The brain as a performance limiting factor

NEIL DALLAWAY

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Who Am I? - Neil Dallaway, M.Phil.

Doctoral researcher investigating the role of the brain in regulating endurance exercise

4 seasons as performance analyst at a professional football club

10 year career as a software engineer in digital broadcast industry

Recreational endurance athlete

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- Theoretical Models of Brain Regulation of Endurance Performance
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  - BET study 2 (Dallaway, 2017)
- Application to coaching practice
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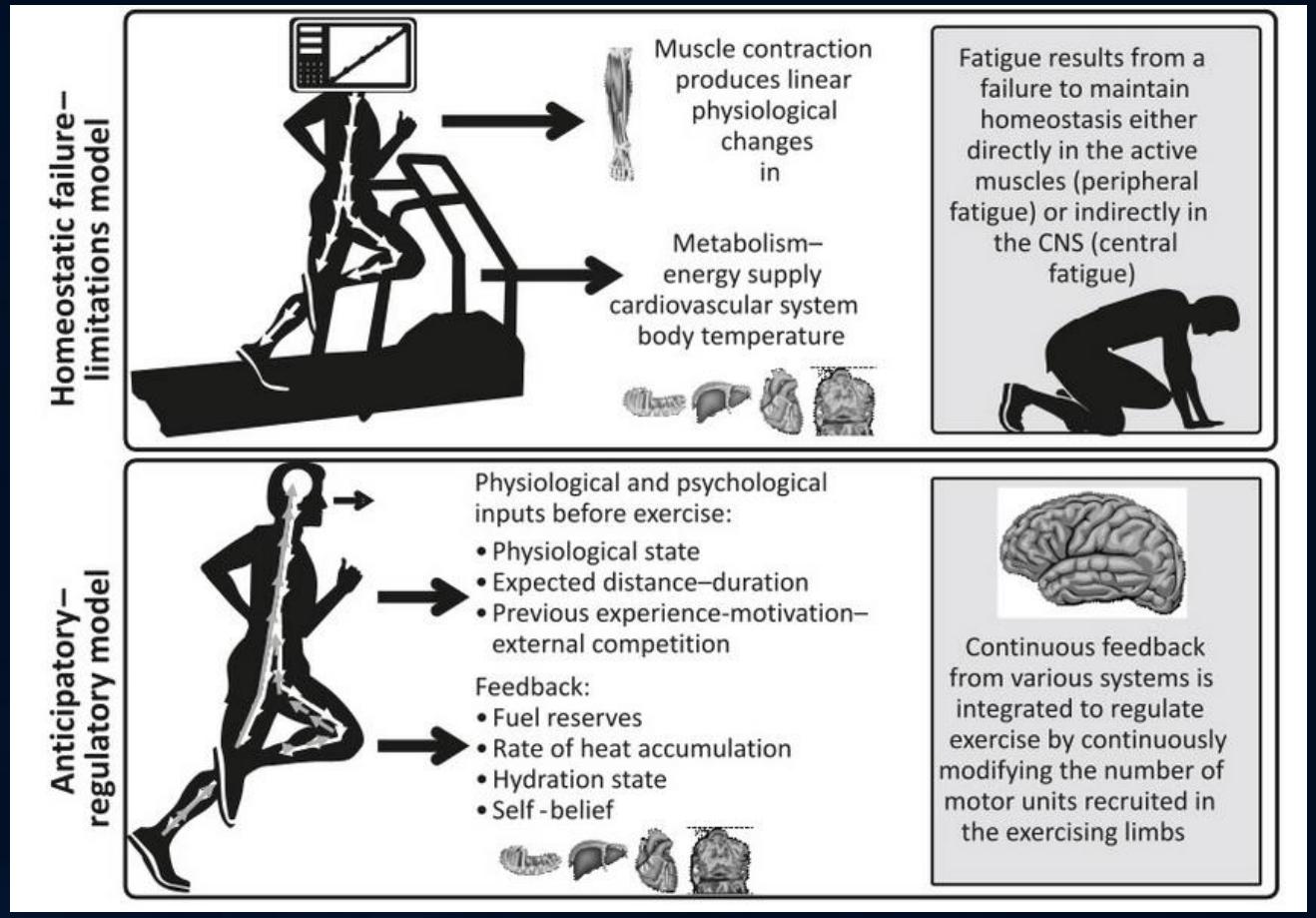
  - BET – seperate, concurrent and subsequent methods
  - Types of cognitive tasks

Theoretical Models of Brain Regulation of Endurance Performance

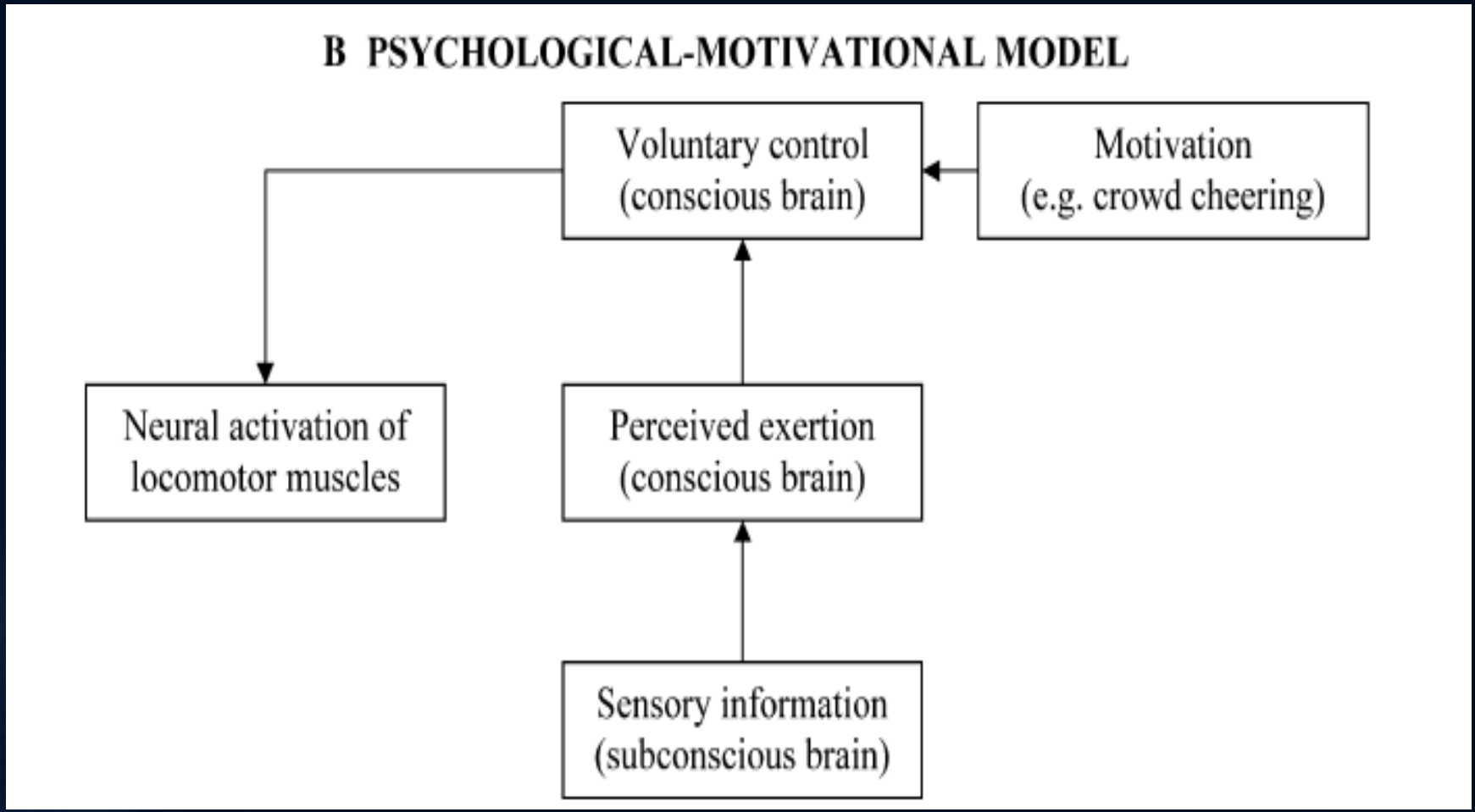
Central Governor Model - Noakes 1996

- In the 1996 Wolf Hall memorial lecture Professor Noakes proposed moving away from the traditional 'brainless' catastrophe model of fatigue and suggested the central governor model



Noakes, Timothy David. "Time to move beyond a brainless exercise physiology: the evidence for complex regulation of human exercise performance." *Applied Physiology, Nutrition, and Metabolism* 36.1 (2011): 23-35.

