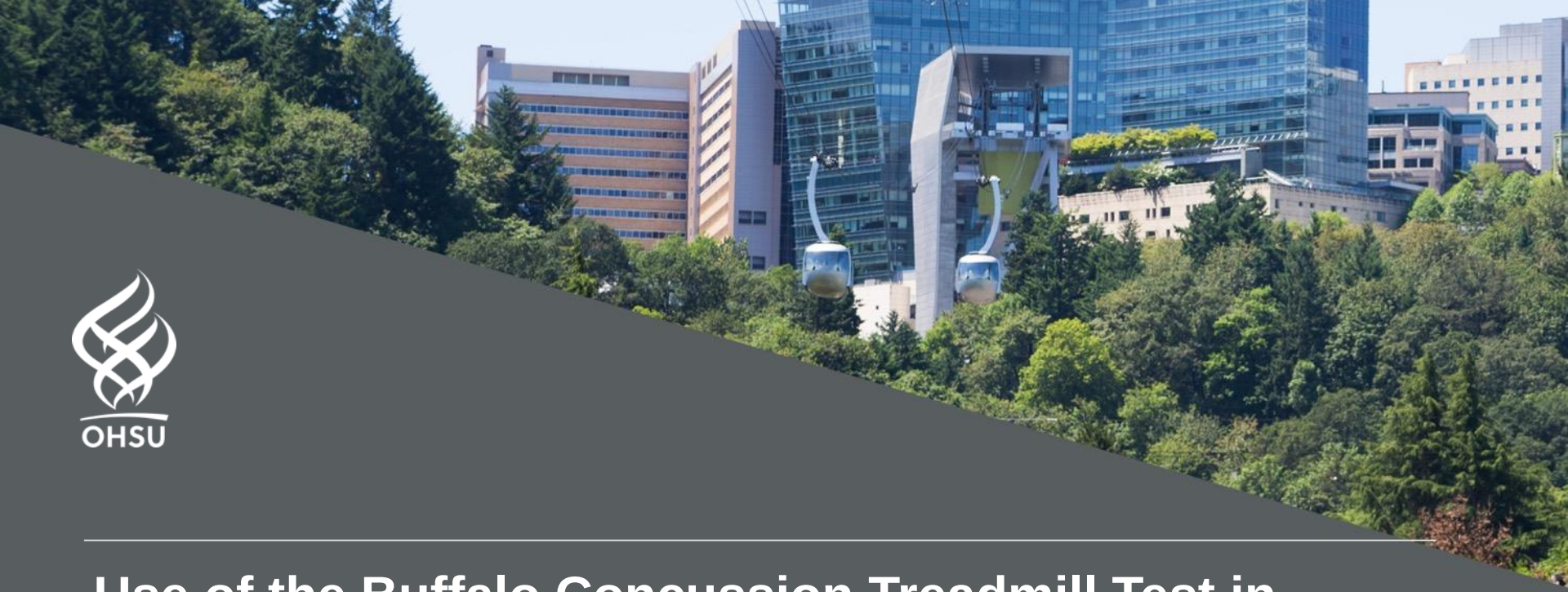
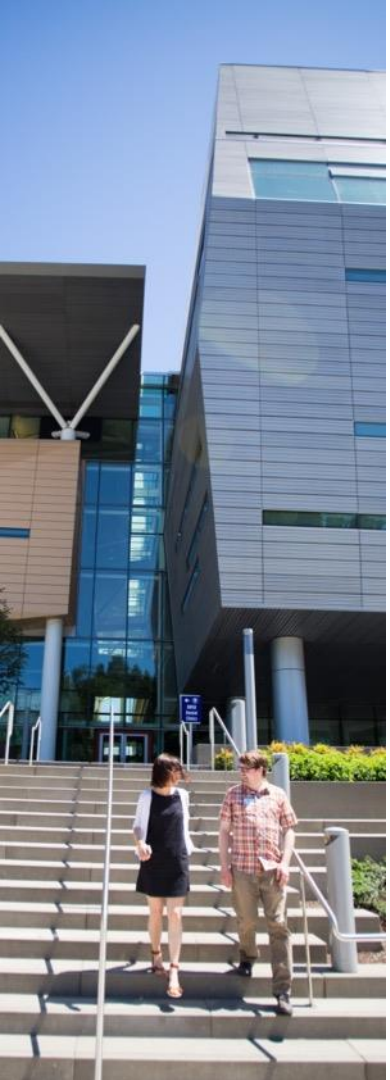


Use of the Buffalo Concussion Treadmill Test in Concussion (BCTT)

DATE: April, 14, 2023

PRESENTED BY: Jennifer L Wilhelm, PT, DPT, NCS



Disclosures

- I have no actual or potential conflicts of interest in relation to this program/presentation
- This work was supported by the Assistant Secretary of Defense for Health Affairs under Award No. W81XWH-15-1-0620 and W81XWH-17-1-0424
- Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the Department of Defense

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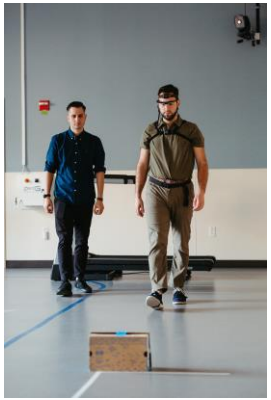
OHSU Balance Disorders Laboratory



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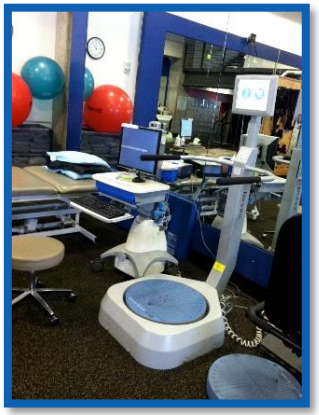

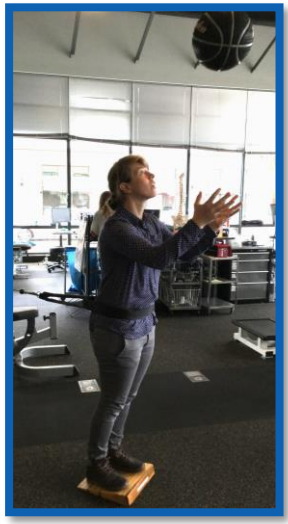

OREGON HEALTH & SCIENCE UNIVERSITY

Objectives

- Describe the Buffalo Concussion Treadmill Test
- Demonstrate appropriate technique while performing a BCTT
- Review 2-3 cases implementing the BCTT into a treatment program and outcomes of said testing and treatment.

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How many of your patients struggle trying to resume activity?

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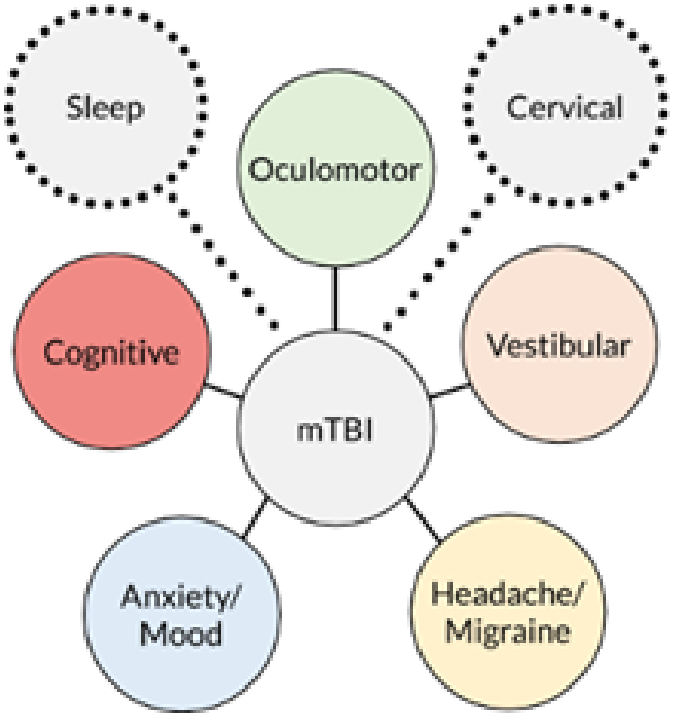
How many times have you given cardio to your patients to help them recover and they do not follow through?

Common Concussion Subtypes



?

Exercise intolerance

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Concussion-Related Exercise Intolerance

- Inability to exercise at/near age-appropriate max HR due to increase in symptoms
- Considered a physiological biomarker of concussion
- Origin of complete symptom resolution in prior concussion guidelines
- Prevalence: 40-100% of patients

Haider MN et al; Operative Techniques in Sports Medicine 2022; Galea O et al; J Head Trauma Rehabil 2022; Kozlowski et al; J Athl Train 2013

Is the neurometabolic crisis actually over after 10 days?

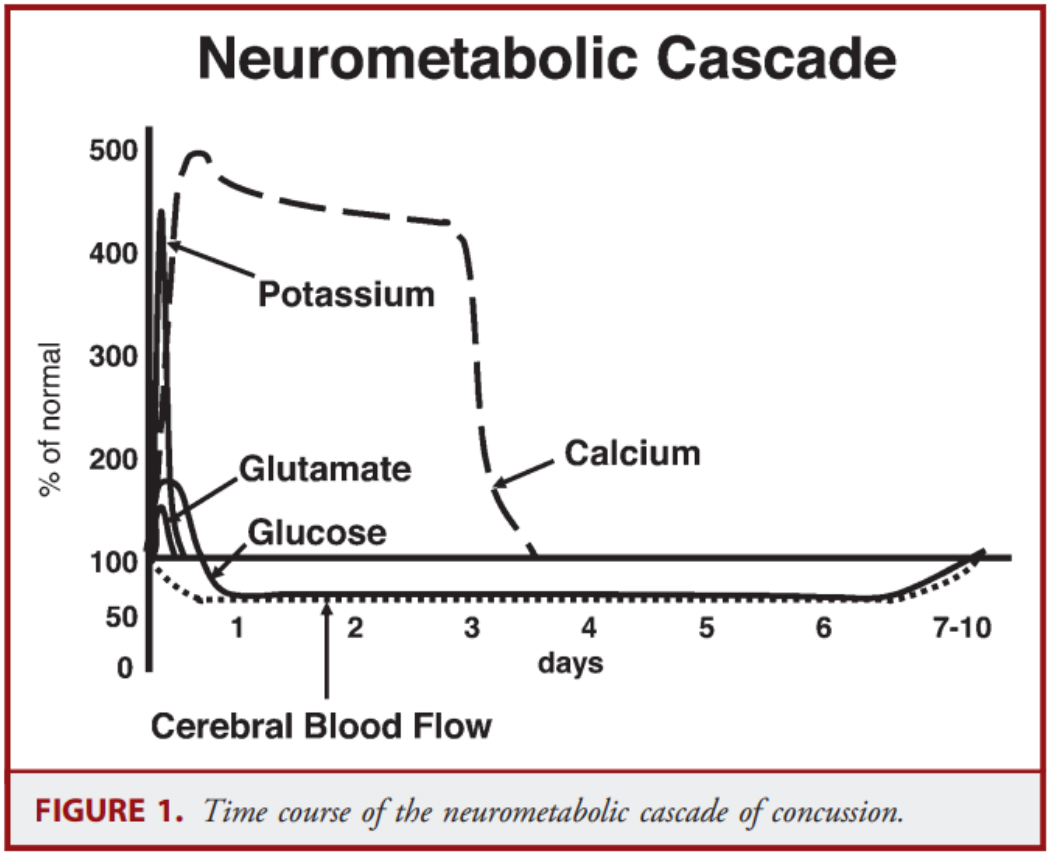

FIGURE 1. *Time course of the neurometabolic cascade of concussion.*

Giza CC and Hovda DA. Neurosurgery. 2014.

