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The Limit of Endurance Performance: Mind over Muscle?

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Outline

- **Definitions** of endurance performance and limit
- The **physiological model** of endurance performance (“**muscle**”)
- The **psychobiological model** of endurance performance (“**mind**”)
- **Practical applications**

Endurance Performance

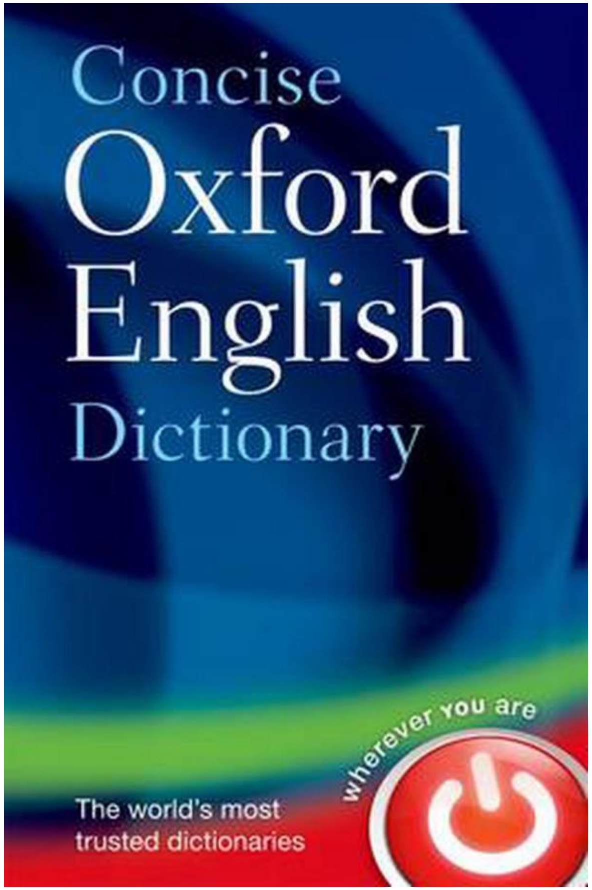
Performance during whole-body physical tasks lasting more than 75 sec up to several hours/days

Limit

Noun

/ˈlɪmɪt/

a point at which something stops being possible or existing



Limit

The point at which cycling at a given/desired power output/speed stops being possible or existing.

Also known as:

- The point of fatigue
- Exhaustion
- Task failure

Aldo Sassi, Cycling Coach and Sport Scientist, 1959-2010

"With the exception of the race winner, for everybody else the race is a time to exhaustion test"

Time to Exhaustion at 5.5 W/kg ("Endurance Test")

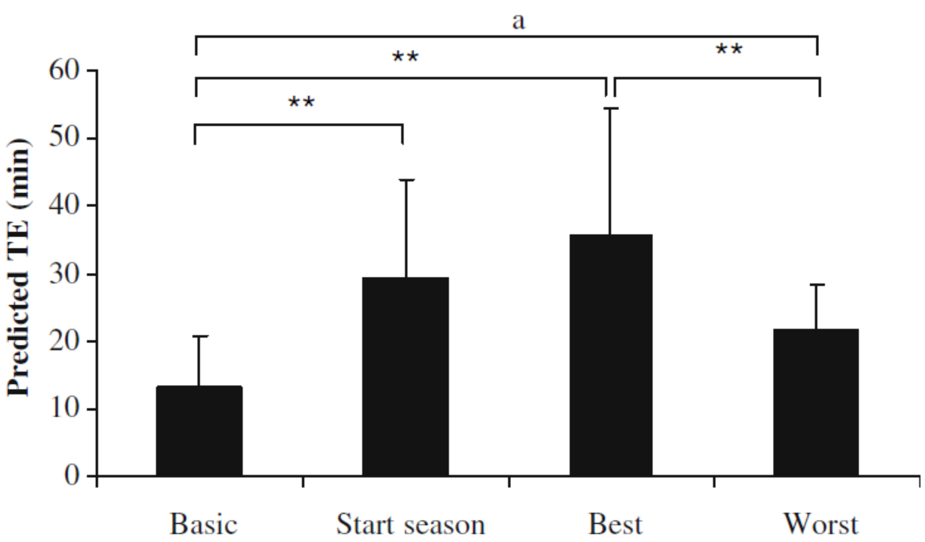


Fig. 3 Seasonal variations in predicted time to exhaustion during the competitive season in a group of professional cyclists ($N=12$). * $P<0.05$; ** $P<0.01$; ^{a} $P=0.052$. Results from one-way repeated measures ANOVA followed by Tuckey's post hoc test

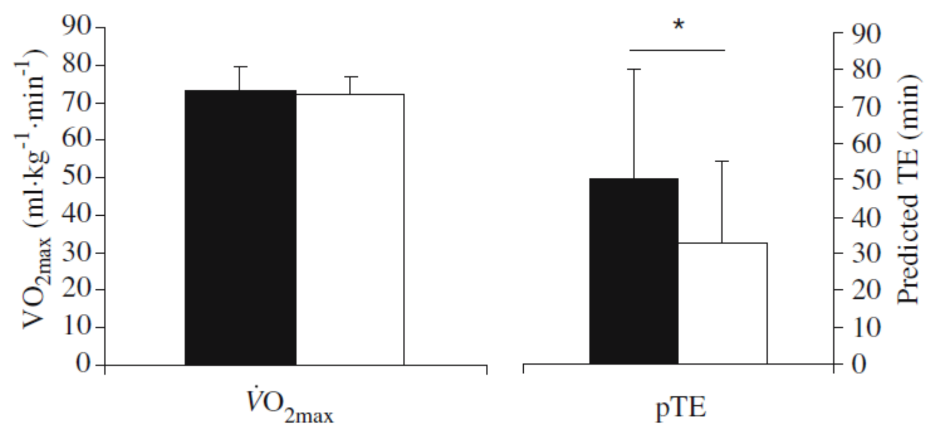


Fig. 4 Comparison between $\dot{V}O_2$ max and pTE between professional cyclists ranked below (*filled square*, elite, $N=19$) and above (*open square*, subelite, $N=30$) the 200th position of the International Cycling Union world ranking at the time of the tests. * $P<0.05$

410W

Elite 423W   Subelite 410W

Sassi et al. (2005)

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What causes exhaustion?

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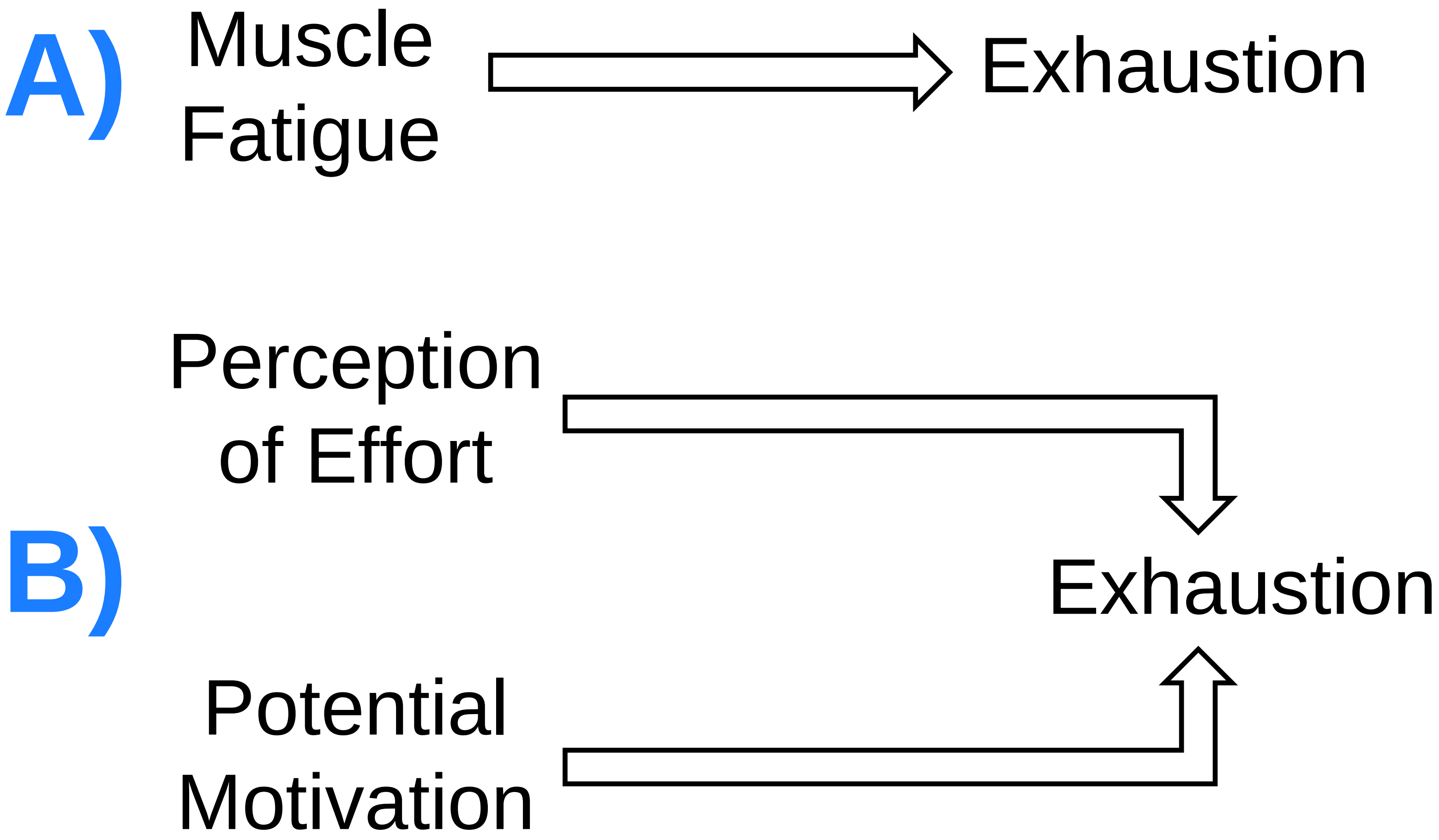
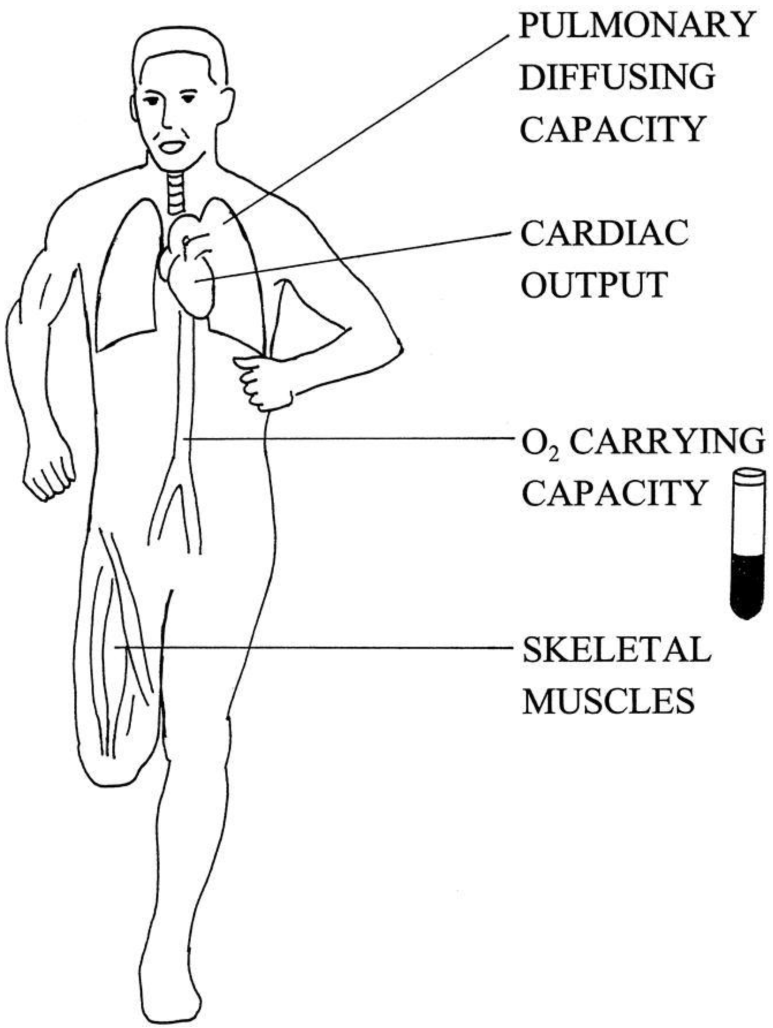
What causes exhaustion?



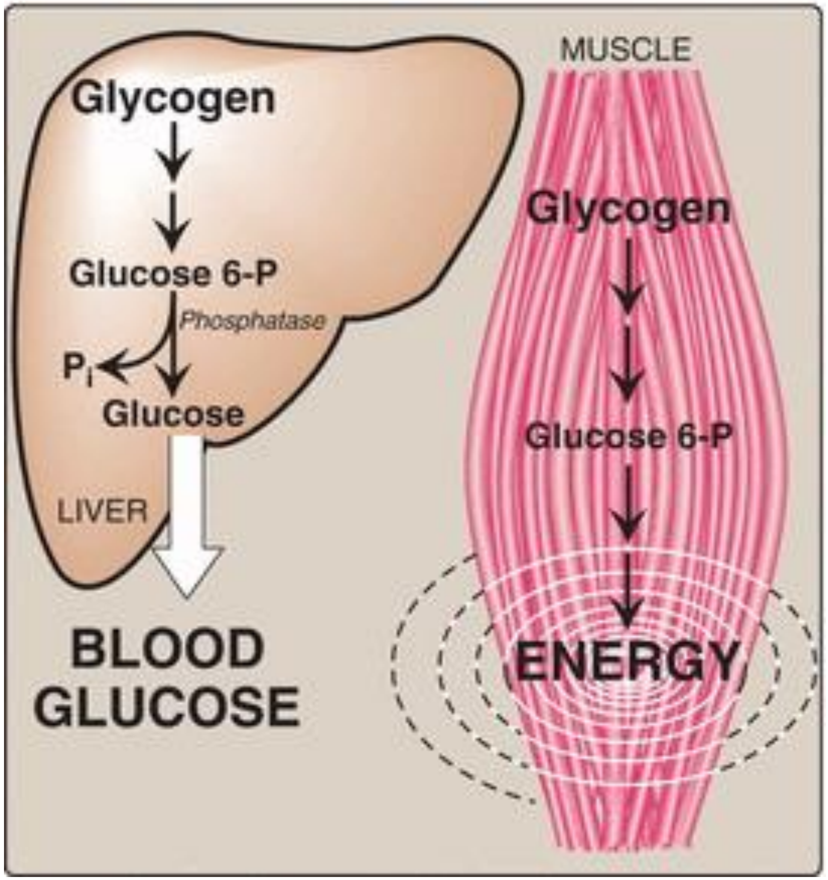
A) Physiological Model

With young athletic people one may be sure that they really have gone "all out", moderately certain of not killing them, and practically certain that their **stoppage is due to oxygen-want and to lactic acid in their muscles**.

AV Hill. *Muscular Activity*. Williams & Wilkins, Baltimore, **1926**.