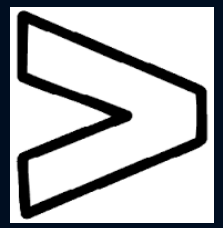
Psychobiological model

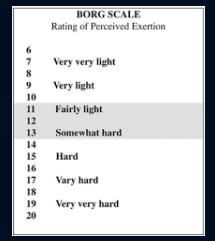


Marcora, Samuele M. "Do we really need a central governor to explain brain regulation of exercise performance?." *European journal of applied physiology*104.5 (2008): 929-931.

Psychobiological Model (2)

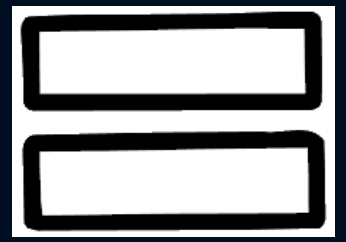
- Motivational Intensity Theory
  - Reward > cost = persistence





BORG SCALE
Rating of Perceived Exertion

6	
7	Very very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Vary hard
18	
19	Very very hard
20	



- Perception of effort is centrally generated
- Fatigue is voluntary due to a response to a high perception of effort
- Any intervention to change performance without changing RPE or motivation disproves model

Psychobiological Model (3)

- **Anterior Cingulate Cortex (ACC) regulates**
  - Heart rate
  - Breathing
  - Autonomic response to exercise
- **ACC more active when performing mental tasks**
  - Sustained attention
  - Conflict resolution
  - Response inhibition

Generating the Sensation of Effort

- **Psychobiological model**
  - Afferent feedback does not contribute to perception of effort
  - The sensation of exertion is centrally generated
  - Efference copy (corollary discharge) from motor to sensory cortical areas due to increased motor unit recruitment
  - Tired at rest when no effort
- **Central governor model**
  - Afferent feedback is centrally integrated and interacts with efferent copy of motor commands
  - Recent CGM models separate fatigue / effort (TEA scale)

Marcora, Samuele. "Perception of effort during exercise is independent of afferent feedback from skeletal muscles, heart, and lungs." *Journal of Applied Physiology* 106.6 (2009): 2060-2062.

Noakes, Timothy David. "Fatigue is a brain-derived emotion that regulates the exercise behavior to ensure the protection of whole body homeostasis." *Frontiers in physiology* 3 (2012).

Serotonin Hypothesis

- Increase in brain serotonergic activity during prolonged activity augments lethargy and a loss of drive
- Reduced motor unit recruitment
- Lack of evidence
  - SSRI studies
  - BCAA interventions
- Neuromodulatory role
  - Dopamine; willingness exert effort, motivation, reward
  - Noradrenaline; attention and arousal
- Brain dopamine and noradrenaline - enhance exercise performance in heat

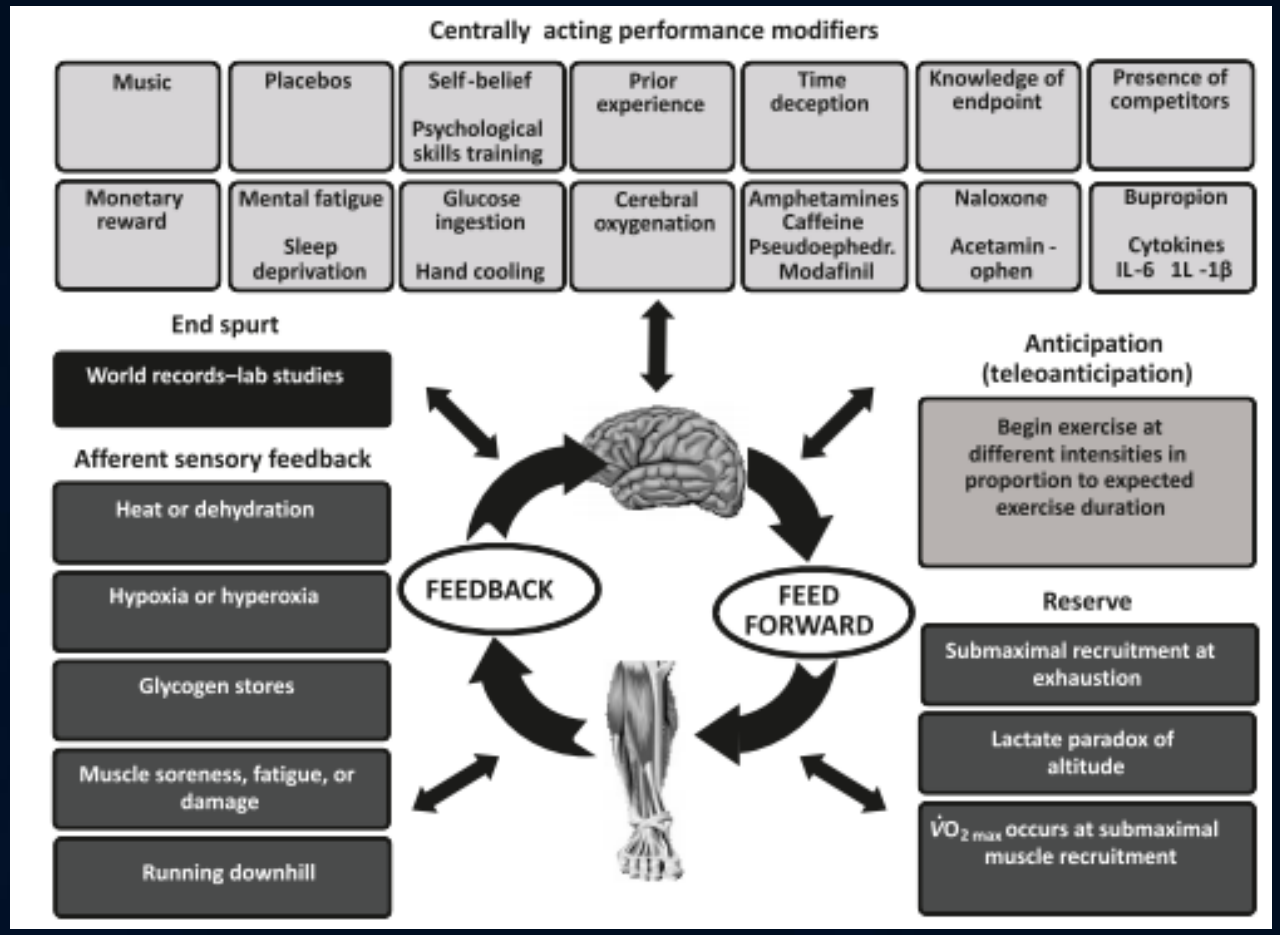
Meeusen, Romain, et al. "Central Fatigue." *Sports Medicine* 36.10 (2006): 881-909.

The Strength Control Model

- Self-control described to a muscle
- The more self-control is exerted the more fatigued it becomes
- Impacting on subsequent events which also require self-control resources
- Initially applied to areas such as:
  - binge eating
  - substance abuse
  - unhealthy lifestyle habits
  - antisocial behaviour
- Recently been applied to the control of effort over exercise

Baumeister, R. F., Vohs, K. D., & Tice, D. M. (2007). The strength model of self-control. *Current Directions in Psychological Science, 16*(6), 351-355.