Summary of exercise intolerance

Symptoms

- Mild/Moderate pounding headache
- Dizziness, nausea, fatigue, light/sound sensitivity
- Difficulty with memory and concentration
- Symptoms increased with physical/cognitive activity

Post Concussion

- Altered autonomic functions
  - ↑ HR response to stress
  - ↑ Sympathetic/↓ Parasympathetic control
  - Inability to increase HR
  - May contribute to other ANS domains: sleep disturbances, orthostatic intolerance and anxiety
- Change in CBF regulation with change in BP that occurs with exercise

Giza 2014; Leddy 2007; Ellis 2018; Haider 2022

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5th International Conference on Concussion (2016)

"*There is currently insufficient evidence that prescribing complete rest achieves these objectives.* ***After a brief period of rest during the acute phase (24–48 hours) after injury, patients can be encouraged to become gradually and progressively more active while staying below their cognitive and physical symptom-exacerbation thresholds*** *(ie, activity level should not bring on or worsen their symptoms). It is reasonable for athletes to avoid vigorous exertion while they are recovering. The exact amount and duration of rest is not yet well defined in the literature and requires further study."*

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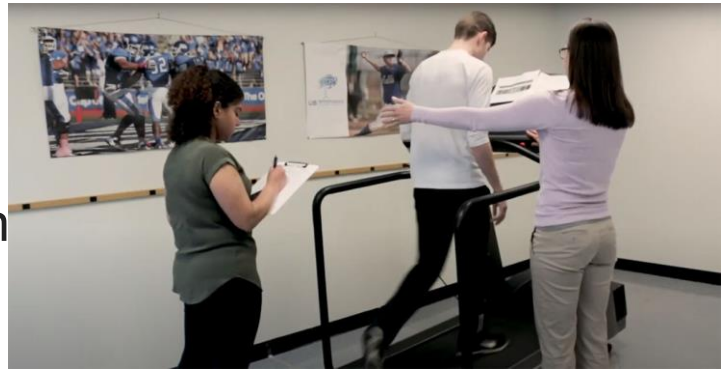
McCroy P et al; Br J Sports Med 2017

Buffalo Concussion Treadmill Test (Modified Balke protocol)

- Protocol
  - Graduated exercise test
  - Constant speed
  - Increased incline (↑ 1.0% incline every min
  - Assess:
    - Heart rate (HR)
    - Borg Rating of Perceived Exertion (RPE)
    - Symptoms



- Demonstrated to be safe within 5 days of sports related concussion
- High inter-rater reliability (95%) and sensitivity (99%)

Leddy et al., JAMA Pediatrics 2019; Leddy et al Clin J Sport Med 2018

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Aerobic Exercise: Buffalo Concussion Treadmill Test (BCTT)

- Protocol: Measure HR and RPE
  - Treadmill: 3.3 mph, 0.0% incline
  - Minute 2: 3.3 mph, 1.0% incline
  - Minute 3: 3.3 mph, 2.0% incline
  - Minute 4: 3.3 mph, 3.0% incline
  - Keep going: ↑ 1.0% incline every min until 15%
- Stopping criteria
  - Exercise intolerant: Symptomatic (≥ 3 points), patient request, or examiner notes decline in condition
  - Exercise tolerant: RPE ≥ 17 or 85% of age-predicted max HR

Leddy 2013; Baker 2012

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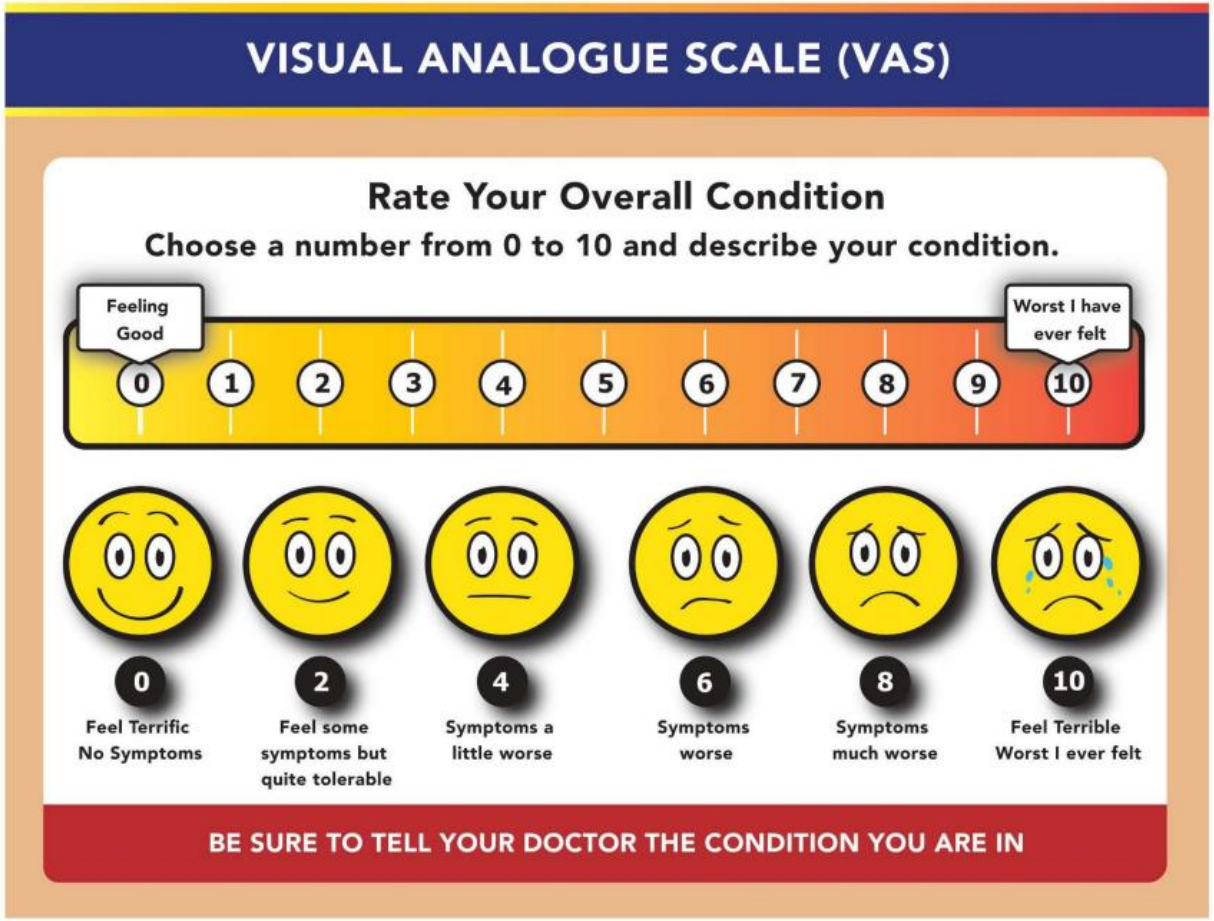

Bezherano I; Clin J Sport Med 2021

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Safety first!

Absolute Contraindications

- Acute myocardial infarction (within 2 days)
- High-risk unstable angina
- Uncontrolled cardiac arrhythmias causing symptoms or hemodynamic compromise
- Symptomatic severe aortic stenosis
- Uncontrolled symptomatic heart failure
- Acute pulmonary embolus or infarction
- Acute myocarditis or pericarditis
- Acute aortic dissection

Relative Contraindications

- Left main coronary stenosis
- Moderate stenotic valvular heart disease
- Electrolyte imbalance
- Severe arterial hypertension (>200 mmHg systolic or >110 mmHg diastolic)
- Tachyarrhythmia or bradyarrhythmia
- Hypertrophic cardiomyopathy and other forms of outflow tract obstruction
- Mental or physical impairment leading to inability to exercise adequately
- High-degree atrioventricular block

Not recommended

- < 24 hours of mTBI
- High symptoms (≥7/10)

Bezherano I; Clin J Sport Med 2021

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BCTT Considerations

- Patient should be dressed for exercise
- Dr. Leddy suggests 2 people for assessment: 1 person behind treadmill for safety
- Talk with your patient throughout the exam
  - Change in cognitive or communicating?
  - Helps determine RPE with breathing/talking
- Observe your patient
  - Slouching, leaning head, looking at floor
  - Pale
  - Pain
- Note symptoms with decrease in HR or “cool down”: do symptoms quickly subside (low irritability) or remain high (high irritability)?

Bezherano I; Clin J Sport Med 2021

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Videos of Buffalo Treadmill: Randy

*Courtesy of University of Buffalo and Dr John Leddy and Dr Barry Willer

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Videos of Buffalo Treadmill: Walter

*Courtesy of University of Buffalo and Dr John Leddy and Dr Barry Willer

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BCTT Changes in Protocol

- % of Heart Rate Max achieved (80-90%)
- Once 15% incline is achieved: 0.3 mph per minute
- Baseline speed (3.2-3.6 mph)
- Timeframe to perform BCTT
- Age
- Population

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BCTT: Adaptations for Clinic

Problem	Solution
I don’t have a treadmill or my patient can not tolerate walking	Bike, rowing machine
My patient has really high baseline symptoms	Use your judgement (<7/10 symptoms)
I do not have a good HR monitor	Borg scale 6-20 correlated with HR

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Buffalo Concussion Bike Test (BCBT)

- Recumbent or upright cycle ergometer
- Power output (Watt conversion table)
- Assess:
  - HR
  - RPE
  - Symptoms severity (VAS) rated **every 2 minutes**

Leddy et al. 2017

BCBT vs BCTT

- There is no significant difference between change in HR over 18 minutes of exercise on the BCBT and BCTT (p=0.112)
- The BCBT is perceived to be more difficult by patients
- Similar to BCTT, the BCBT is **not** recommended:
  - < 24 hours of mTBI
  - High symptoms (≥7/10)

Leddy et al. 2017

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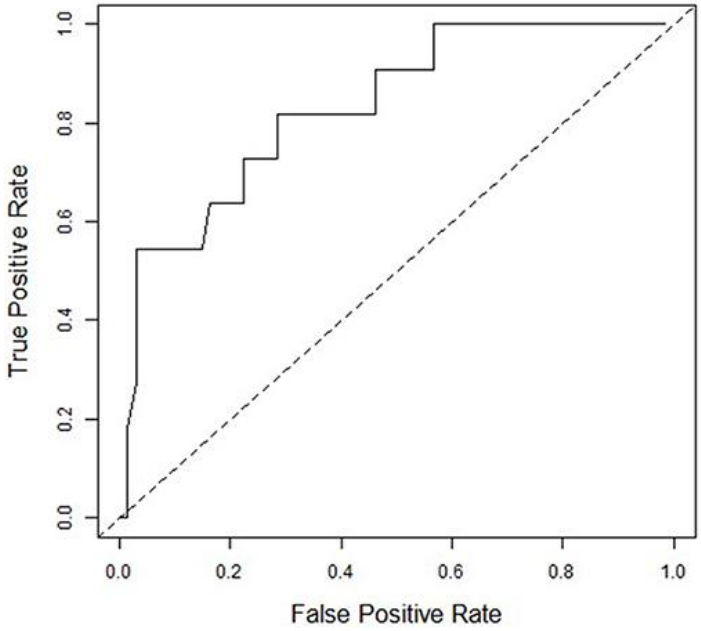
BCTT: Predictive of Delayed Recovery?