A) Physiological Model



Energy Depletion

A) Physiological Model

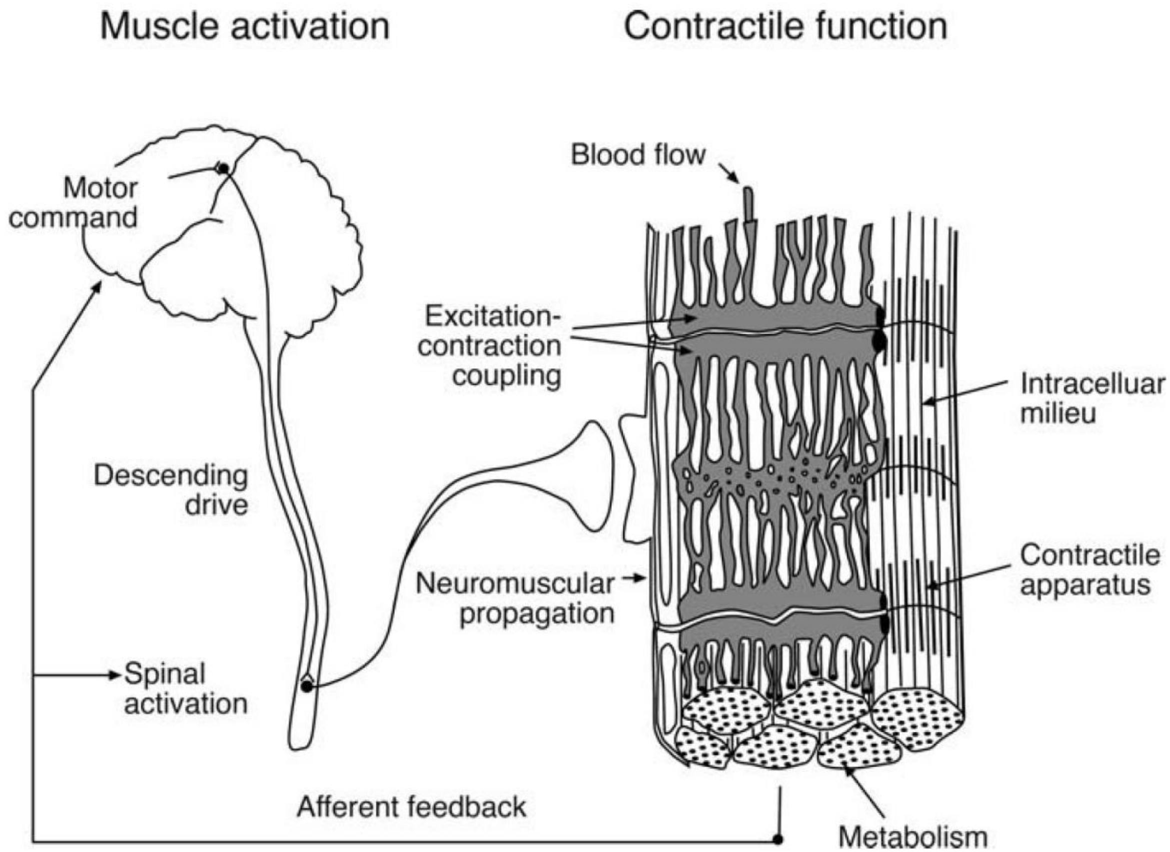
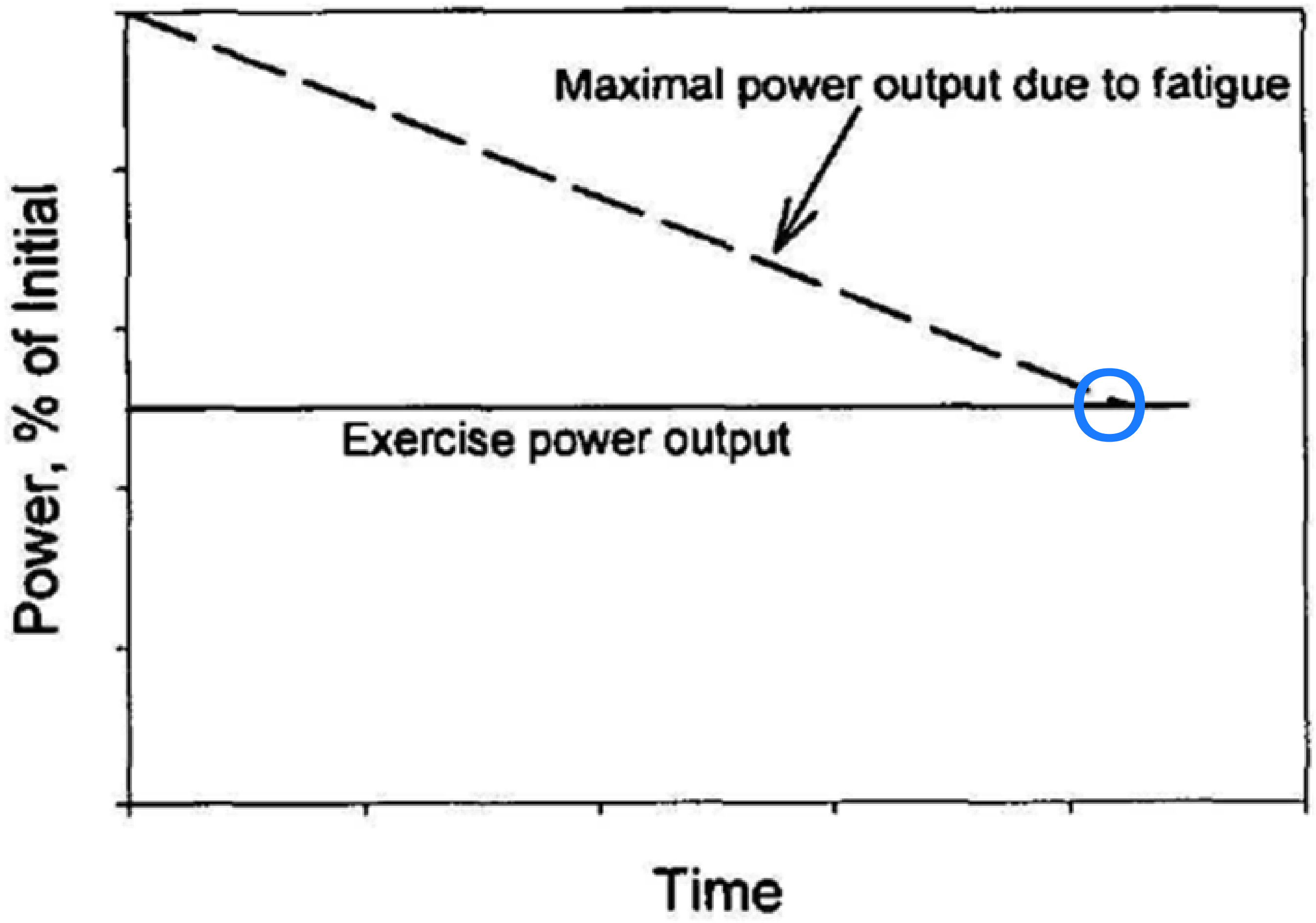


FIGURE 1—The physiological processes that can contribute to fatigue are classically categorized into two domains, those that establish the level of muscle activation (central) and those that influence contractile function (peripheral). Reprinted from the study by Enoka (16).

Central Fatigue

Basic Assumption of Physiological Model: Muscle Fatigue Causes Exhaustion



Hepple, R.T. (2002). The role of O_2 supply in muscle fatigue. **Can. J. Appl. Physiol.** 27(1): 56-69. ©2002 Canadian Society for Exercise Physiology.

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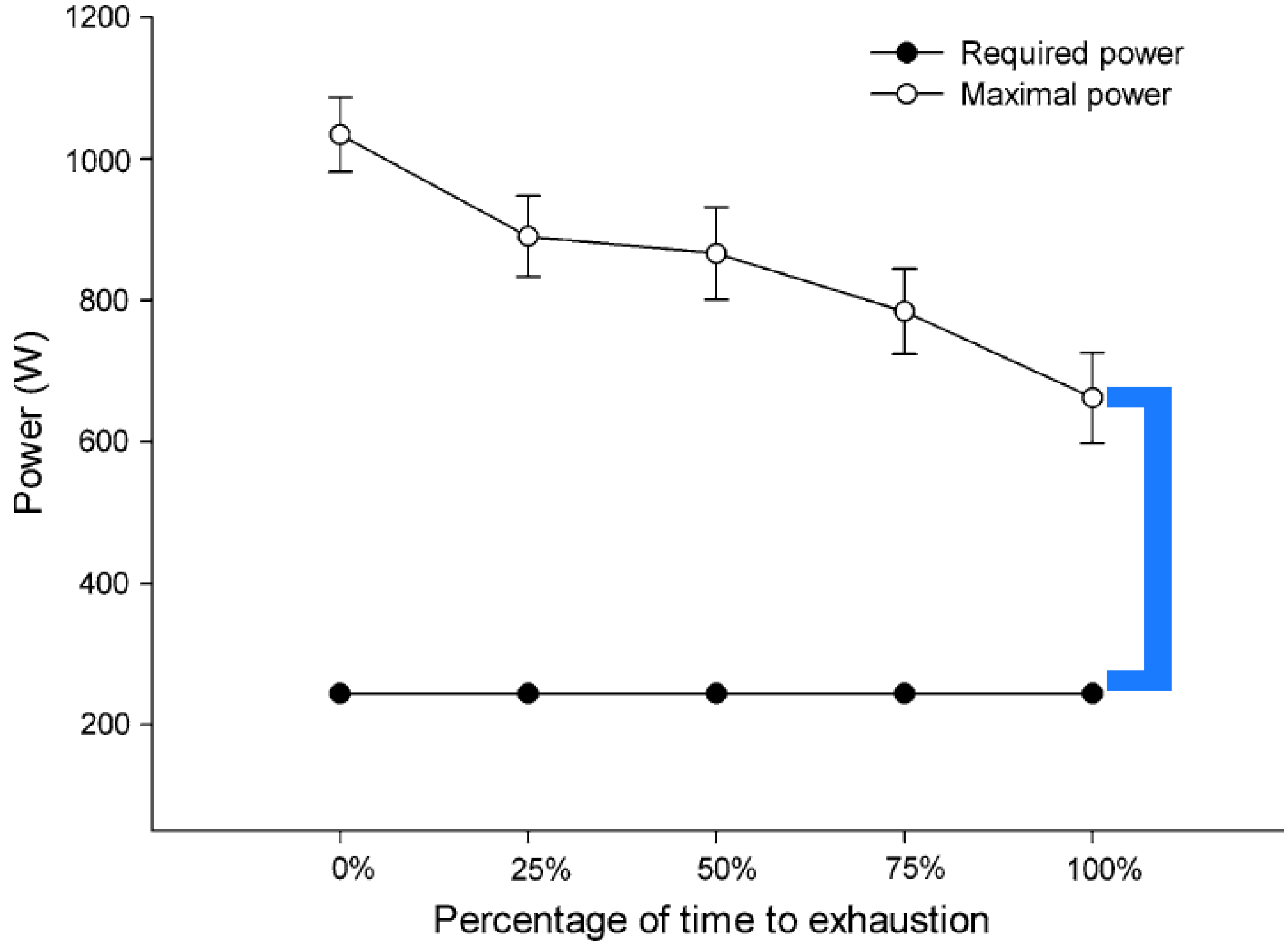
The limit to exercise tolerance in humans: mind over muscle?

Samuele Maria Marcora · Walter Staiano



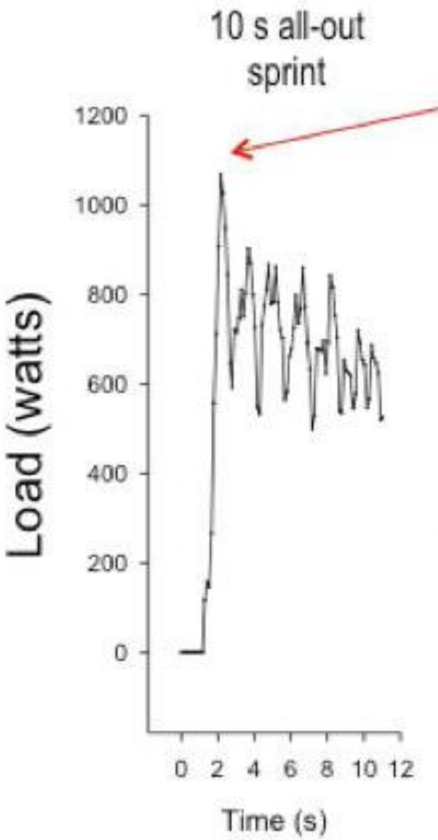
10 ± 2 minutes

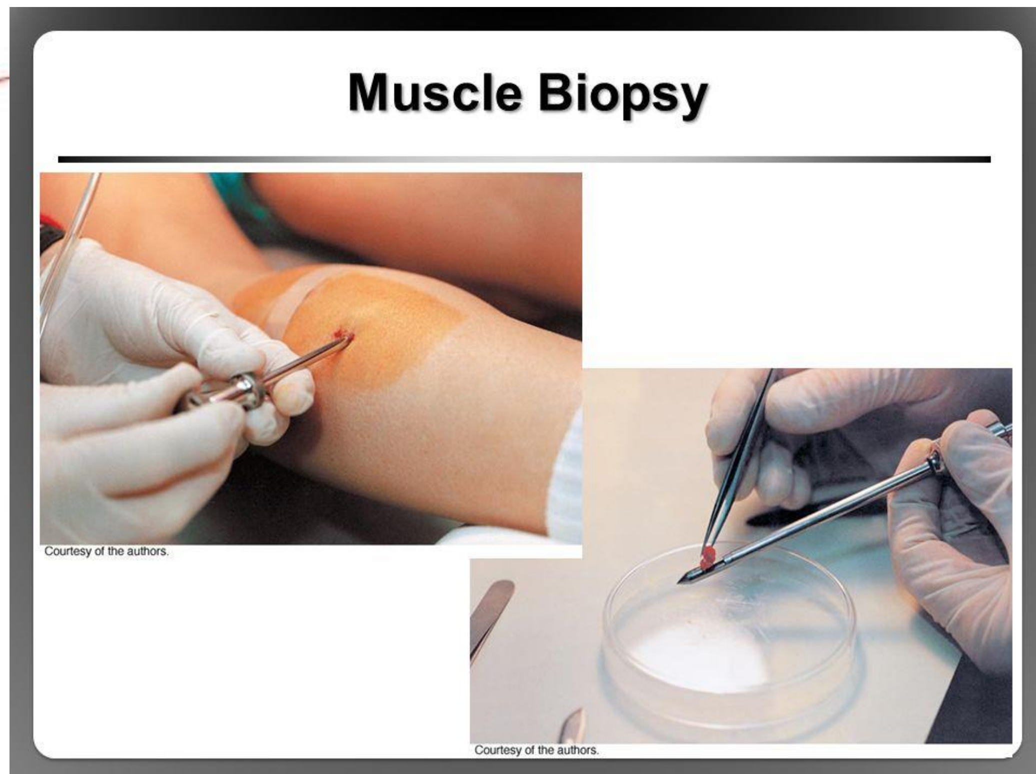
EJAP 2010; 109(4):763-70

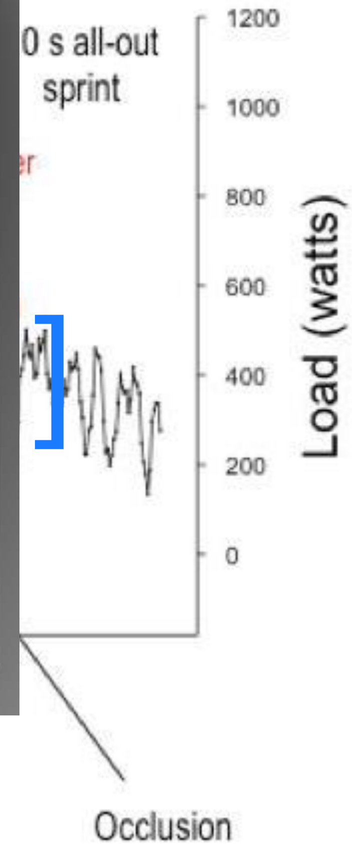
What limits performance during whole body incremental exercise to exhaustion in humans?

David Morales-Alamo[1, 2], José Losa-Reyna[1,2]; Rafael Torres-Peralta[1,2], Marcos Martin-Rincon[2,3], Mario Perez-Valera[1,2], David Curtelin[2,4], Jesús Gustavo Ponce-González[1], Alfredo Santana[1,2,5]; José A.L. Calbet[1,2].

The Journal of Physiology







Cadence fixed at 80 RPM

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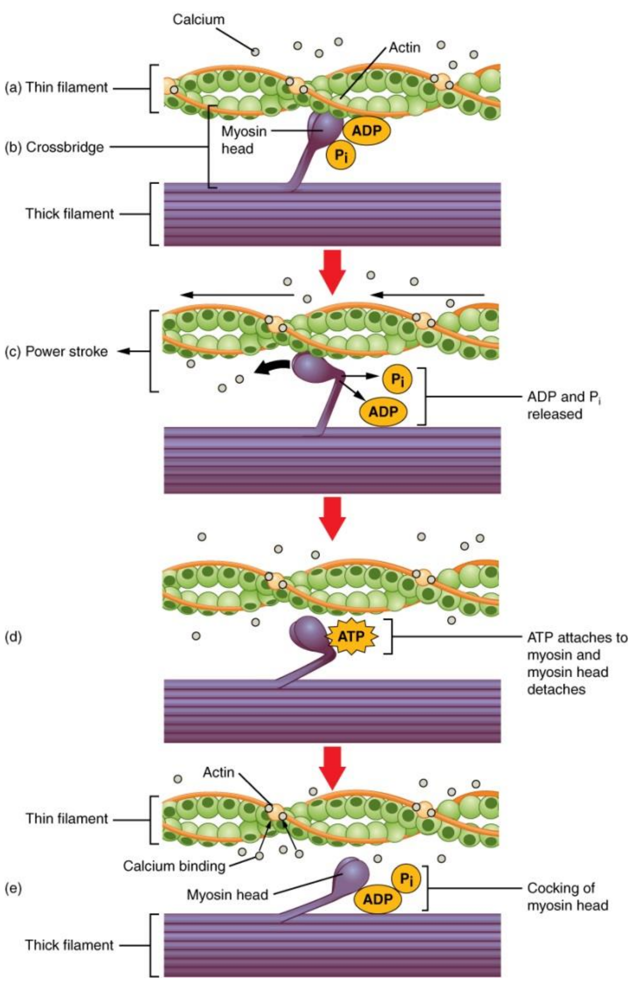

ATP at exhaustion = 17-18 mmol/kg of wet muscle

This amount of anaerobic energy would permit **7-8 extra minutes of exercise** at 100% of VO2max

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Sports Med (2015) 45:997–1015
DOI 10.1007/s40279-015-0319-6

SYSTEMATIC REVIEW

Psychological Determinants of Whole-Body Endurance Performance

Alister McCormick · Carla Meijen · Samuele Marcora

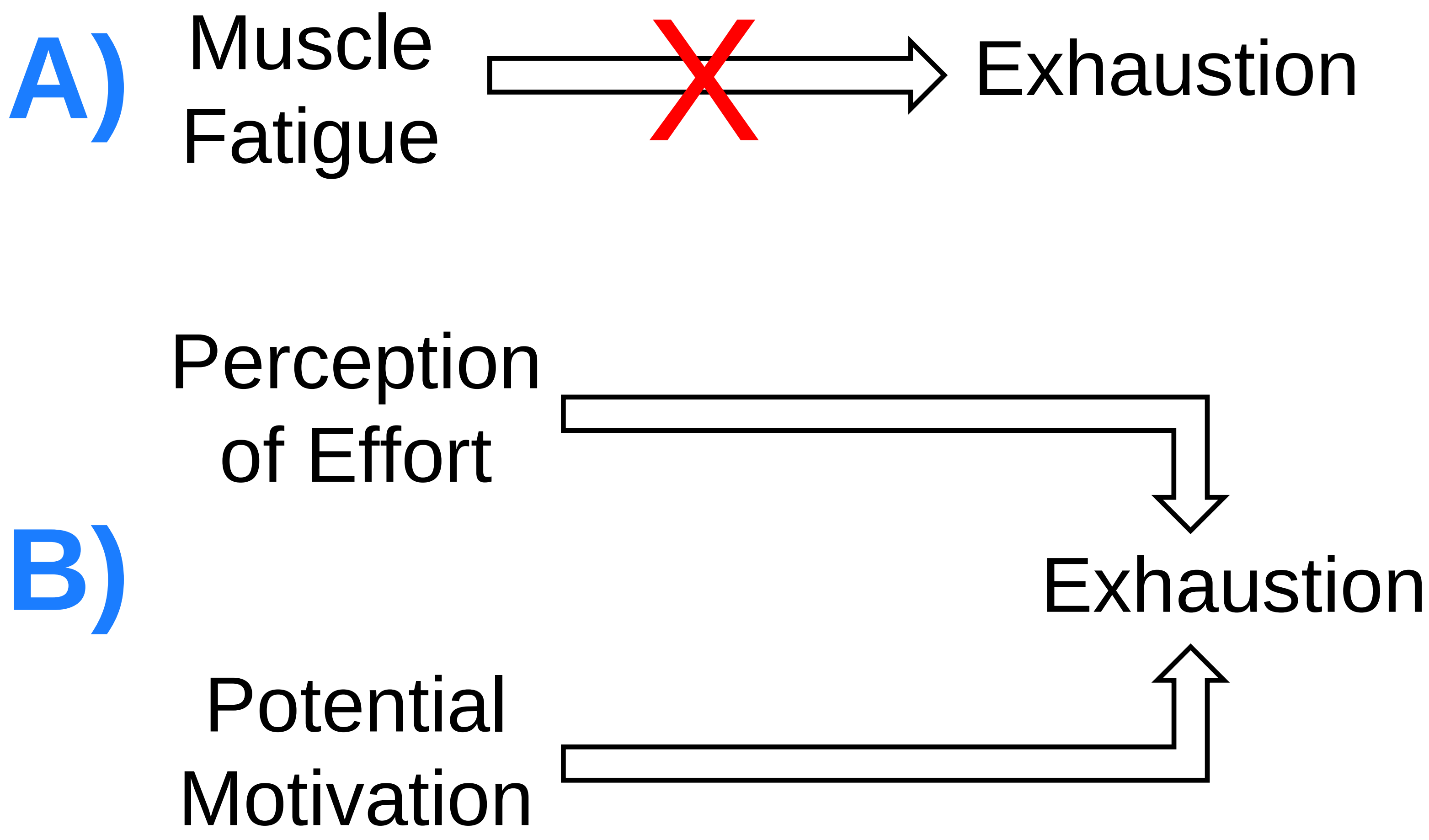
Key Points

Practical psychological interventions consistently improve endurance performance in published studies. Psychological skills training could therefore benefit an endurance athlete. There is more to learn, however, about how (i.e. mediating variables) and for whom (i.e. moderating variables) these interventions work.

