R strongly supports public policies that reduce injuries, including concussions, in youth sports.

aaPM&R
American Academy of Physical Medicine and Rehabilitation
Physicians Adding Quality to Life

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AMERICAN ACADEMY OF NEUROLOGY

*****EMBARGOED UNTIL 12PM ET, MONDAY, NOVEMBER 1, 2010*****

AMERICAN ACADEMY OF NEUROLOGY POSITION STATEMENT ON SPORTS CONCUSSION

...ment

Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016

Paul McCrory,[1] Willem Meeuwisse,[2] Jiří Dvorak,[3,4] Mark Aubry,[5] Julia... Steven Broglio,[7] Robert C Cantu,[8] David Cassidy,[9] Ruben J Echemen... Rudy J Castellani,[12] Gavin A Davis,[13,14] Richard Ellenbogen,[15] Caroly...

NCAA SPORT SCIENCE INSTITUTE

INTERASSOCIATION CONSENSUS:

DIAGNOSIS AND MANAGEMENT OF SPORT-RELATED CONCUSSION BEST PRACTICES

Older people unlikely to be seen by sports medicine where most rehabilitation referrals occur

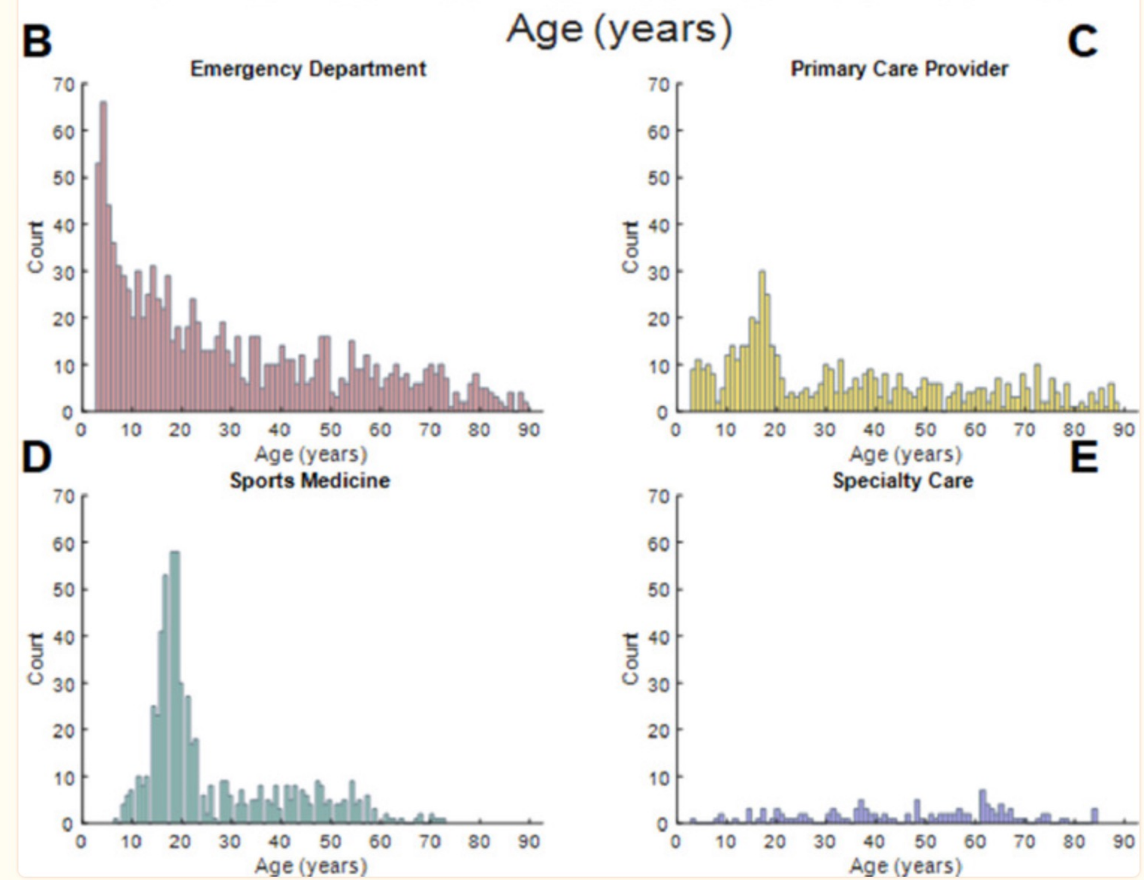


Fig 2

Histograms displaying the age distributions for **(A)** all points of entry (N=2417), **(B)** ED (n=1137), **(C)** primary care provider (n=554), **(D)** sports medicine (n=607), and **(E)** specialty departments (n=119).

Table 1

Odds ratios for rehabilitation referrals

	Odds Ratio	**95% Confidence Interval**	***P* Value**
Sex (ref=male)	1.92	1.54-2.39	<.0001
Point of entry (ref=ED)			
Primary care provider	7.98	4.67-13.61	<.0001
Sports medicine	75.05	45.87-122.79	<.0001
Specialty care	7.62	3.64-15.99	<.0001
Comorbidity diagnosis (ref=no comorbidity)*	2.12	1.70-2.66	<.0001

Martini et al., 2022

Balance deficits after mTBI/concussion

- Balance and dizziness are common after mTBI- typically resolve within 2-4 weeks
- Approximately 20% of people who sustain an mTBI have chronic (> 3 months) balance deficits
- Impaired balance, even subtle, can interfere with return to work, duty, sport
- Documentation of balance deficits depend on how ‘balance’ is measured

Campbell et al, 2021; Akin et al; 2017; Hoffer et al; 2017; Ryan L, Warden D. Post concussion syndrome. Int Rev Psychiatry. 2003;15(4):310–16. doi:10.
Cripps A, Livingston SC. The value of balance-assessment measurements in identifying and monitoring acute postural instability among concussed athletes. J Sport Rehabil. 2013 Feb;22(1):67-71.

How do we measure balance?

Symptom-based

STEP 2: SYMPTOM EVALUATION

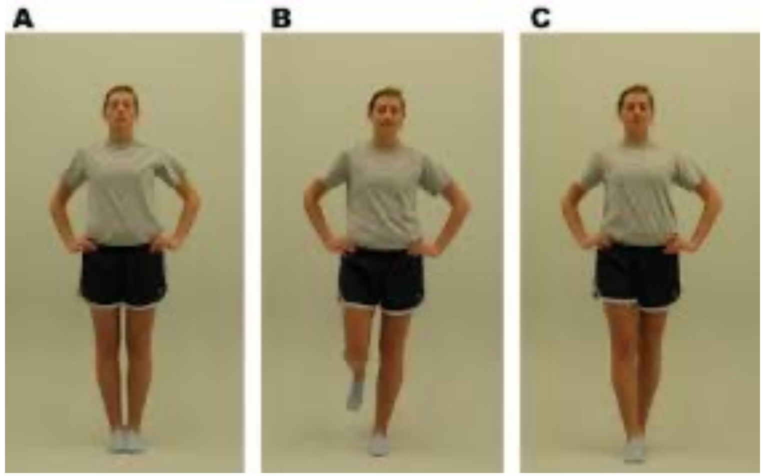
The athlete should be given the symptom form and asked to read this instruction paragraph out loud then complete the symptom scale. For the baseline assessment, the athlete should rate his/her symptoms based on how he/she typically feels and for the post injury assessment the athlete should rate their symptoms at this point in time.

Please Check: ☐ **Baseline** ☐ **Post-Injury**

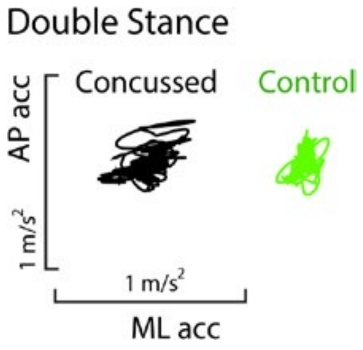
Please hand the form to the athlete

	none	mild		moderate		severe	
Headache	0	1	2	3	4	5	6
"Pressure in head"	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	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
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	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
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
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
Trouble falling asleep (if applicable)	0	1	2	3	4	5	6