	Rest Group ($n = 27$)		p-value
	Developed PPCS ($n = 4$)	Normal Recovery ($n = 23$)	
Mean ΔHR[a] (bpm)	35.25 ± 9.5	75.57 ± 26.4	**0.01**
	Placebo Group ($n = 51$)		
	Developed PPCS ($n = 7$)	Normal Recovery ($n = 44$)	
Mean ΔHR (bpm)	43.43 ± 20.5	63.73 ± 20.9	**0.04**

a Heart rate difference, PPCS > 30 days recovery duration, normal recovery ≤ 30 days recovery duration.



ΔHR of ≤ 50 bpm in placebo and rest groups predictive of delayed (> 30 days) recovery:

- 73% sensitive
- 78% specific

Haider et al; Front Neurol 2019

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Treatment

We now have an idea of how to assess exercise intolerance: how do we improve our patient's ability to exercise without symptoms?

Treatment

You can perform aerobic exercise how you want (i.e. walking, jogging, stationary cycling), but it is important to avoid a lot of neck motion during exercise. Exercise should include a warm-up, minimum of 20 minutes at the prescribed heart rate, and then a cool-down.

It is very important that you only exercise according to your prescription, and that you follow the instructions given by your doctor very carefully. Even if you start to feel better while you are at home, you should not change the heart rate at which you are exercising until you have seen your doctor again. Each clinical visit, your doctor will see how you are doing and provide a new exercise prescription if you have no

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When to stop?

If you experience an increase in your current symptoms (by 2 points on a 0-10 scale) or onset of two new symptoms of concussion while exercising at home and cannot continue, please stop for that day and try again the following day. If you experience a prolonged or severe increase of your concussion-related symptoms during exercise, then do not perform the prescribed exercises and contact your doctor.

Bezherano I; Clin J Sport Med 2021

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Treatment

- Home exercise program: Cardio
  - 90% of HR from BCTT
  - STOP if increase > 2 points from baseline
  - Reassess every 2-3 weeks to establish a new target HR
  - HR Progression:
    - Athletes: 10 BPM every 1-2 weeks
    - Non-athletic: 5 BPM every 2 wks

Davenport 2022; Health Serv Insights

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Graded RTP can safely occur before resolution of symptoms

Frequency of Top 10 symptoms at Initiation of Graded RTP

Symptom	%
Headache	18.7
Pressure in head	14.0
Fatigue	11.8
Neck pain	10.7
Trouble concentrating	9.1
Don’t feel right	8.0
Feeling Drowsy	7.0
Feeling slowed down	6.8
Light sensitivity	6.4
Trouble falling asleep	6.0

Symptom Score	N (%)	Graded RTP Initiation post injury Mean (SD)	Total time RTP Mean (SD)
0-5	1378 (90.0)	8.9 (9.4)	16.9 (14.5)
6-10	76 (5.0)	9.2 (8.9)	17.5 (15.4)
11-20	42 (3.0)	7.3 (8.3)	17.9 (16.3)
≥ 21	35 (2.0)	5.2 (5.2)	17.7 (11.4)

Brett 2020; AJSM

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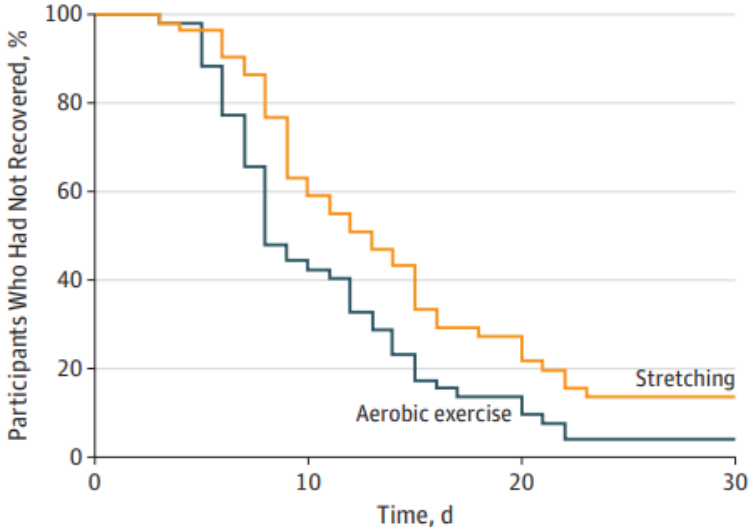
Prescribed subsymptom threshold aerobic exercise 48 hr post SRC can safely and significantly speed recovery

Figure 2. Kaplan-Meier Estimates of Time to Recovery

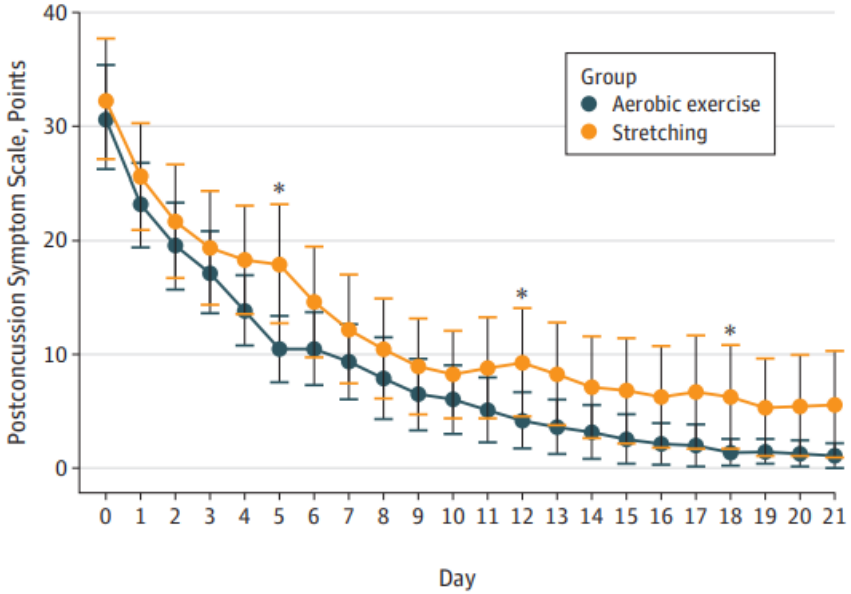


No. at risk

Aerobic exercise	52	23	7	2
Stretching	51	32	14	7

Delayed recovery

Figure 3. Daily Symptom Severity Score per the Postconcussion Symptom Scale



Bars indicate 95% CIs; asterisks, a significant difference on analysis of variance.

Leddy et al; JAMA Pediatrics 2019

Treatment: Adaptations

Problem	Solution
The patient doesn't have a treadmill	Bike, rowing machine, over ground walking; avoid strength training initially
My patient has really high baseline symptoms	Use your judgement (<7/10 symptoms)
My patient doesn't have a HR monitor	Borg scale 6-20 correlated with HR
My patient failed quickly and has low HR threshold	Don't get lost in the numbers: start with gentle exercise. Consider Levine or CHOP protocol
My patient isn't improving	Keep them moving but think about other systems (HA, vestibular, etc)

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And then.... Progression of athlete post BCTT

- Push ups x 30
- Sit ups x 30
- Jumping jacks x 3 min
- Up/downs or Burpees x 30
- Squat jumps x 30
- Wall sit x 2 min + cognitive
- 1 mile run
- Sport specific drills!

Clinical application of BCTT

- Data collection from larger RCT on subacute mTBI looking at timing of rehabilitation
- All subjects still endorsed symptoms and performed BCTT both before and after rehabilitation


Protocols

The Sensor Technology and Rehabilitative Timing (START) Protocol: A Randomized Controlled Trial for the Rehabilitation of Mild Traumatic Brain Injury

Lucy Parrington, Deborah A. Jehu, Peter C. Fino, Samuel Stuart, Jennifer Wilhelm, Natalie Pettigrew, Charles F. Murchison, Mahmoud El-Gohary, Jess VanDerwalker, Sean Pearson, Timothy Hullar, James C. Chesnutt, Robert J. Peterka, Fay B. Horak, Laurie A. King

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

Exercise intolerance in people with subacute mTBI using the BCTT

	Exercise tolerant (n = 37)	Exercise intolerant (n = 41)	Group difference p value
Age (years)	37.5 (11)	38.62 (10.92)	0.07
Height (m)	1.68 (0.09)	1.67 (0.09)	0.61
Mass (kg)	71.60 (17.21)	69.33 (14.24)	0.52
Sex (M/F/Other)	7 M / 30 F	6 M / 33 F / 2 Other	
BMI	25.2 (5.6)	24.8 (11.2)	0.74
NSI Total Score (out of 88)	31.7 (12.9)	38.5 (16.4)	0.04
Days Since Injury	75.5 (33.3)	73.9 (29.8)	0.67
Overall Recovery (0-100)	65.14 (20.67)	59.76 (23.07)	0.29
Exercise Recovery (0-100)	51.62 (26.56)	41.24 (29.72)	0.12
Injury Mechanism (N and Percent)			
Bike	2 (5.41%)	3 (7.32%)	
Fall	7 (18.92%)	9 (21.95%)	
Motor Vehicle Accident	14 (37.84%)	12 (29.27%)	
Sport	8 (21.62%)	7 (17.07%)	
Other	6 (16.22%)	10 (24.39%)	

Means and standard deviations are presented unless noted otherwise for injury mechanism.
Independent T-test was used for testing group differences
Abbreviations: BMI: Body mass index; NSI: Neurobehavioral Symptom Inventory

Antonellis, P., Campbell, K.R., Wilhelm, J.L., Shaw, J.D., Chesnutt, J.C., & King, L.A. Exercise intolerance after mild traumatic brain injury occurs in all subtypes. The American Journal of Sports Medicine (in review)

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

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Exploring performance measures on the BCTT

	Exercise tolerant (n = 37)	Exercise intolerant (n = 41)	Group difference p value
BCTT Outcomes			
Resting HR (BPM)	74.75 (17.66)	81.61 (11.37)	0.048
HR Achieved (%)	81.03 (0.08)	67.07 (0.09)	< 0.001
RPE	15.78 (1.70)	13.08 (2.13)	< 0.001
Pre Symptoms	3.59 (3.18)	4.90 (3.44)	0.043
Post Symptoms	3.73 (3.48)	8.20 (3.57)	< 0.001
Change in Symptoms	0.14 (1.60)	3.29 (0.78)	< 0.001
Duration (minutes)	10.92 (3.19)	6.56 (2.61)	< 0.001

Means and standard deviations are presented unless noted otherwise for injury mechanism.
T-test was used for testing group differences
Abbreviations: BCTT: Buffalo Concussion Treadmill Test, HR: Heart rate, RPE: Borg Rate of Perceived Exertion

Antonellis, P., Campbell, K.R., Wilhelm, J.L., Shaw, J.D., Chesnutt, J.C., & King, L.A. Exercise intolerance after mild traumatic brain injury occurs in all subtypes. The American Journal of Sports Medicine (in review)