Implications



Noakes, Timothy David. "Time to move beyond a brainless exercise physiology: the evidence for complex regulation of human exercise performance." *Applied Physiology, Nutrition, and Metabolism* 36.1 (2011): 23-35.

Summary: Brain Regulation of Exercise

- Exercise starts and ends in the brain
  - Recruit motor units – move – stop recruiting motor units
- Integrated approach to fatigue
- RPE very important
- Pharmaceutical Interventions
- Terms – mental toughness, self control, resilience, grit, will power, focus, self regulation, determination, persistence, stubbornness etc. etc.
  - Are there structural / connective brain differences?

St Clair Gibson, A., J. Swart, and R. Tucker. "The interaction of psychological and physiological homeostatic drives and role of general control principles in the regulation of physiological systems, exercise and the fatigue process– The Integrative Governor theory." *European Journal of Sport Science* (2017): 1-12.

Mental Fatigue

A psychobiological state caused by prolonged periods of demanding cognitive activity and characterized by subjective feelings of "tiredness" and "lack of energy"

Mental Fatigue Impairs Endurance Performance

- Mental fatigue group vs. control group
- AX continuous performance test
  - Working memory
  - Response Inhibition
  - Error monitoring
- 15% reduction in fixed workload cycle task
- 754 ± 339s to 640 ± 316s
- Both groups quit at the same level of RPE

Marcora, Samuele M., Walter Staiano, and Victoria Manning. "Mental fatigue impairs physical performance in humans." *Journal of Applied Physiology* 106.3 (2009): 857-864.

Mental fatigue

- Well established to impair sub-maximal endurance performance
- Does not impair maximal anerobic exercise performance
- Can impair sport specific skills
  - Implications for field based athletes
- Elite athletes (recreational vs professional cyclists)
  - Superior cognitive performance – suggests higher inhibitory control
  - 30 minutes of cognitive task did not impair elite groups performance
  - Greater resistance to the negative effects of mental fatigue
  - Psychobiological characteristics either genetic or developed

Van Cutsem, Jeroen, et al. "The effects of mental fatigue on physical performance: a systematic review." *Sports Medicine* (2017): 1-20.
Martin, Kristy, et al. "Mental fatigue does not affect maximal anaerobic exercise performance." *European journal of applied physiology* 115.4 (2015): 715-725.
Smith, Mitchell R., et al. "Impact of mental fatigue on speed and accuracy components of soccer-specific skills." *Science and Medicine in Football* 1.1 (2017): 48-52.
Martin, Kristy, et al. "Superior inhibitory control and resistance to mental fatigue in professional road cyclists." *PloS one* 11.7 (2016): e0159907.

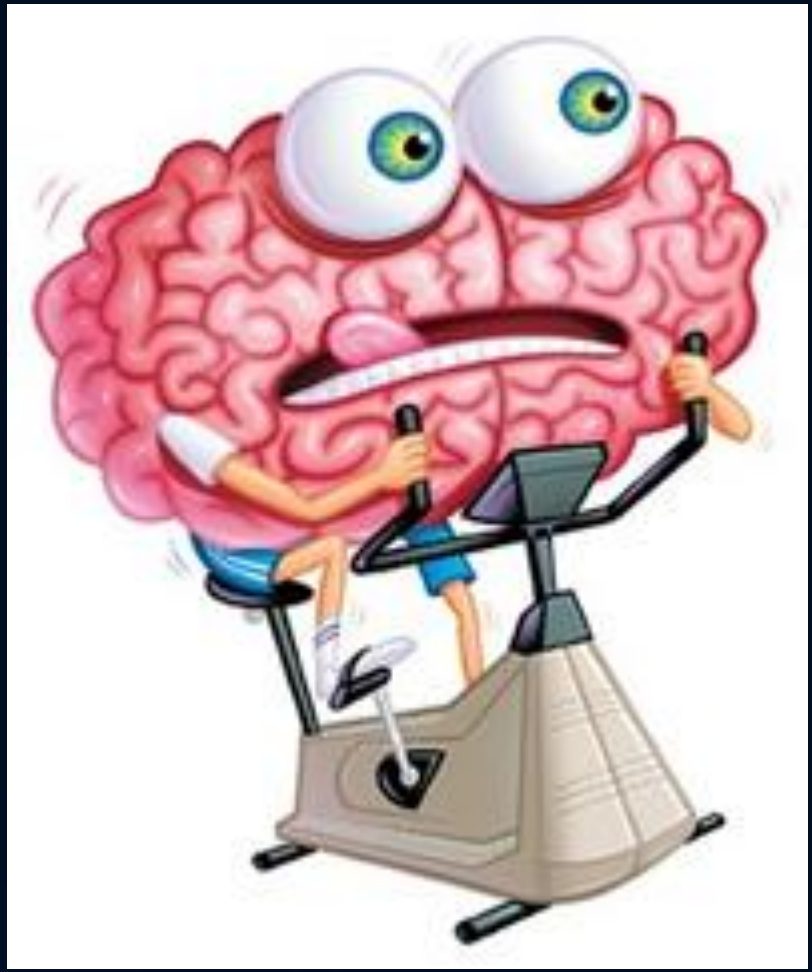
Brain Endurance Training (BET)

Hypotheses

Proposed by Marcora

Systematic repetition of mentally fatiguing tasks:

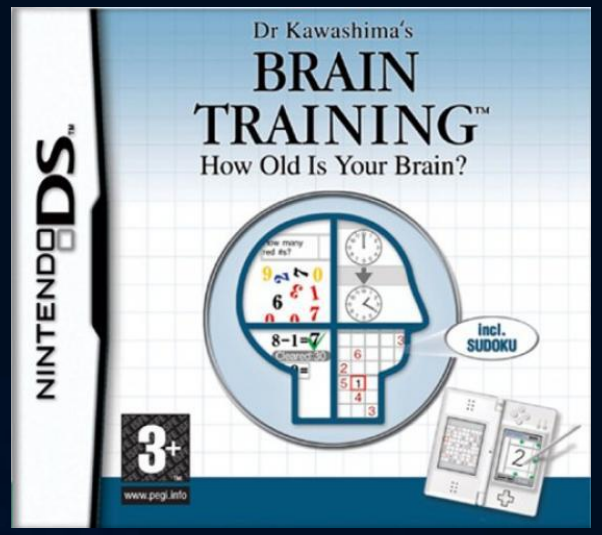
- increases training load on the brain
- induces adaptations in the ACC or other relevant cortical areas
- reduces perception of effort
- Increases endurance performance



Brain Endurance Training

BET = systematic repetition of mentally fatiguing tasks aimed at improving endurance performance

Different from standard brain training aimed at improving or maintaining cognitive functions like attention and working memory for which there is limited evidence of efficacy (Owen et al., 2010)



Brain Endurance Training (BET)

Study 1 – Marcora 2013

Brain Endurance Training

40 healthy and physically active males were randomly assigned to two different training groups: BET and control. Five dropouts (12%).