Verbal encouragement and head-to-head competition can have a beneficial effect on endurance performance and should be controlled in experiments.

Mental fatigue has a negative effect on endurance performance.

What causes exhaustion?



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Perception of Effort

Physical Workload

RPE Scale

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

Psychophysical Construct

(Borg, 1965)

Leg Effort and Dyspnea

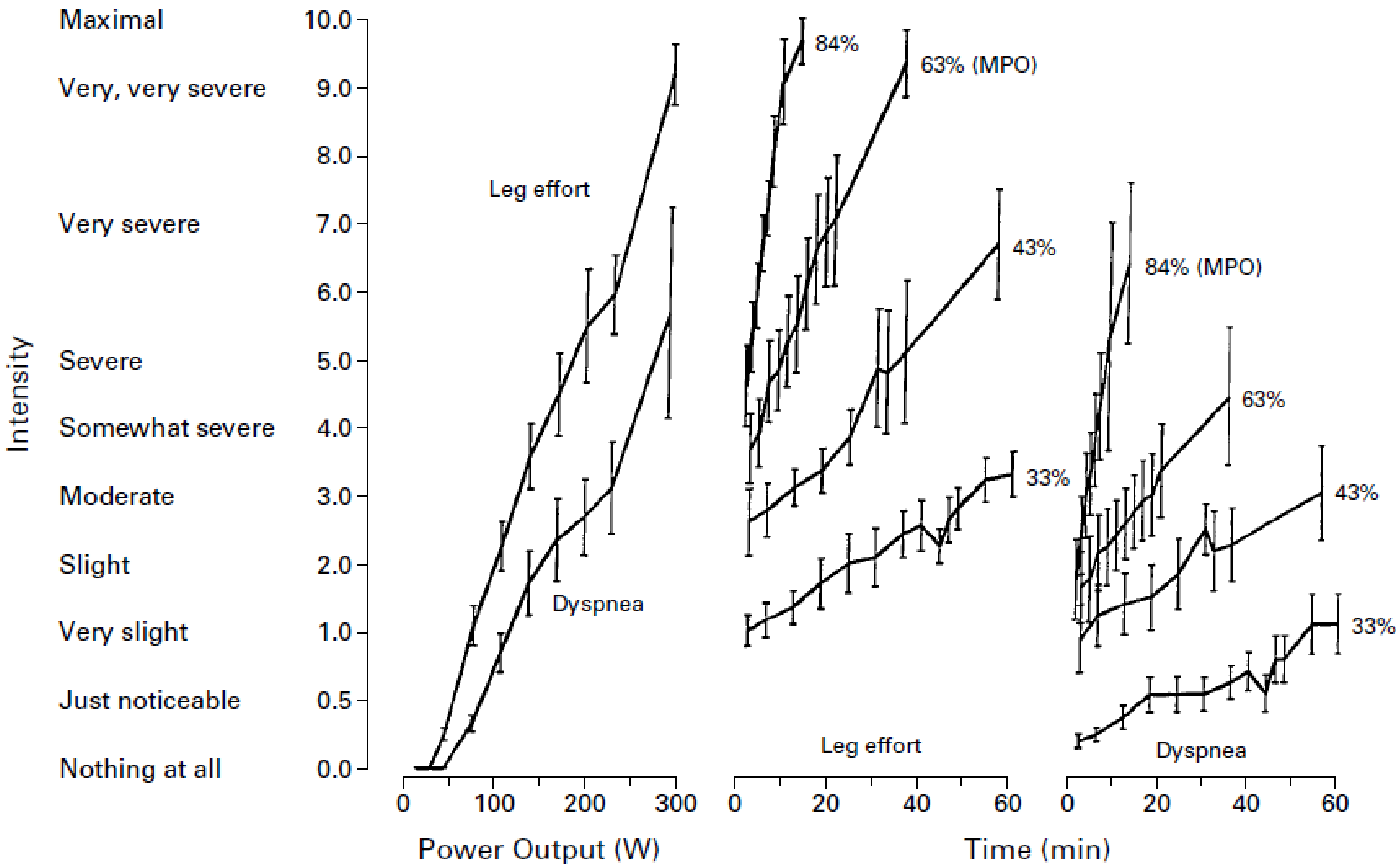

Figure 3. Intensity of Leg-Muscle Effort and Dyspnea Measured by the Borg Scale during Cycle-Ergometer Exercise in Fit Young Men. The left-hand panel shows leg effort and the degree of dyspnea during incremental exercise; the middle and right-hand panels show leg effort and the degree of dyspnea, respectively, during constant exercise at several levels, expressed as percentages of peak oxygen consumption ($\dot{V}_{O_2,max}$). MPO denotes maximal power output. Adapted from Kearon et al.,[8] with the permission of the publisher.

(Jones and Killian, 2000)

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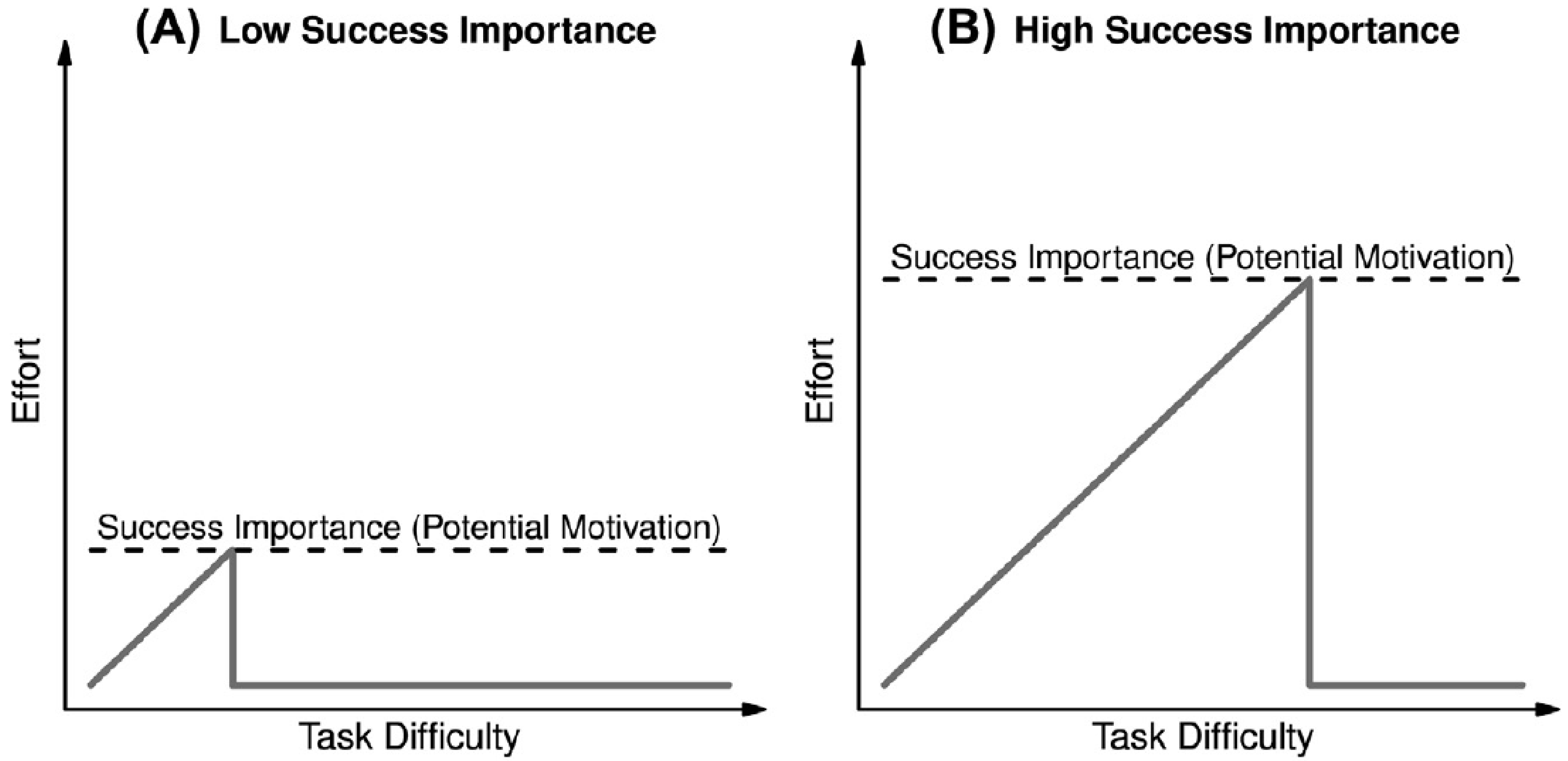
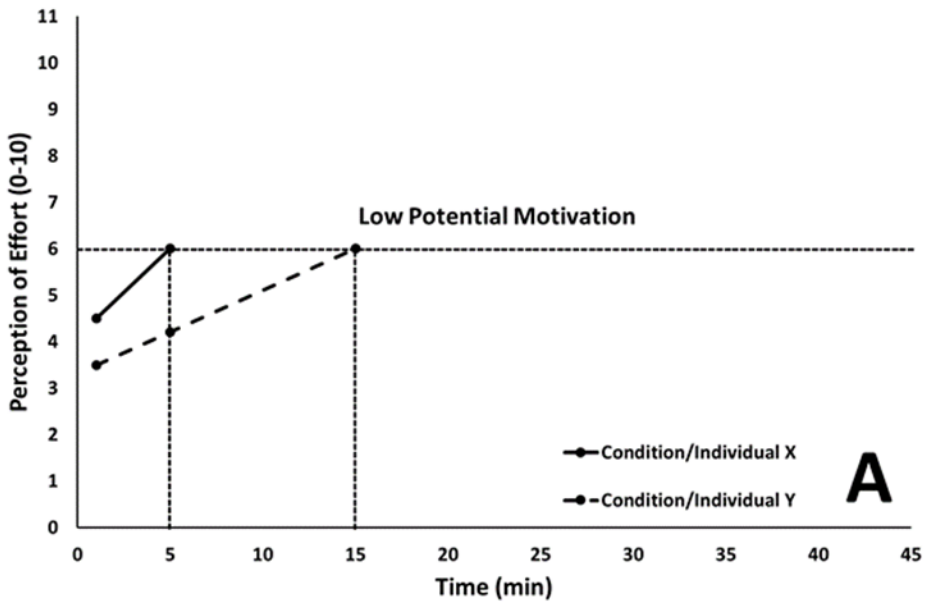
THE INTENSITY OF MOTIVATION

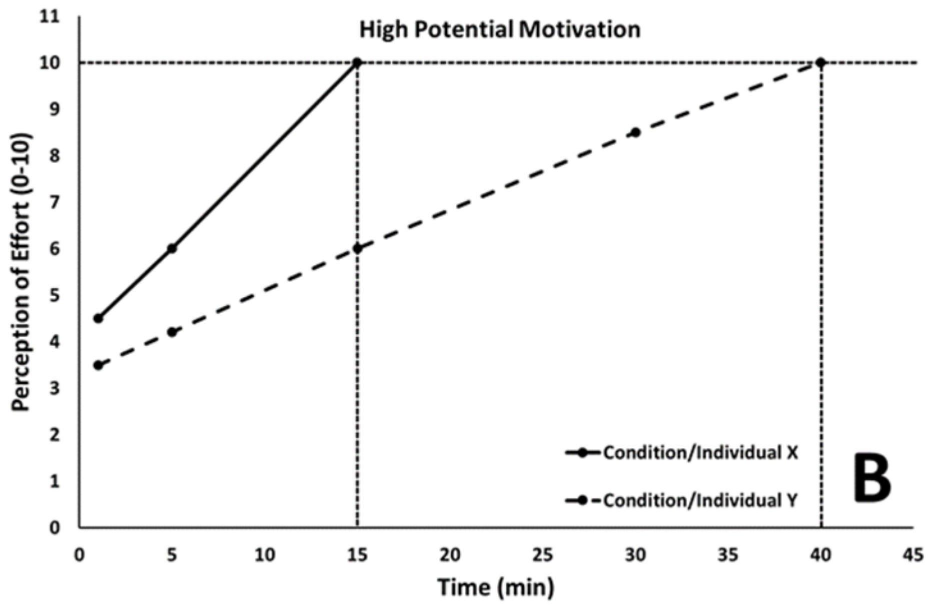
Jack W. Brehm and Elizabeth A. Self *Ann. Rev. Psychol. 1989. 40:109–31*



Potential motivation = maximum effort one is willing to exert in order to succeed in the task.

B) Psychobiological Model of Endurance Performance





(Marcora, 2007, 2008a, 2008b, 2009, 2010, 2012, 2015, 2020)

B) Psychobiological Model of Endurance Performance

Experimentally testable predictions:

- **An increase in motivation increases time to exhaustion**
- An increase in perception of effort reduces time to exhaustion
- A reduction in perception of effort increases time to exhaustion

(Marcora, 2007, 2008a, 2008b, 2009, 2010, 2012, 2015, 2020)

Wilmore JH. Influence of motivation on physical work capacity and performance. *Journal of Applied Physiology* 24: 459-463, 1968.

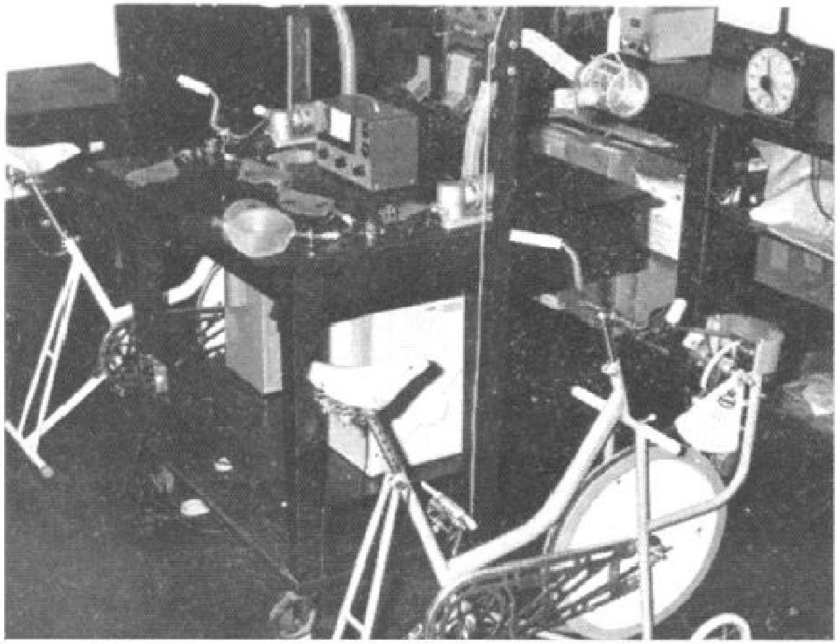
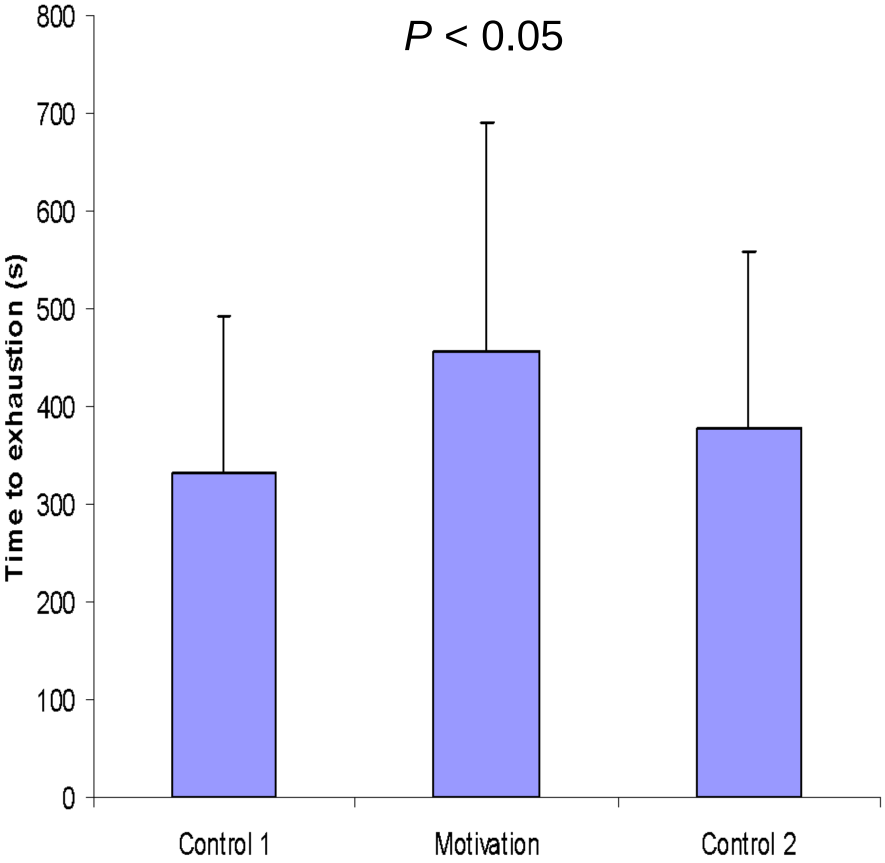


FIG. 1. Physical arrangement which permitted the simultaneous testing of endurance capacity of two paired subjects under condition E. It should be noted that the subjects were placed side by side, each having an independent but identical system for monitoring and collecting expired air and each having an unhindered view of the timer which indicated the duration of the test.