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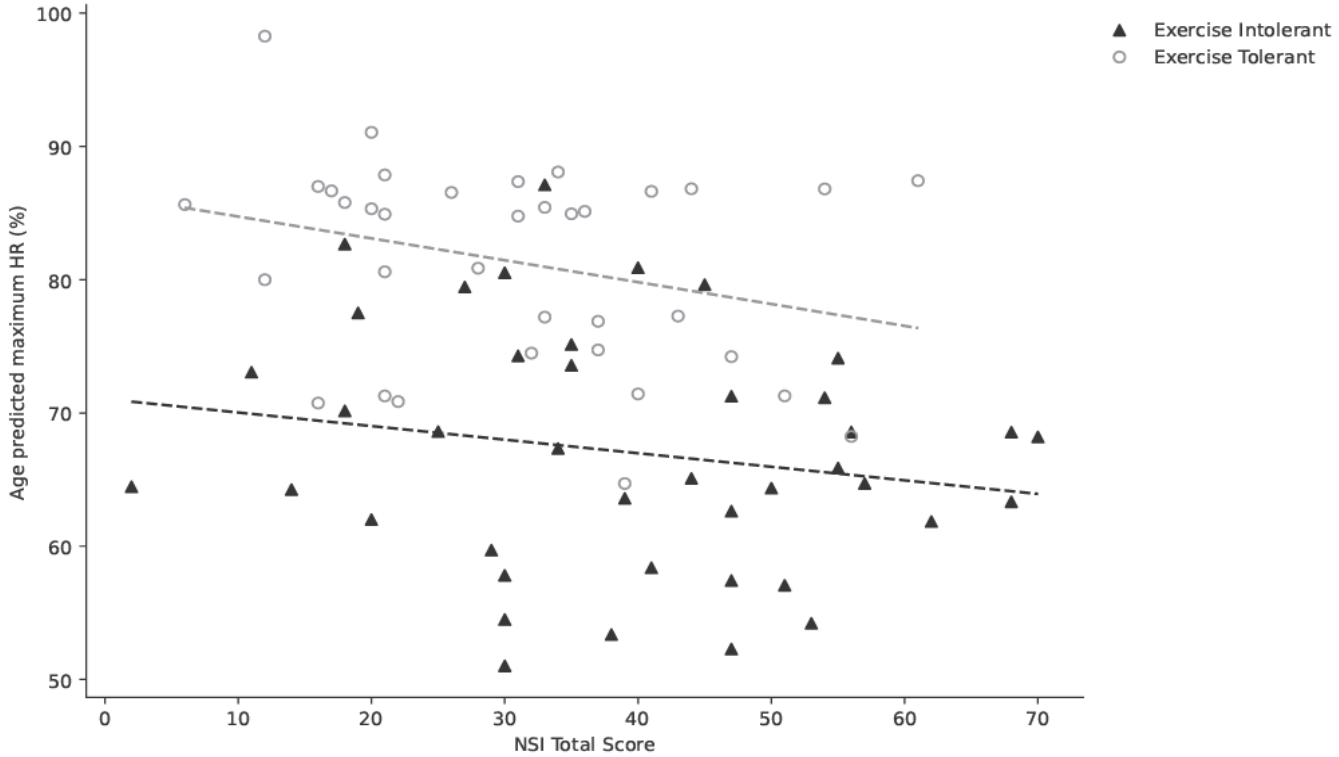
Global mTBI symptom score and %HRMax were not correlated in both exercise tolerant and intolerant group



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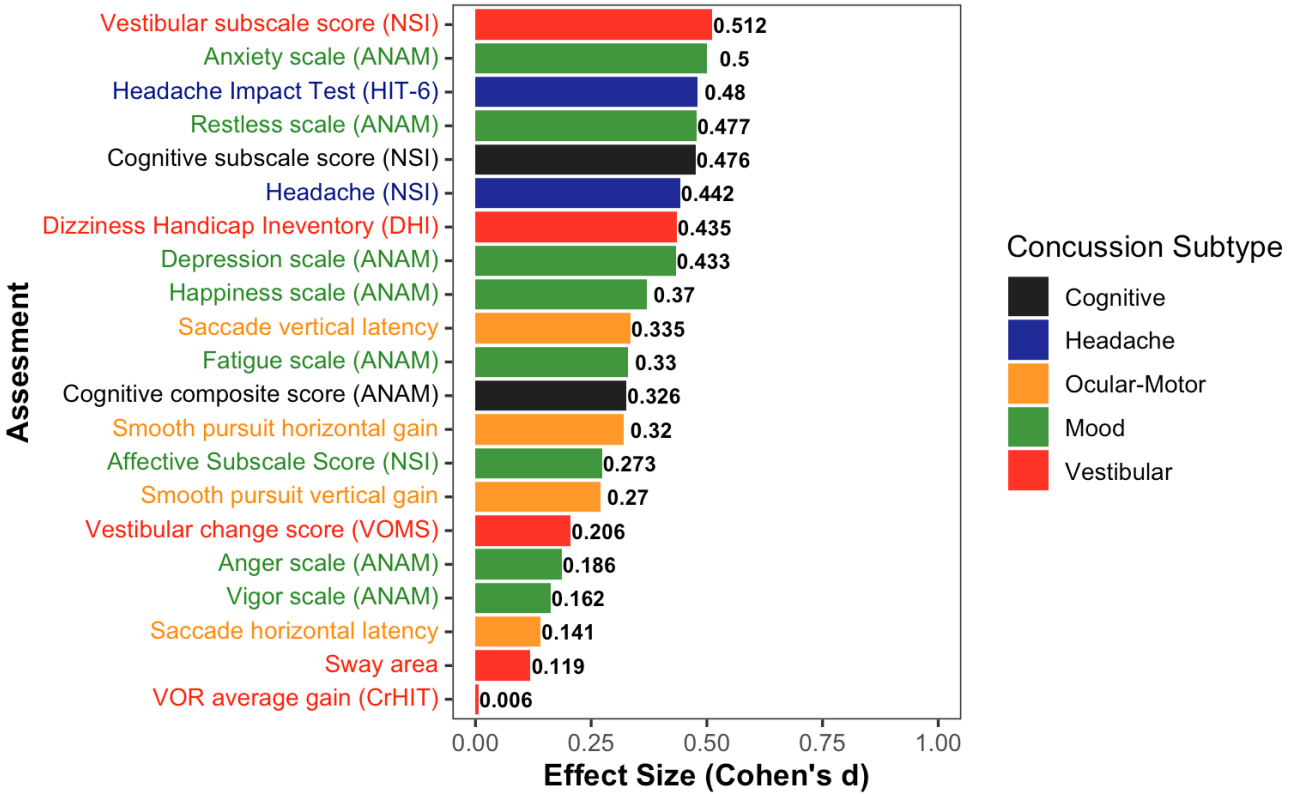
Effect size calculations between exercise tolerant and exercise intolerant groups showed no pattern across subtypes



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

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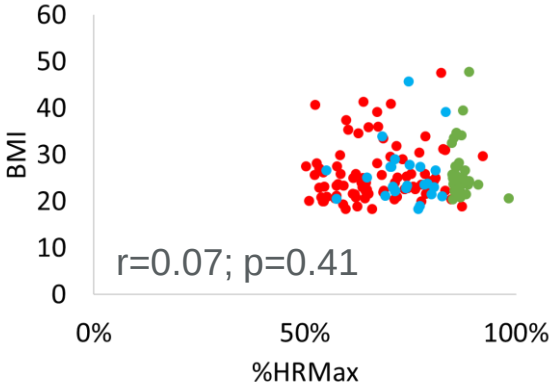
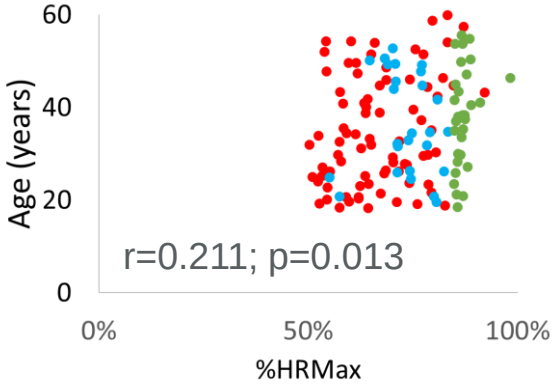
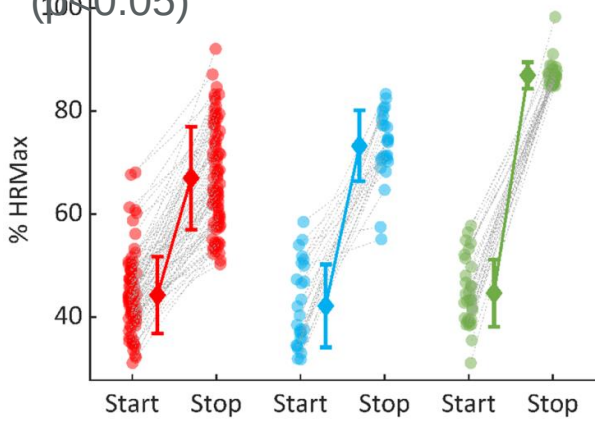
Exploring Exercise Intolerance

Demographics: There is no relationship between %HR Max and BMI and a negligible relationship between %HR Max and Age





Performance: Participants who failed the BCTT had a flatter HR response from start to stop than those who passed the BCTT ($p<0.05$)



≥3 symptoms

≥17 on Borg

≥85% HR Max

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Case Studies

An example: Collegiate football player (offensive line)

	Week 1 (10/17)
Rest	HR 92/HA 0/ Dizzy 0
3.6 mph, 0% x 2’	HR 107/HA 2/ Dizzy 0
3.6 mph, 2% x 1’	HR 120/HA 4/ Dizzy 1
3.6 mph, 3% x 1’	
3.6 mph, 4% x 1’	
3.6 mph, 5% x 1’	
3.6 mph, 6% x 1’	
3.6 mph, 7% x 1’	
3.6 mph, 8% x 1’	
3.6 mph, 9% x 1’	
3.6 mph, 10% x 1’	
3.6 mph, 11% x 1’	
3.6 mph, 12% x 1’	
3.6 mph, 13% x 1’	
3.6 mph, 14% x 1’	
3.6 mph, 15% x 1’	

*MaxHR=220-20; 85%=187 bpm

- 20 yo Male
- Football injury 9/13
- Reporting symptoms:
- Inability to exercise
- Dizziness or “light headedness” (4/10): increased with aerobic exercise
- Headaches (crown of forehead): increased with bright lights, noises and aerobic exercise
- C-spine: WNL for all ROM but reported “fogginess” and “head pressure” with testing
- Balance: mBESS 9/30
- VOMS: convergence was abnormal; VOR horizontal and VMS increased symptoms
- HEP: light cardio, pencil push ups, VOR horizontal and VMS

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An example: Collegiate football player (offensive line)

	Week 1 (10/17)	Week 2 (10/24)	Week 4 (11/6)
Rest	HR 92/HA 0/ Dizzy 0	HR 93/HA 0/ Dizzy 0	HR 98/HA 0/ Dizzy 0
3.6 mph, 0% x 2’	HR 107/HA 2/ Dizzy 0	HR 110/HA 0/ Dizzy 0	HR 101/HA 0/ Dizzy 0
3.6 mph, 2% x 1’	HR 120/HA 4/ Dizzy 1	HR 116/HA 0/ Dizzy 0	HR 104/HA 0/ Dizzy 1
3.6 mph, 3% x 1’		HR 127/HA 0/ Dizzy 0	HR 109/HA 0/ Dizzy 1
3.6 mph, 4% x 1’		HR 137/HA 0/ Dizzy 0	HR 116/HA 0/ Dizzy 0
3.6 mph, 5% x 1’		HR 146/HA 0/ Dizzy 0	HR 128/HA 0/ Dizzy 0
3.6 mph, 6% x 1’		HR 151/HA 0/ Dizzy 0	HR 139/HA 0/ Dizzy 0
3.6 mph, 7% x 1’		HR 156/HA 0/ Dizzy 0	HR 147/HA 0/ Dizzy 0
3.6 mph, 8% x 1’		HR 165/HA 0/ Dizzy 0	HR 152/HA 0/ Dizzy 0
3.6 mph, 9% x 1’		HR 177/HA 0/ Dizzy 0	HR 155/HA 0/ Dizzy 0
3.6 mph, 10% x 1’		HR 187/HA 0/ Dizzy 0	HR 159/HA 0/ Dizzy 0
3.6 mph, 11% x 1’			HR 160/HA 0/ Dizzy 0
3.6 mph, 12% x 1’			HR 169/HA 0/ Dizzy 0
3.6 mph, 13% x 1’			HR 170/HA 0/ Dizzy 0
3.6 mph, 14% x 1’			HR 181/HA 0/ Dizzy 0
3.6 mph, 15% x 1’			HR 185/HA 0/ Dizzy 0