Characteristic	BET (n=17)	Control (n=18)
Age (years)	28.9 ± 5.7	27.3 ± 6.4
Height (cm)	179 ± 6	180 ± 6
Weight (kg)	85.3 ± 10.9	80.0 ± 9.3
Body Mass Index (kg/m^2)	26.5 ± 2.8	24.8 ± 2.3

Brain Endurance Training (2)

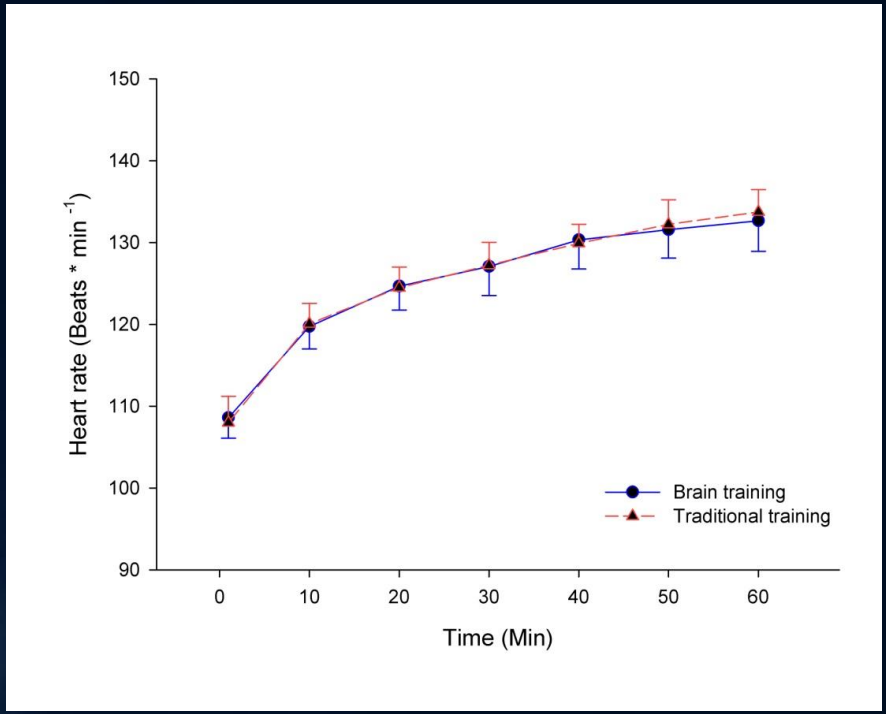
Experimental Treatment:

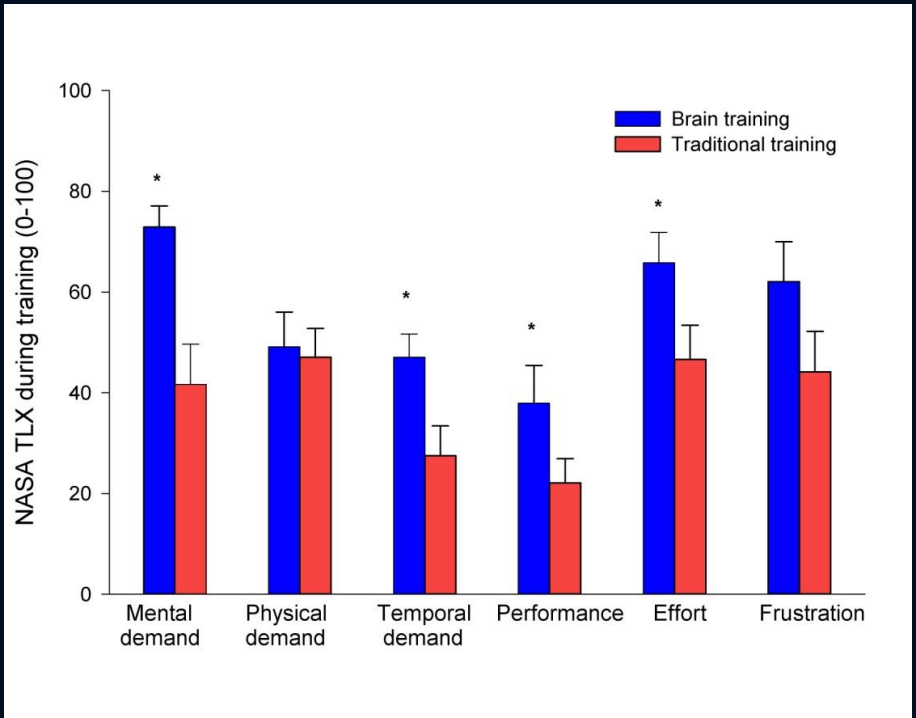
- Both groups trained on a cycle ergometer for 60 min at 65% VO2max, three times a week for 12 weeks.
- Whilst cycling, the BET group performed a mentally fatiguing task on a computer (60 min of the AX-CPT task).
- The control group was not involved in any mentally fatiguing task whilst cycling.

Study Protocol:

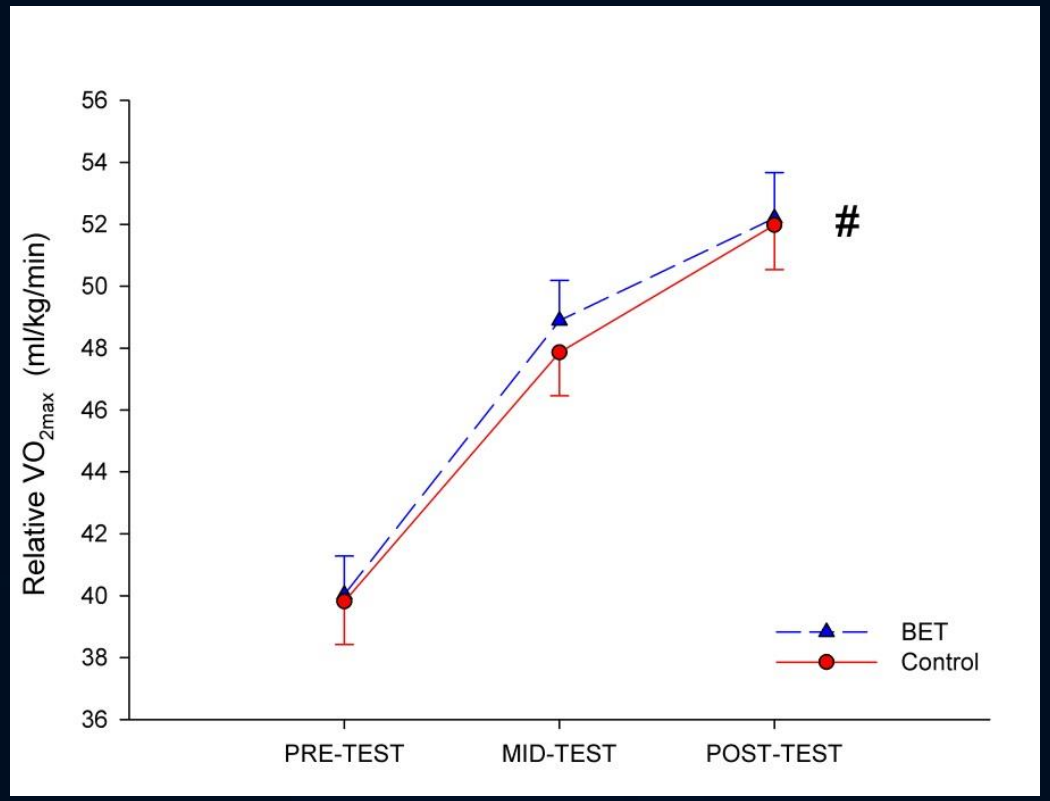
PRE-TEST Week 1-2	Training Week 3-8	MID-TEST Week 9-10	Training Week 11-16	POST-TEST Week 17-19
1) VO_2 Max Test (1h) 2) Time to Exhaustion (2h) 3) Foot Patrol (3h)	18 one-hour training sessions	1) VO_2 Max Test (1h) 2) Time to Exhaustion (2h) 3) Foot Patrol (3h)	18 one-hour training sessions	1) VO_2 Max Test (1h) 2) Time to Exhaustion (2h) 3) Foot Patrol (3h) 4) Sleep Deprivation (38h)

Brain Endurance Training (3)