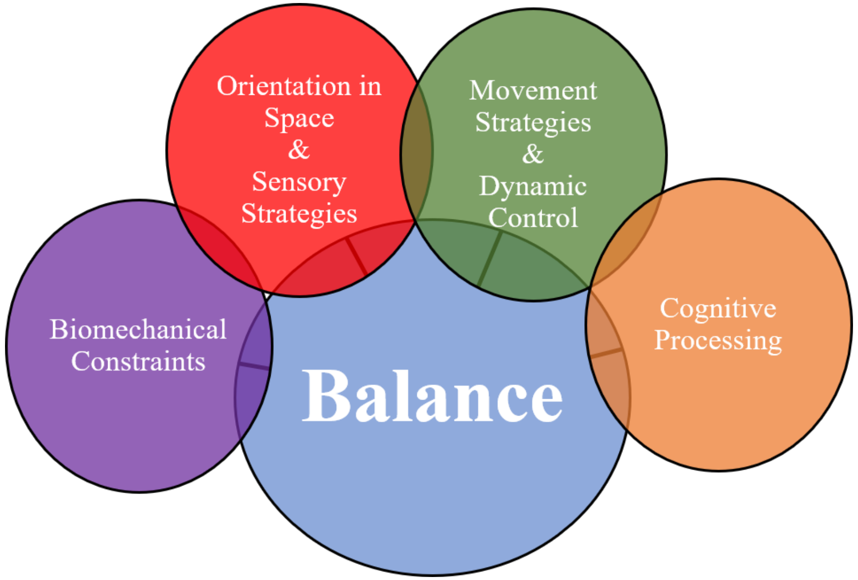
Clinician-rated

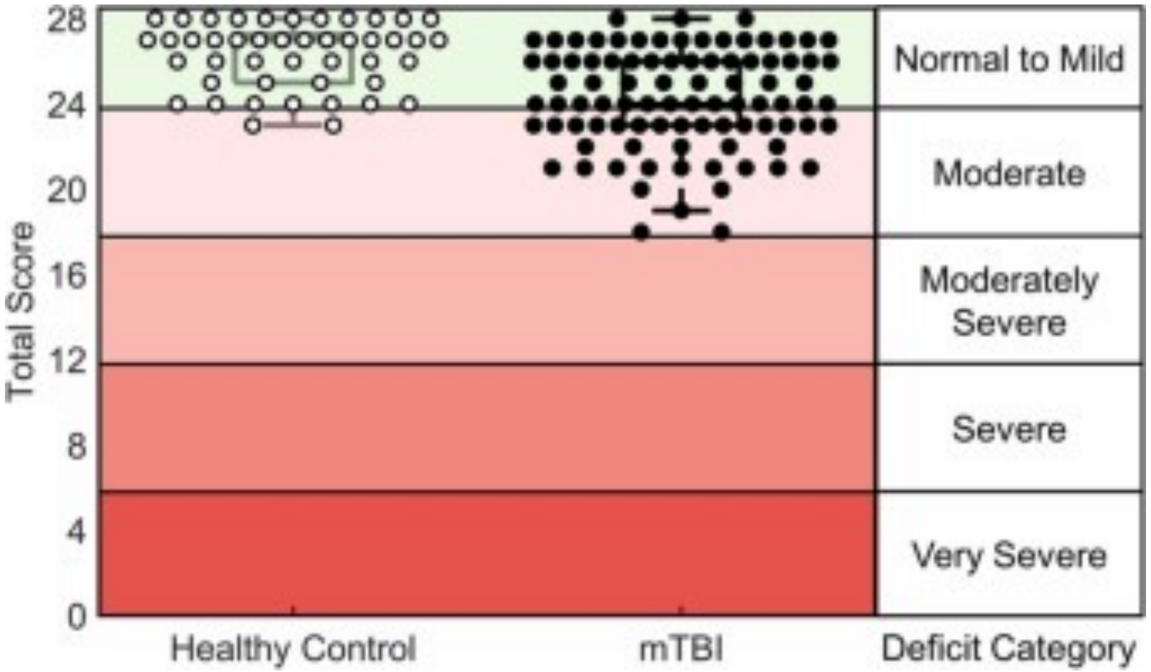


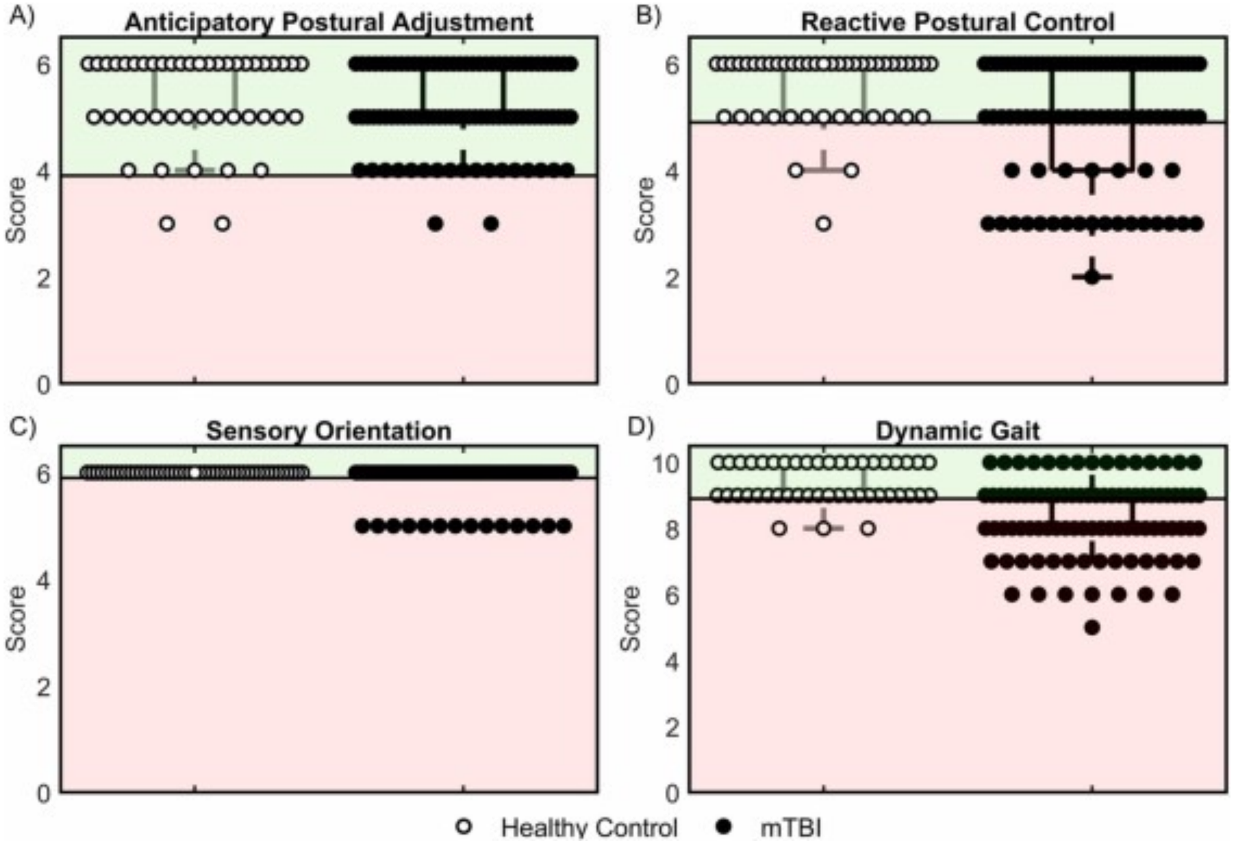
Instrumented



There is more to balance than quiet standing

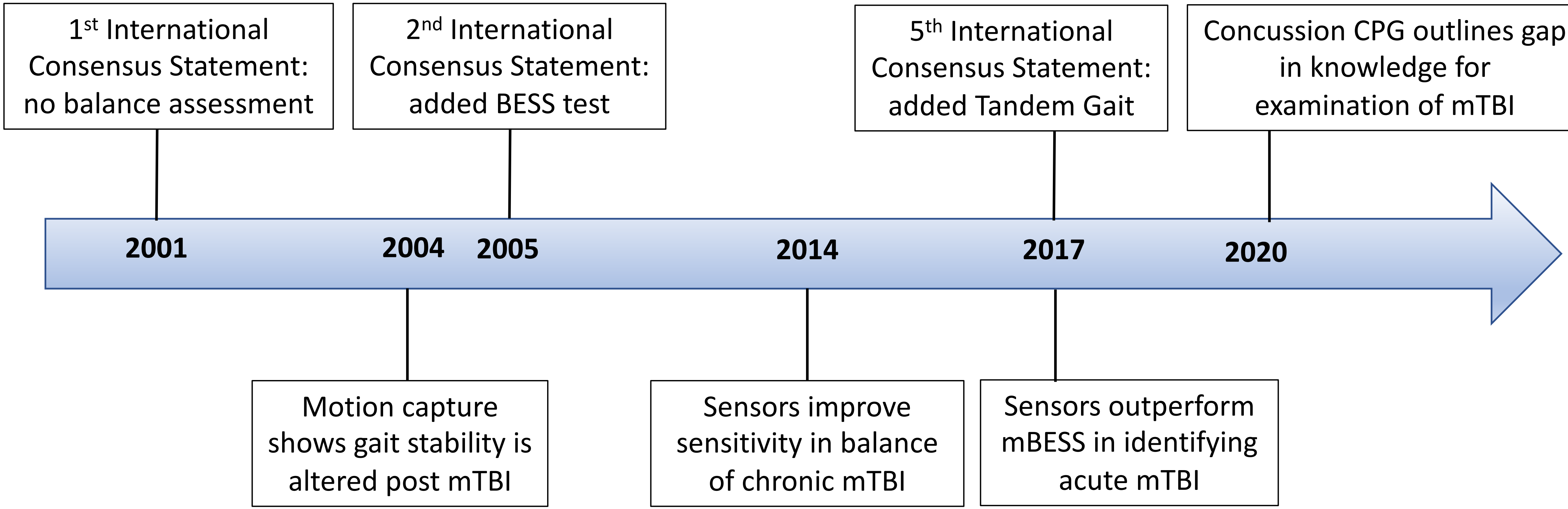






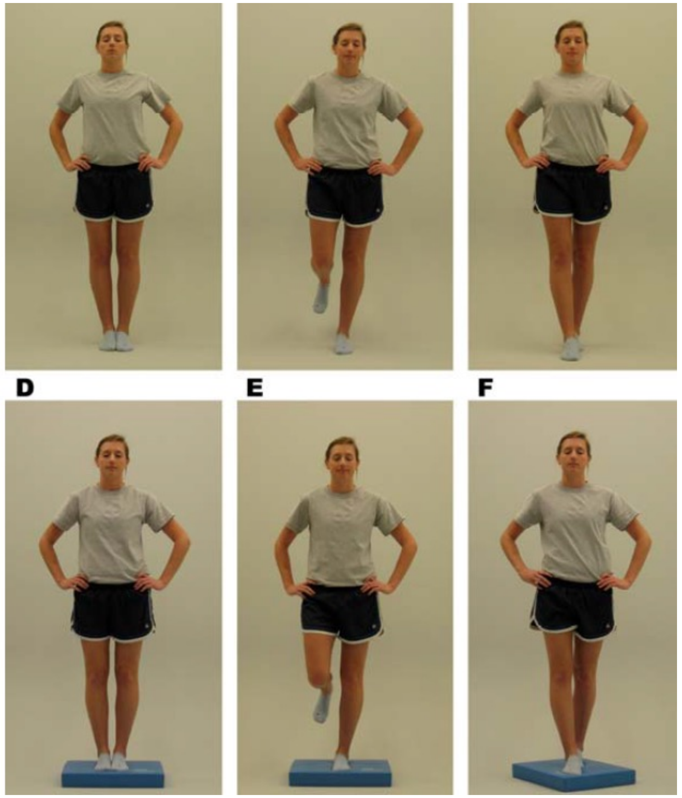
Campbell K; Gait & Posture, 2023

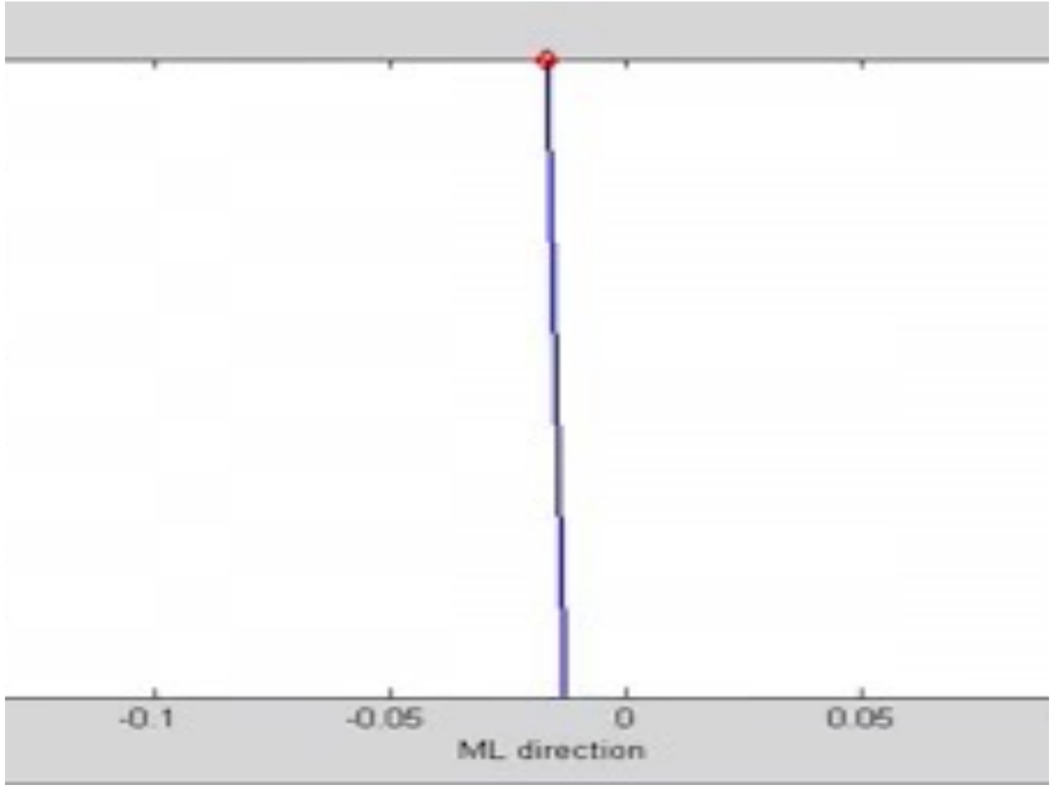
Move towards using objective measures



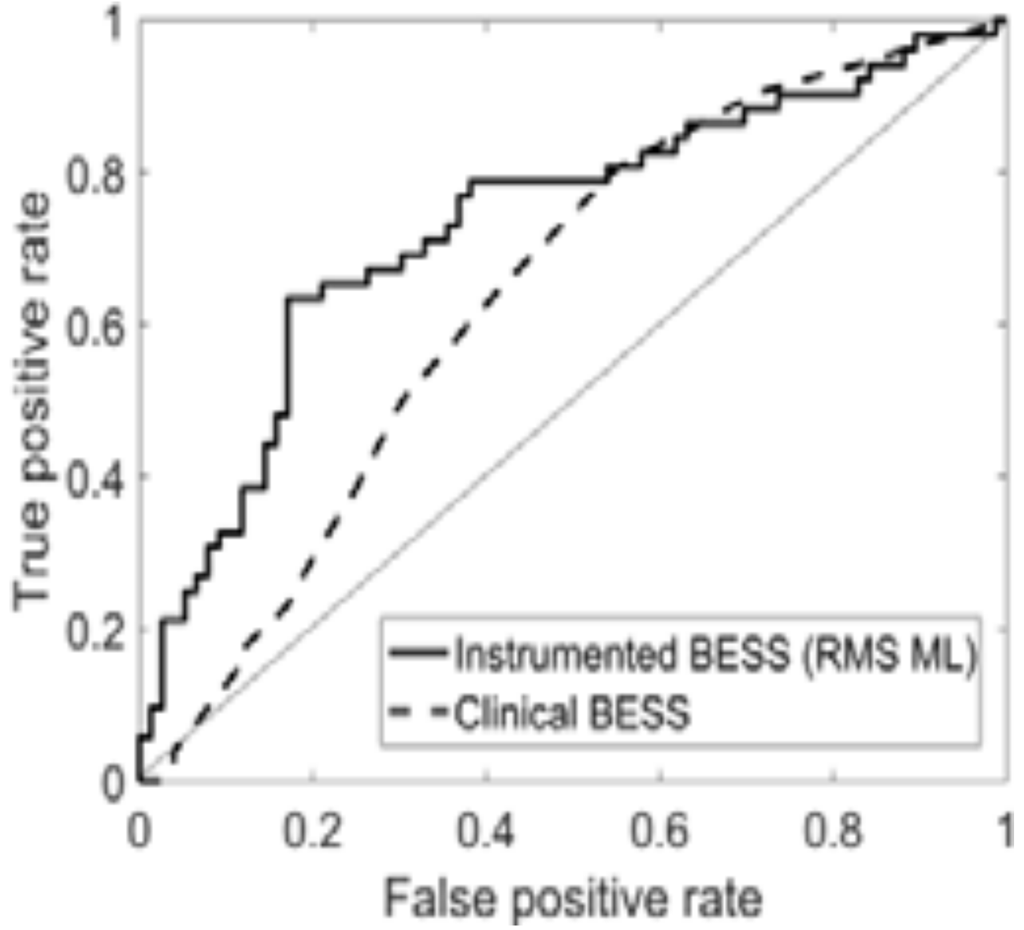
Aubry M et al Br J Sports Med. 2002; Chou LS Gait Posture 2004; McCrory P et al Br J Sports Med. 2005; King LA Arch Phys Med Rehabil. 2014; 4 McCrory P Br J Sports Med. 2017; King LA et al Ann Biomed Eng. 2017; Quatman-Yates CC et al J Orthop Sports Phys Ther. 2020

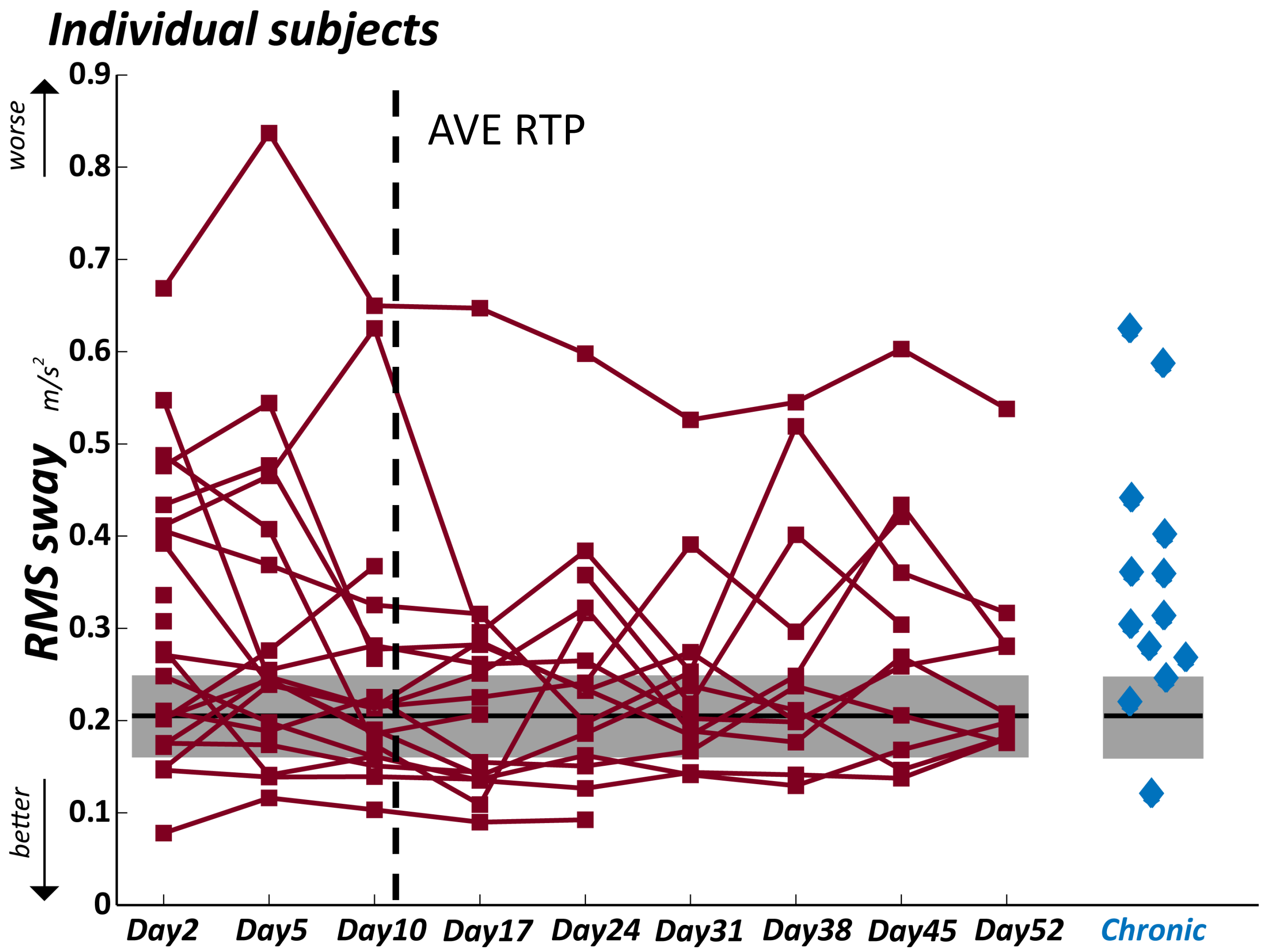
Objective measures for balance control





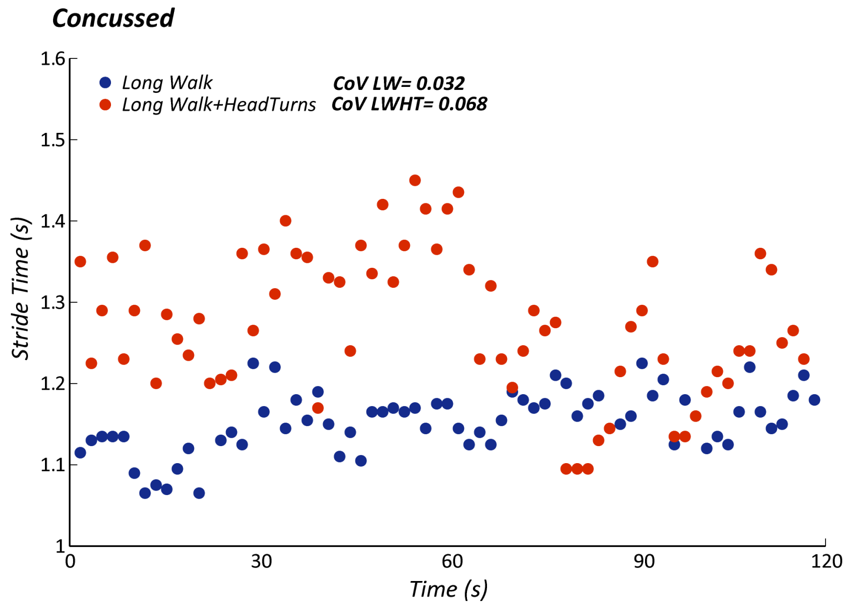
Objective measures more sensitive than clinical across timepoints