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(Marcora, 2007, 2008a, 2008b, 2009, 2010, 2012, 2015, 2020)

Muscle Fatigue

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Mental Fatigue and Endurance Performance

Muscle Fatiguing Task

100 Drop Jumps
(one jump every 20 seconds)

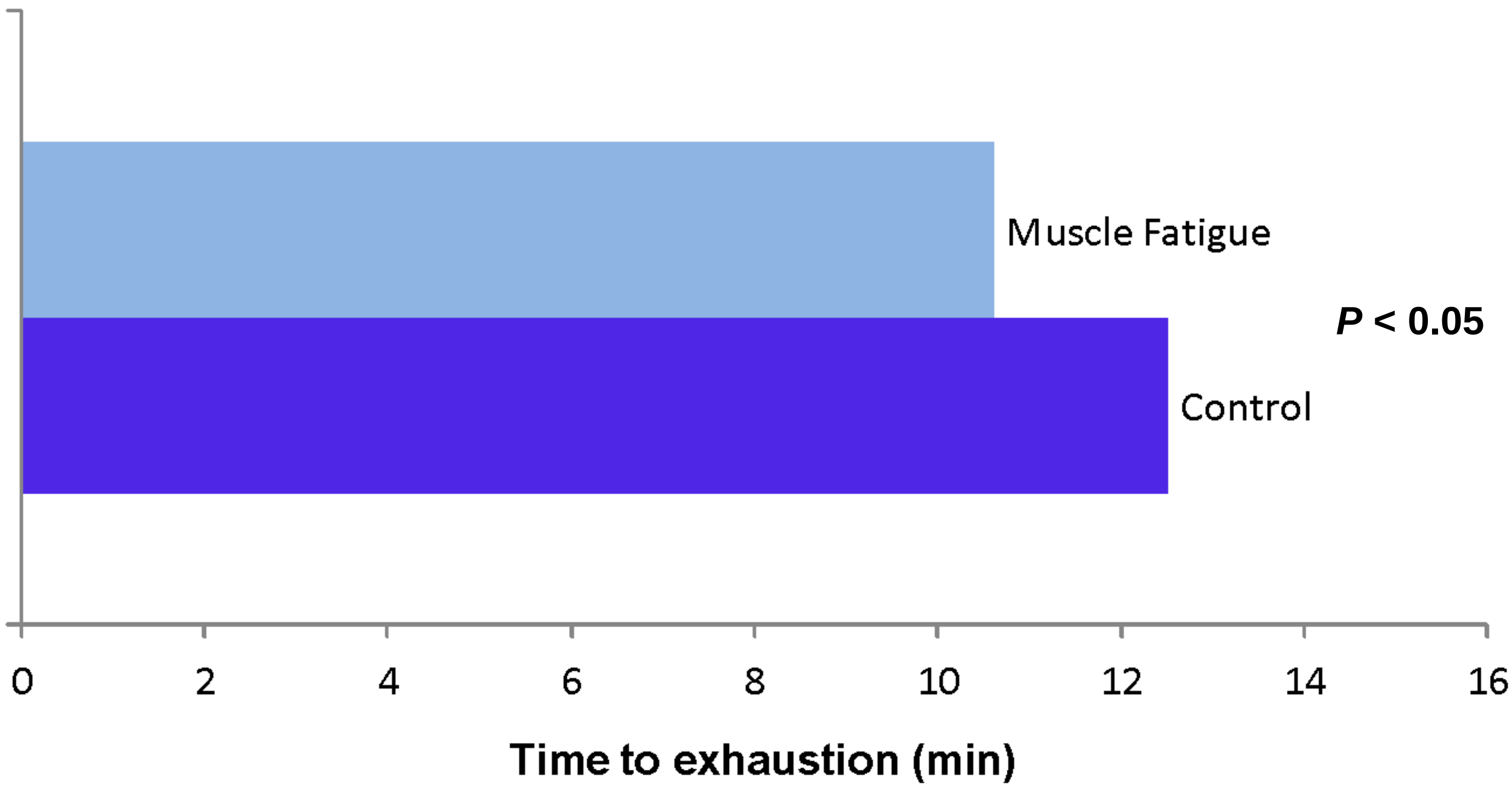
Endurance Performance

Time to Exhaustion at 230W
(80% of Peak Power Output)

(Marcora et al., JAP 2008)

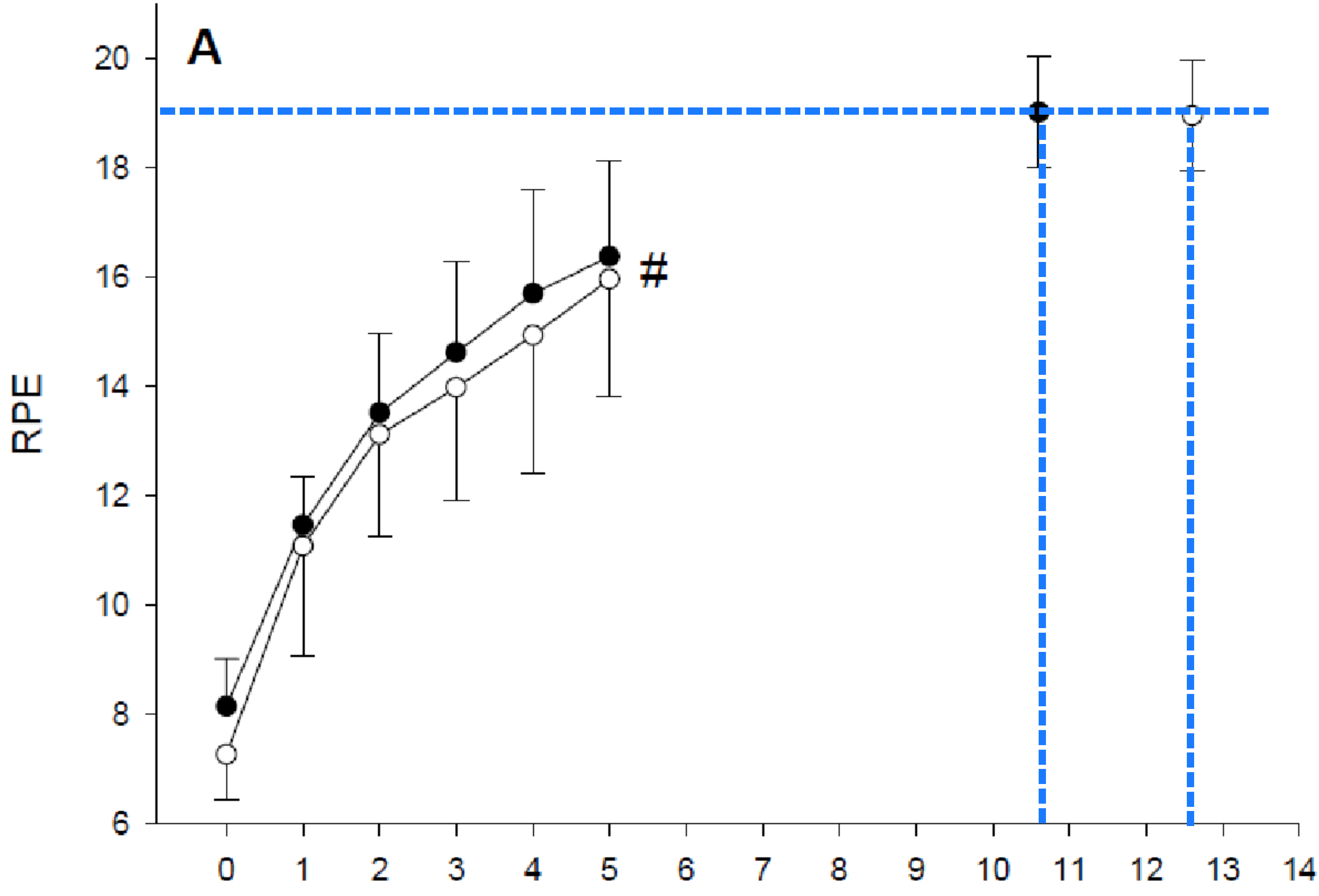
Randomized crossover experiment N = 10

Muscle Fatigue and Endurance Performance



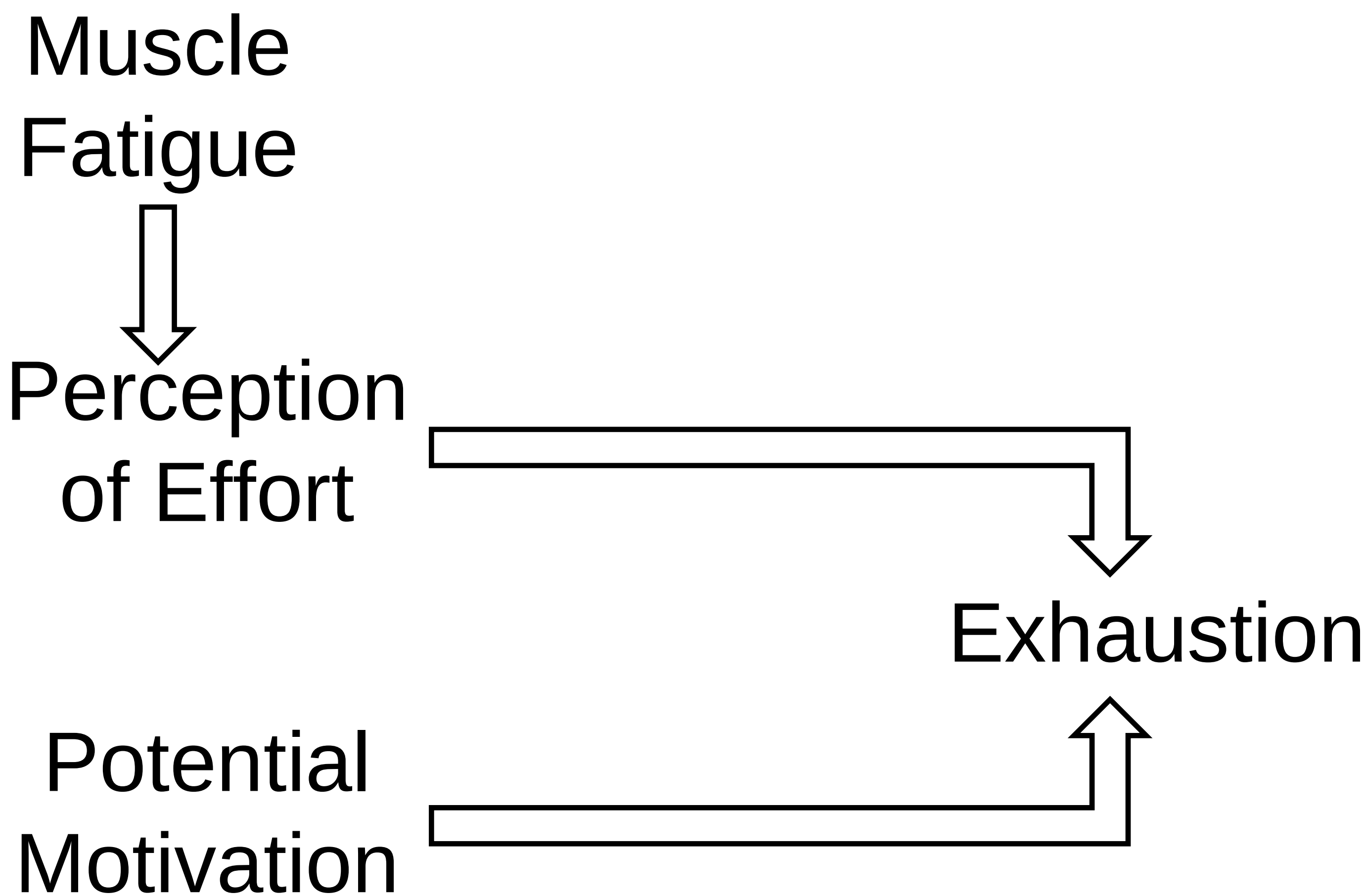
Marcora et al. AJP- Reg, Integr and Comp Physiol, 2008.

Muscle Fatigue and Endurance Performance



Marcora et al. AJP- Reg, Integr and Comp Physiol, 2008.

What causes exhaustion?



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Mental Fatigue

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Mental Fatigue and Endurance Performance

Mentally Fatiguing Task

AX-Continuous Performance Task (AX-CPT) for 90 min

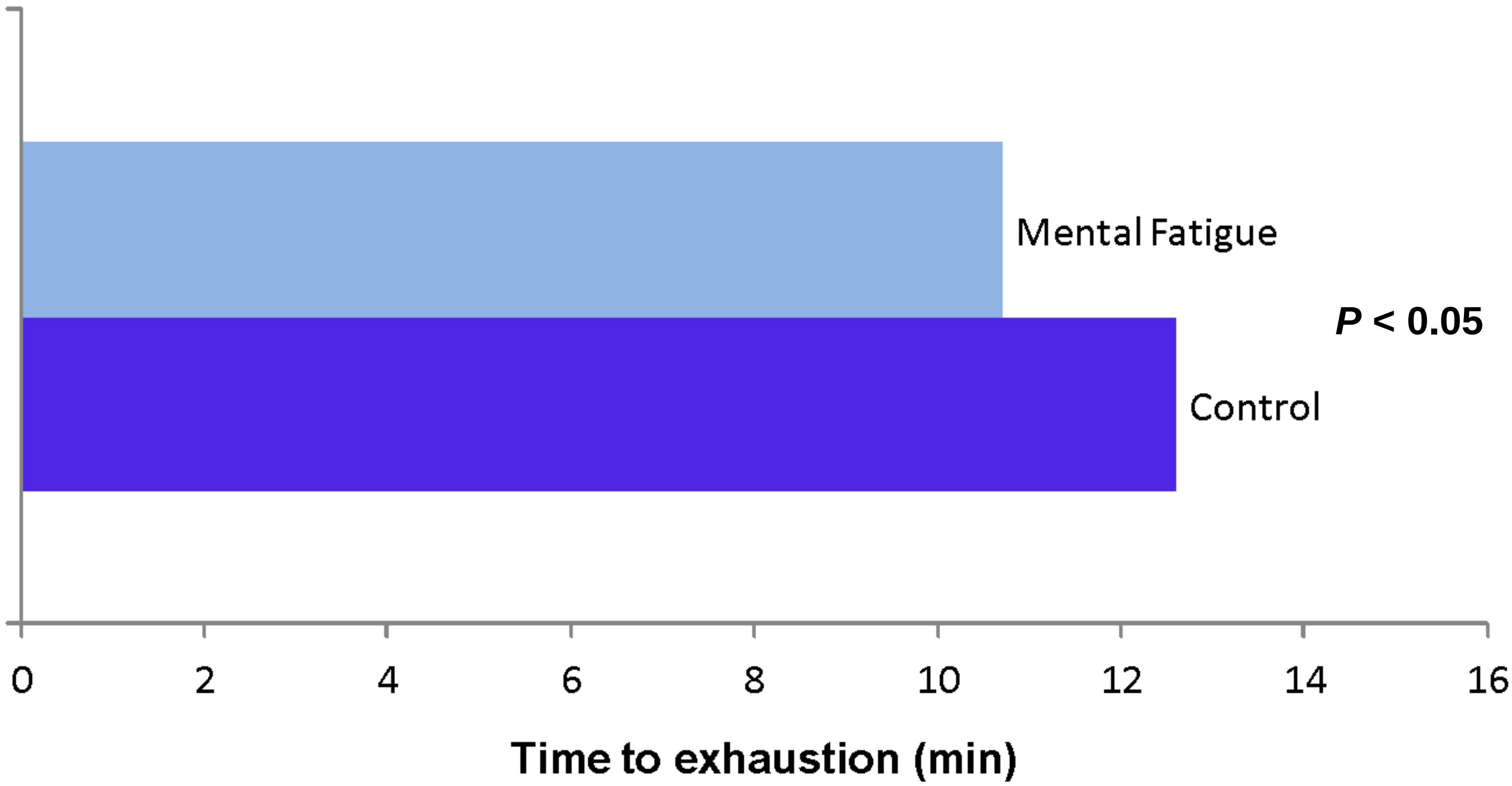
Endurance Performance

Time to Exhaustion at 230W (80% of Peak Power Output)