Subsequent PT visits:

- Week 2: progression of visual-vestibular, added low weights, modified cardio to bike
- Week 3: dynamic VOR exercises, up/down otilth challenges, agility drills
- Week 4:
  - mBESS: 2/30
  - VOMS: convergence normal; no symptoms on testing
  - Discussion of RTP

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An example: Collegiate football player (offensive line)

	Week 1 (10/17)	Week 2 (10/24)	Week 4 (11/6)
Rest	HR 92/HA 0/ Dizzy 0	HR 93/HA 0/ Dizzy 0	HR 98/HA 0/ Dizzy 0
3.6 mph, 0% x 2’	HR 107/HA 2/ Dizzy 0	HR 110/HA 0/ Dizzy 0	HR 101/HA 0/ Dizzy 0
3.6 mph, 2% x 1’	HR 120/HA 4/ Dizzy 1	HR 116/HA 0/ Dizzy 0	HR 104/HA 0/ Dizzy 1
3.6 mph, 3% x 1’		HR 127/HA 0/ Dizzy 0	HR 109/HA 0/ Dizzy 1
3.6 mph, 4% x 1’		HR 137/HA 0/ Dizzy 0	HR 116/HA 0/ Dizzy 0
3.6 mph, 5% x 1’		HR 146/HA 0/ Dizzy 0	HR 128/HA 0/ Dizzy 0
3.6 mph, 6% x 1’		HR 151/HA 0/ Dizzy 0	HR 139/HA 0/ Dizzy 0
3.6 mph, 7% x 1’		HR 156/HA 0/ Dizzy 0	HR 147/HA 0/ Dizzy 0
3.6 mph, 8% x 1’		HR 165/HA 0/ Dizzy 0	HR 152/HA 0/ Dizzy 0
3.6 mph, 9% x 1’		HR 177/HA 0/ Dizzy 0	HR 155/HA 0/ Dizzy 0
3.6 mph, 10% x 1’		HR 187/HA 0/ Dizzy 0	HR 159/HA 0/ Dizzy 0
3.6 mph, 11% x 1’			HR 160/HA 0/ Dizzy 0
3.6 mph, 12% x 1’			HR 169/HA 0/ Dizzy 0
3.6 mph, 13% x 1’			HR 170/HA 0/ Dizzy 0
3.6 mph, 14% x 1’			HR 181/HA 0/ Dizzy 0
3.6 mph, 15% x 1’			HR 185/HA 0/ Dizzy 0

Following April: R ankle injury: deltoid ligament injury and proximal fibular shaft fracture; ended up surgery for stabilization… **was he really ready for RTP?**

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Modification of Speed: A successful case

- 20 yo F; MOI: "walked into doorframe" 7/10/21
  - Prior activity: Full time student, working retail part-time. Lifting weights, walks: 5-6 times/week for 30-60 min
  - Comorbidities: history of depression, 1 prior concussion (2015)
  - Rehab 1: Overall: 80% recovered; 60% for exercise
    - Neck pain 2/10, ROM normal
    - Oculomotor issues: symptomatic with smooth pursuit and saccades
    - DVA: normal but dizziness
    - Dynamic balance: symptomatic

	Speed (mph)		Incline	HR/Borg		Symptoms	
	Start	Stop	Stop	Start	Stop	Start	Stop
Rehab 1 8/10/21	2.8	2.8	5%	HR 95 Borg 6	HR 124 Borg 10	HA 4 Dizzy 0	HA 6 Dizzy 1

*MaxHR=220-20; 85%=170 bpm

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

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Modification of Speed: A successful case

- Rehab progression:
  - Rehab 1: Overall: 80% recovered; 60% for exercise
  - Rehab visits: Attended 8/8 visits
    - Neck: manual, JPE and strength/motor control
    - Cardio: progressed speed and incline each rehab
    - Oculomotor issues: improved but still symptomatic after rehab
    - DVA and dynamic balance: improved to doing without symptoms
  - Rehab 8: Overall: 95% recovered; 85% for exercise

	Speed (mph)		Incline	HR/Borg		Symptoms		
	Start	Stop	Stop	Start	Stop	Start	Stop	
Rehab 1 8/10/21	2.8	2.8	5%	HR 95 Borg 6	HR 124 Borg 10	HA 4 Dizzy 0	HA 6 Dizzy 1	
Rehab 8 9/16/21	3.6	3.6	12%	HR 100 Borg 6	HR 170 Borg 14	HA 0 Dizzy 0	HA 0 Dizzy 0	

*MaxHR=220-20; 85%=170 bpm

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

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BCTT on older adult: moderate success

- 57 yo F, MOI: "hit head on washing machine" 1/8/22
  - Prior activity: Business owner (online consulting), Taekwondo 4x/wk, weight lifting, dog walks daily
  - Comorbidities: Migraines, anxiety, history of ADHD and motion sickness
  - Rehab 1: Overall: 65% recovered; 60% for exercise
    - Neck pain 6/10, ROM limited in all planes
    - Oculomotor issues: symptomatic with saccades
    - DVA: normal but significant dizziness
    - Dynamic balance: symptomatic (dizzy and nausea)

	Speed (mph)		Incline	HR/Borg		Symptoms	
	Start	Stop	Stop	Start	Stop	Start	Stop
Rehab 1 4/1/22	2.3	2.3	4%	HR 111 Borg 6	HR 142 Borg 14	HA 2 Dizzy 3 Nausea 1	HA 4 Dizzy 4 Nausea 1

*MaxHR=220-57; 85%=139 bpm

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

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BCTT on older adult: moderate success

- Rehab progression:
  - Rehab 1: Overall: 65% recovered; 60% for exercise
  - Rehab visits: Attended 8/8 visits
    - Neck: manual, foam roller stretching and strength/motor control
    - Cardio: progressed speed and incline each rehab
    - Oculomotor issues: still symptomatic after rehab, started OT and SLP
    - DVA: normal but still symptomatic (less than initial)
    - Dynamic balance: still symptoms
  - Rehab 8: Overall: 65% recovered; 70% for exercise

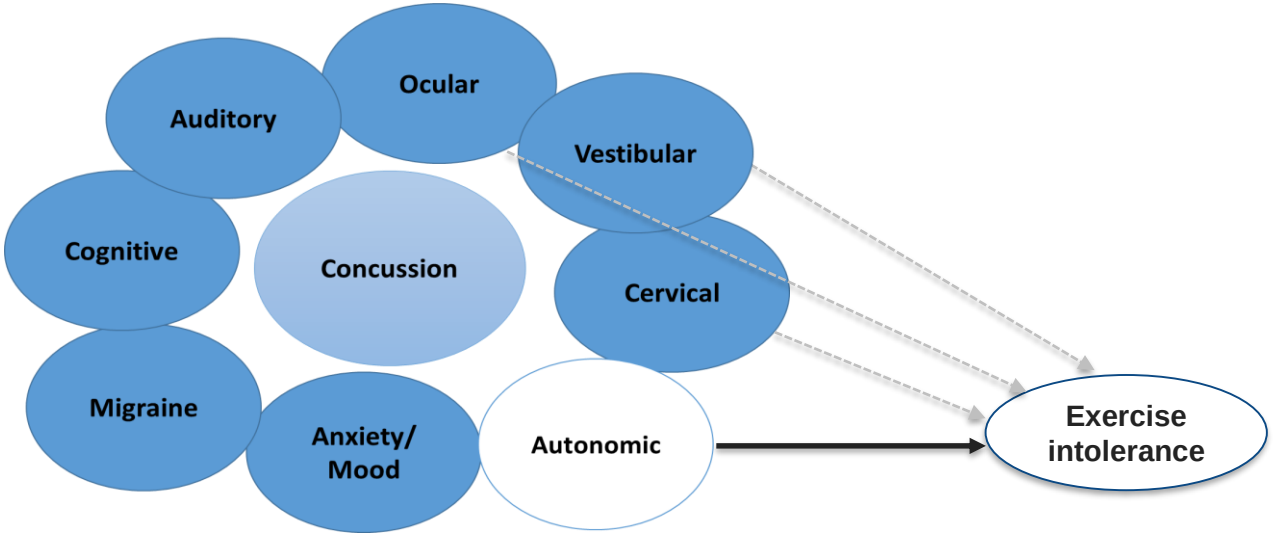
	Speed (mph)		Incline	HR/Borg		Symptoms		
	Start	Stop	Stop	Start	Stop	Start	Stop	
Rehab 1 4/1/22	2.3	2.3	4%	HR 111 Borg 6	HR 142 Borg 14	HA 2 Dizzy 3 Nausea 1	HA 4 Dizzy 4 Nausea 1	
Rehab 8 5/5/22	2.3	2.3	8%	HR 101 Borg 6	HR 141 Borg 14	HA 4 Dizzy 3 Nausea 1	HA 2 Dizzy 2 Nausea 1	

*MaxHR=220-57; 85%=139 bpm

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

How do we treat exercise intolerance?

- Could addressing multiple other mTBI symptoms help improve exercise intolerance?