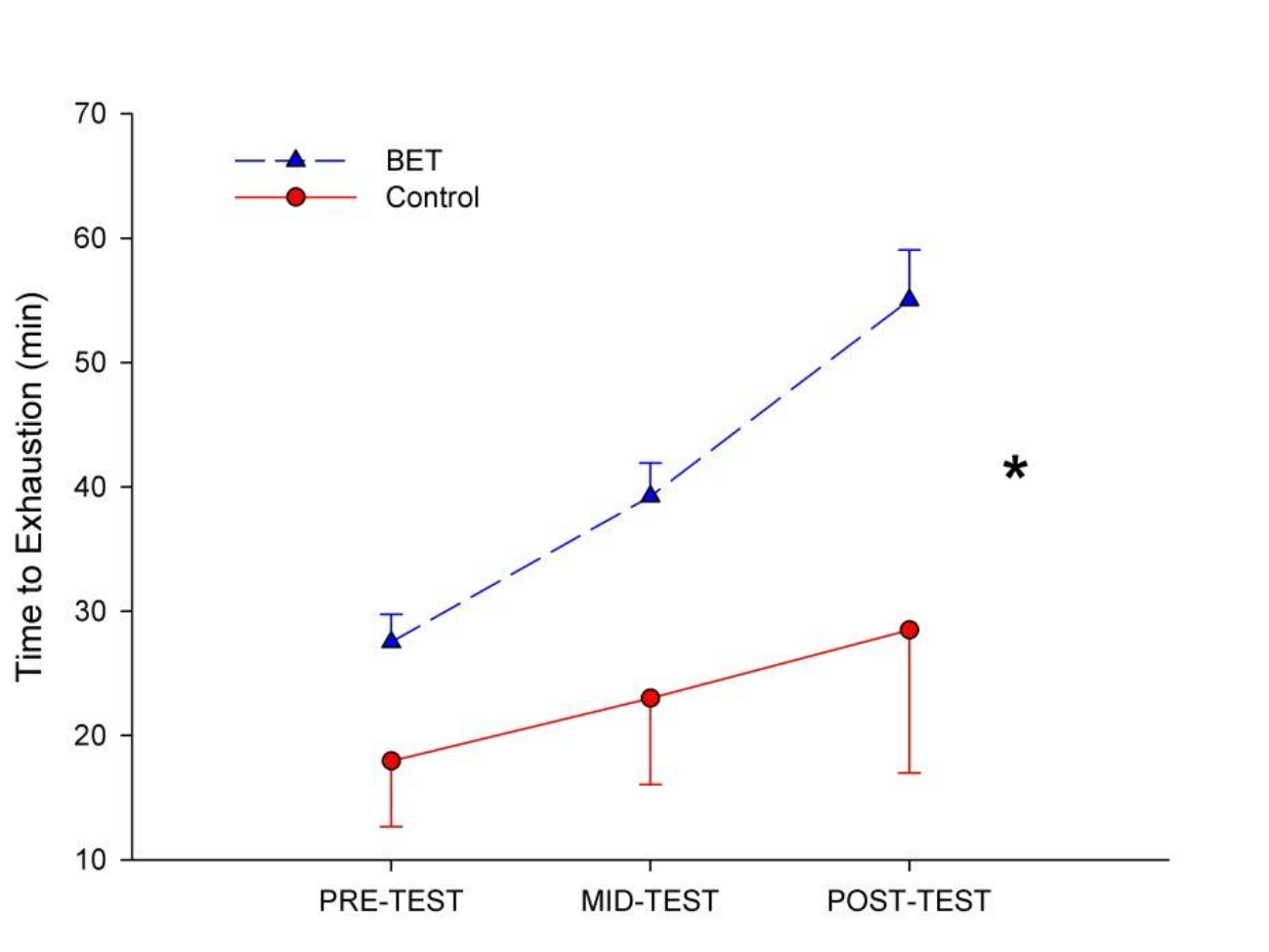




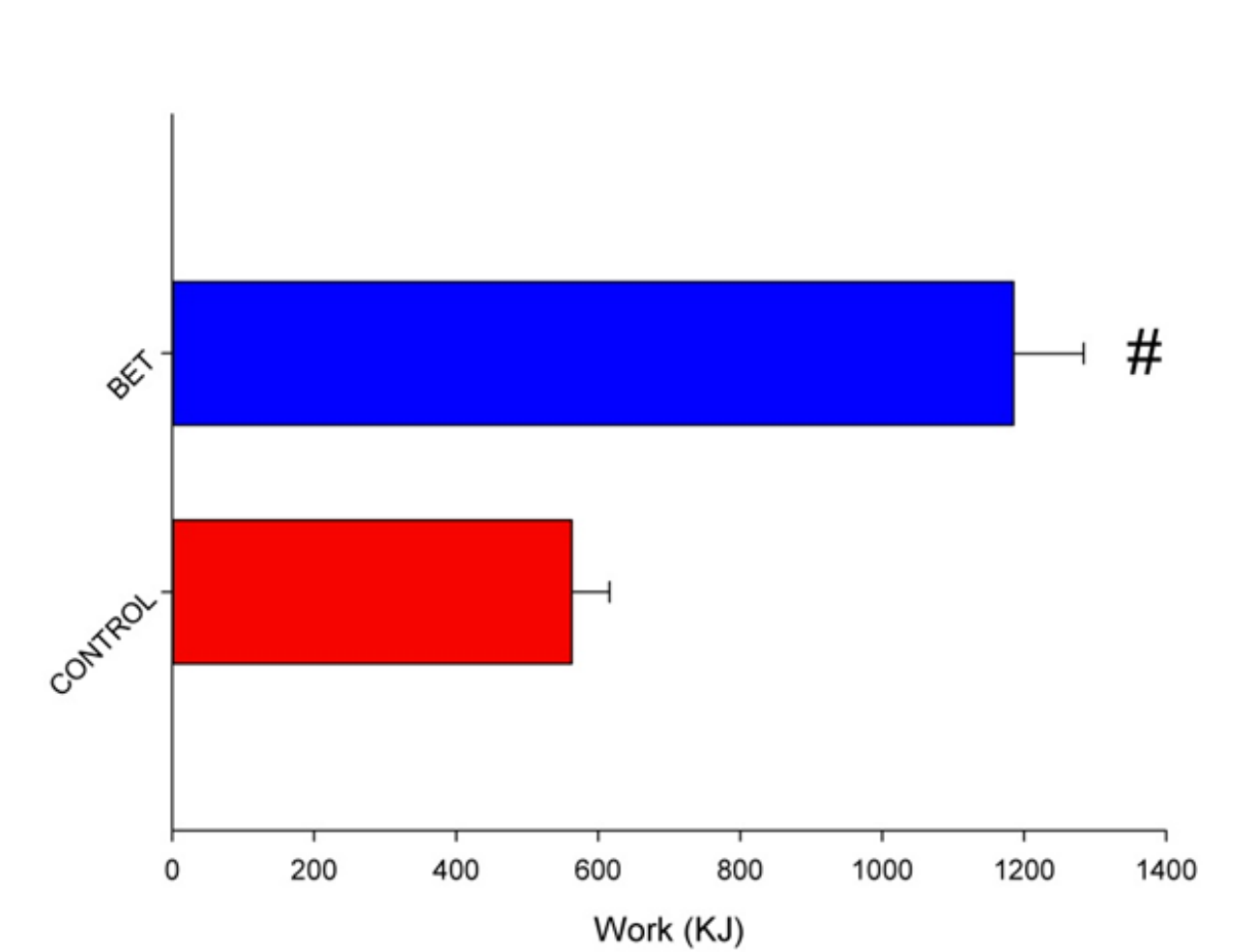
Results: VO_{2max} Test



Results: Time to Exhaustion Test



Results: Time to Exhaustion Test



Brain Endurance Training (BET)

Study 2 – Dallaway 2017

Introduction

- Mental fatigue impairs endurance exercise performance (Van Cutsem et al, 2017)
- Engaging in cognitive tasks during exercise (i.e., BET) can develop resilience to mental fatigue and improve physical performance compared to physical training alone (Marcora et al, 2015)
- Only this one study to date has demonstrated the effectiveness of BET and the underlying mechanisms have yet to be determined.

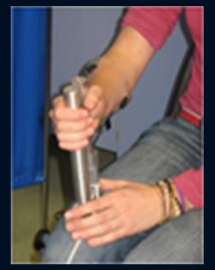
Aims

1) To investigate if BET enhances endurance performance over physical training alone.
2) To investigate potential mechanisms.