(Marcora et al., JAP 2009)

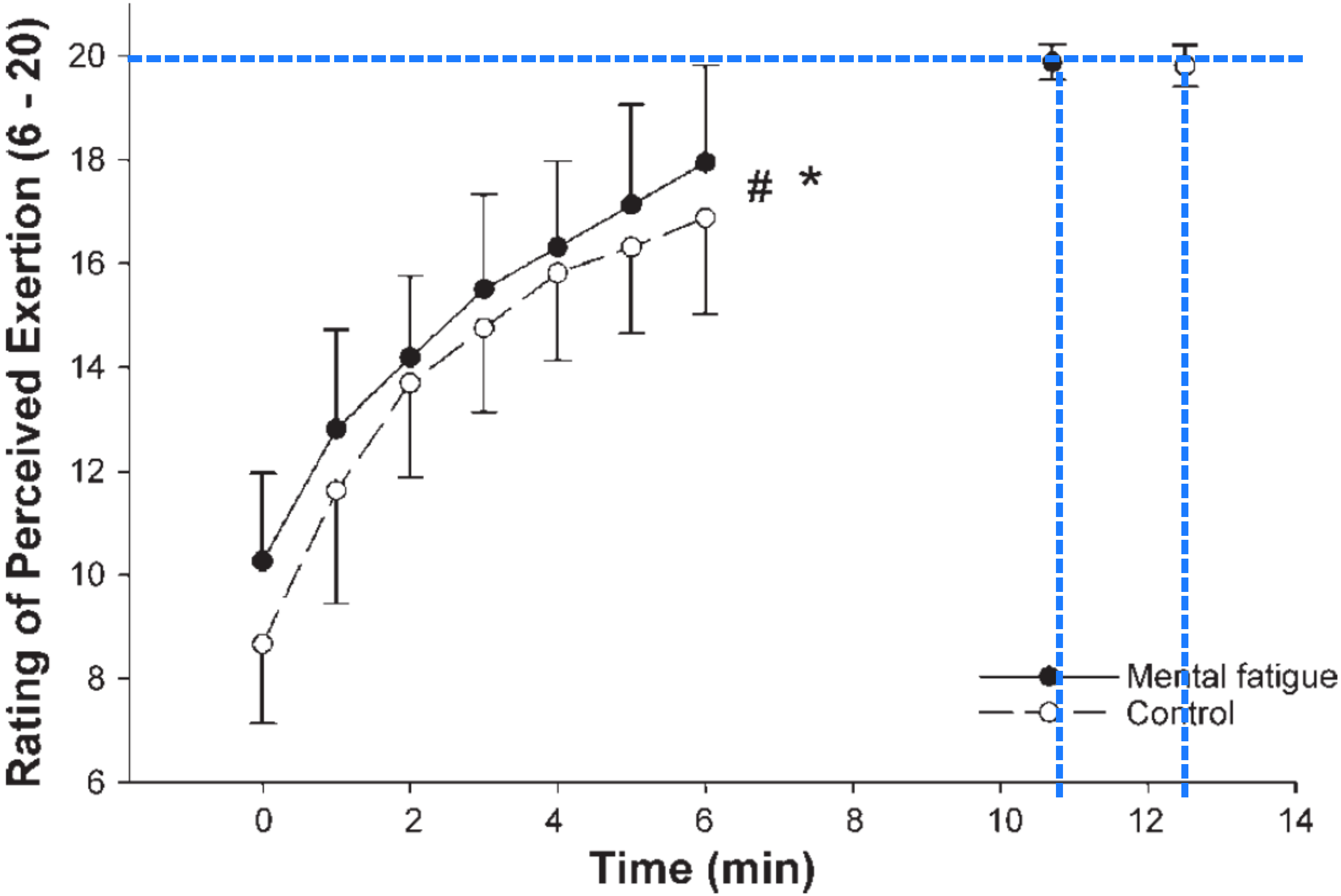
Randomized crossover experiment N = 16

Mental Fatigue and Endurance Performance



(Marcora et al., JAP 2009)

Mental Fatigue and Endurance Performance



(Marcora et al. JAP 2009)

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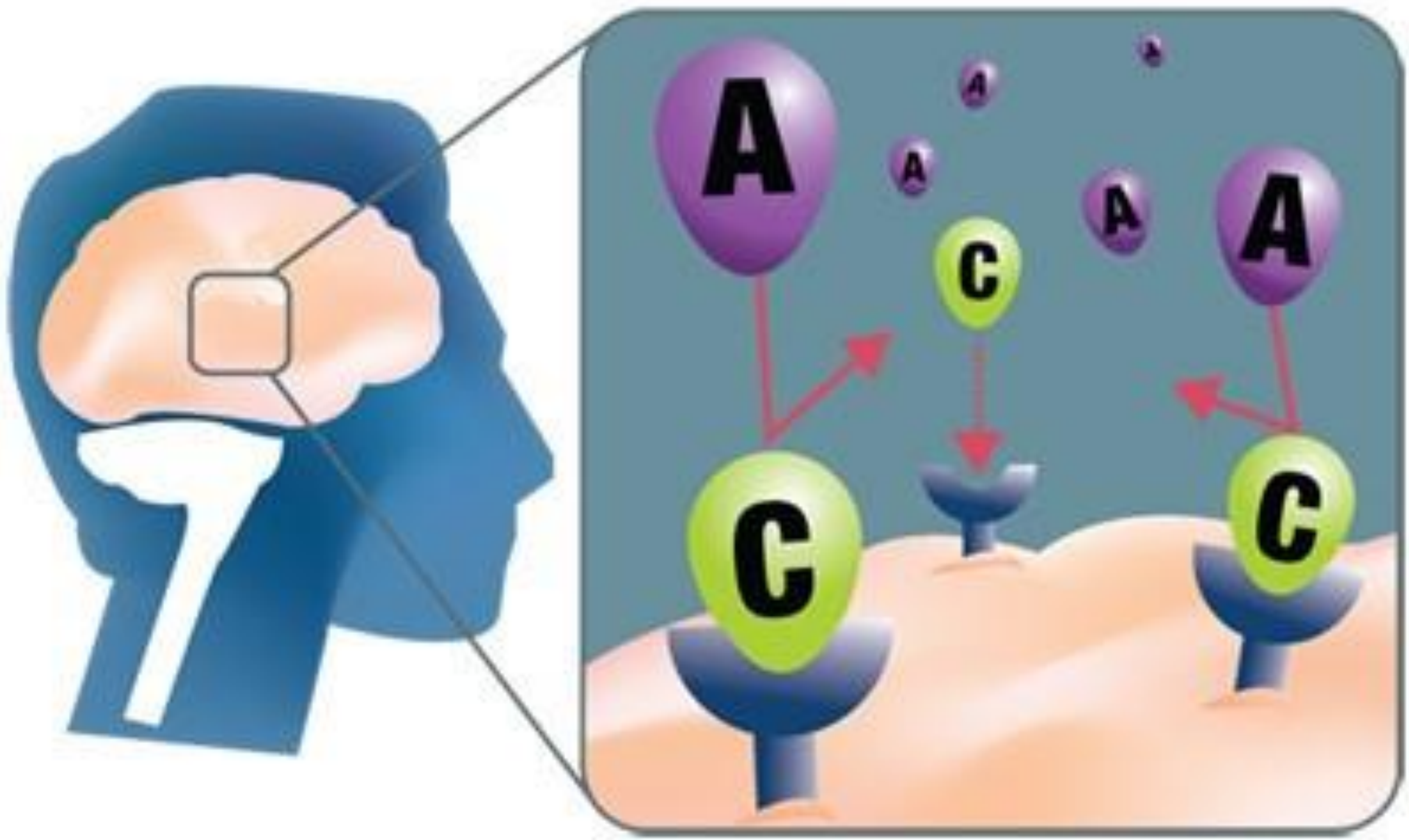
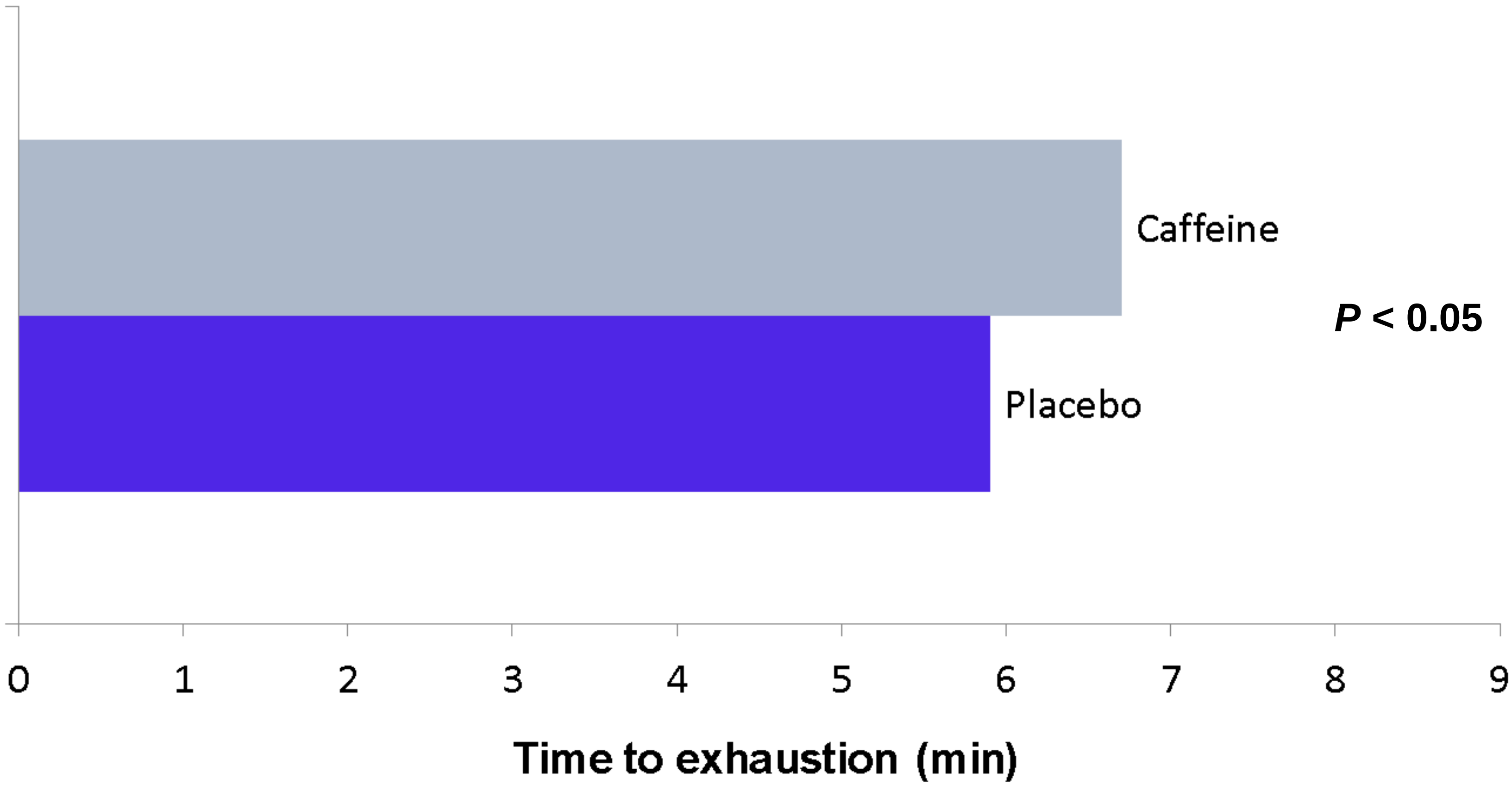
(Marcora, 2007, 2008a, 2008b, 2009, 2010, 2012, 2015, 2020)

Caffeine Supplementation

Caffeine Supplementation

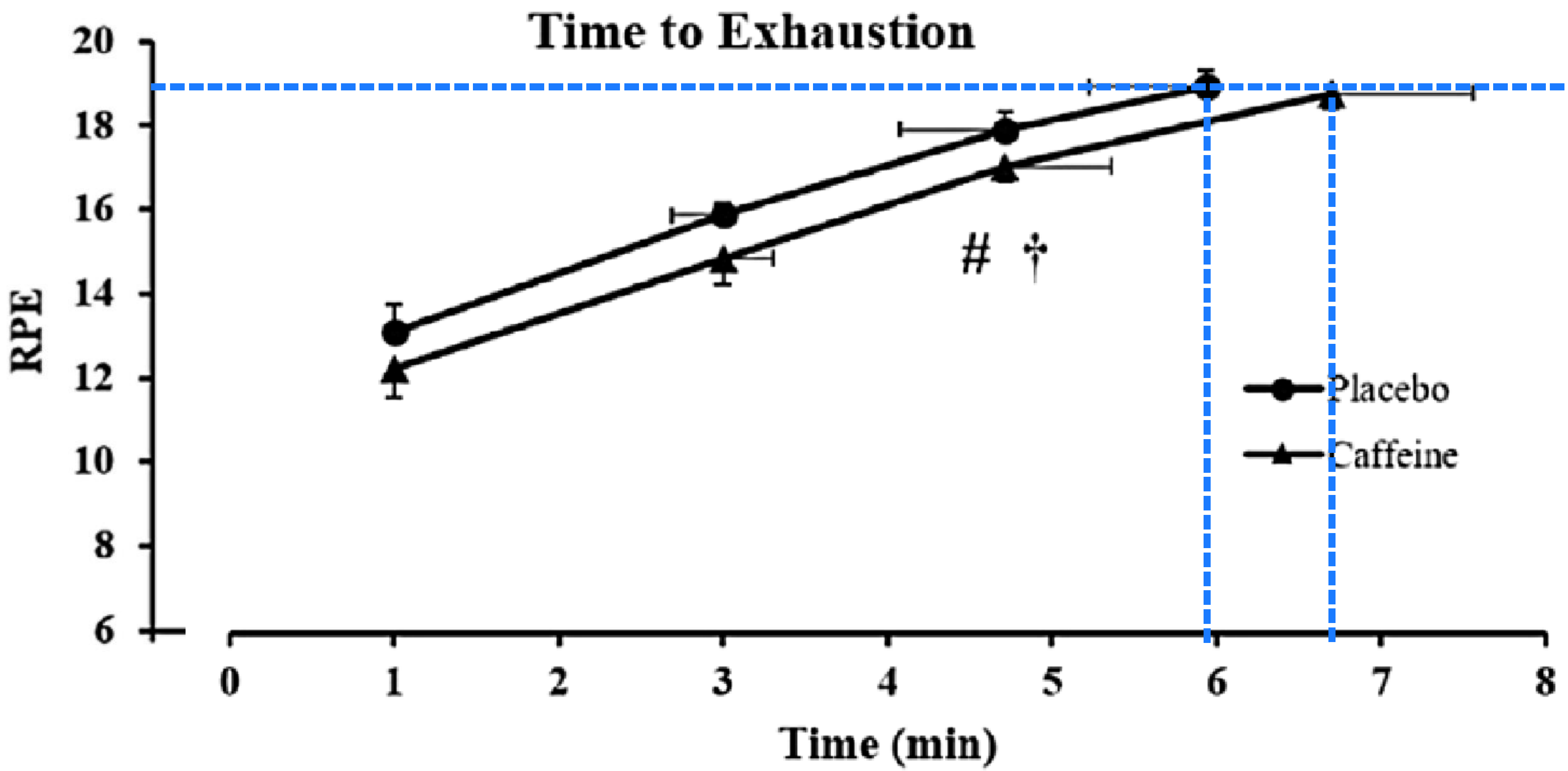


Caffeine Supplementation



Smirmaul et al. EJAP, 2017.

Caffeine Supplementation



Smirmaul et al. EJAP, 2017.