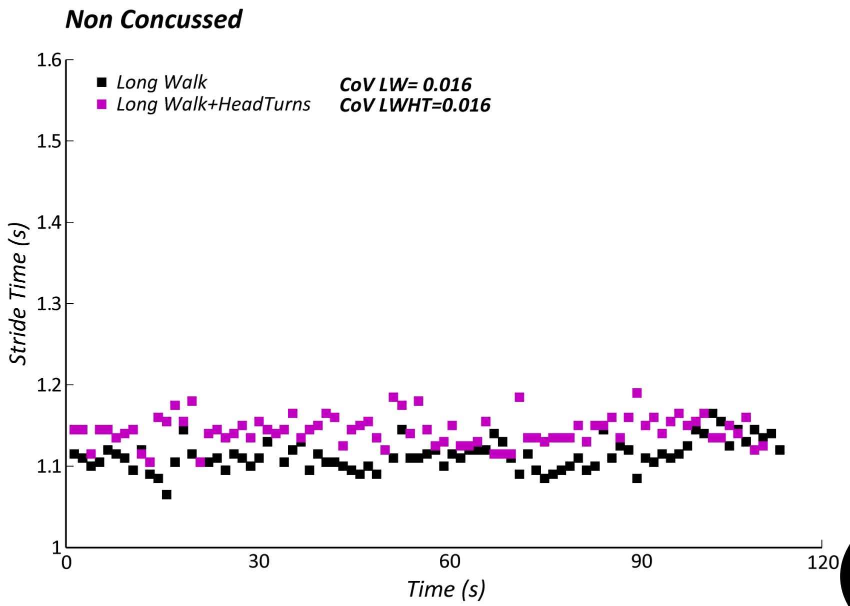


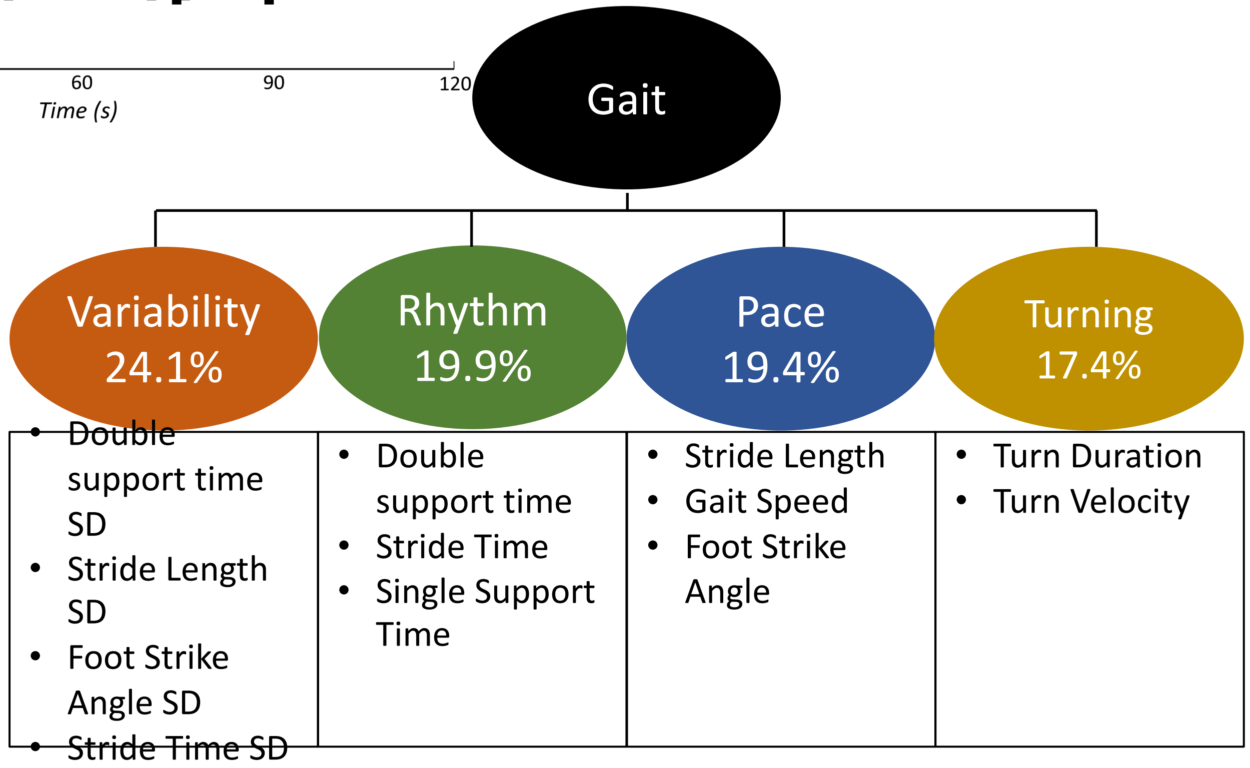


King et al, 2014, 2017

Objective measures of gait are important- not just speed







Stuart et al., 2019
Martini et al., 2020
King et al, pilot data

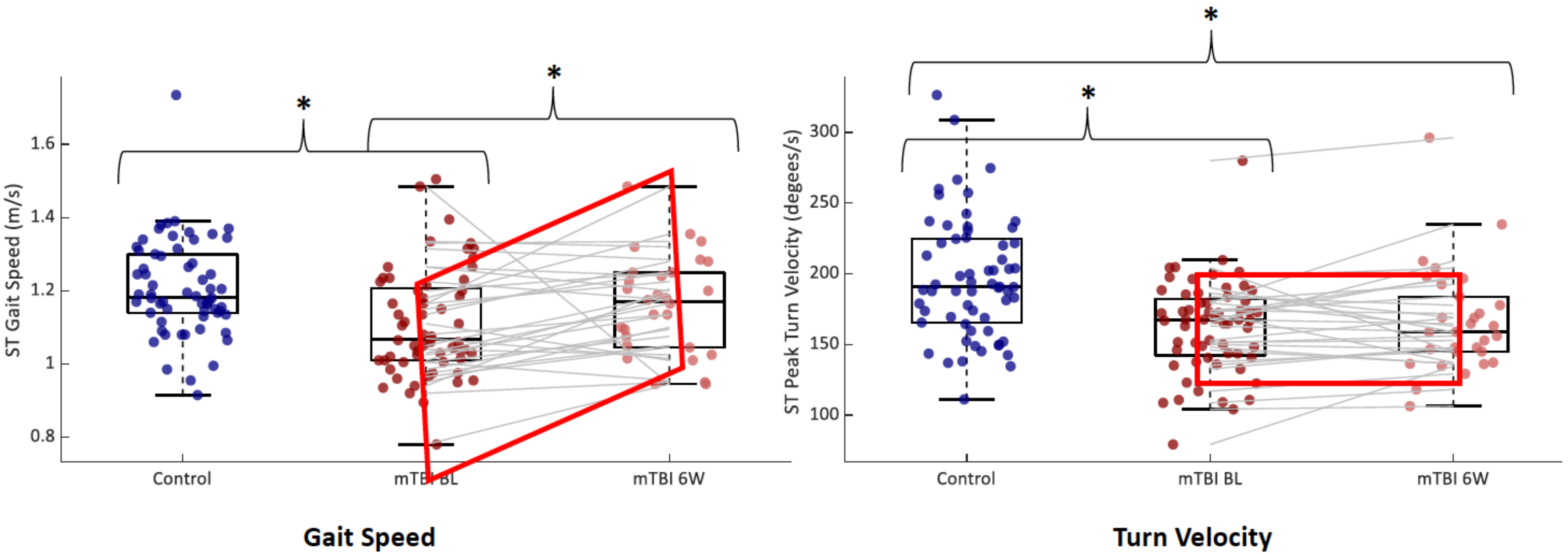
Gait domains impaired after mTBI, especially with dual task

TABLE 2. GAIT DOMAIN SCORES

		Control	*mTBI*	F *Statistic*	p *value*	*Cohen's* d
ST	Stroop Acc (%)	98.8 (4.2)	97.7 (6.3)	$F_{(1,96)} = 1.25$	0.267	0.23
	Pace	**0.38 (0.73)**	**–0.32 (0.82)**	$\mathbf{F_{(1,109)} = 22.56}$	**<0.001**	**0.91**
	Variability	–0.15 (0.76)	0.14 (0.82)	$F_{(1,109)} = 3.88$	0.051	0.38
	Rhythm	0.06 (0.32)	–0.09 (0.35)	$F_{(1,109)} = 5.39$	0.022	0.45
	Turning	**0.38 (0.85)**	**–0.31 (0.85)**	$\mathbf{F_{(1,109)} = 18.15}$	**<0.001**	**0.82**
DT	Stroop Acc (%)	98.5 (1.7)	95.8 (7.8)	$F_{(1,96)} = 5.53$	0.021	0.48
	Pace	**0.39 (0.80)**	**–0.32 (0.85)**	$\mathbf{F_{(1,108)} = 29.99}$	**<0.001**	**0.87**
	Variability	–0.13 (0.72)	0.18 (1.00)	$F_{(1,108)} = 3.44$	0.066	0.36
	Rhythm	**0.10 (0.28)**	**–0.11 (0.37)**	$\mathbf{F_{(1,108)} = 10.86}$	**0.001**	**0.64**
	Turning	**0.37 (0.61)**	**–0.33 (1.05)**	$\mathbf{F_{(1,112)} = 17.73}$	**<0.001**	**0.81**

Martini DN, Parrington L, Stuart S, Fino PC, King LA. Gait Performance in People with Symptomatic, Chronic Mild Traumatic Brain Injury. J Neurotrauma. 2021 Jan 15;38(2):218-224.

Rehabilitation May Affect Domains Differently

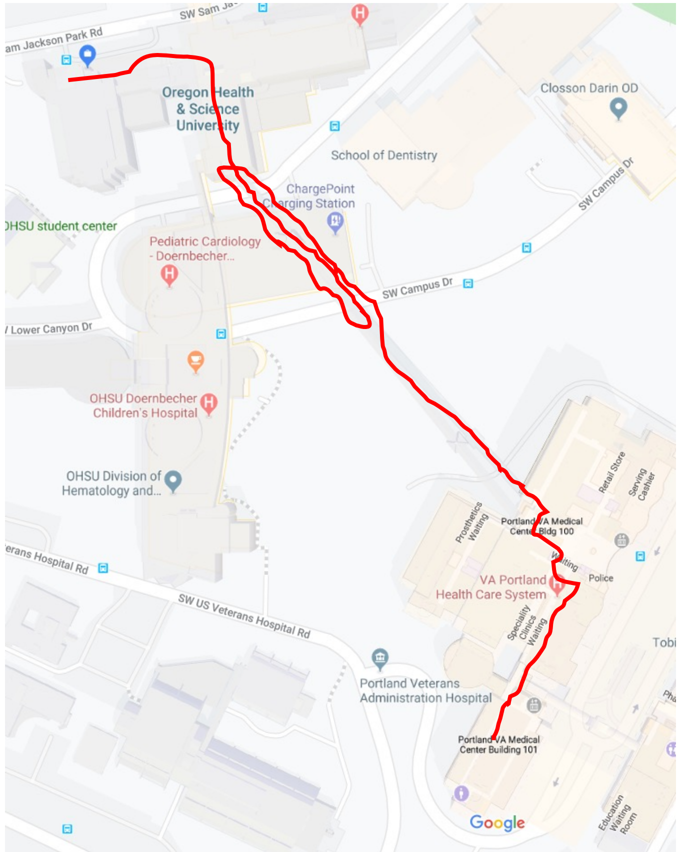


Gray lines connect participants across time.

* Indicates p < 0.05

King Pilot data; 2022

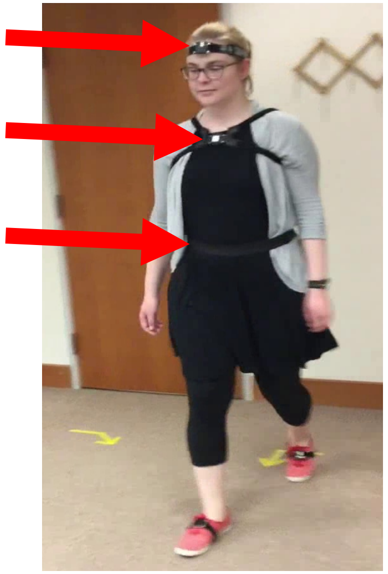
Locomotion is not always in a straight line

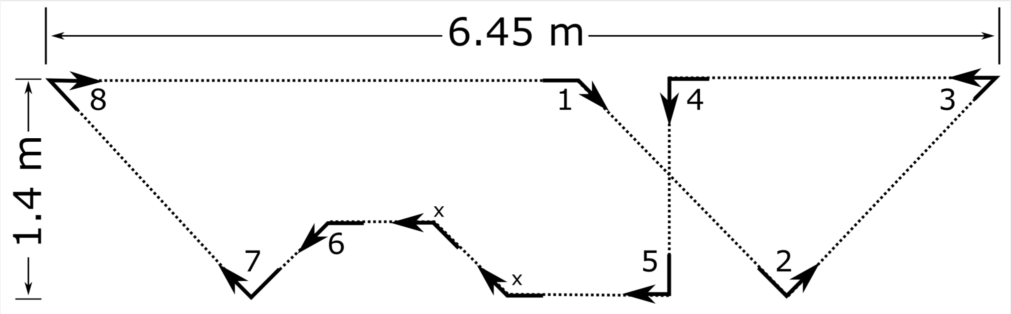


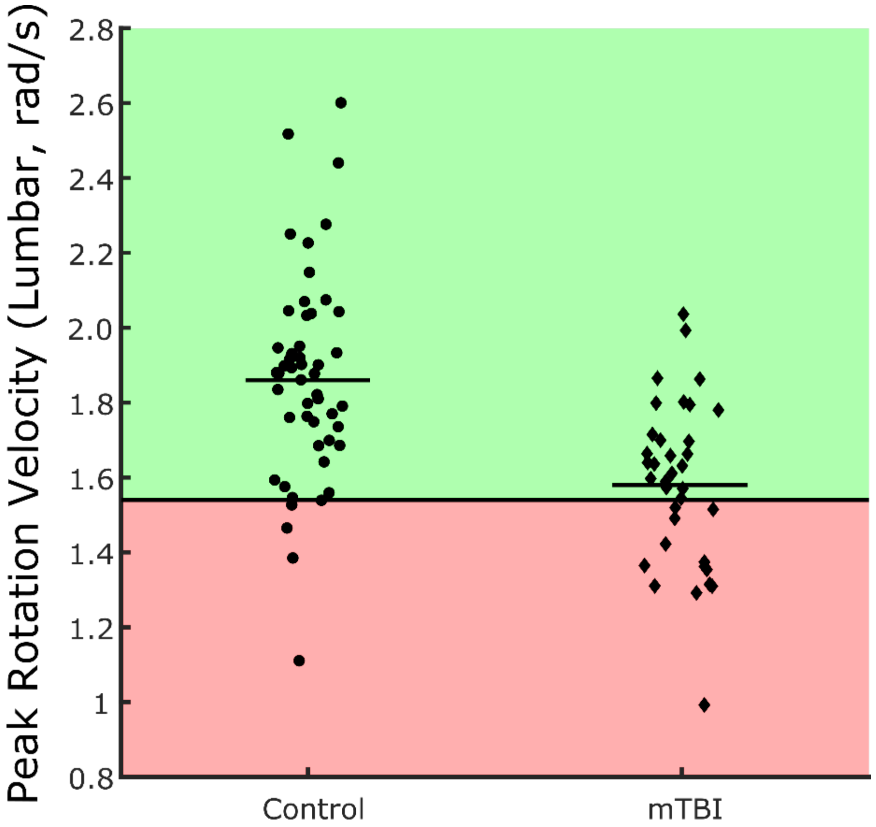
- Segmental reorientation to new direction
- 800-1000 turns per day, ~35-45% of steps
- Rehabilitation does not target turning
- Rapid, transient movements can exacerbate symptoms

Mancini 2016; Shah 2020; 1. Authie et al. Front Hum Neuro 2015; 2. Raphan et al. Annal NY Acad Sci 2001; 3. Bernardin et al Exp Brain Res 2012; 4. Mancini et al. NeuroRehab 2015; 5. Glaister et al. Gait Posture 2007;

Turning velocities during a planned turns course simulating the demands of everyday ambulation