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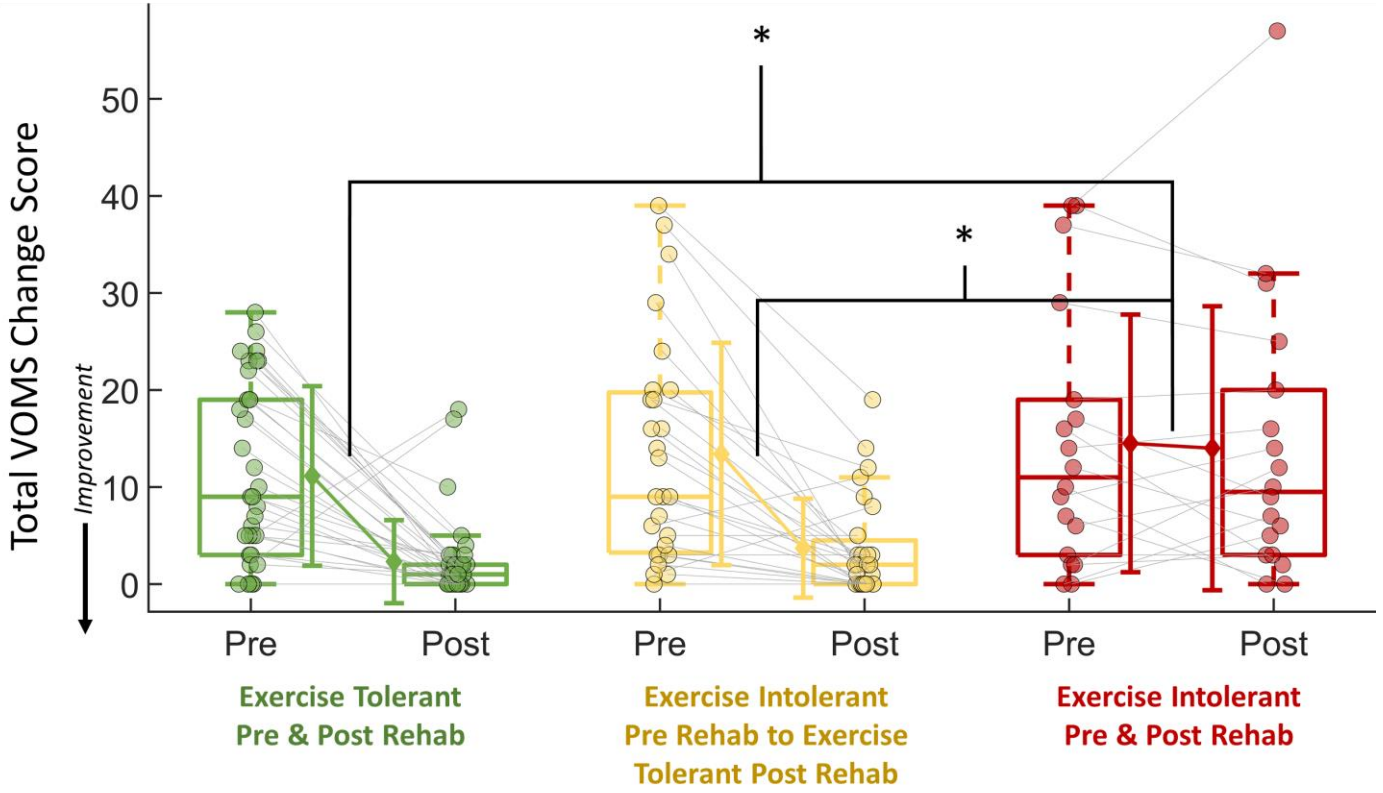
Participants with subacute mTBI who remain exercise intolerant after a rehabilitation also did not improve on VOMS testing



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Where are we?

What we know	What we don't know
Exercise intolerance is common after mTBI	Mechanism of what is causing exercise intolerance
Assessment is crucial as self report of exercise is not reliable and intolerance is widely spread across various subtypes	Role of dysautonomia or other mTBI deficits in exercise intolerance
Some people improve with graded aerobic exercise or a multi-modal rehab program	How do we successfully treat exercise intolerance
BCTT/BCBT is a valuable tool but only one aspect with RTP	When is it safe to return an athlete back to play? Is passing the BCTT enough?

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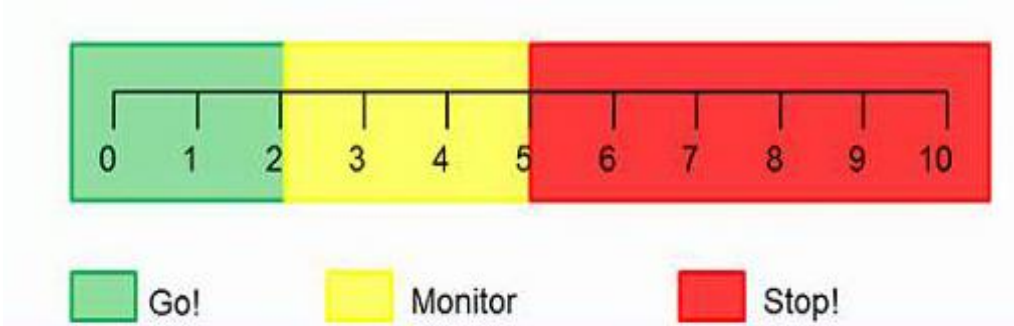
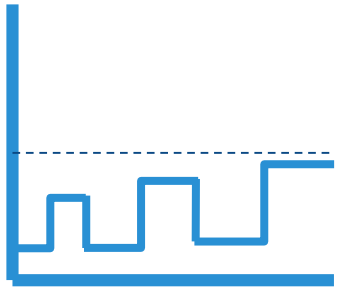
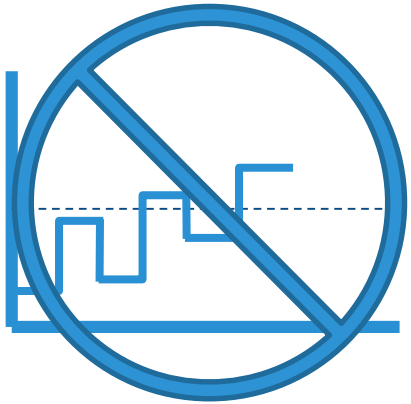
Key concepts

- Work below the threshold!
- Use the BCTT as assessment but also education tool on finding threshold







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Key concepts

- BCTT:
  - Useful biomarker for mTBI
  - Can be prognostic in determining protracted recovery
  - Helps determine exercise prescription to aid in recovery
- Don’t be afraid to assess your patients and get them moving after 24 hours of rest
- Slowly progress your patient
  - Realize there are inherent good and bad days with recovery
- Likely exercise intolerance is complex
  - Assess and treat other factors that are likely contributing to symptoms

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Thank You

Bonus slides

Stopping Criteria: Clinical Application

	≥3 symptoms (FAIL) (n = 82)	Borg ≥17/20 (PASS) (n = 26)	≥85% HRMax (PASS) (n =31)	Group difference p-value
Age (years)	35.5 (12.4)	37.0 (11.7)	38.0 (10.5)	0.59
Sex (M/F/Other)	14/65/3	7/19/0	5/26/0	
BMI	25.9 (6.1)	25.5 (6.1)	26.5 (6.1)	0.82
NSI Total Score	38.2 (15.0)	32.0 (14.0)	29.9 (11.8)	0.01
Days Since Injury	77.6 (28.9)	77.1 (29.9)	82.9 (35.4)	0.68
Injury Mechanism (N and Percent)				
MVA	28 (34%)	8 (31%)	11 (35%)	
Fall	19 (23%)	7 (27%)	4 (13%)	
Sport	13 (16%)	5 (19%)	6 (19%)	
Bike	3 (4%)	0 (0%)	3 (10%)	
Other	19 (23%)	6 (23%)	7 (23%)	

Means and standard deviations are presented unless noted otherwise for injury mechanism.

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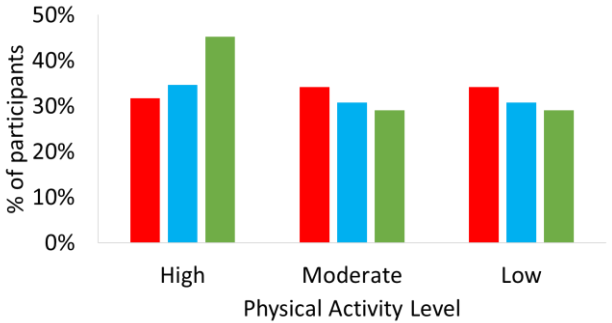
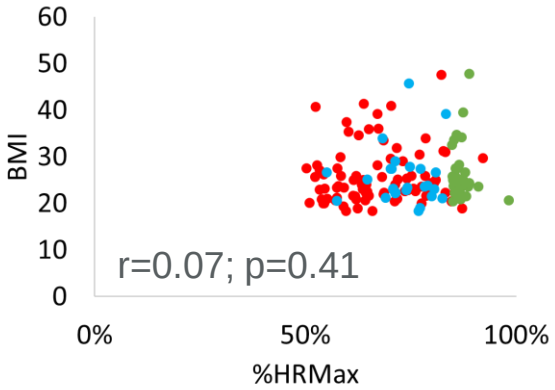
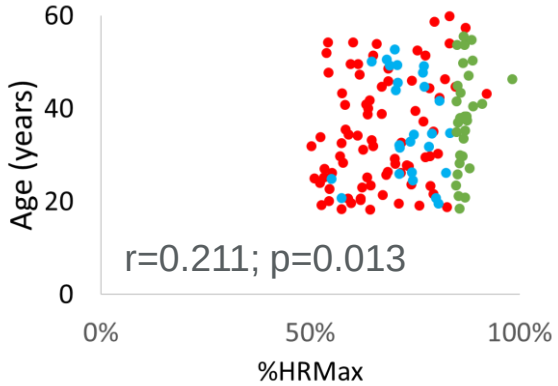
Demographic Differences in Exercise Intolerance

There was no difference in the % of exercise tolerance and intolerance according to activity levels (p>0.05)



There is no relationship between %HR Max and BMI and a negligible relationship between %HR Max and Age





≥3 symptoms

≥17 on Borg

≥85% HR Max

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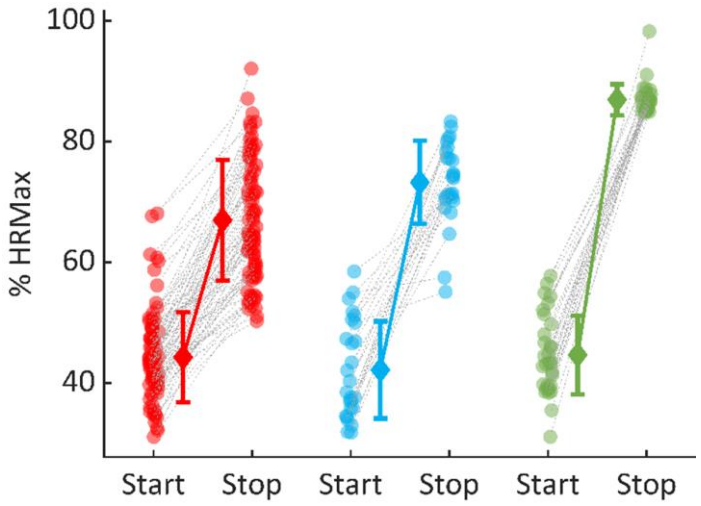
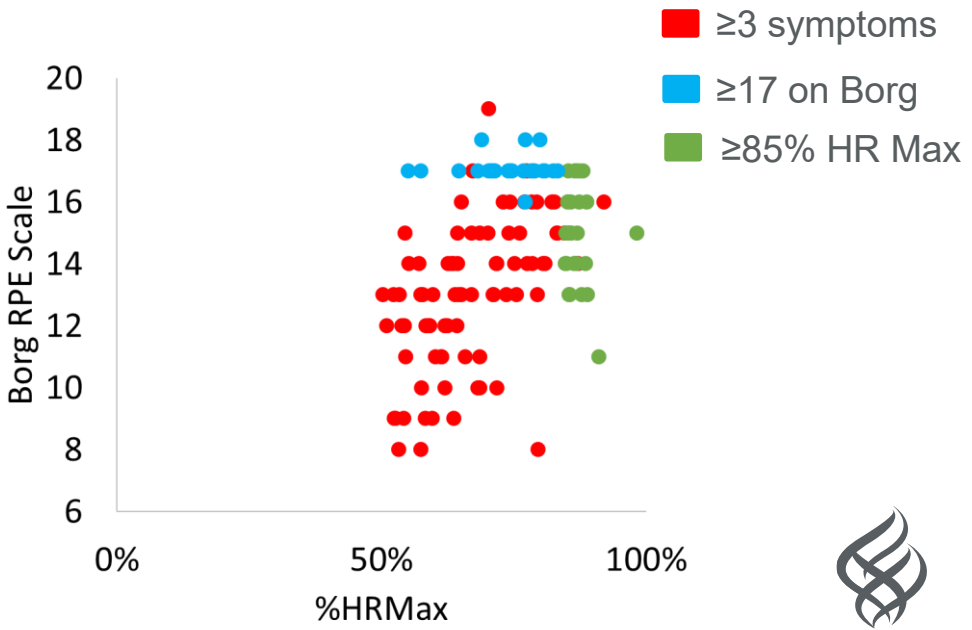
Exploring Exercise Intolerance