Self-Talk and Endurance Performance

Self-Talk and Endurance Performance

Self-Talk Statements

Hang on in there

Come on, get up for it

Go for it

Dig Depp

Push It

You're a winner

You can do it

Keep going, be strong

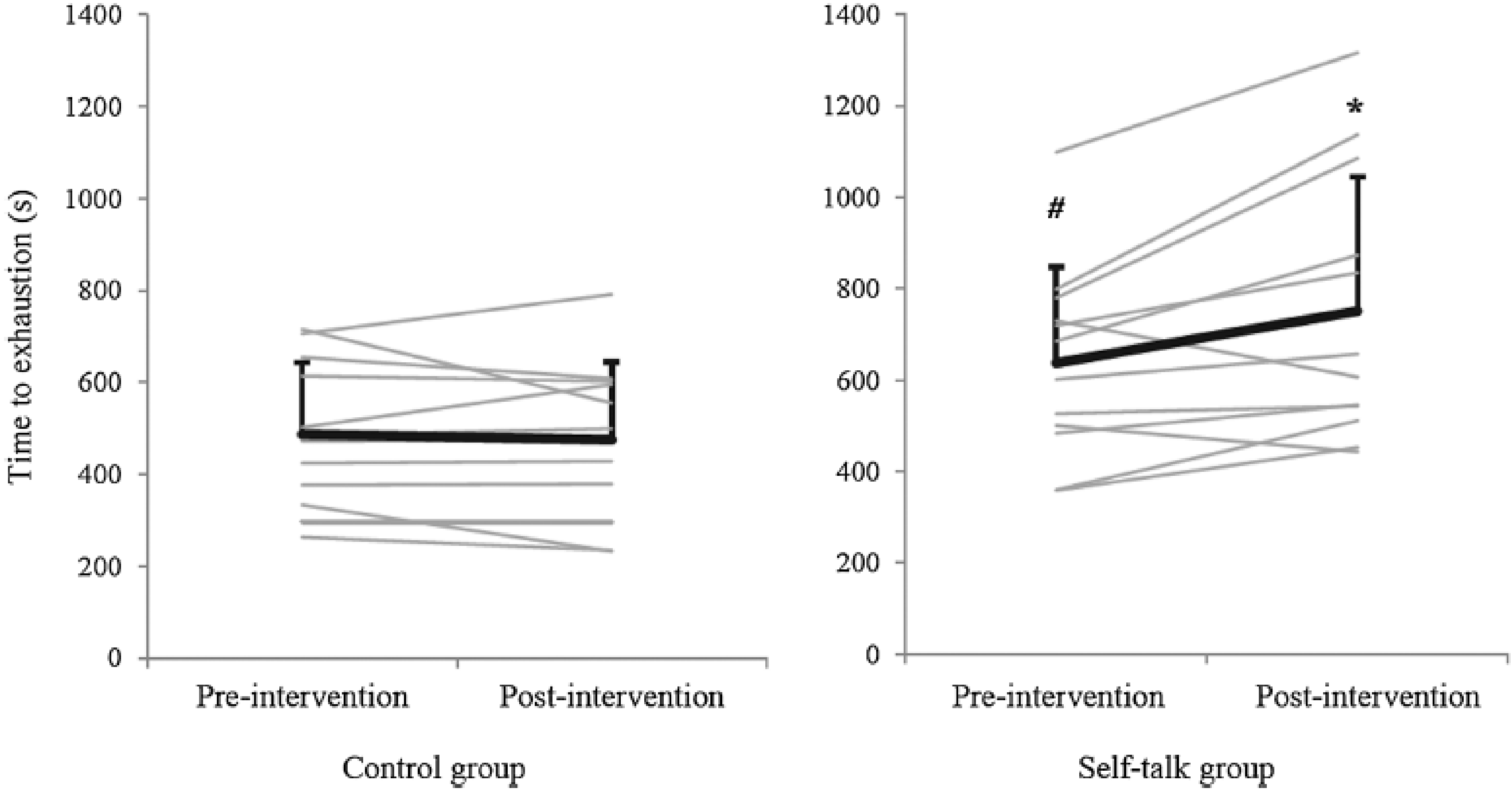
Endurance Performance Test

Time to Exhaustion at 80% Peak Power Output

(Blanchfield et al., MSSE 2014)

RCT: n = 12 Self-Talk vs. n = 12 Control

Self-Talk and Endurance Performance



(Blanchfield et al., MSSE 2014)

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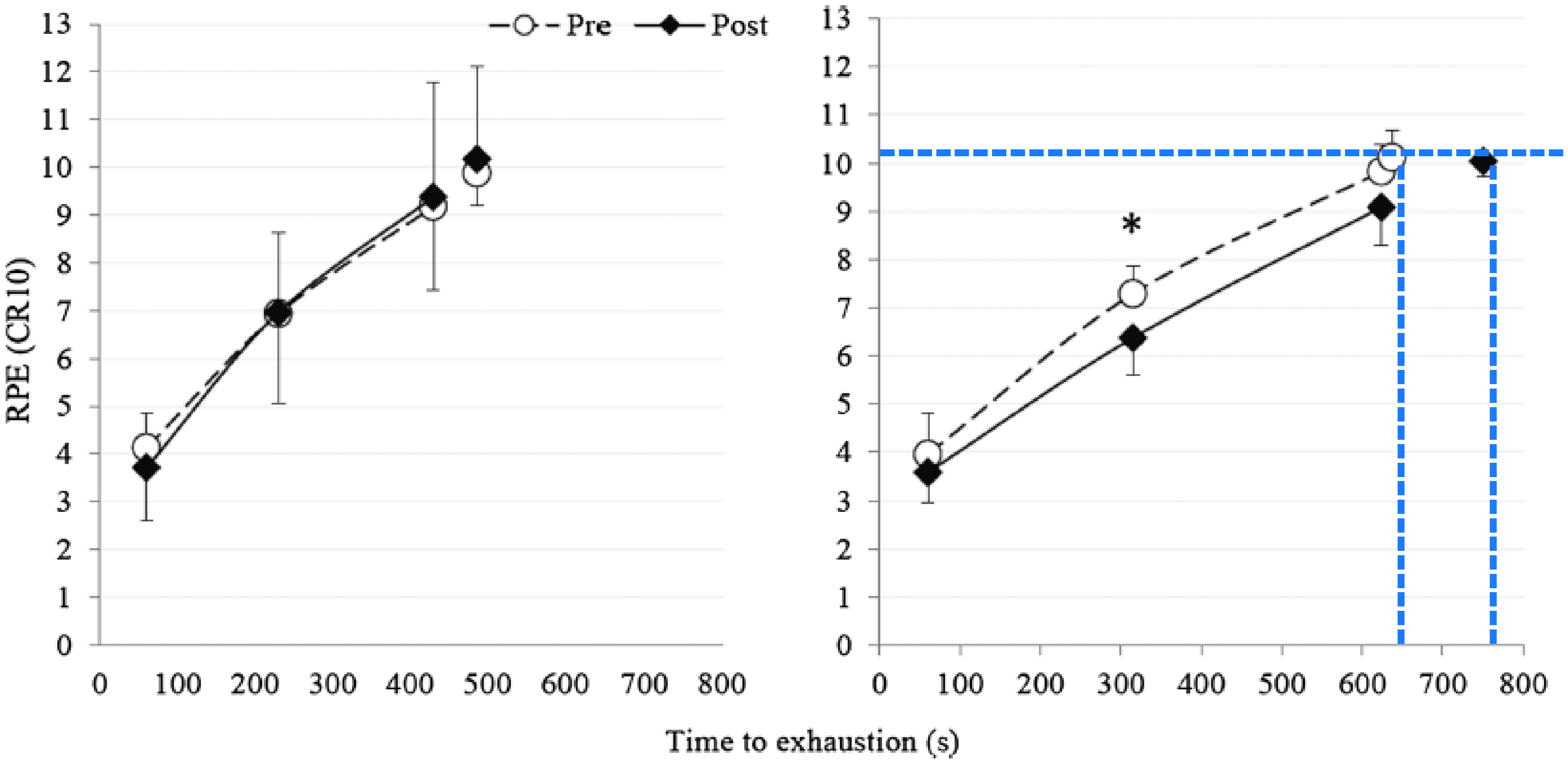
Self-Talk and Endurance Performance



(Blanchfield et al., MSSE 2014)

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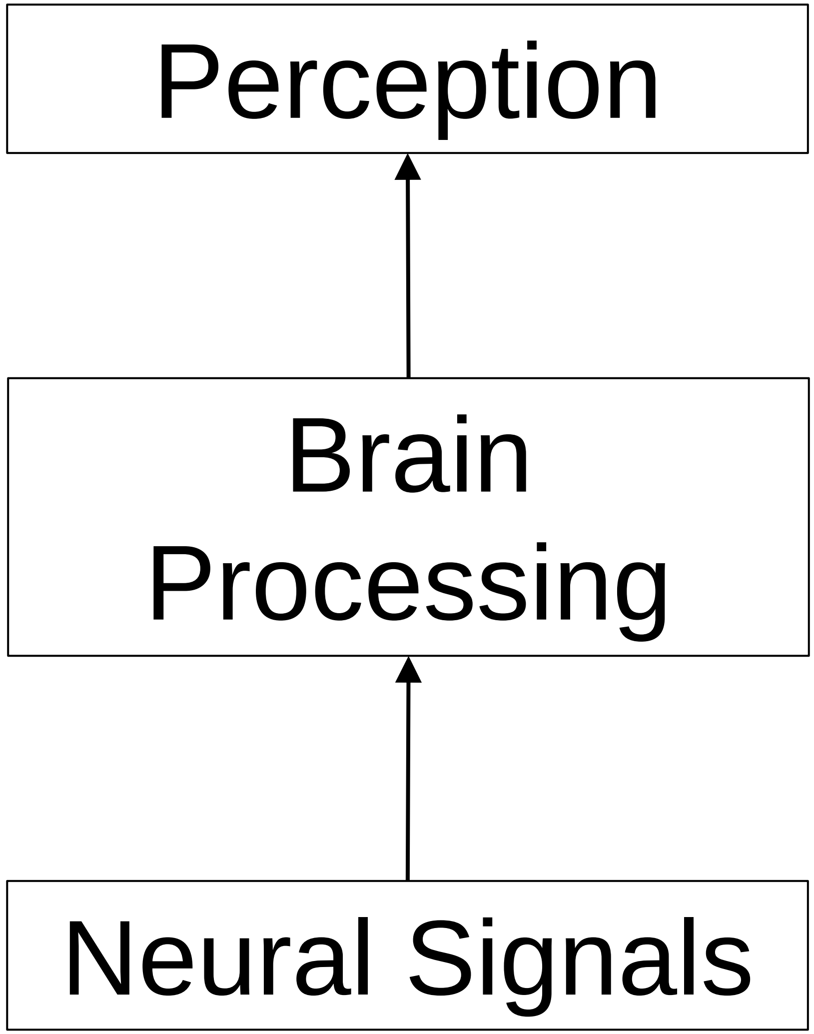
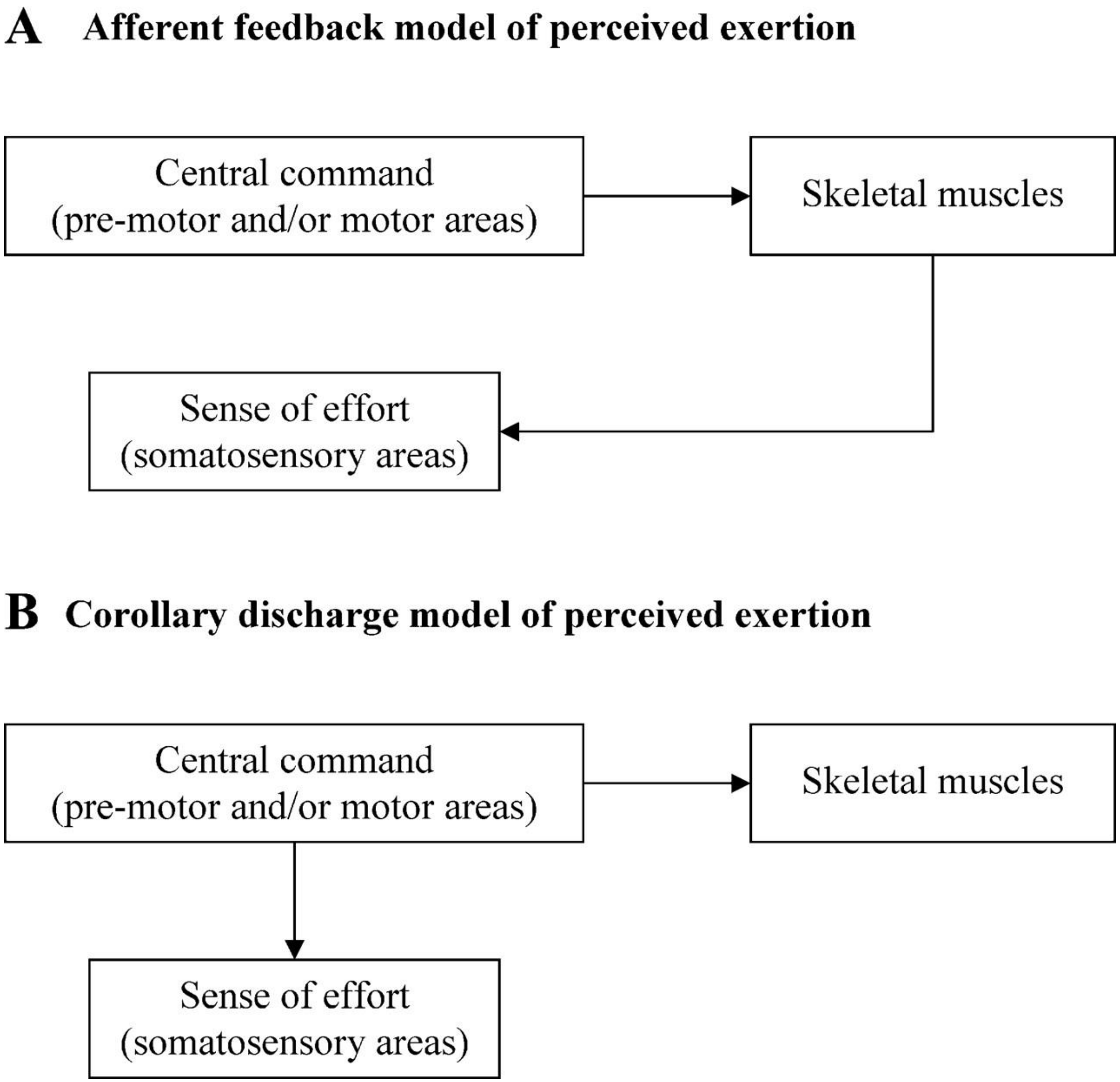
Neurophysiology of Perception of Effort

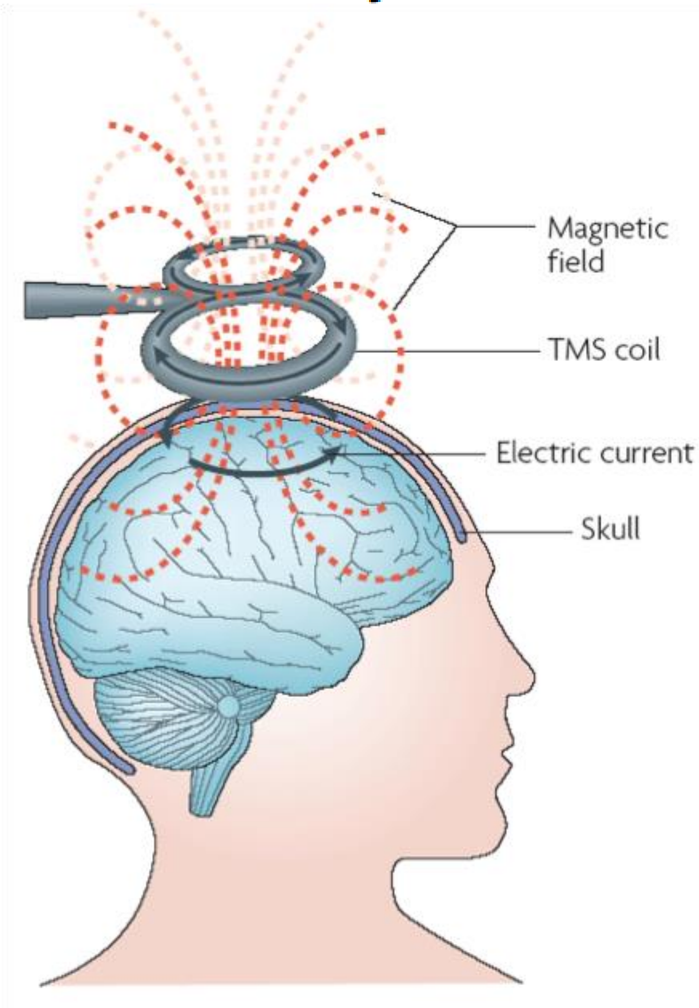


Neurophysiology of Perception of Effort



(Marcora. JAP 2009)

Disrupting the Supplementary Motor Area Makes Physical Effort Appear Less Effortful



These findings indicate that **effort perception relies on the processing of a signal originating from motor-related neural circuits upstream of M1** and that SMA is a key node of this network

Zenon et al. The Journal of Neuroscience. 2015, 35(23): 8737-8744.

Practical Applications:

- **Improve physical fitness and minimize muscle fatigue** through regular physical training, monitoring, tapering, and nutrition (e.g. carbs and hydration)
- **Minimize mental fatigue** through monitoring, tapering, reduction of sport-related and external psychological load, caffeine
- **Make systematic use of psychological interventions** known to improve endurance performance
- **Future**: Brain Endurance Training (BET), brain stimulation, neurofeedback, non-conscious psychological interventions, […]

Ekblom, B. and A. N. Goldbarg. *The influence of physical training and other factors on the subjective rating of perceived exertion.* Acta physiol. scand. 1971. *83*. 399—406.

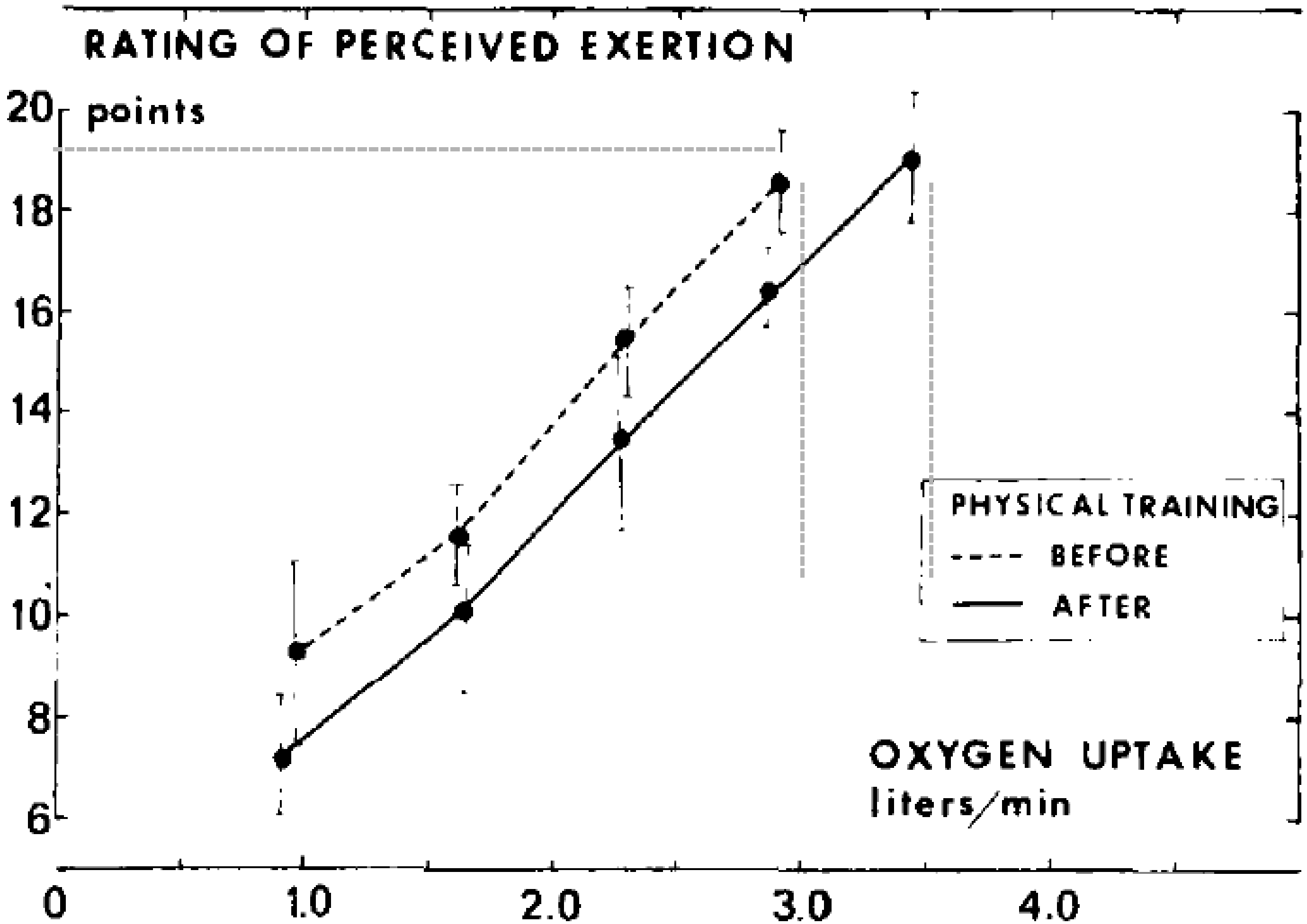


Fig. 6. Effects of physical training on perceived exertion. Means and standard deviations (8 subjects).