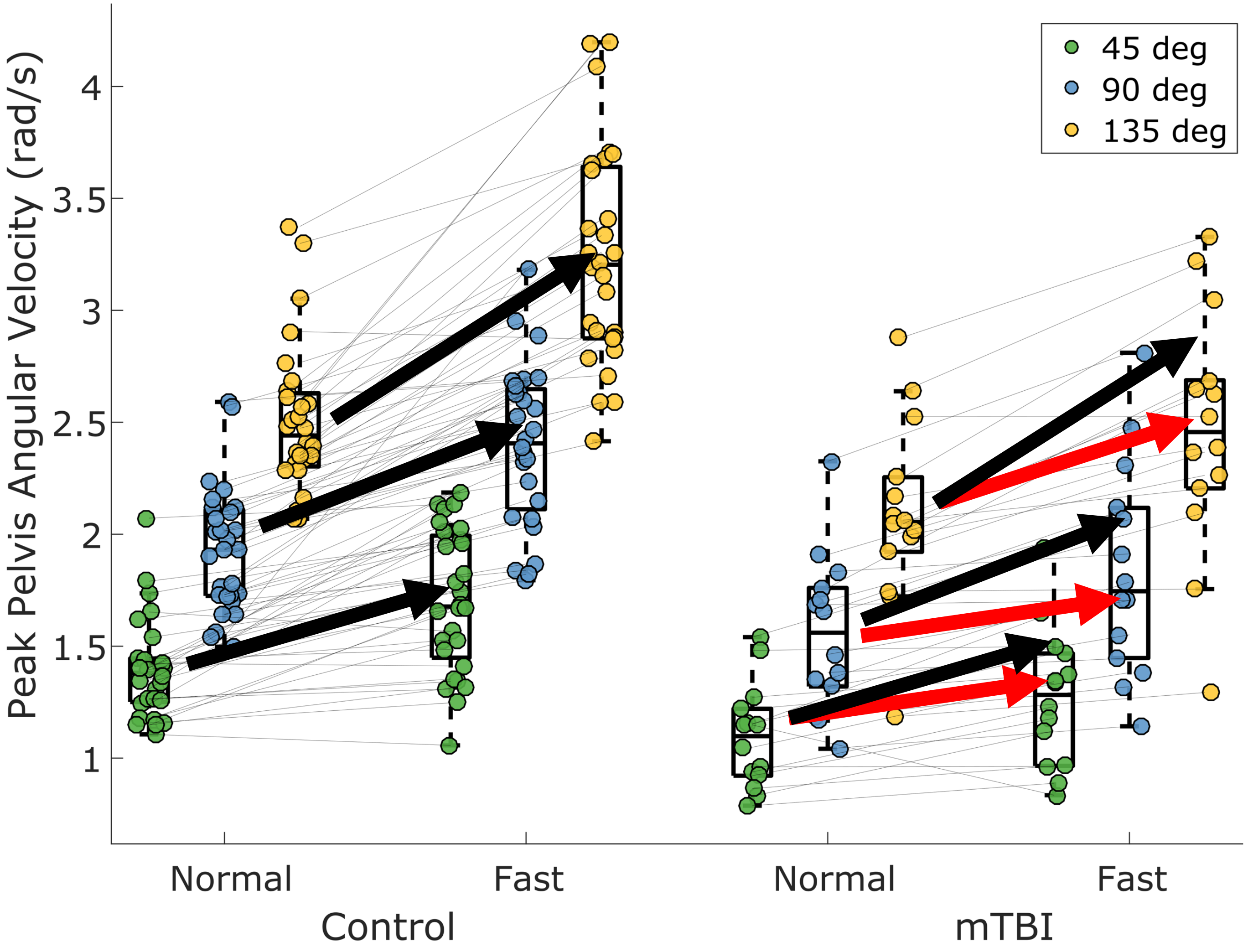


- Chronic mTBI (>3 months post-injury with self-reported complaints of imbalance)

OHSU

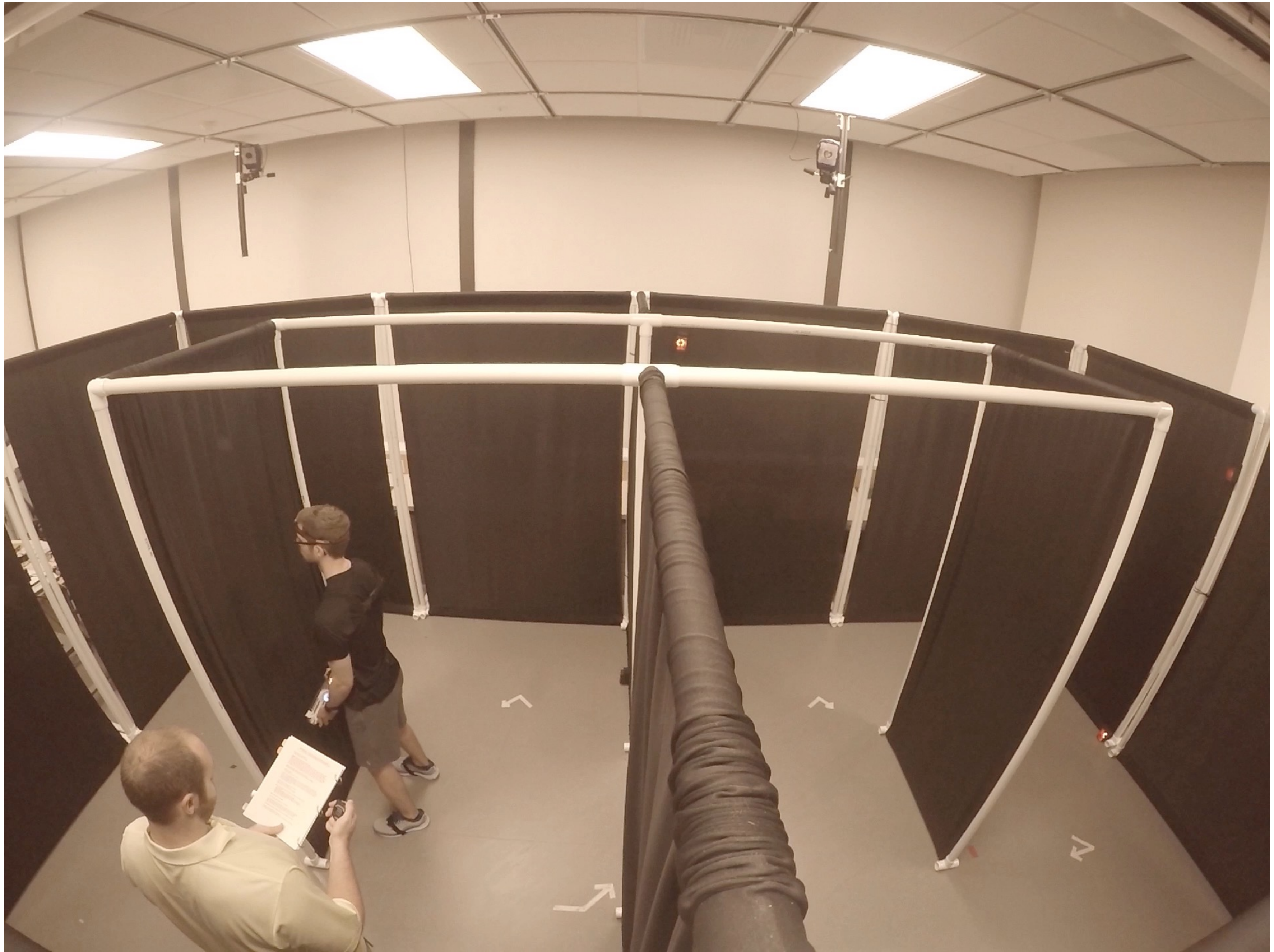
1. Powers et al. Gait Posture 2014; 2. Fino et al. JNER 2016; 3. Kolev and Sergeeva Funct Neurol 2016; 4. Hak et al. 2012 G&P

People with chronic mTBI had slower turn velocities and could not increase speed as much as healthy controls



Fino pilot data

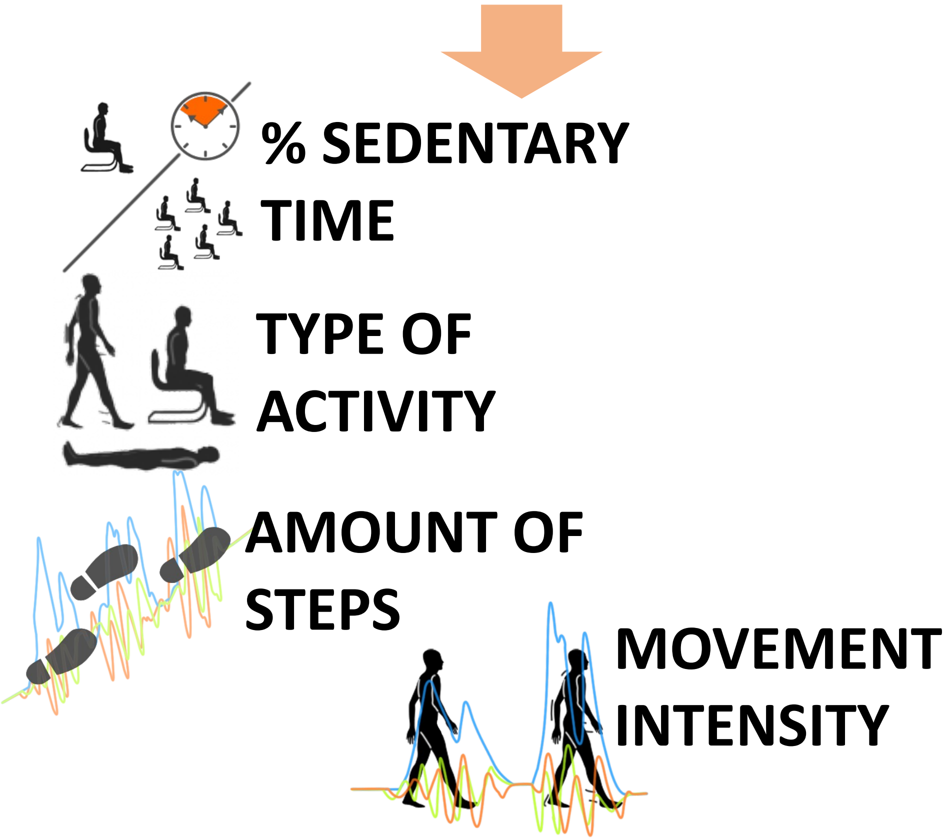
How to determine if military personnel are ready to return to duty?



Funded by department of defense
W81XWH-18-2-0049; King PI

Measuring movement in natural environment--Activity Monitor versus Movement Monitor

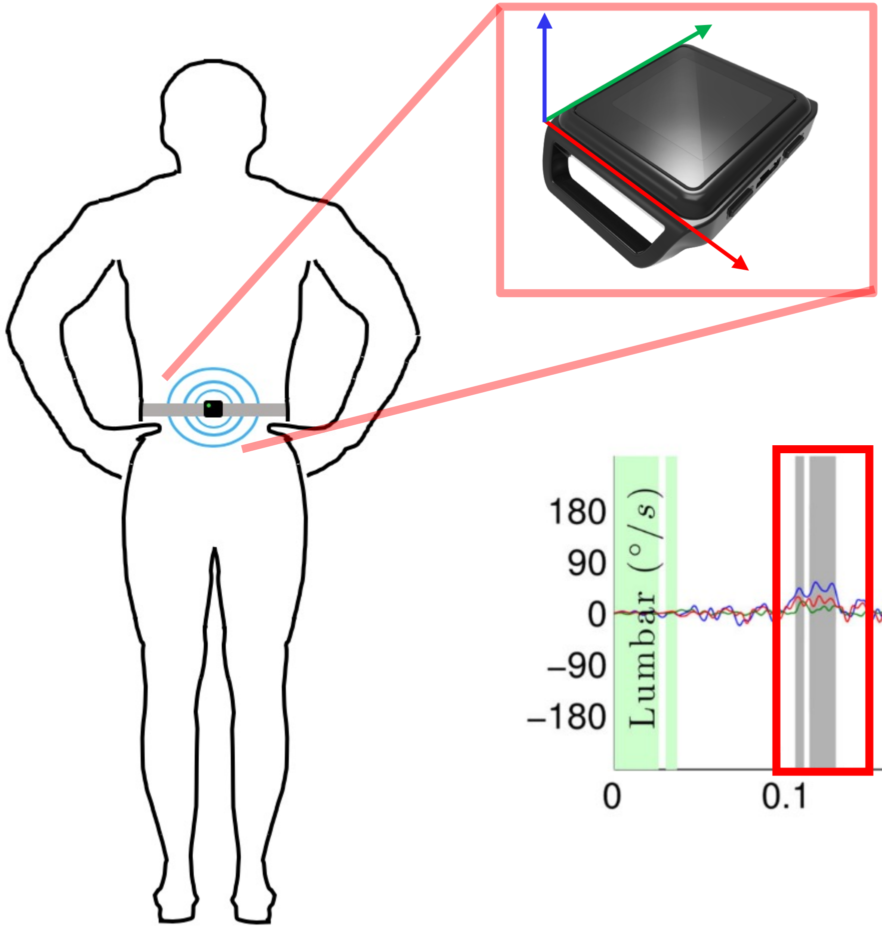
QUANTITY **vs** ***QUALITY***



Characterize how people walk and turn:

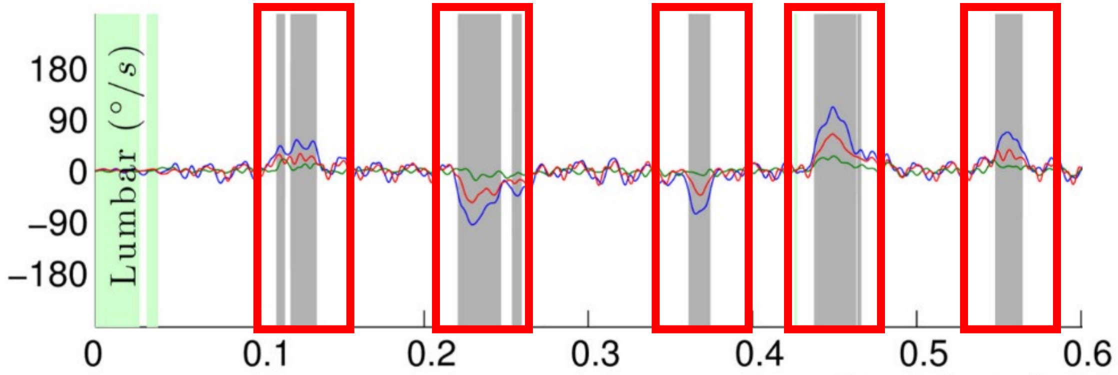
1) Turn duration
2) Turn amplitude
3) Turn peak velocity
4) Variability of turns
5) Gait characteristics

What can we learn from Continuous Monitoring?