Methods

Pre-intervention Testing

Control	**BET**
Exercise only	Exercise & Cognitive Task



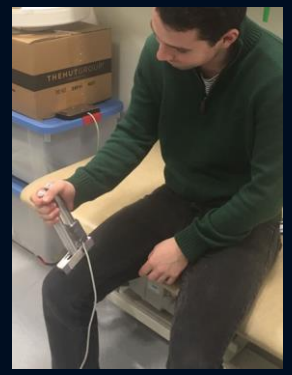
6 Weeks training intervention
x4 ~30 minute sessions per week

Post-intervention Testing

Pre- and Post Training Testing

- 36 participants completed a rhythmic handgrip task requiring generation of as much force as possible once a second for 5 minutes
- Performed under 3 counter-balanced conditions:
  - following 10 minutes of a 2-back memory/attention task (**subsequent**)
  - while performing a 2-back task (**concurrent**)
  - on its own (**solo**)
- Physiological measures
  - Cardiac activity (ECG)
  - Electromyographic (EMG) forearm activity
  - Pre-frontal cerebral haemodynamic (near infrared spectroscopy)
  - Force – performance
- Psychological measures motivation
  - rate of perceived exertion (RPE)
  - mental exertion,
  - mental fatigue
  - mood states

Performance Tasks



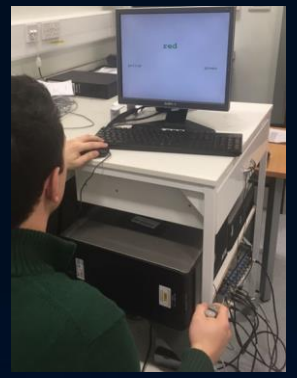
Subsequent Task:

10 min **2-back** cognitive test followed by 5 min physical performance task.

Solo Task: 5 min physical task only

Concurrent Task:

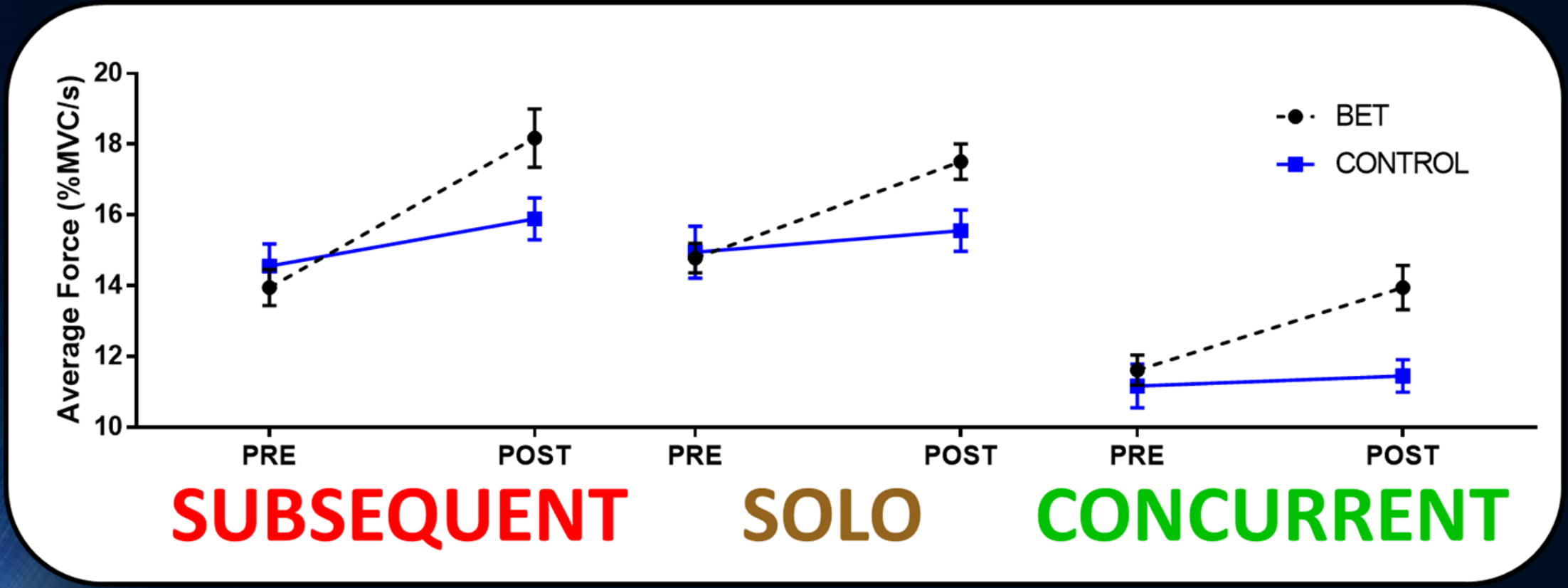
5 min **2-back** (non-dominant hand) and physical task (dominant hand).



Training

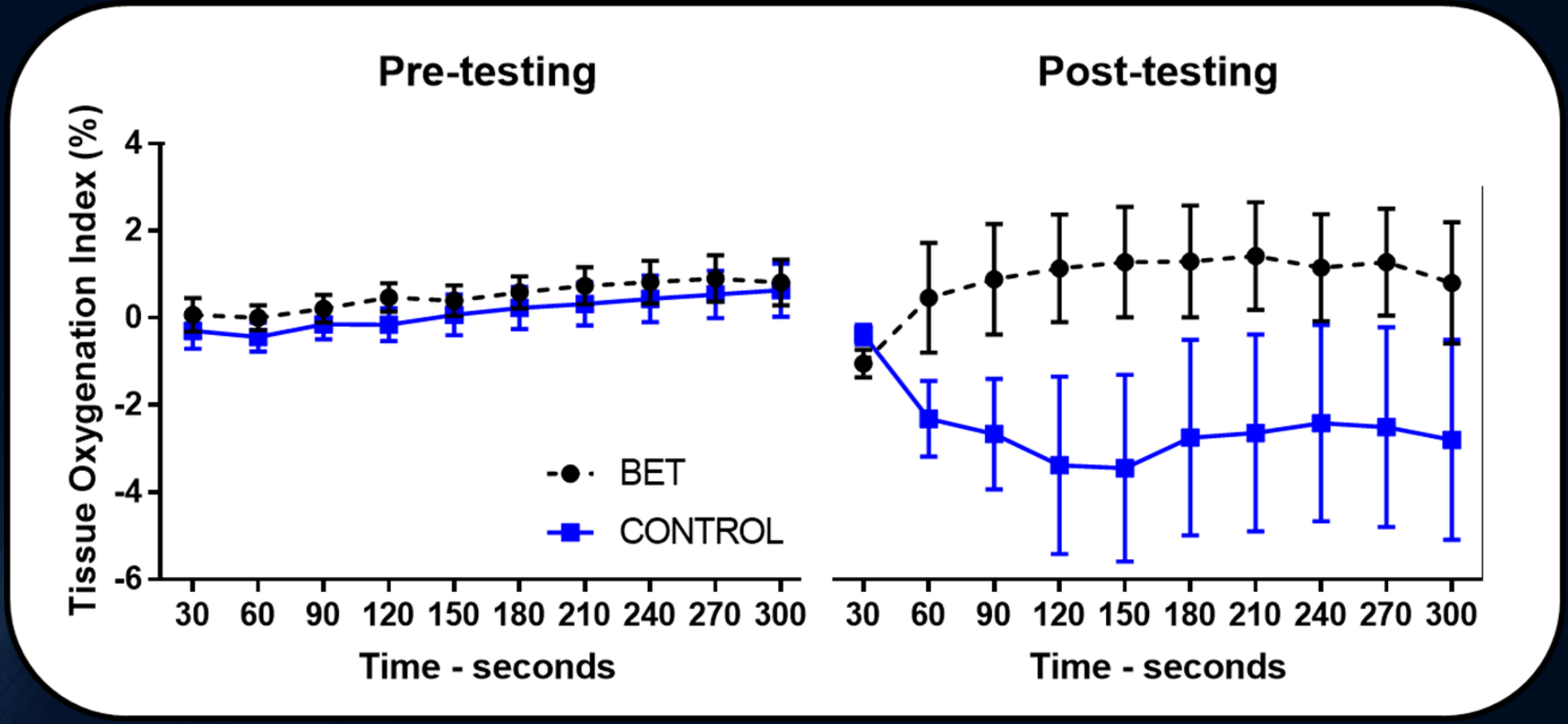
- Participants (randomized to a Control or BET group) completed 24 (over 6 weeks) submaximal hand contractions sessions (c. 15 min of exercise).
- The BET group also completed concurrent cognitive tasks (2-back, word incongruence Stroop) that imposed demands on attention, memory and response inhibition processes.
- **Physical workload was matched between the 2 groups**.
- Both physical and cognitive tasks became progressively more challenging each week.