Participants who failed the BCTT had a flatter HR response from start to stop than those who passed the BCTT ($p<0.05$)



There is a weak relationship between RPE and %HR Max



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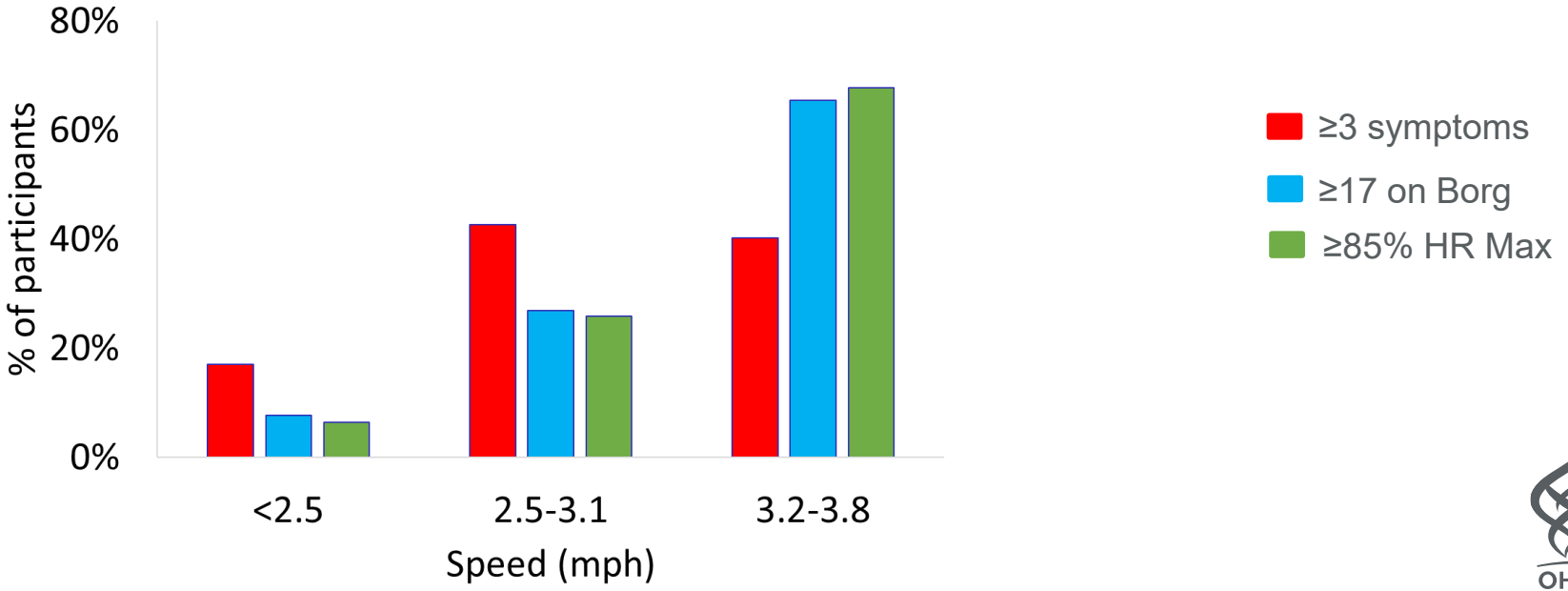
Modifications of BCTT

- Speed modifications across groups; there was no significant difference between the 3 groups ($p>0.05$).
- Speed was decreased from suggested 3.3-3.6 mph in 66% of the participants



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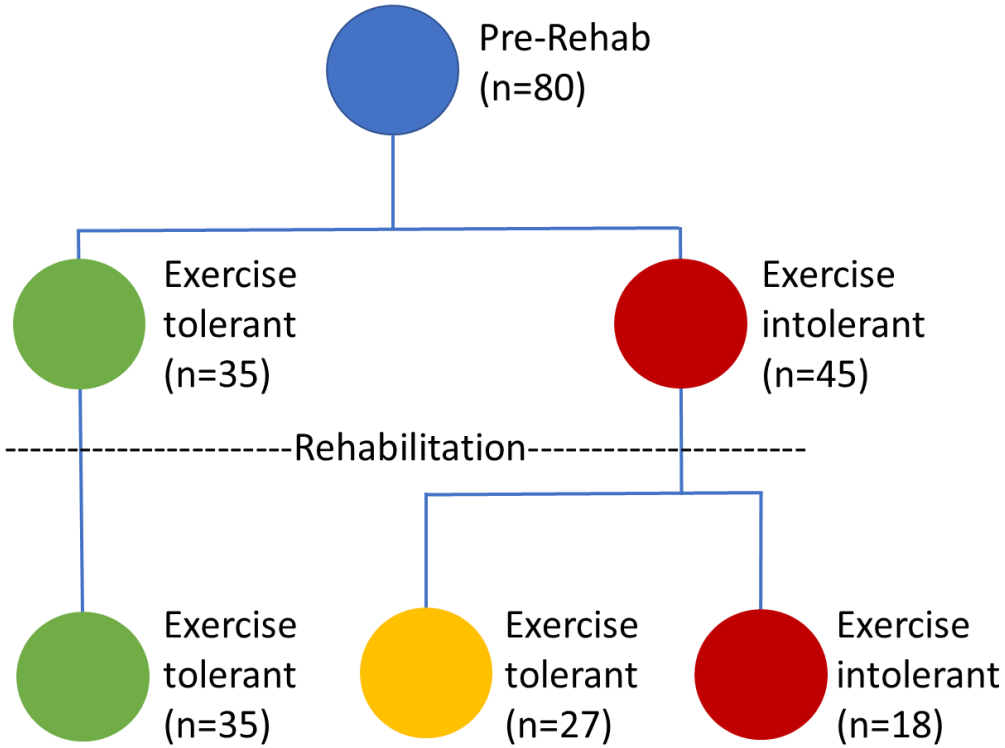
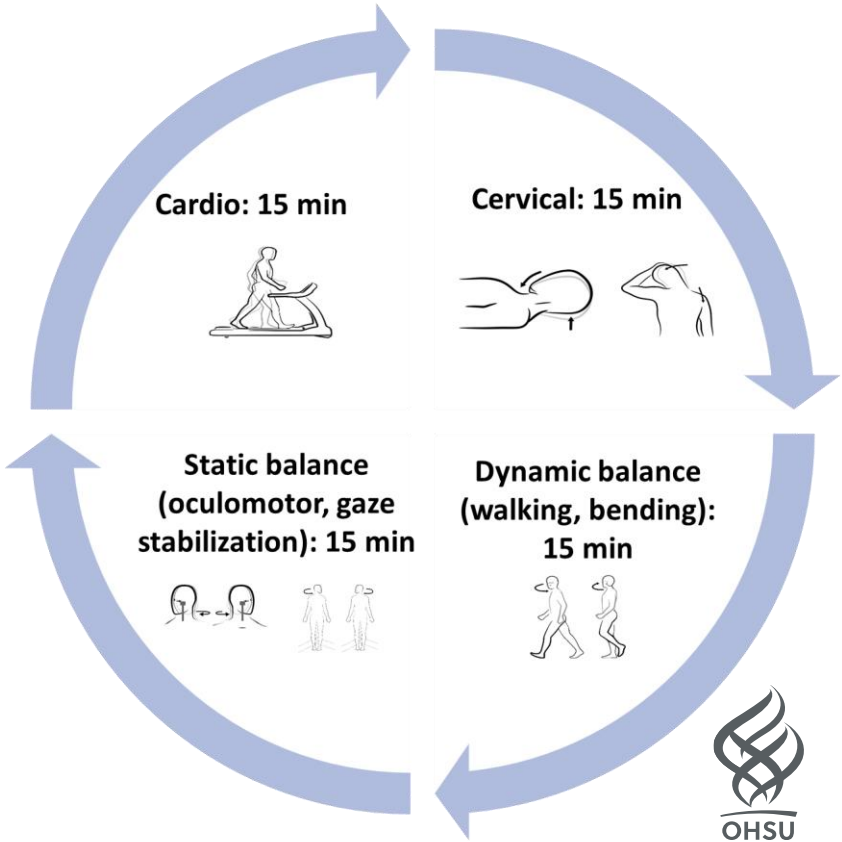
What are the effects of multi-modal rehabilitation?





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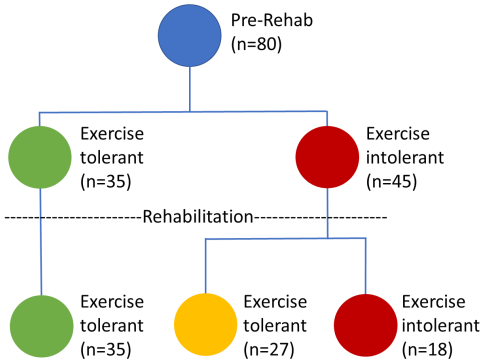
Nearly a quarter of participants remained exercise intolerant: Baseline demographics did not differ between groups



	Pass/Pass (n= 35)	Pass/Fail (n= 27)	Fail/Fail (n= 18)	Group difference, p-value
Age	37.9(11.3)	34.6(12.3)	36.0 (12.9)	p=0.56
Gender (F/M/O)	26/9/0	21/5/1	15/2/1	
BMI	25.7(5.6)	23.4(2.6)	25.9(5.4)	p=0.12
Time since injury (days)	75.9(31.5)	70.4(28.1)	79.3(24.2)	p=0.57
NSI	32.3(14.0)	34.4(15.9)	38.1(14.8)	p=0.42
Mechanism of Injury (%)				
MVA	15 (43%)	8 (30%)	5 (28%)	
Sport	8 (23%)	5 (18.5%)	3 (17%)	
Fall	6 (17%)	5 (18.5%)	6 (33%)	
Other	6 (17%)	6 (22%)	3 (17%)	
Bike	0	3 (11%)	1 (5%)	
Blast	0	0	0	

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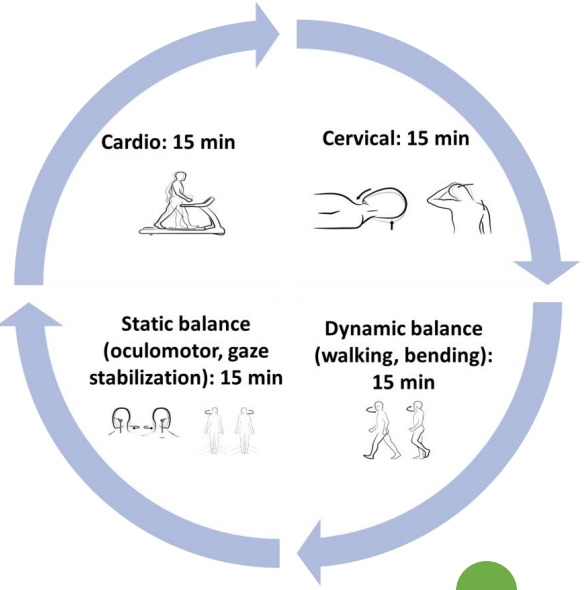
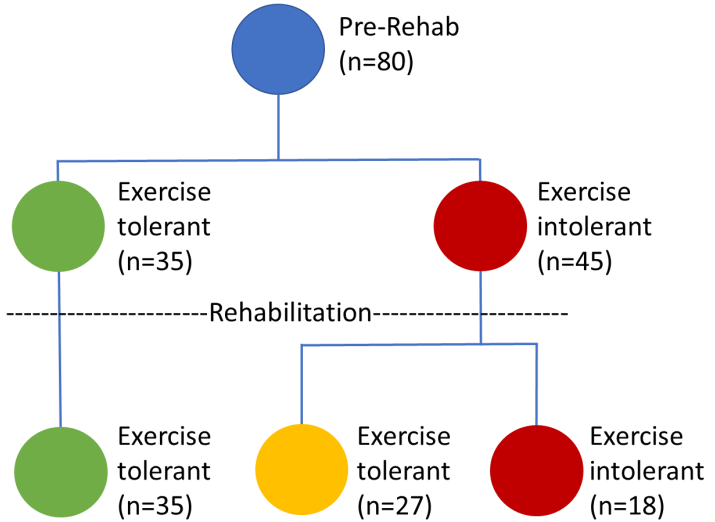
Rehab attendance and cardio HEP compliance did not differ between groups