Opal (APDM Inc, an ERT Company)

- Triaxial Linear Accelerometer (± 16g & ± 200g)
- Triaxial Gyroscope (± 2000°/s)
- Triaxial Magnetometer (± 8 Gauss)
- Sample Rate up to 128 Hz
- 12 Hour Battery Life
- 8 Gb Internal Memory



Turn Quality
Turn Angle Magnitude (°)
Turn Duration (s)
Peak Turn Velocity (°/s)
Average Turn Velocity (°/s)

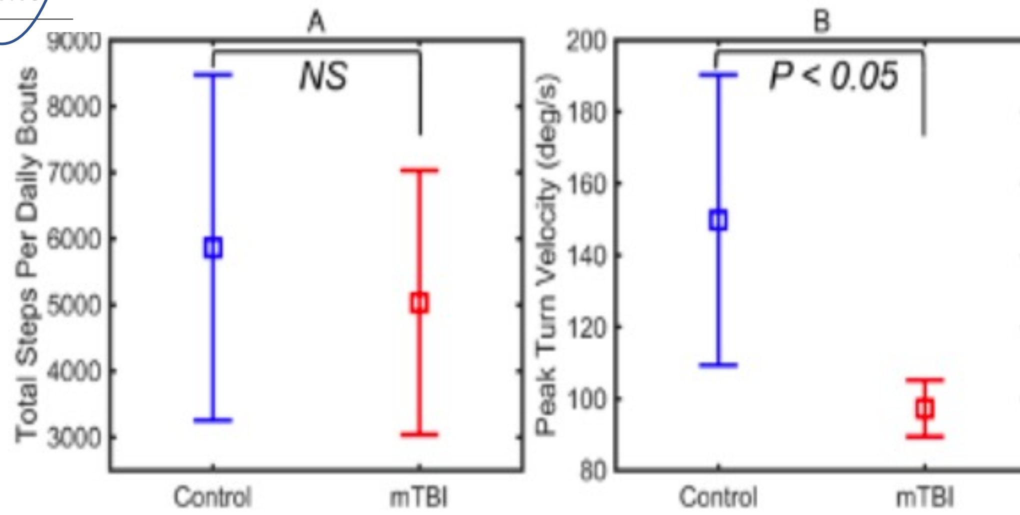
El-Gohary 2013; Sensors,

People with chronic mTBI had similar quantity but not quality compared to healthy controls at home

TABLE 2. TURNING AND PHYSICAL ACTIVITY MEASURES IN MTBI AND CONTROLS

	Chronic mTBI (n=29) *Mean (SD)*	*Controls* (n=23) *Mean (SD)*	*F*	p
Macro-level physical activity				
Number of bouts per hour *(n)*	16 (5)	15 (5)	0.89	0.352
Bout duration (sec)	48.41 (17.58)	44.89 (17.79)	0.52	0.476
Bout duration CV (sec)	0.83 (0.12)	0.82 (0.12)	0.00	0.962
Average steps per bout *(n)*	48 (24)	46 (32)	0.08	0.786
Total steps per daily bouts *(n)*	5863 (2606)	5034 (1997)	1.13	0.294
Active rate (%)	19.53 (7.34)	16.44 (4.62)	3.05	0.087
Micro-level turning				
Number of turns per hour (*n*/h)	85 (33)	60 (24)	7.46	**0.009***
Angle (°)	97.79 (3.63)	82.02 (12.62)	60.57	**<0.001***
Angle CV (°)	0.48 (0.02)	0.39 (0.09)	41.89	**<0.001***
Duration (sec)	1.73 (0.11)	1.14 (0.39)	75.95	**<0.001***
Duration CV (sec)	0.42 (0.02)	0.36 (0.07)	15.80	**<0.001***
Peak velocity (°/sec)	97.22 (7.92)	149.84 (40.09)	58.26	**<0.001***
Peak velocity CV (°/sec)	0.36 (0.03)	0.32 (0.03)	16.60	**<0.001***
Average velocity (°/sec)	48.94 (3.68)	73.45 (18.63)	57.35	**<0.001***
Average velocity CV (°/sec)	0.34 (0.02)	0.32 (0.04)	4.90	**0.032***

Seven days of continuous passive monitoring--Control and mTBI subjects had similar daily step counts (A) but had slower peak turning velocities (B)



Stuart et al., 2020; Pilot data Campbell, King2022

What are the underlying causes of balance deficits after mTBI?

- Some evidence of impaired vestibular and ocular-motor function, especially in the acute populations, blast exposed
- However, normal vestibular and ocular-motor function in people with more chronic (> 3 months) mTBI- still with balance complaints
- Some indication of sensory integration deficits but less work has been done in this area

Campbell et al., 2021; Haran et al., Akin et al, Hoffer et al; Zhou G, Brodsky JR. 2015

Peripheral Vestibular and Ocular motor function in chronic mTBI

Table 1: Overview of abnormal and normal oculomotor, peripheral vestibular, and central sensory integration for static balance function for healthy control and chronic mild traumatic brain injury (mTBI) groups.

Parameter	Abnormal Cutoff Value	Healthy Control N Abnormal / Total N (%)	Chronic mTBI N Abnormal / Total N (%)	Chi Square *p* Value
Oculomotor				
Saccades - Accuracy	< 85 %	5 / 52 (10%)	4 / 50 (8%)	1.000
Saccades - Latency	> 218 ms	6 / 52 (12%)	6 / 50 (12%)	0.942
Saccades - Velocity	< 339 deg/s	6 / 52 (12%)	1 / 50 (2%)	0.113
Smooth Pursuit – Average Velocity Gain	< 0.72	6 / 52 (12%)	5 / 49 (10%)	0.830
Smooth Pursuit - Velocity Gain Asymmetry	> 6 %	6 / 52 (12%)	7 / 49 (14%)	0.680
Peripheral Vestibular				
Caloric - Unilateral Weakness	> 30 %	4 / 49 (8%)	6 / 33 (18%)	0.302
Caloric - Average Slow Phase Velocity	< 9.35 deg/s	5 / 49 (10%)	5 / 33 (15%)	0.733
vHIT - Average VOR Gain	< 0.87	6 / 52 (12%)	1 / 49 (4%)	0.113
vHIT - VOR Gain Asymmetry	> 8% %	6 / 52 (12%)	7 / 49 (14%)	0.680
cVEMP - Asymmetry	> 31 %	5 / 49 (10%)	3 / 40 (8%)	0.726
oVEMP - Asymmetry	> 39 %	4 / 41 (10%)	5 / 29 (17%)	0.473
Central Sensory Integration				
SOT - Composite Score	< 61.8	6 / 60 (10%)	***28 / 54 (52%)***	***< 0.001***
SOT - Somatosensory Ratio	< 93.1	6 / 60 (10%)	***33 / 54 (61%)***	***< 0.001***
SOT - Visual Ratio	< 55.5	6 / 60 (10%)	***23 / 54 (43%)***	***< 0.001***
SOT - Vestibular Ratio	< 35.5	6 / 60 (10%)	***22 / 54 (41%)***	***< 0.001***

Abnormal cutoff values were derived from 10 percentile cutoffs calculated from healthy control data. Parameters bolded and italicized indicates a significant difference in the proportion of abnormal function for the mTBI group compared to the healthy control group ($p < 0.05$). N – number of participants; vHIT – video Head Impulse Test; VOR – Vestibular Ocular Reflex; cVEMP – cervical vestibular evoked myogenic potential; oVEMP – ocular vestibular evoked myogenic potential; SOT – Sensory Organization Test.

Campbell 2021, *J Vestib Res*

Award#: W81XWH-15-1-0620 (King; PI)

Peripheral Vestibular or Ocular motor deficits in chronic mTBI

Table 1: Overview of abnormal and normal oculomotor, peripheral vestibular, and central sensory integration for static balance function for healthy control and chronic mild traumatic brain injury (mTBI) groups.

Parameter	Abnormal Cutoff Value	Healthy Control N Abnormal / Total N (%)	Chronic mTBI N Abnormal / Total N (%)	Chi Square *p* Value
Oculomotor				
Saccades - Accuracy	< 85 %	5 / 52 (10%)	4 / 50 (8%)	1.000
Saccades - Latency	> 218 ms	6 / 52 (12%)	6 / 50 (12%)	0.942
Saccades - Velocity	< 339 deg/s	6 / 52 (12%)	1 / 50 (2%)	0.113
Smooth Pursuit – Average Velocity Gain	< 0.72	6 / 52 (12%)	5 / 49 (10%)	0.830
Smooth Pursuit - Velocity Gain Asymmetry	> 6 %	6 / 52 (12%)	7 / 49 (14%)	0.680
Peripheral Vestibular				
Caloric - Unilateral Weakness	> 30 %	4 / 49 (8%)	6 / 33 (18%)	0.302
Caloric - Average Slow Phase Velocity	< 9.35 deg/s	5 / 49 (10%)	5 / 33 (15%)	0.733
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Central sensory integration deficits

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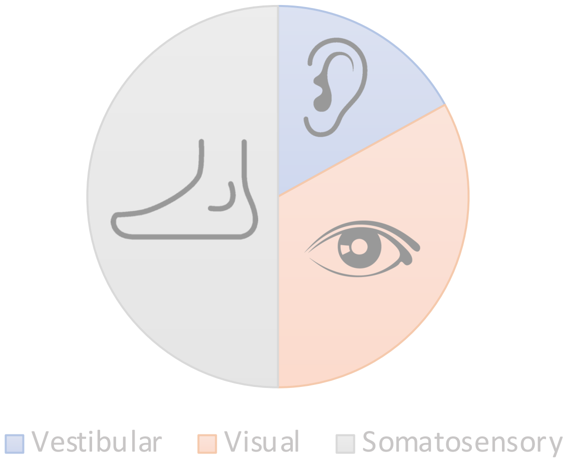
Use of sensory systems will change depending on the availability of sensory information



(Derived from sway responses evoked by low amplitude surface motion stimuli, Peterka 2002)

Comprehensive view of balance

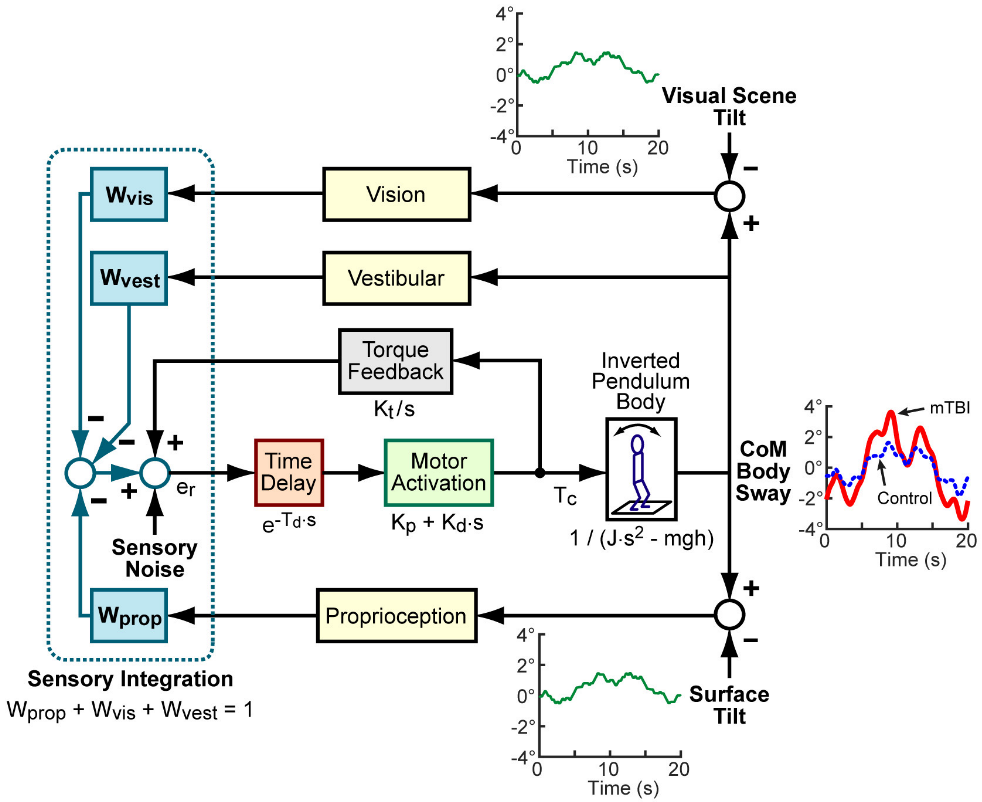
- Balance control can be represented as a feedback control system involving motor as well as sensory contributions
- Goal is to maintain upright orientation
- Body sway detected by Vision, Vestibular, Proprioception
- Central sensory integration combines information
- Then a motor activation mechanism generates appropriate joint torques
- Sensory and motor central processing takes time so there is a time delay

CSMI Test Method

Uses engineering system identification methods to characterize balance control.

- Uses externally applied stimuli (surface and surround) to evoke a body sway response
- A stimulus-response analysis to characterize dynamic properties of the balance control system

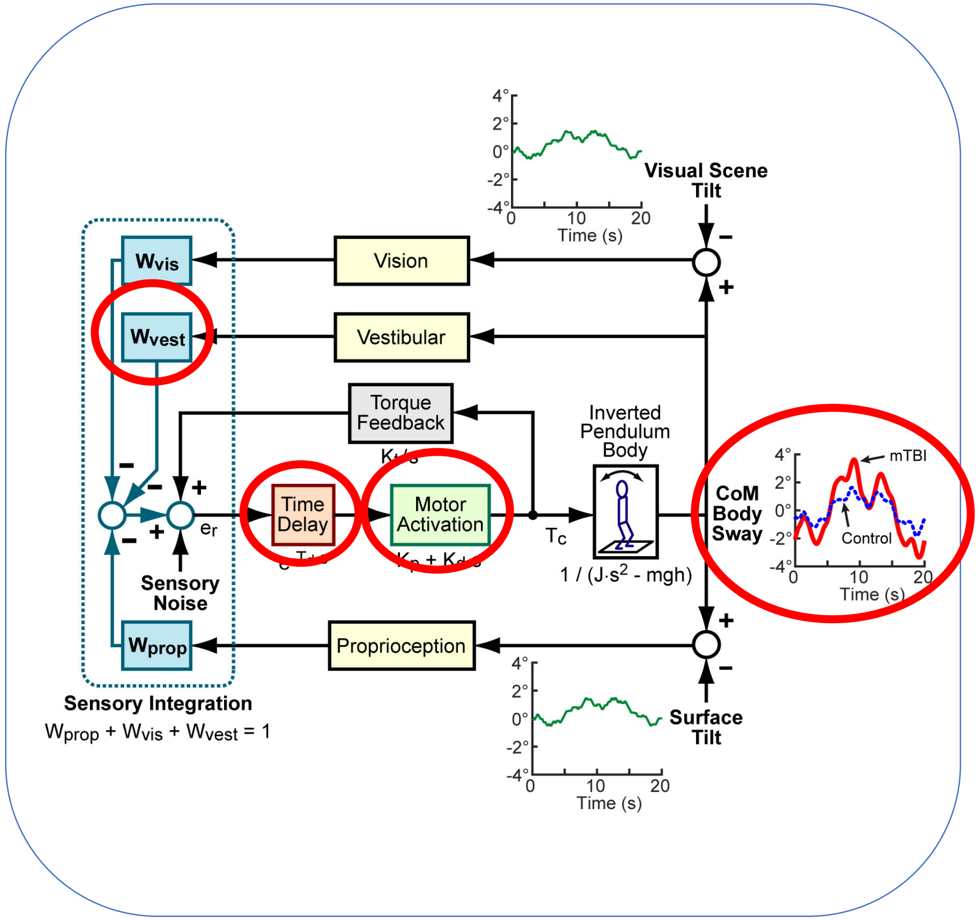
Central Sensorimotor Integration (CSMI) Test