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Psychobiological Monitoring

Viveiros et al. (2011)

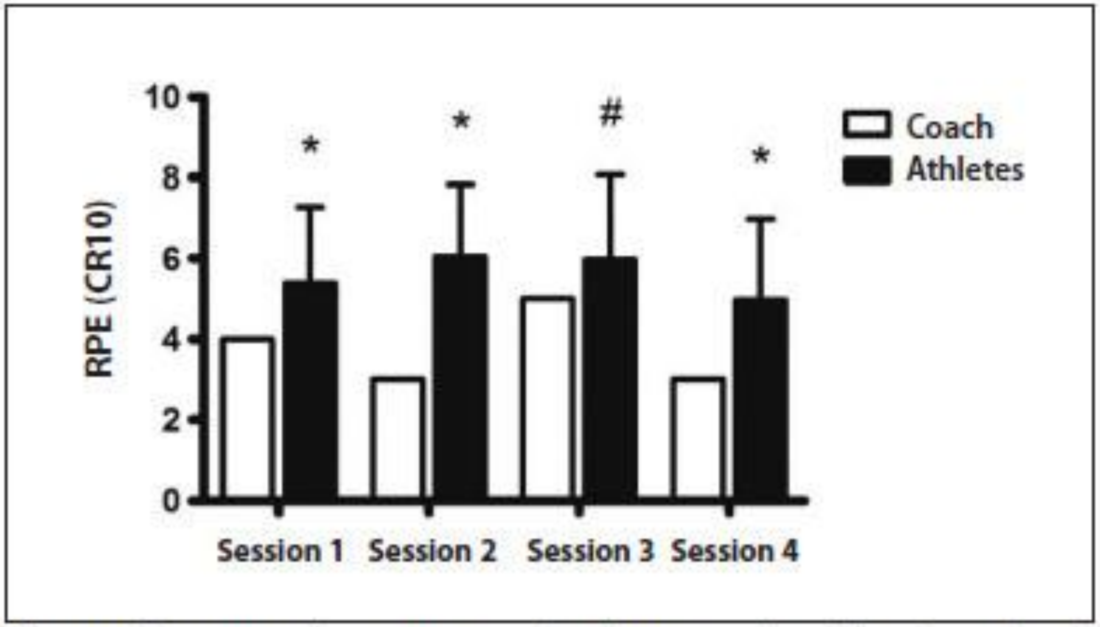


Figure 1. Comparison between training load intensity planned by the coach and the training load intensity experienced by the athletes (n = 40) through the session RPE method.

* = $p < 0.0001$ concerning the load intensity expected by the coach; # = $p < 0.02$ concerning the load intensity expected by the coach.

Psychobiological Monitoring

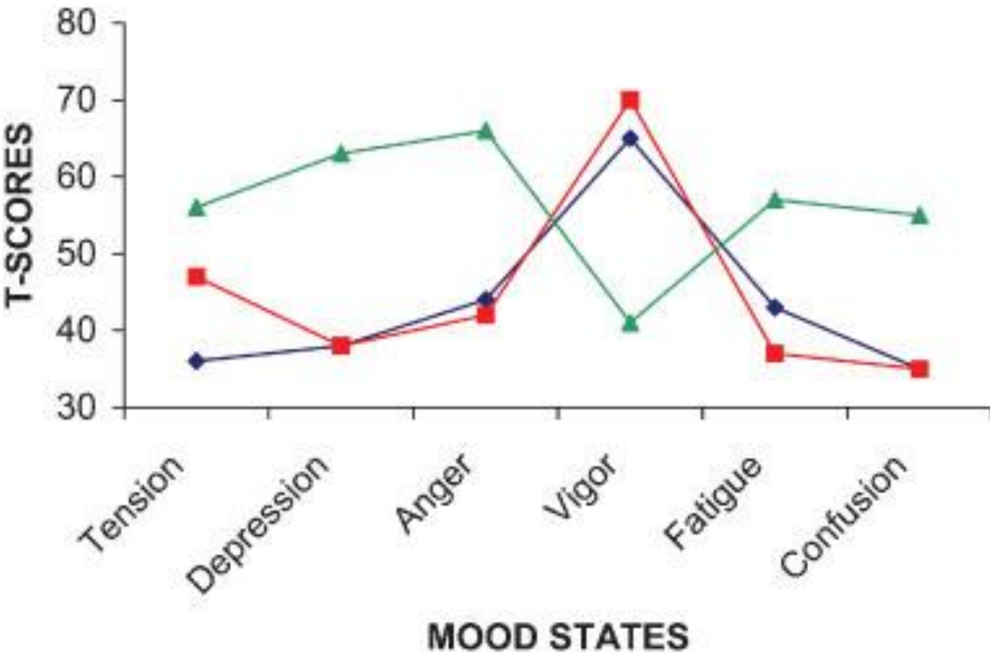
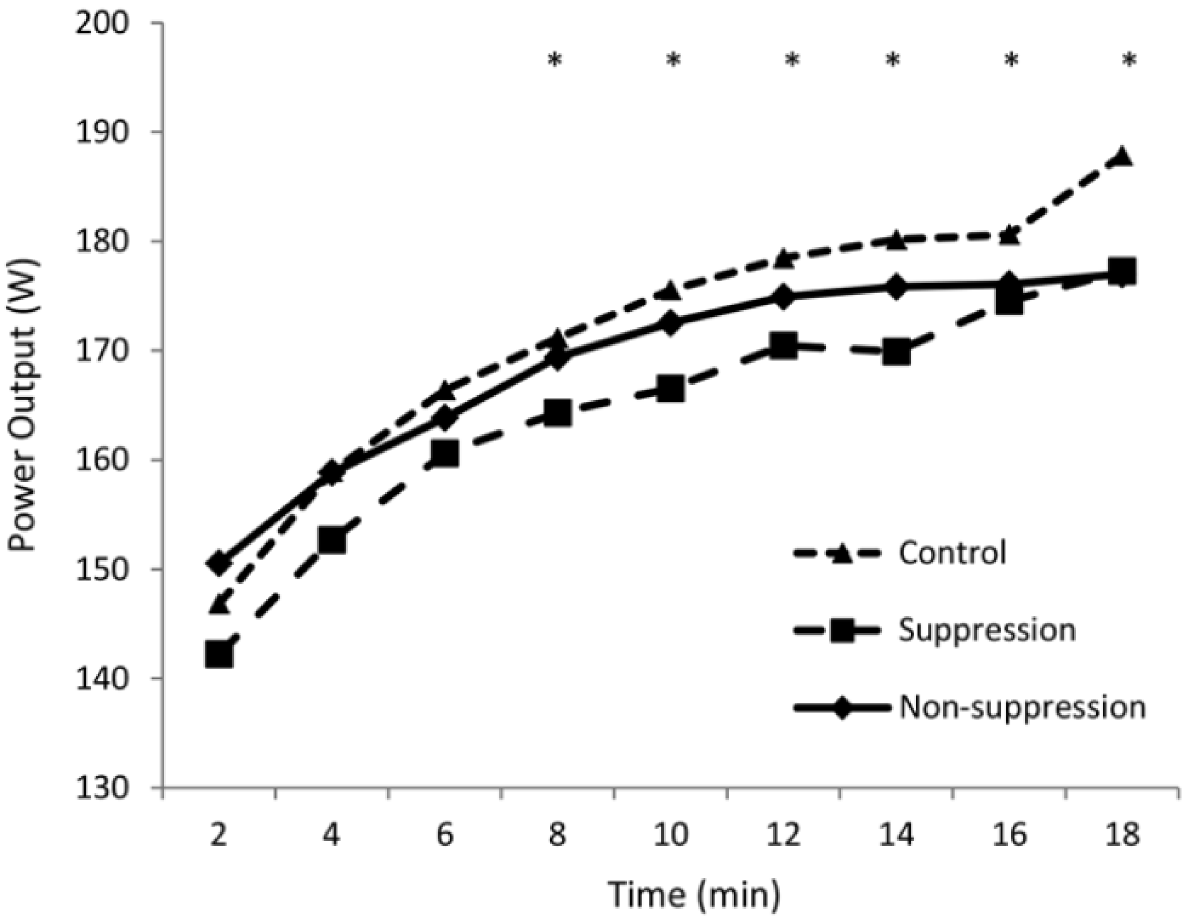


Figure 1 - Comparison of the POMS profile of the physical fitness center members (♦) with those of elite athletes with signs of overtraining[1] (▲) and elite athletes who show no signs of overtraining[22] (■).

Sleep well and avoid mentally draining activities before competitions

Sleep well and avoid mentally draining activities before competitions

Emotion Regulation and Sport Performance



Christopher R. D. Wagstaff

Journal of Sport & Exercise Psychology, 2014, 36, 401-412
http://dx.doi.org/10.1123/jsep.2013-0257

University of Kent

Reduce cognitive workload during competitions

Cognitive Drafting

(Hutchinson, 2018)

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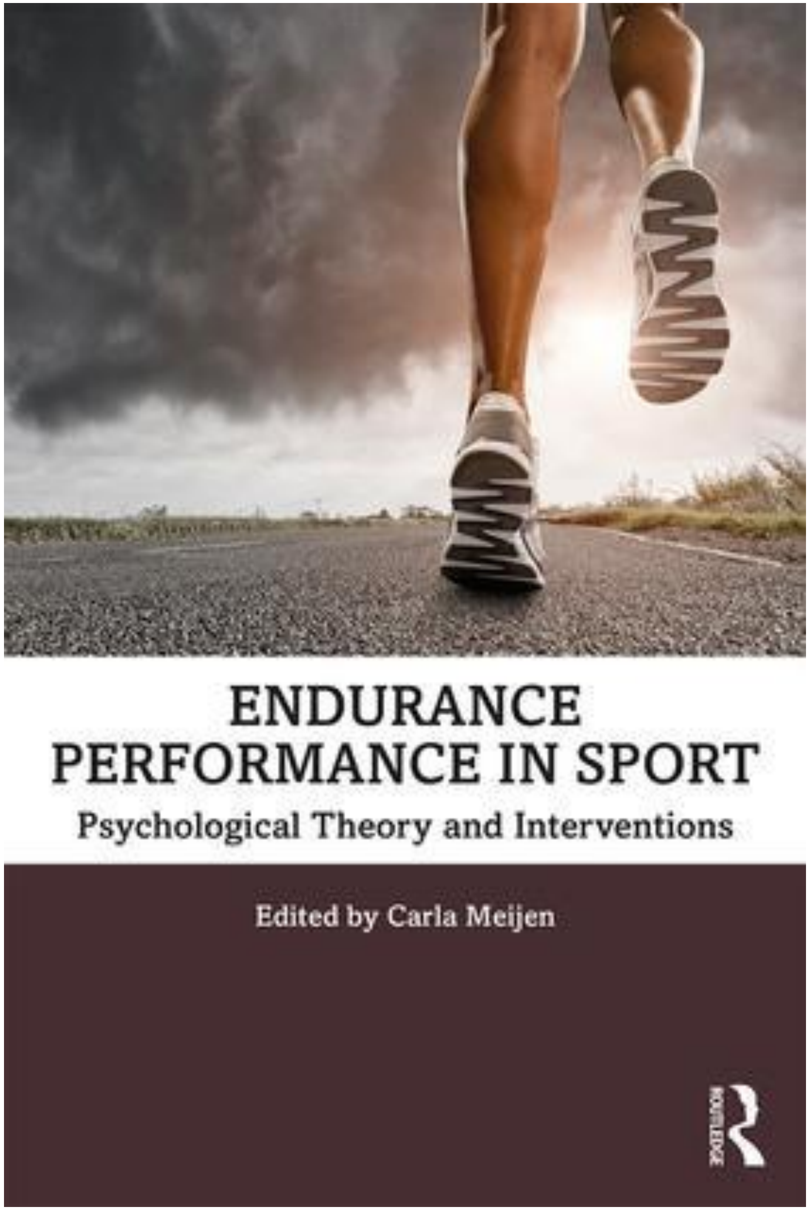
- **Future**: Brain Endurance Training (BET), brain stimulation, neurofeedback, non-conscious psychological interventions, […]

Psychological Interventions:

- Self-talk
- Reappraisal
- Pacing
- Attentional focus
- Goal-setting
- Cue your form
- Relaxation

www.resist-stopping.com



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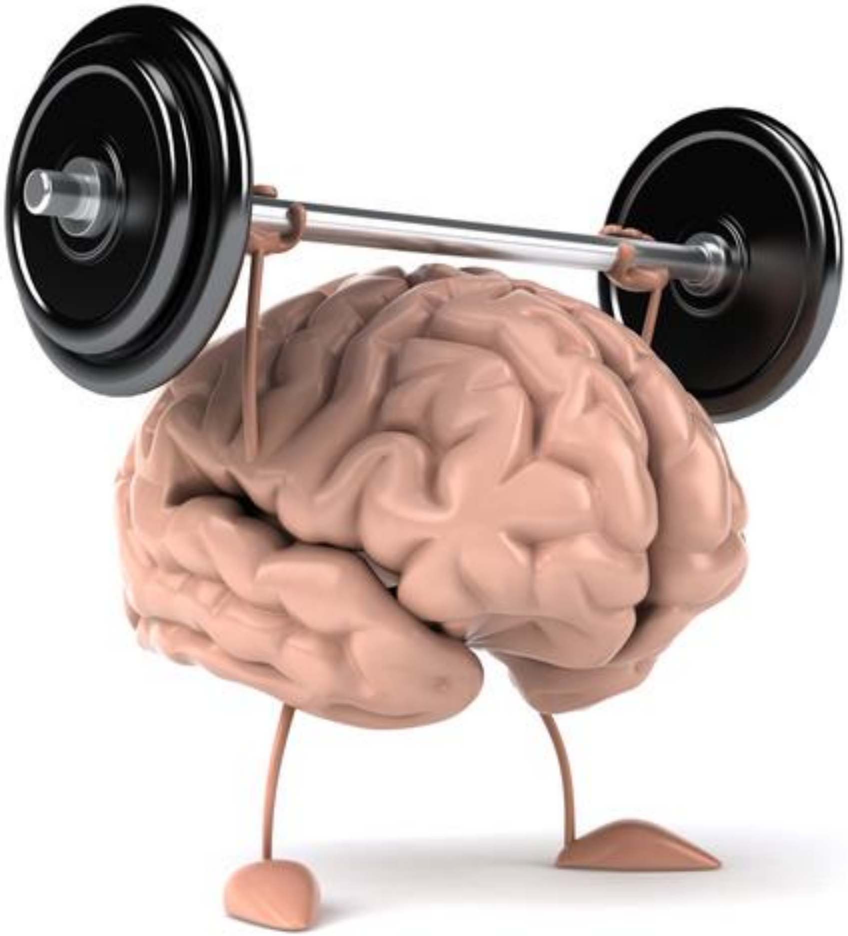
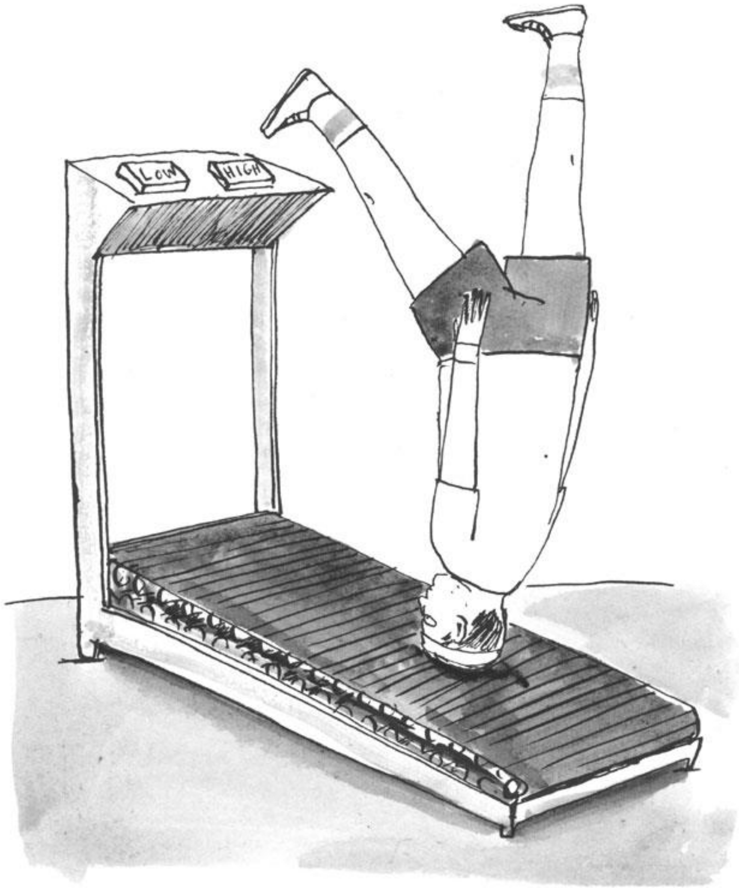
- **Make systematic use of psychological interventions** known to improve endurance performance
- **Future**: Brain Endurance Training (BET), brain stimulation, neurofeedback, non-conscious psychological interventions, psychoactive nutrients other than caffeine […]

Questions?