Results: Performance



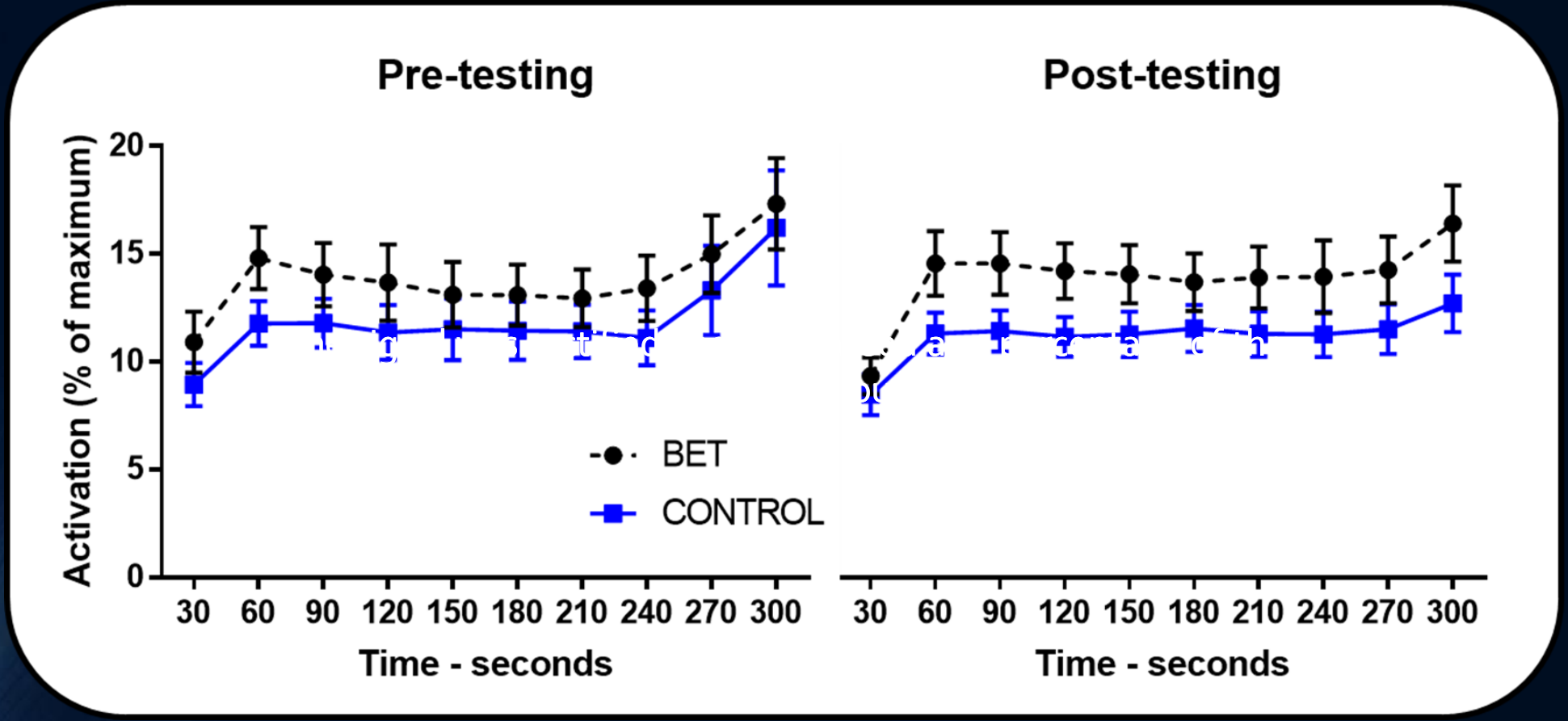
All participants improved following training ($p<.001$), with BET improving more than Control ($p=.001$).

Results: Prefrontal Cortex Activation



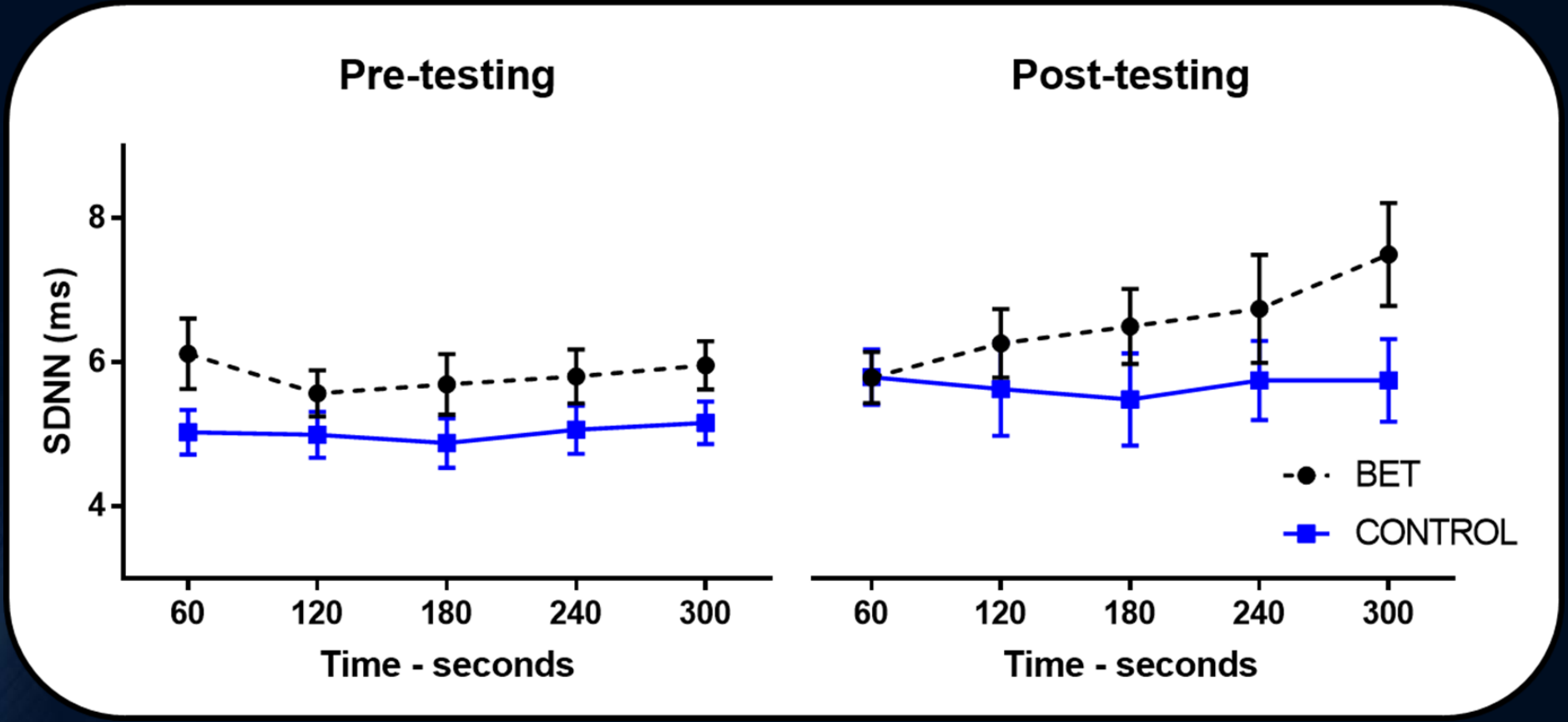
Increased performance in Controls was associated with reduced pre-frontal cortex oxygenation over time relative to pre training and post-training BET group responses ($p<.05$).