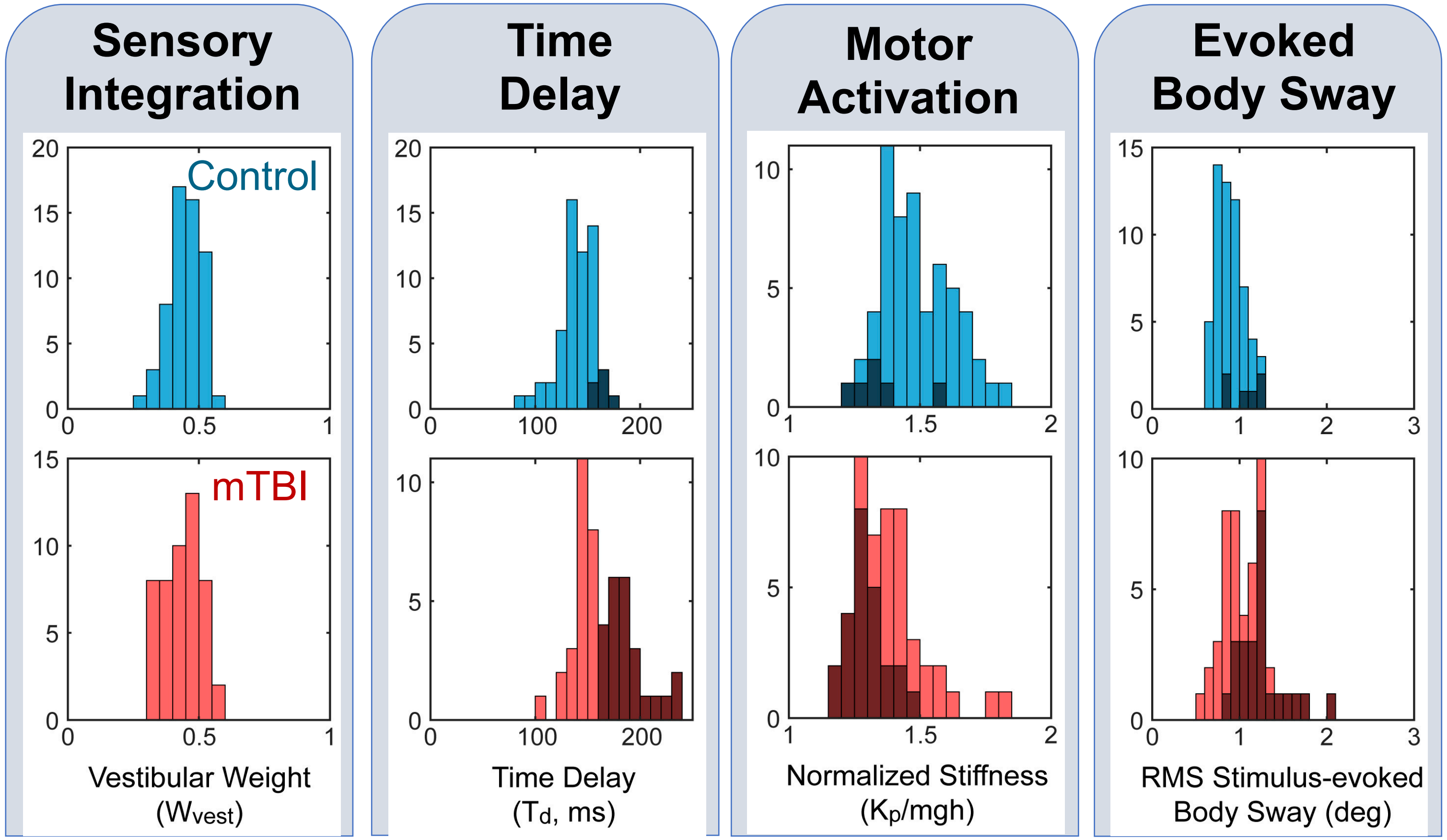


Feedback Control of Balance

Peterka et al, 2002, 2018

CSMI Results





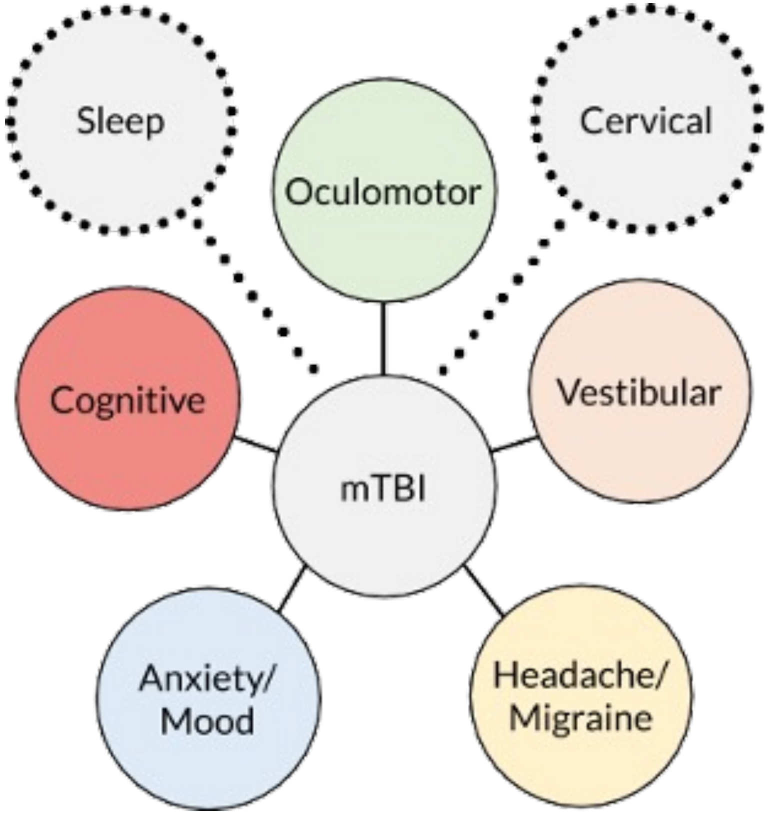
- Increased Time Delay is the fundamental balance dysfunction
- Decreased Motor Activation compensates for increased time delay
- Consequence is increased sensitivity to balance disturbances
- Physical Therapy: Focus on response timing rather than sensory dysfunction

Campbell , Peterka, King., Frontiers Neurol 2022

Rehabilitation- what's new?

- Concussion subtypes
- When to initiate rehabilitation
- How to work on turning and motor activation/time delay?

Concussion Subtypes



- Will using objective measures help define subtypes better to enable early rehabilitation?
- Would physical therapy be most effective for vestibular and oculomotor subtypes?
- Are there other subtypes or modifiers that we need to consider?
  - Auditory? Autonomic?

Guidelines for initiating rehabilitation inconsistent and unclear

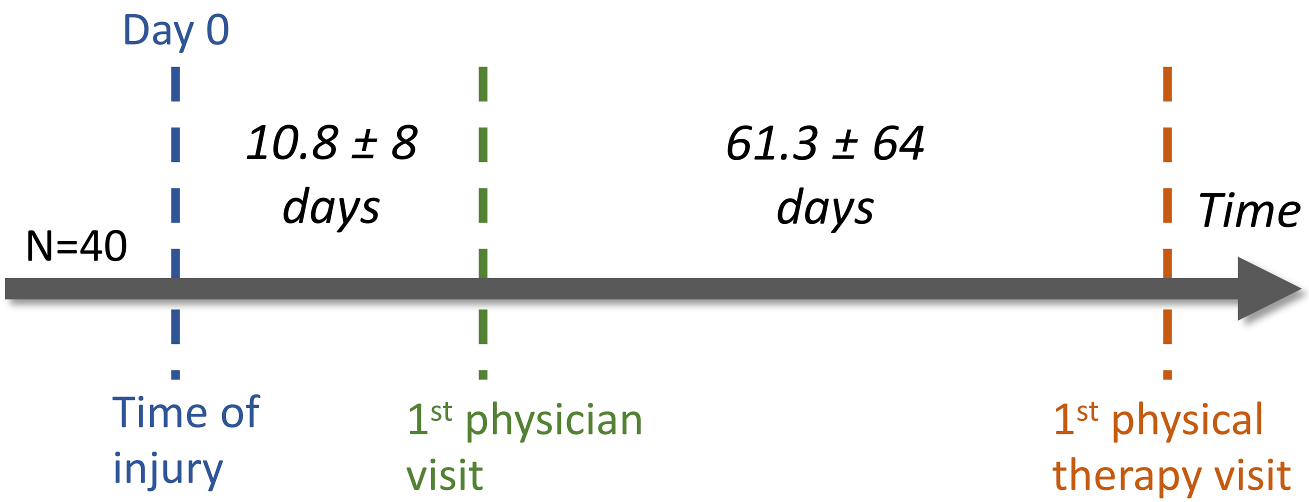


Figure 1. *Average time from injury to first visit with a physician and time from first physician visit to first visit with a physical therapist*

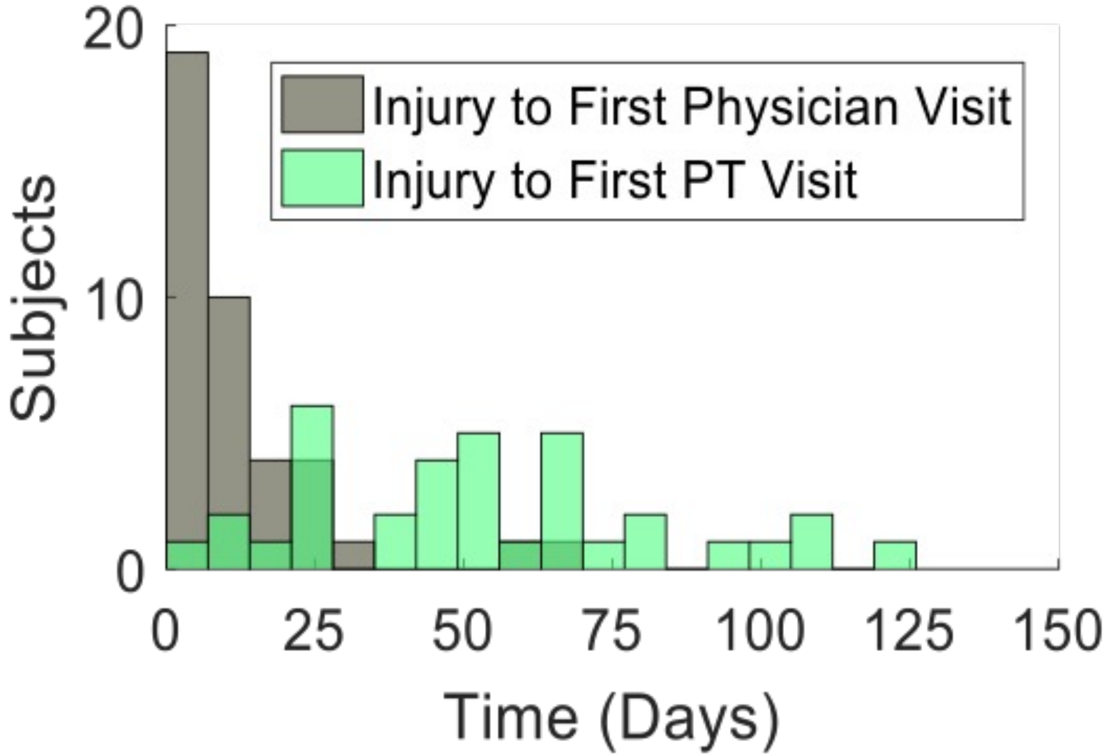
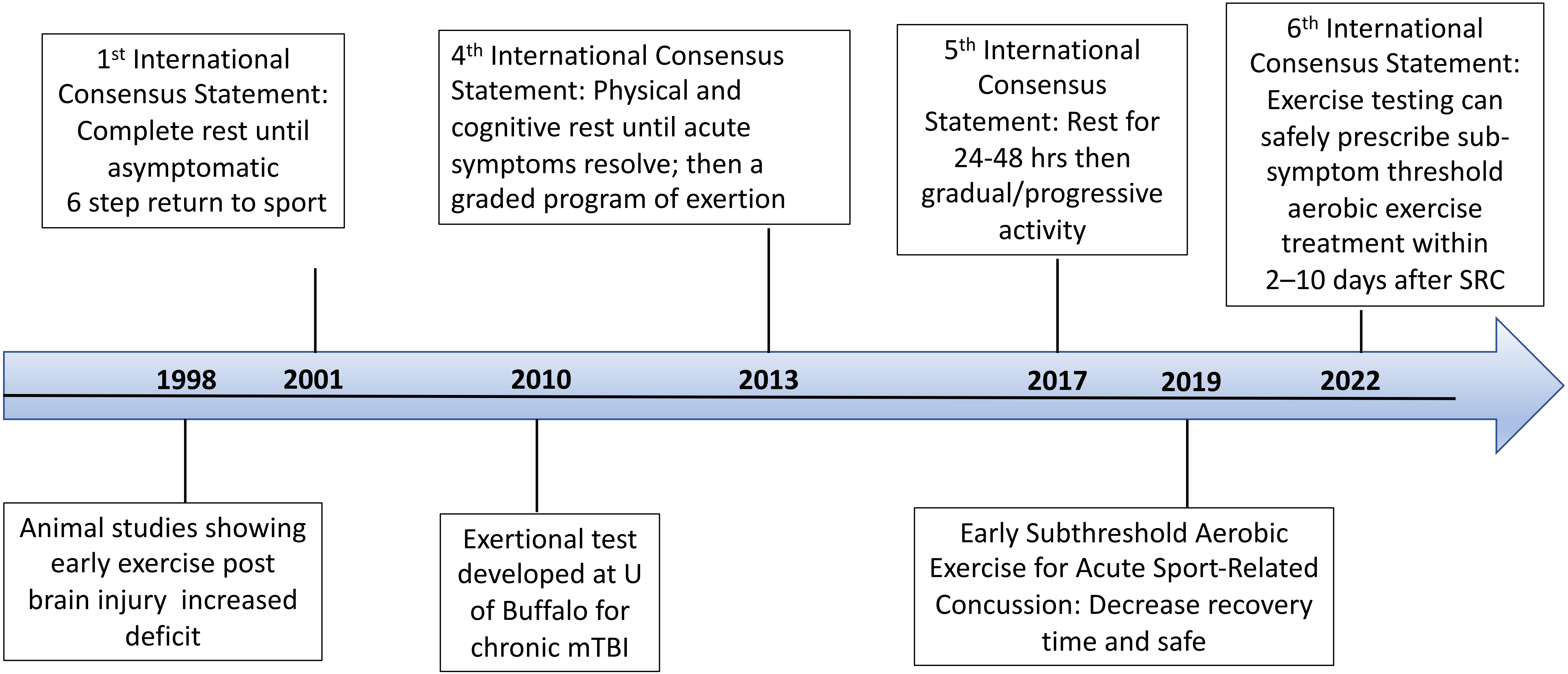


Figure 2. *Histograms showing distribution of time from injury until the first physician visit and until the first physical therapy visit.*

A move from complete rest to gradual activity



Humm JL et al Brain Res. 1998; Aubry M et al Br J Sports Med. 2002; Leddy JJ et al. Clin J Sport Med. 2010; McCrory P et al J Athl Train. 2013;
McCrory P et al Br J Sports Med. 2017; King LA et al Ann Biomed Eng. 2017; Leddy JJ et al. JAMA Pediatr. 2019;
Patricios, JS et al British Journal of Sports Medicine 2022

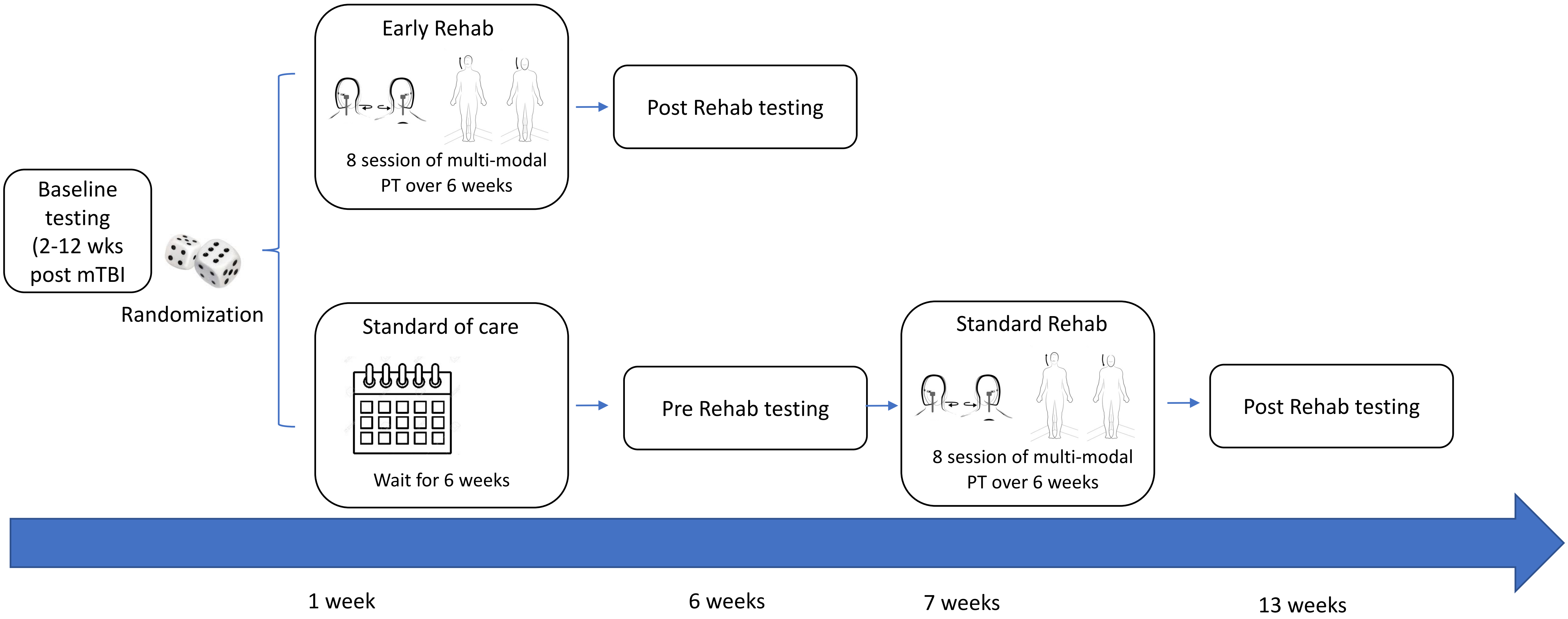
Early rehabilitation?