	Pass/Pass	Fail/Pass	Fail/Fail	
Rehabilitation attendance	93.6±8.1%	97.2±8.6%	97.9±4.7%	p=0.09
Home exercise program (Cardio)	70.3±26.5%	71.1±24.9%	74.5±26.2%	p=0.85

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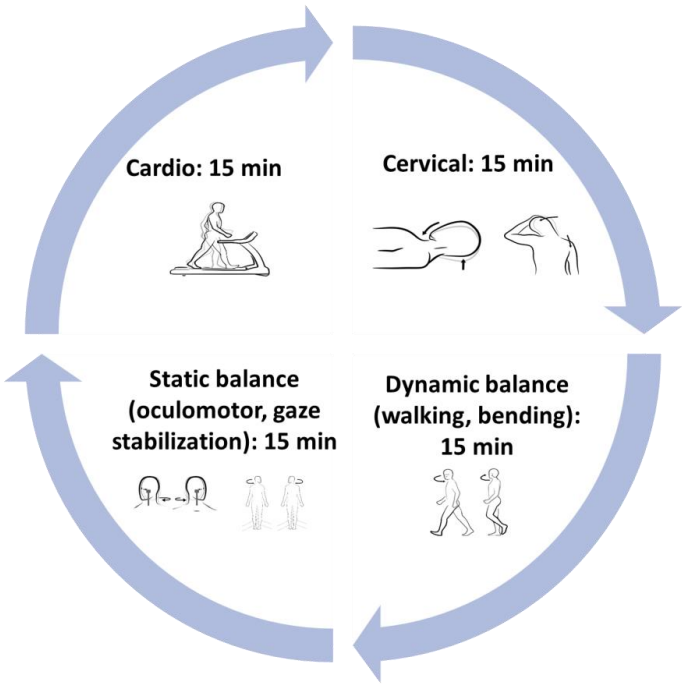
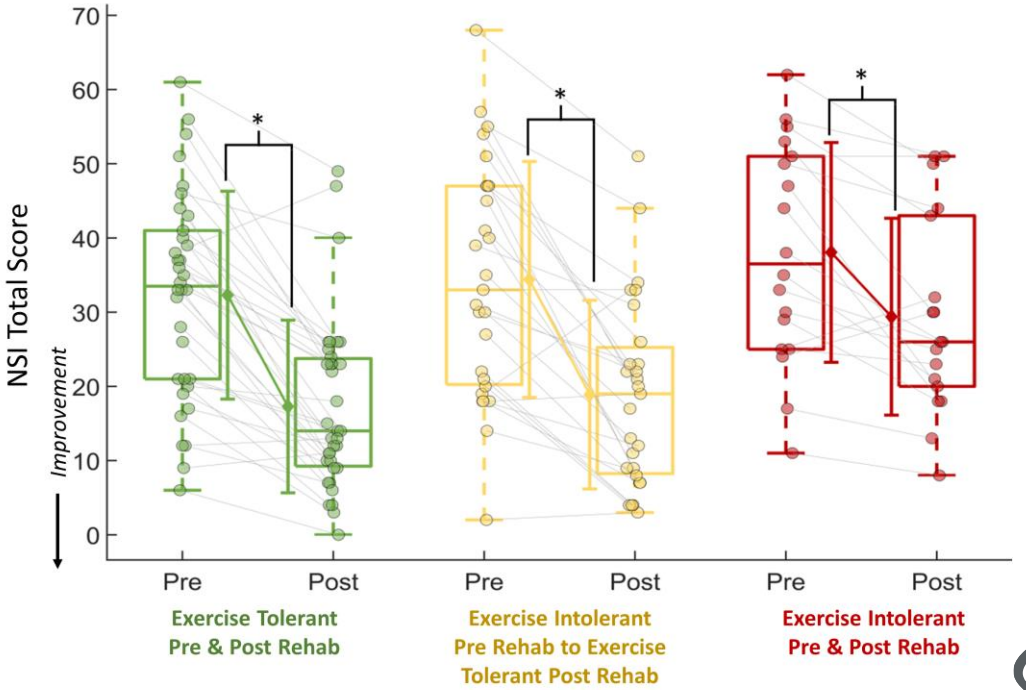
Participants with subacute mTBI who remain exercise intolerant after a rehabilitation program show similar improvements in overall symptoms





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Conclusions

- Multimodal rehabilitation is effective in improving exercise intolerance and global mTBI symptoms

- Further work needs to be done in the non-responders since not all subjects improved in exercise intolerance after rehabilitation
  - Determine mTBI symptom clusters of exercise intolerance
  - Functional Near-Infrared Spectroscopy (fNIRS): Brain oxygenation in the brain
  - Indirect calorimetry: Oxygen consumption

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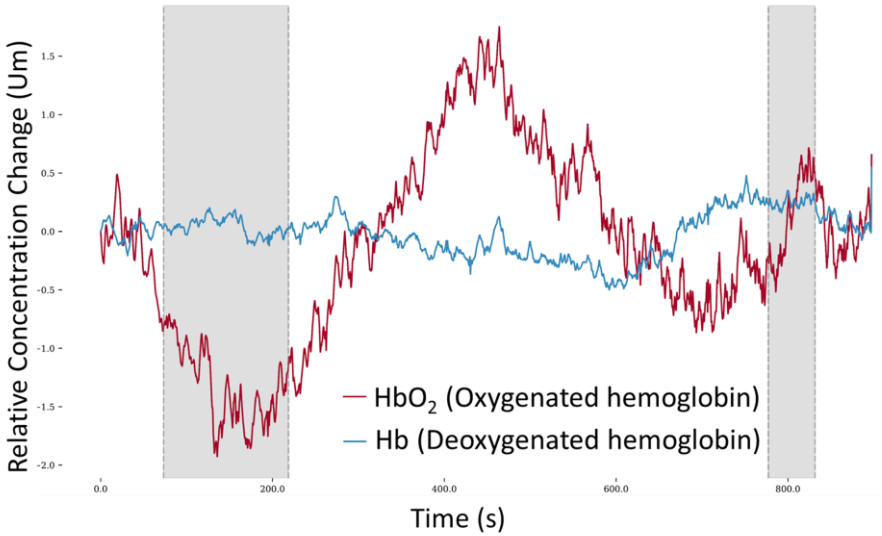
Prefrontal cortex brain activity

- The prefrontal cortex (PFC) has been found to be an integral part of the central autonomic network and healthy people show a moderate-to large oxygenated hemoglobin (HbO2) increases in the PFC during exercise
- It is unknown if PFC is abnormal in people with mTBI during exercise and if abnormalities relate to exercise intolerance
- PFC activity during exercise was simultaneously measured using a mobile, functional, near-infrared spectroscopy (fNIRS) system



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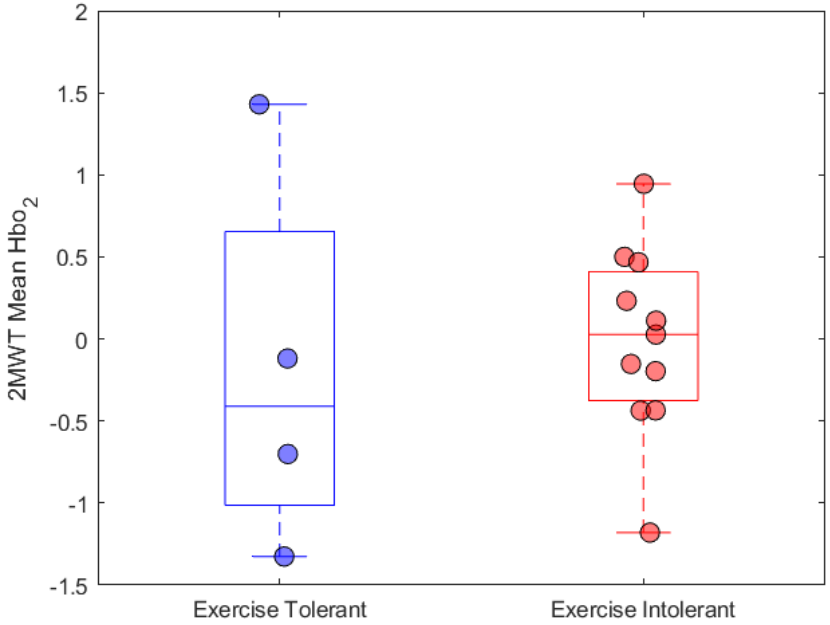
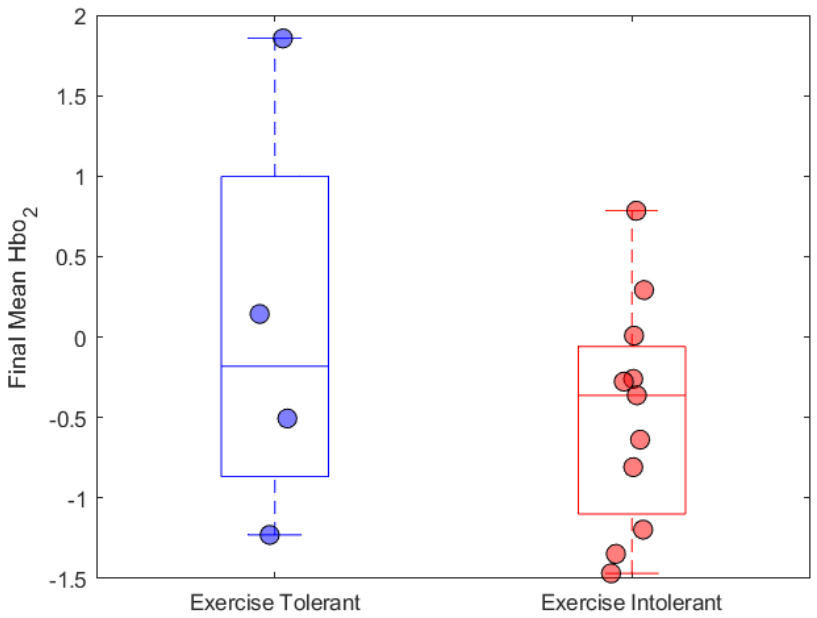
Differences of prefrontal cortex activity between exercise tolerant and intolerant participants





Antonellis, P., Liu, W., Campbell, K.R., Wilhelm, J.L., Pettigrew, N., Mancini, M., & King, L.A. Effects of exercise intolerance on prefrontal cortex activity after mild traumatic brain injury. Society for Neuroscience, November 2022, San Diego, California

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