Results: Muscle Activity



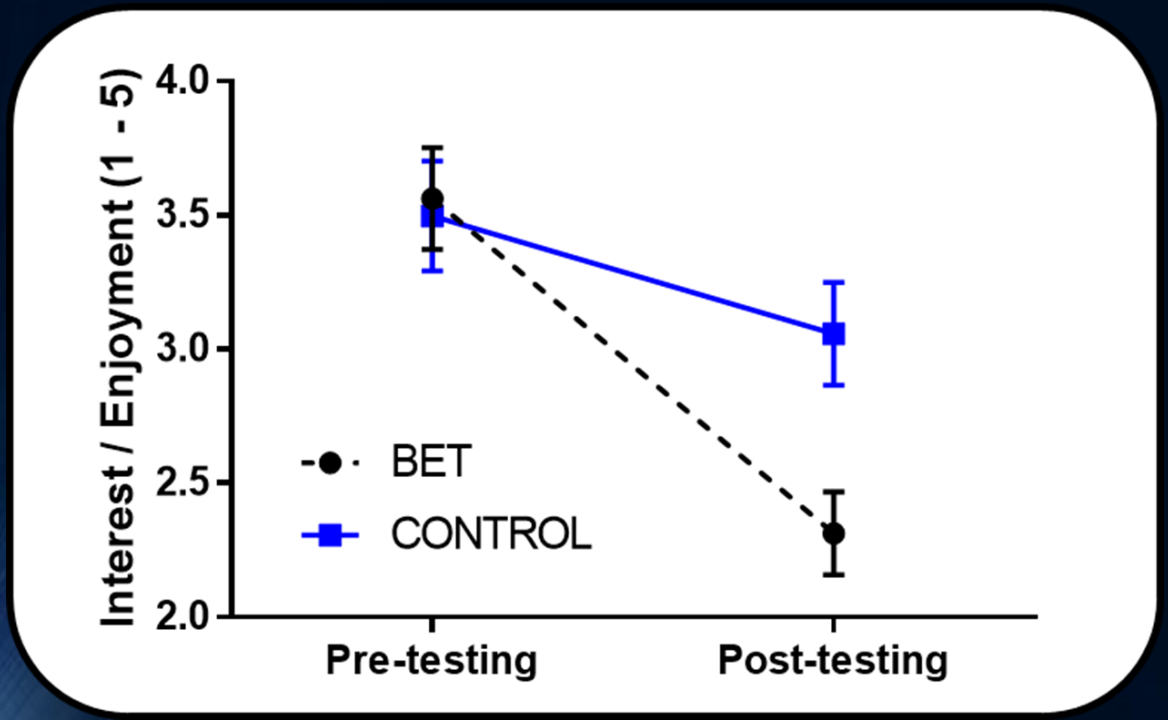
The signal was rectified and normalised as a percentage of the MVC activity. No main effects for group, task or training.

Results: Cardiac Activity



Heart rate variability (SDNN) increased more in the BET group, over time, post training ($p<.05$), suggesting less effort during the tasks.

Results: Psychological Measures



Interest and enjoyment of the tasks declined more in the BET group following training (p=.01). All other self-reported measures for RPE, motivation, mental exertion, fatigue and vigour were similar between groups and unaffected by the type of training.

Discussion of Findings

- Six weeks of brain endurance training improved physical performance more (23%) than physical training alone (5%).
- This higher performance in the BET group was achieved for the same heart rate, muscle activity, motivation and RPE as the Control group.
- The performance increase in the BET group occurred without a decrease in pre-frontal oxygenation (as was seen in control group), while the increase in heart rate variability in the BET group post training (relative to Controls) indicates a reduction in sympathetic nervous system activity.
- The reduction in interest and enjoyment for BET relative to Control, post training, suggests a need for more challenging and exciting tasks.

Application of BET

Brain Endurance Training Methods:

SEPARATE METHOD
(Preliminary Study)

CONCURRENT METHOD
(Proof of Concept and Randomized Controlled Trial x2)

PRE-FATIGUE METHOD
(To be tested)

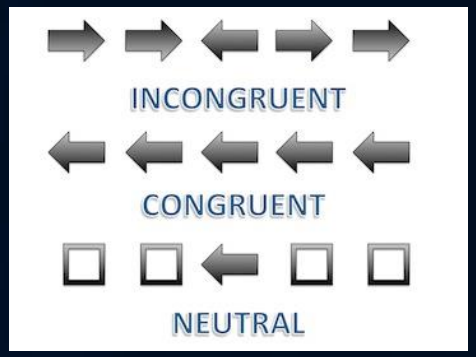
Applications of Concurrent BET

Auditory Tasks via Smartphone App

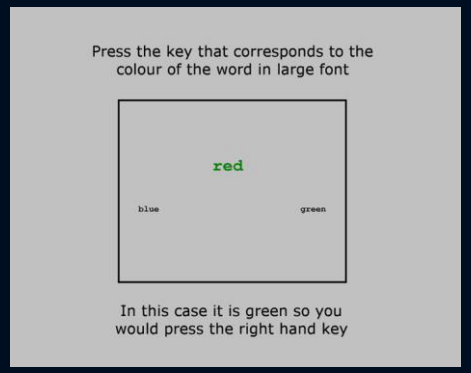
Cognitive Tasks

- **Tasks different each session and increase in difficulty each week and selected from:**
  - N back test; 2back, 3 back
  - AX continuous performance test
  - Incongruent Stroop Tests

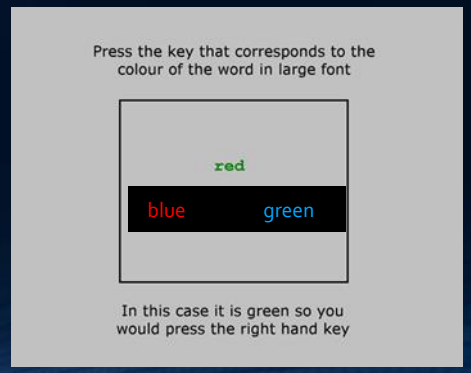
Flanker



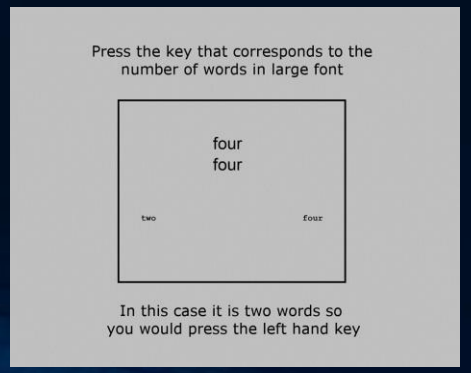
Colour word



Double Incongruent Colour Word



Number



Application - summary

- Types of cognitive tasks important
- Carefully monitor athletes mental fatigue and RPE
- Potentially test athletes mental alertness and cognitive responses
- Reduce mental fatigue and stress close to competition
- BET may improve performance
- Can be utilised with injured athletes or in the off season
- More research needed
- Exciting new area of research

Thanks and Acknowledgments

Professor Christopher Ring, University of Birmingham

Doctor Sam Lucas, University of Birmingham

UNIVERSITY OF BIRMINGHAM

The University of Birmingham

Professor Samuele Marcora, University of Kent

Thanks for listening

Any Questions?