- **Early is the new Normal:**
  - **Early** mobilization in the ICU on mechanical ventilation improves LOS
  - **Early** rehab for muscle injury: faster RTP
  - Current model for neurological rehabilitation

- Waiting: maladaptive strategies
- Other occurances with 'rest'
  - Depression, anxiety, deconditioning, isolation, sleep disturbances

Bamiou DB et al Scand Audio 2000; Shen J et al; Brain Research 2016
Hashem MD et al; Respir Care 2016; Bayer et al; N Engl J Med 2017

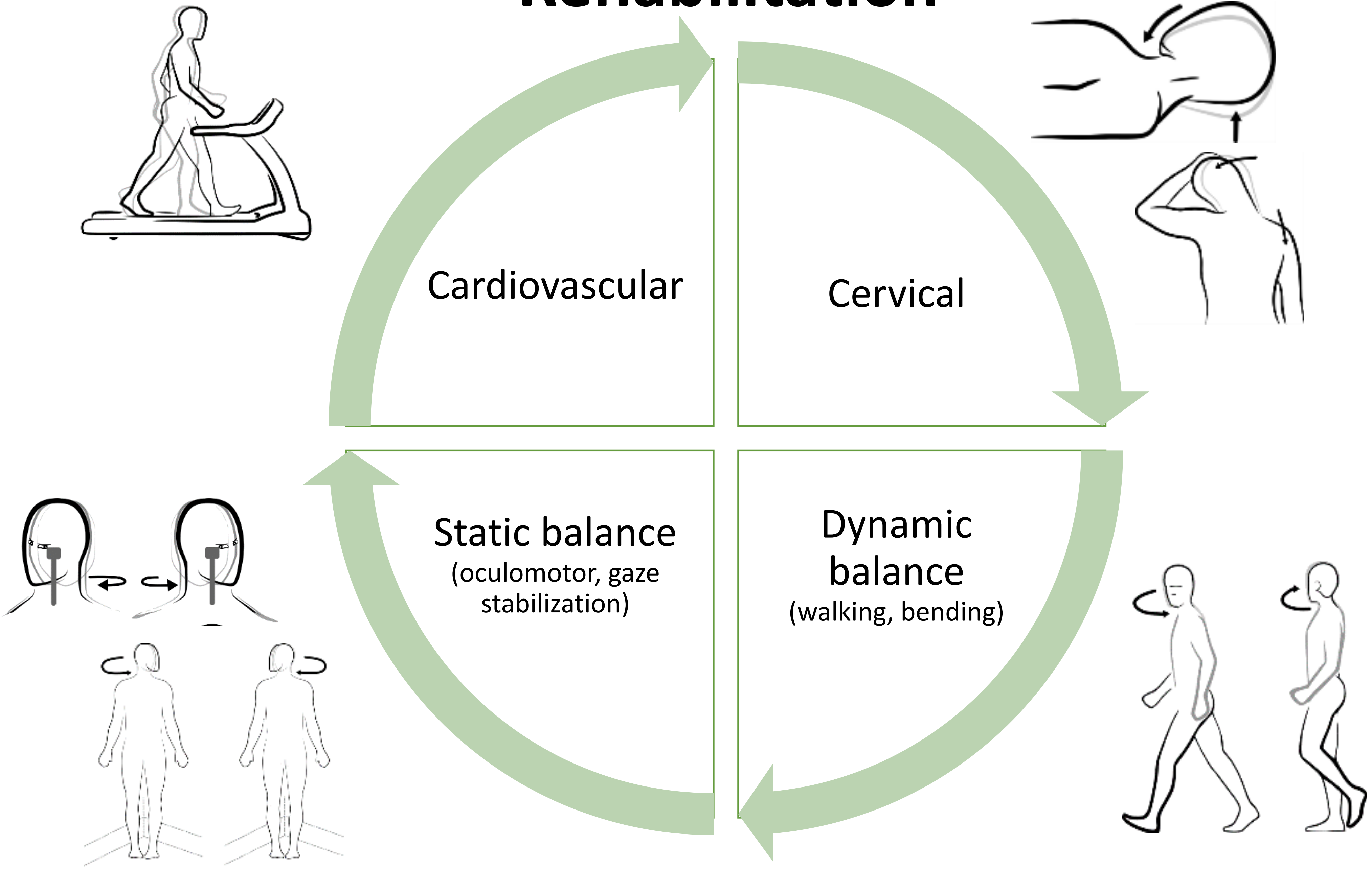
Overview of the study



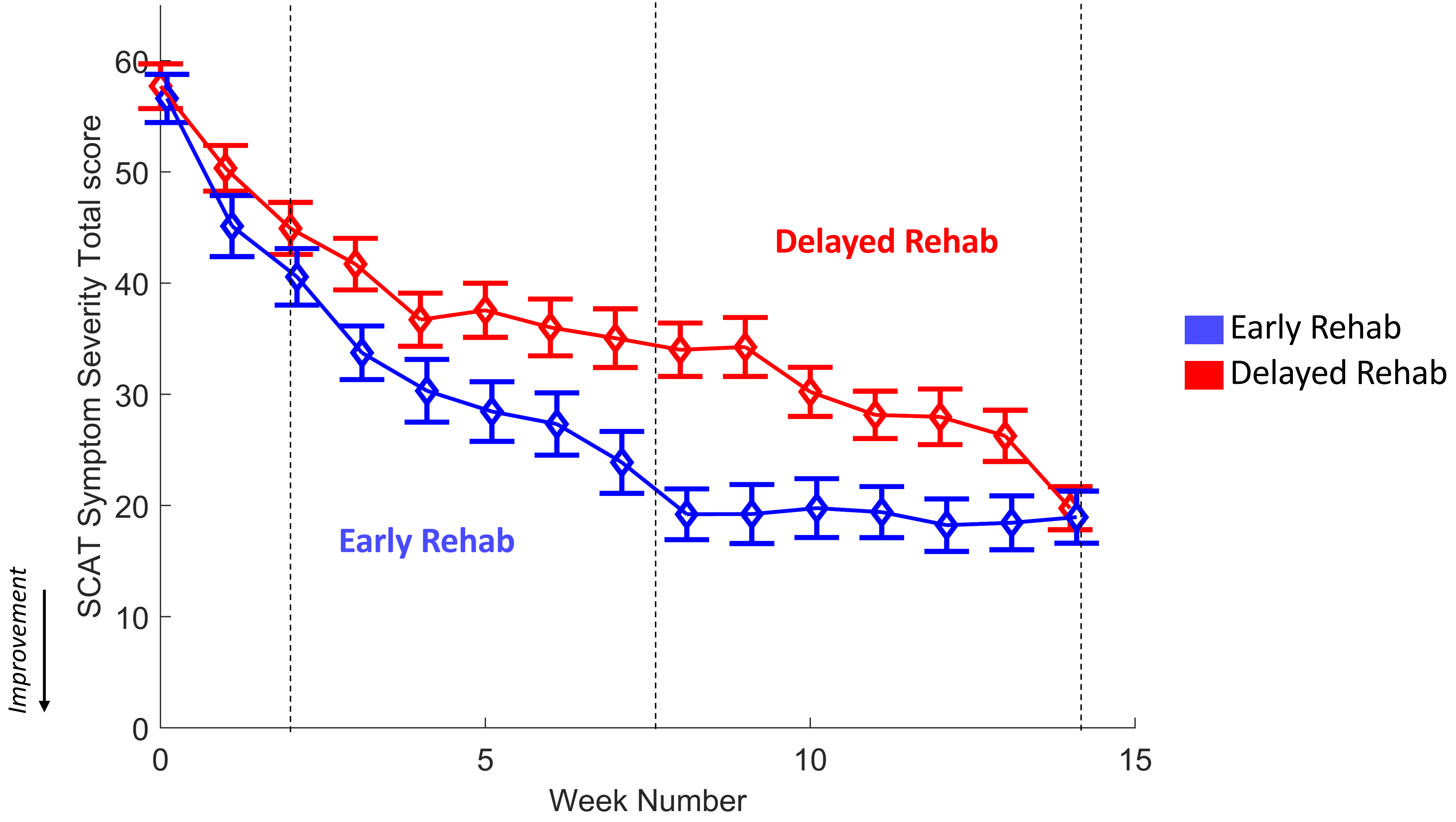
Parrington et al; 2020

Award # W81XWH-17-1-0424 (King; PI)

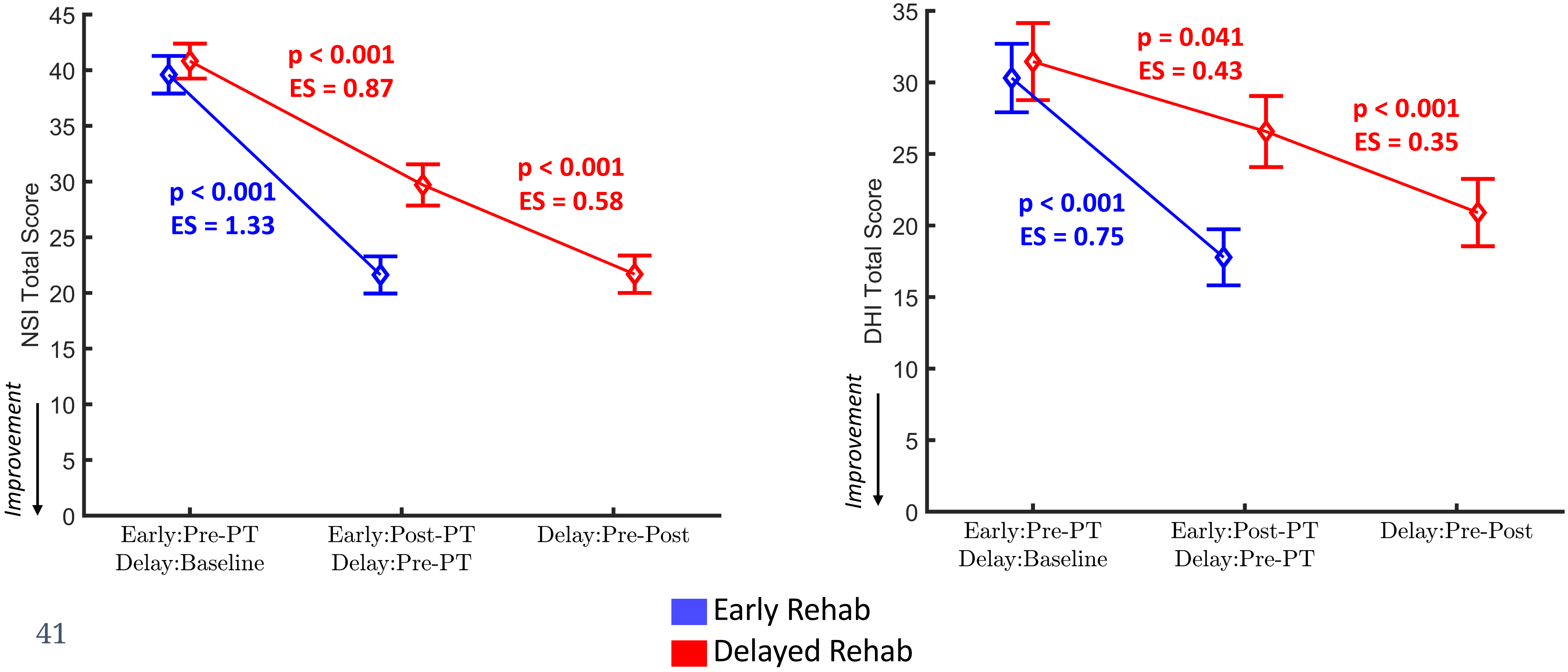
Rehabilitation



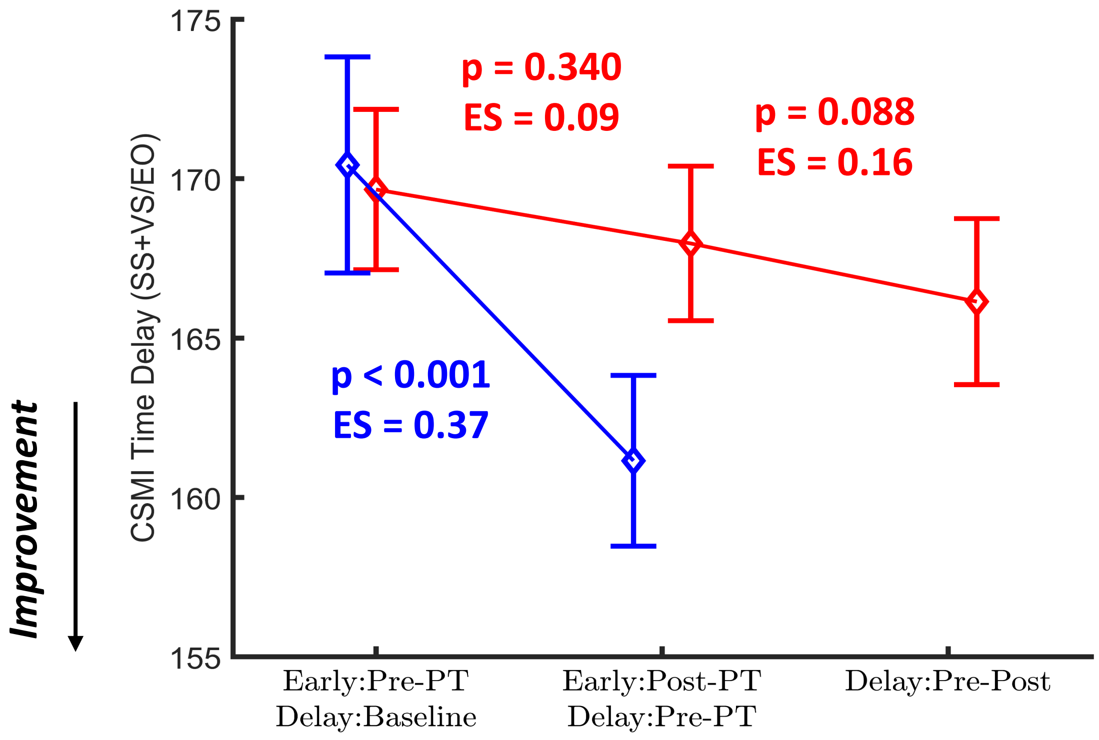
Early initiation of rehab leads to symptom improvement at a faster rate than delayed rehab

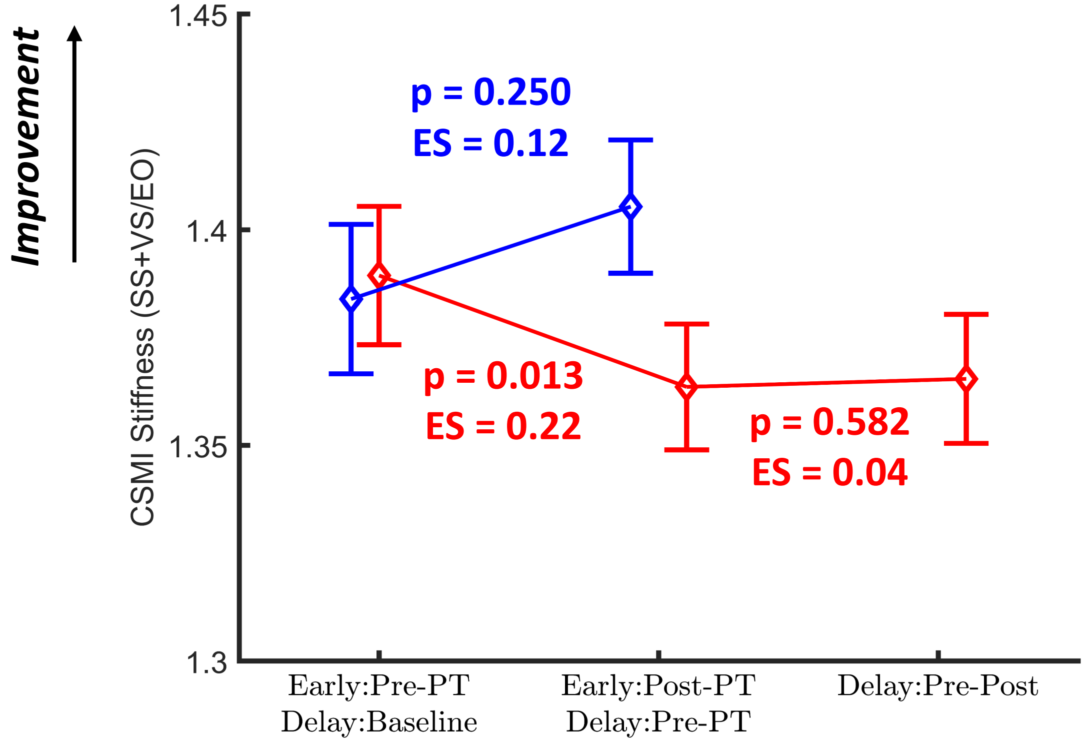


Improvements in global mTBI and vestibular specific symptoms faster more with early initiation of PT



Delaying rehab may induce maladaptive motor activation responses that do not improve with rehabilitation

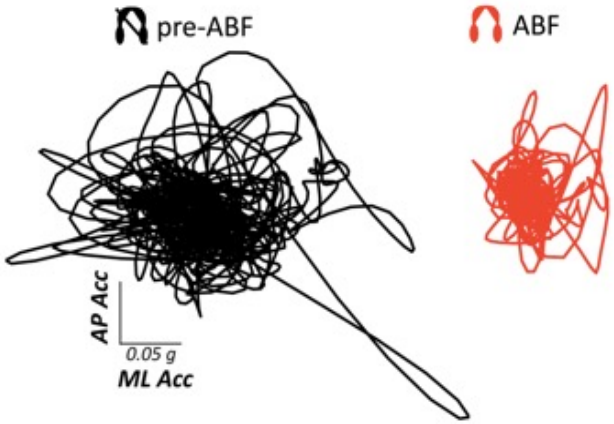




Early Rehab
Delayed Rehab

Award # W81XWH-17-1-0424 (King; PI)

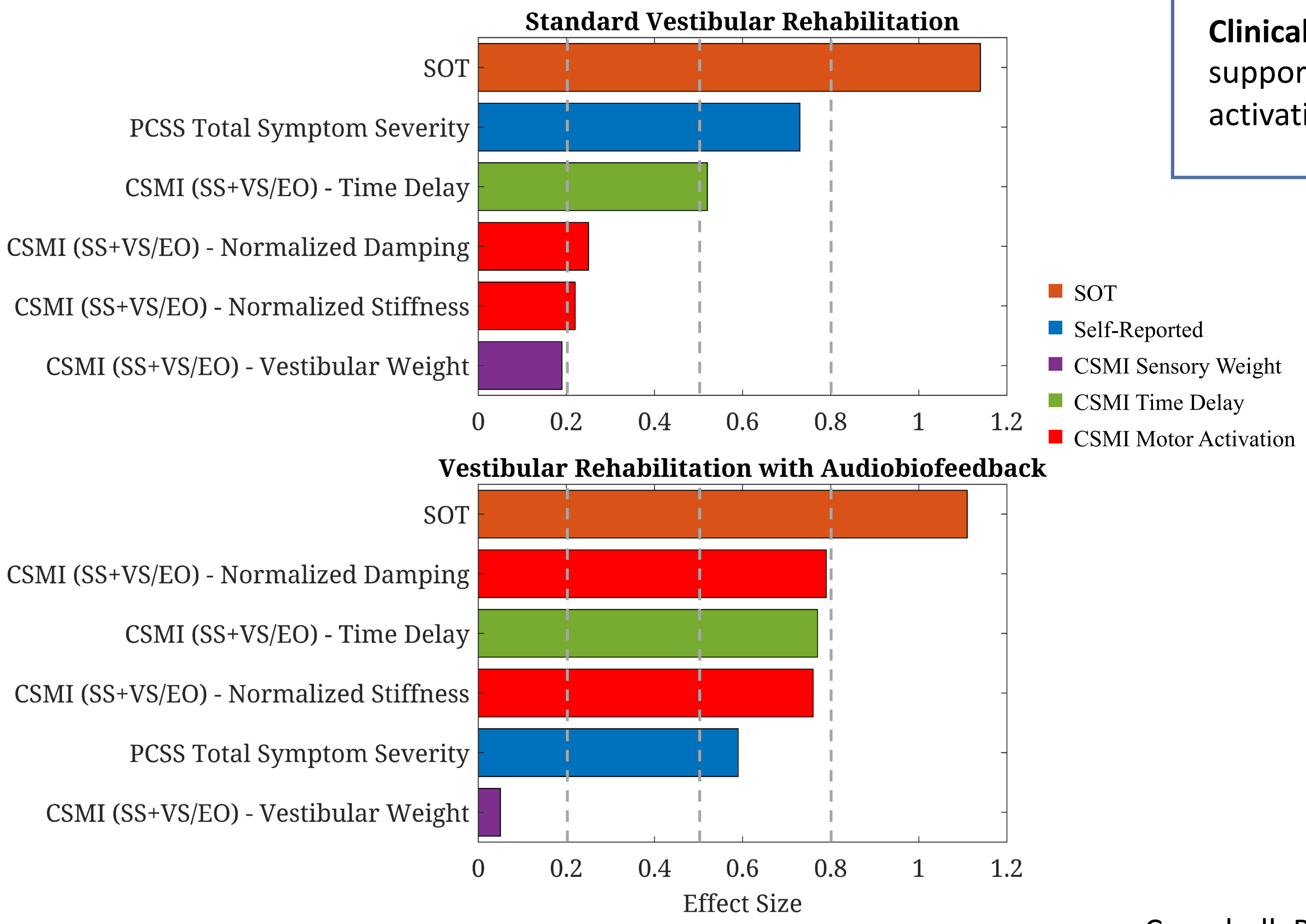
How can we work on motor componants such as time delay and stiffness?



Auditory biofeedback to augment vestibular rehabilitation

	Eyes Open				Eyes Closed			
	Feet Together (DS), Firm							
Static	1) Standing Still	2) Tossing Ball	3) Rotating Head (L/ R)	7) Bobbing Head (U/ D)	1) Standing Still	2) Rotating Head (L/ R)	3) Bobbing Head (U/ D)	
			4) Smooth Pursuit	8) Smooth Pursuit				
			5) Gaze Stabilization	9) Gaze Stabilization				
			6) Saccades	10) Saccades				
	Feet Together (DS), Foam							
	1) Standing Still	2) Tossing Ball	3) Rotating Head (L/ R)	4) Bobbing Head (L/ R)	1) Standing Still	2) Rotating Head (L/ R)	3) Bobbing Head (U/D)	
Dynamic	Tandem Gait, Firm							
	1) Walking	2) Tossing Ball	3) Rotating Head (L/ R)	4) Bobbing Head (L/ R)	1) Walking			
	Tandem Gait, Foam							
	1) Walking	2) Tossing Ball	3) Rotating Head (L/ R)	4) Bobbing Head (L/ R)	1) Walking			
Bending	1) Chair	2) Side of Treadmill	3) Floor		1) Chair	2) Side of Treadmill	3) Floor	
Squatting	Squat Firm							
	1) Sit to stand (mini squat)	2) Lunge	3) Lunge onto unstable surface	4) Lunge + Twist	1) Sit to stand (mini squat)	2) Lunge	3) Lunge onto unstable surface	4) Lunge + Twist
	Squat Foam							
	1) Sit to stand (mini squat)	2) Lunge	3) Lunge onto unstable surface	4) Lunge + Twist	1) Sit to stand (mini squat)	2) Lunge	3) Lunge onto unstable surface	4) Lunge + Twist

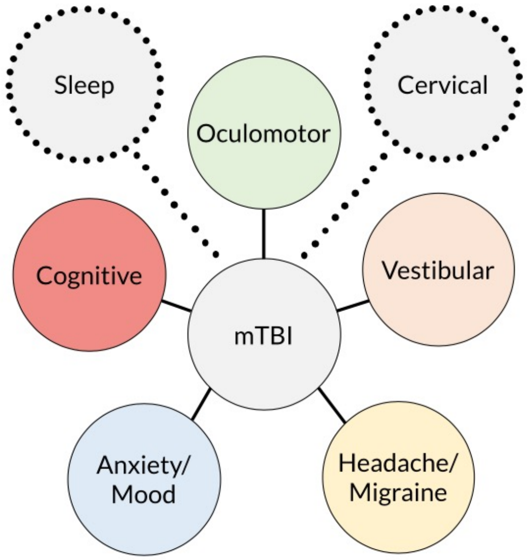
Fino, et al., 2017; Dozza et al, 2005; Campbell et al., frontiers neurol 2022

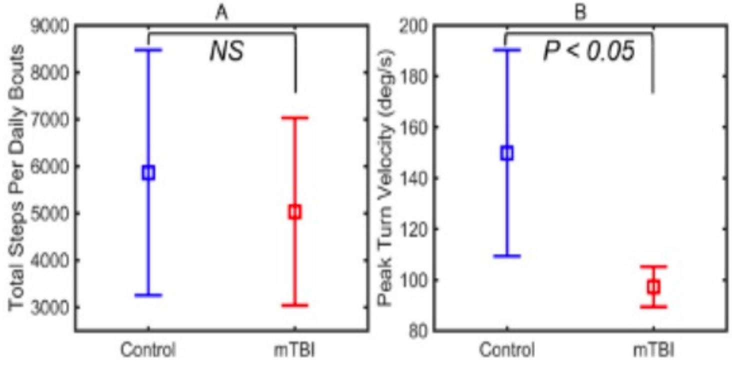


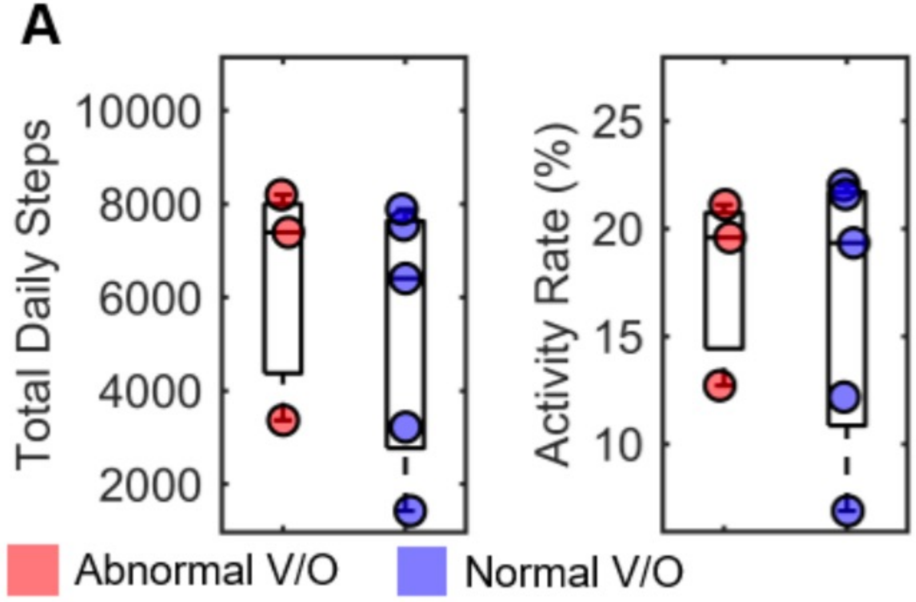
Clinical Relevance: ABF may be supporting other mechanisms such as activation and latency of response

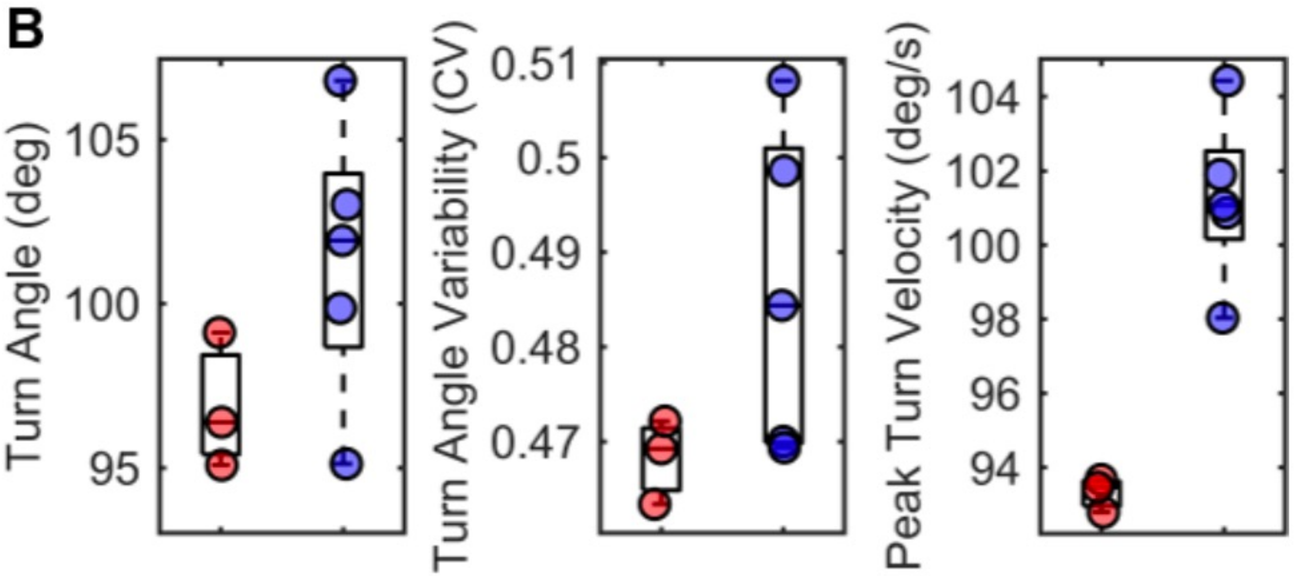
Campbell, Peterka, King Frontiers neurol 2022

NEXT STEPS: better and more objective measures to identify subtypes for more appropriate referrals









TP220395; Department of Defense: King PI)

Discussion/Conclusions

Changing landscape for mTBI rehabilitation care

- Need better (objective) outcome measures for comprehensive gait and balance including turning
- Central sensorimotor integration deficits versus peripheral vestibular and oculomotor deficits in chronic mTBI

  Latency and motor activation may be more impaired than sensory weighting/vestibular in people with mTBI;
  Rehabilitation implications
- Need better guidelines for non-athletes (i.e. older, neurologic conditions) after concussion
  - Early rehabilitation/activity
  - Subtypes of concussion

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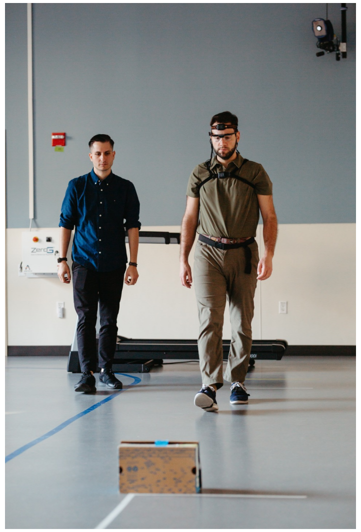

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Funding: This work was supported by the Assistant Secretary of Defense for Health Affairs under the following awards numbers: **W81XWH-17-1-0424; TP220395; W81XWH-15-1-0620; W81XWH-18-2-0049 (King PI).** Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the Department of Defense.