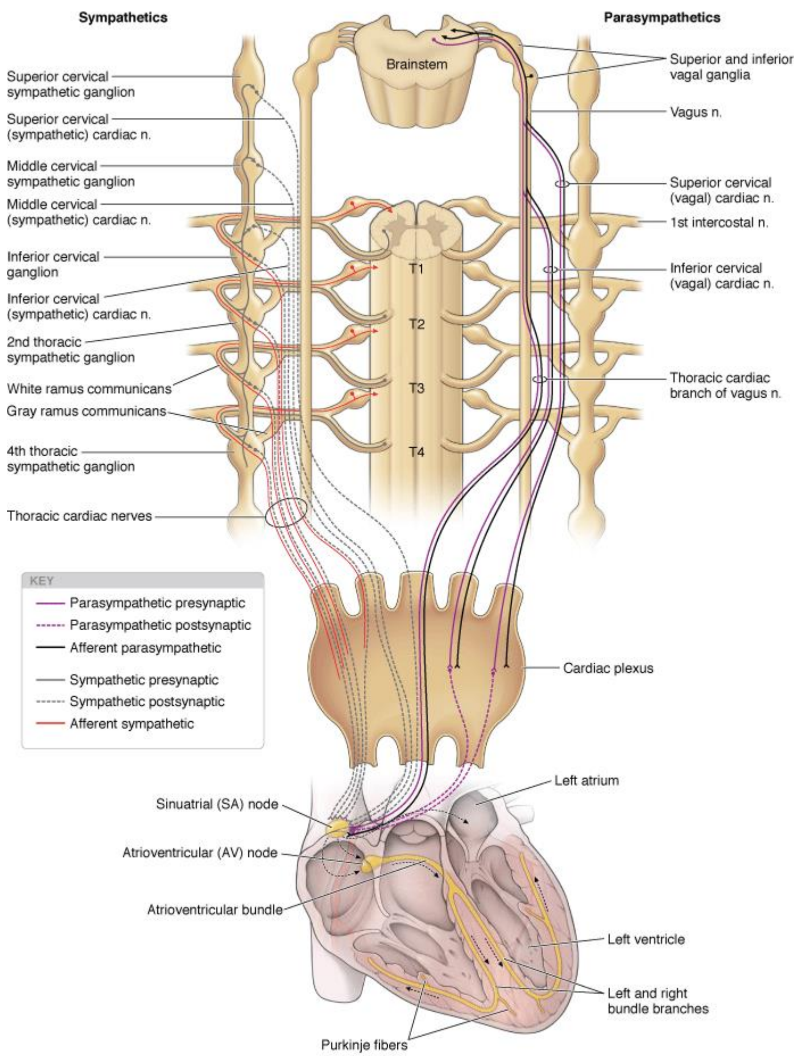
Afferent Feedback Model of Perceived Effort

Table I. Sources of afferent information that may alter ratings of perceived exertion

Cardiopulmonary	Peripheral/metabolic
Heart rate	Blood lactate level
Oxygen uptake	Blood and/or muscle pH
Respiratory rate	Mechanical strain
Ventilatory rate	Muscle damage
	Core temperature
	Carbohydrate availability
	Skin temperature

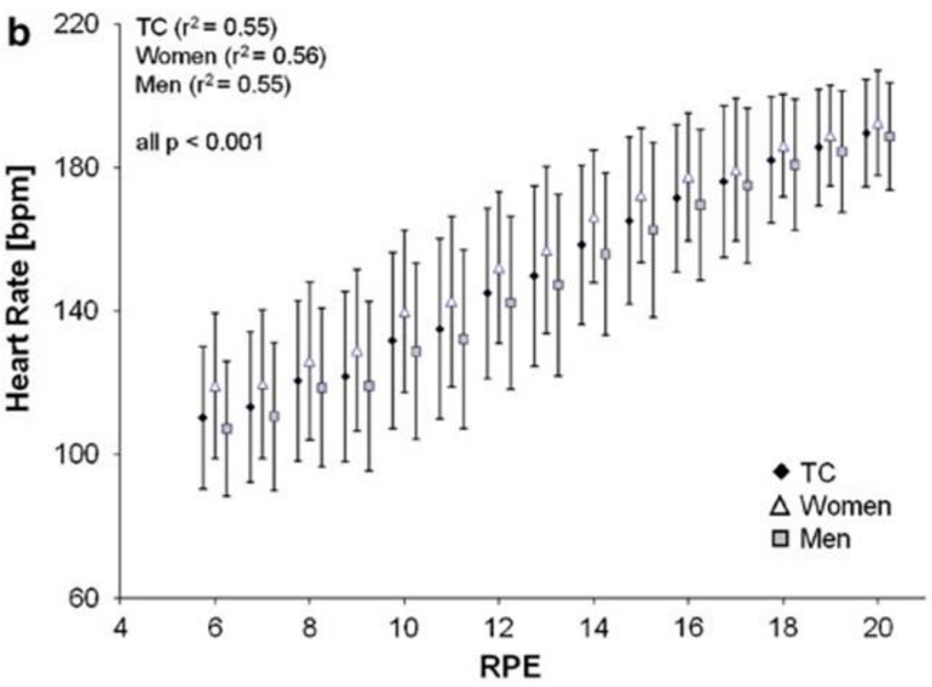
(Hampson et al., 2011)

Cardiopulmonary Sources of Afferent Feedback



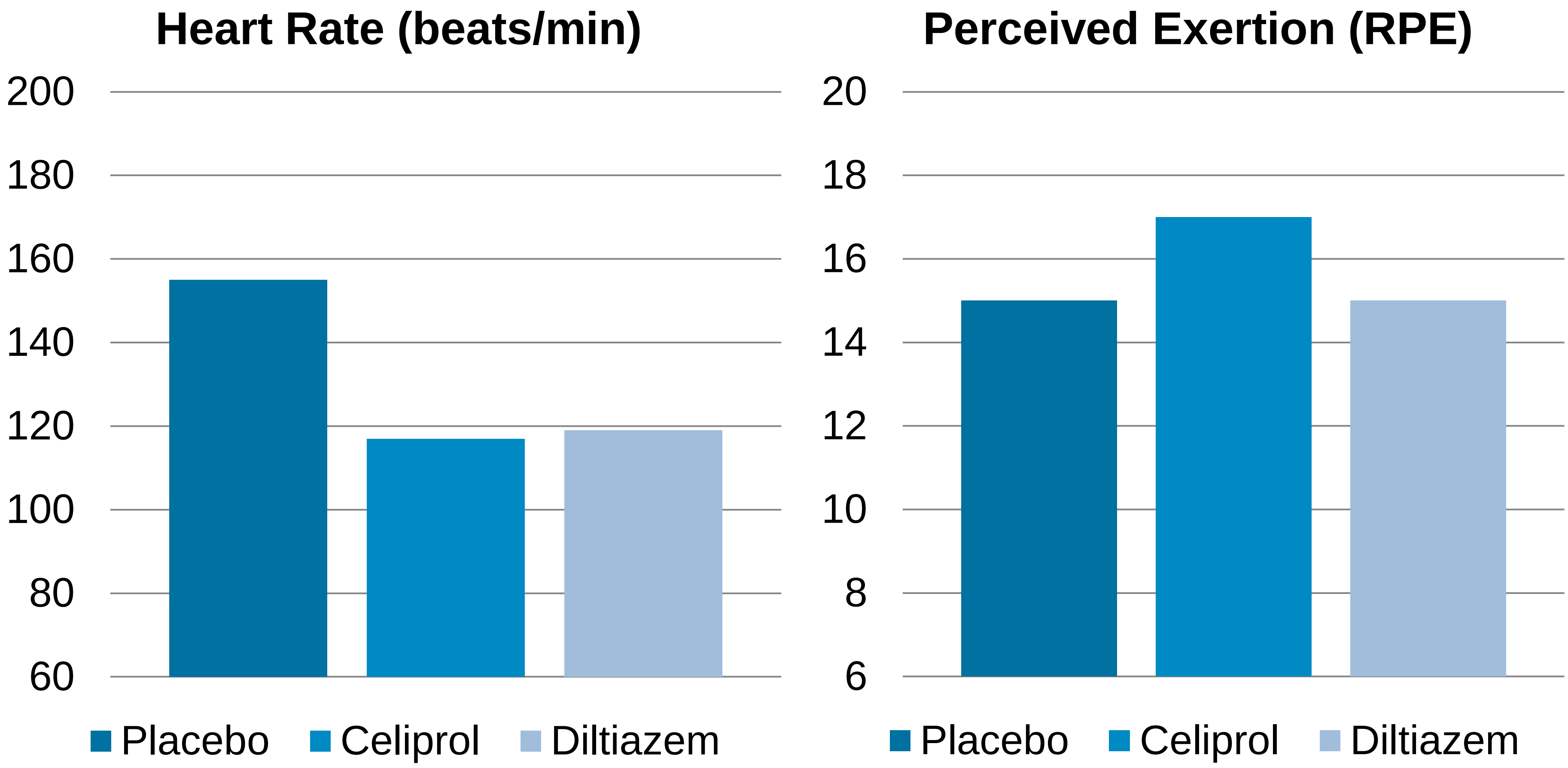
Source: Morton DA, Foreman KB, Albertine KH: *The Big Picture: Gross Anatomy:* www.accessmedicine.com

RPE and heart rate during incremental exercise tests in 2,560 Men and Women



(Scherr et al., 2013)

Cardiopulmonary Sources of Afferent Feedback



Nine men with chronic atrial fibrillation during treadmill exercise testing

(Myers et al., 1987)

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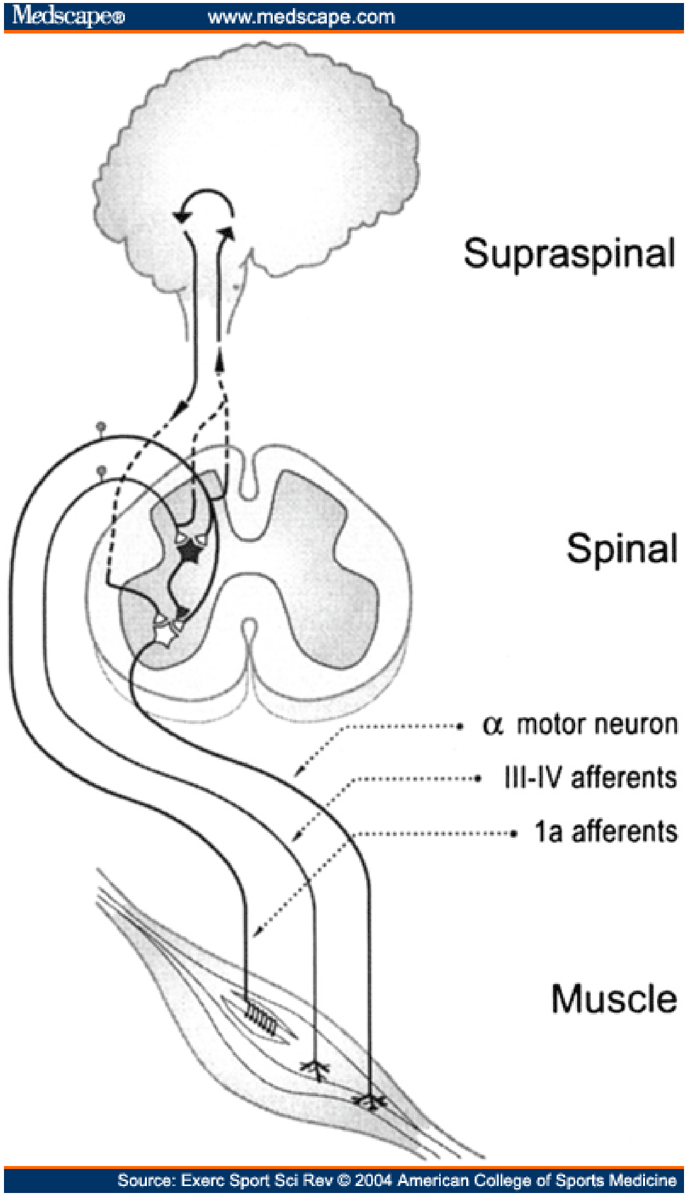
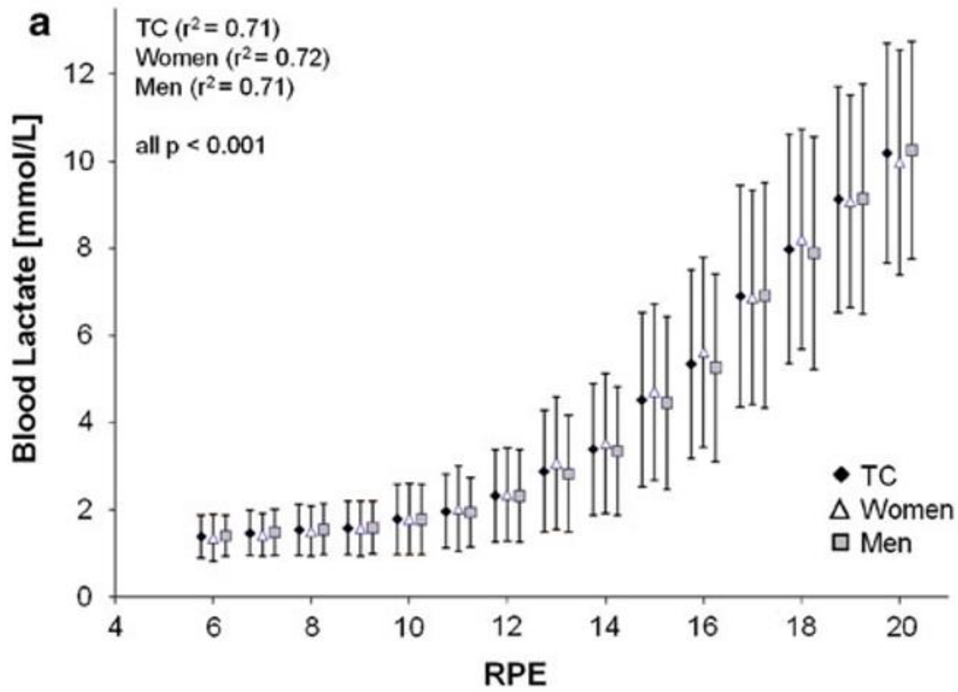
Peripheral/Metabolic Sources of Afferent Feedback

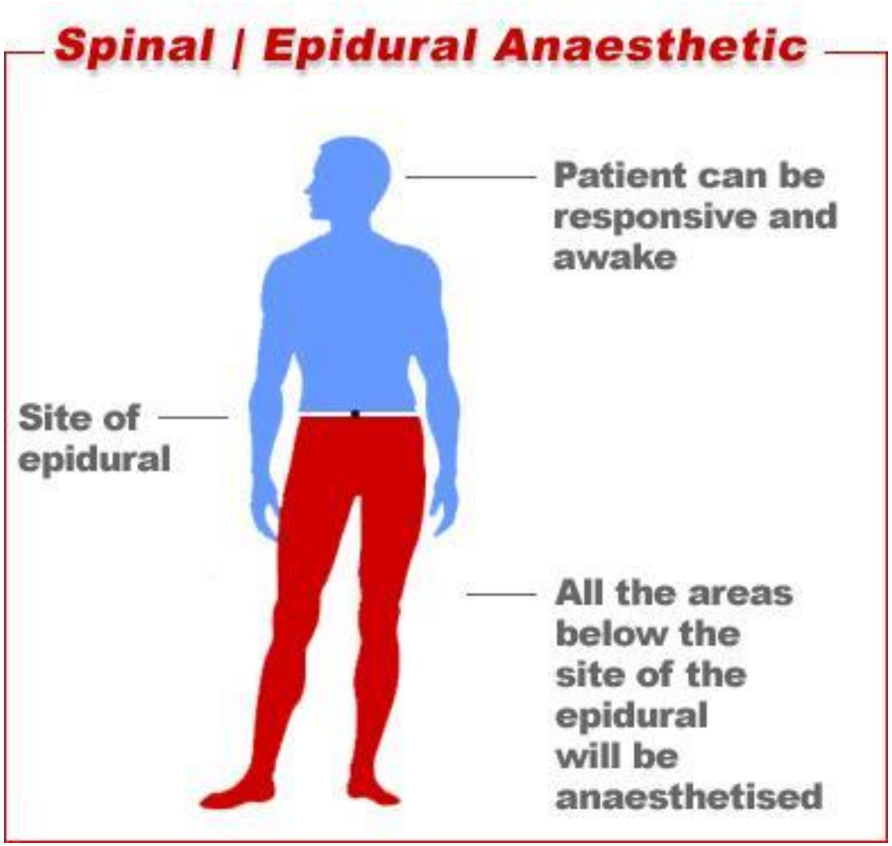


RPE and blood lactate during incremental exercise tests in 2,560 Men and Women



(Scherr et al., 2013)

Afferent Feedback and Perception of Effort



Epidural anaesthesia at lumbar level

Cycling exercise for 20 min at 46% VO2max

(Kjaer et al. 1999)

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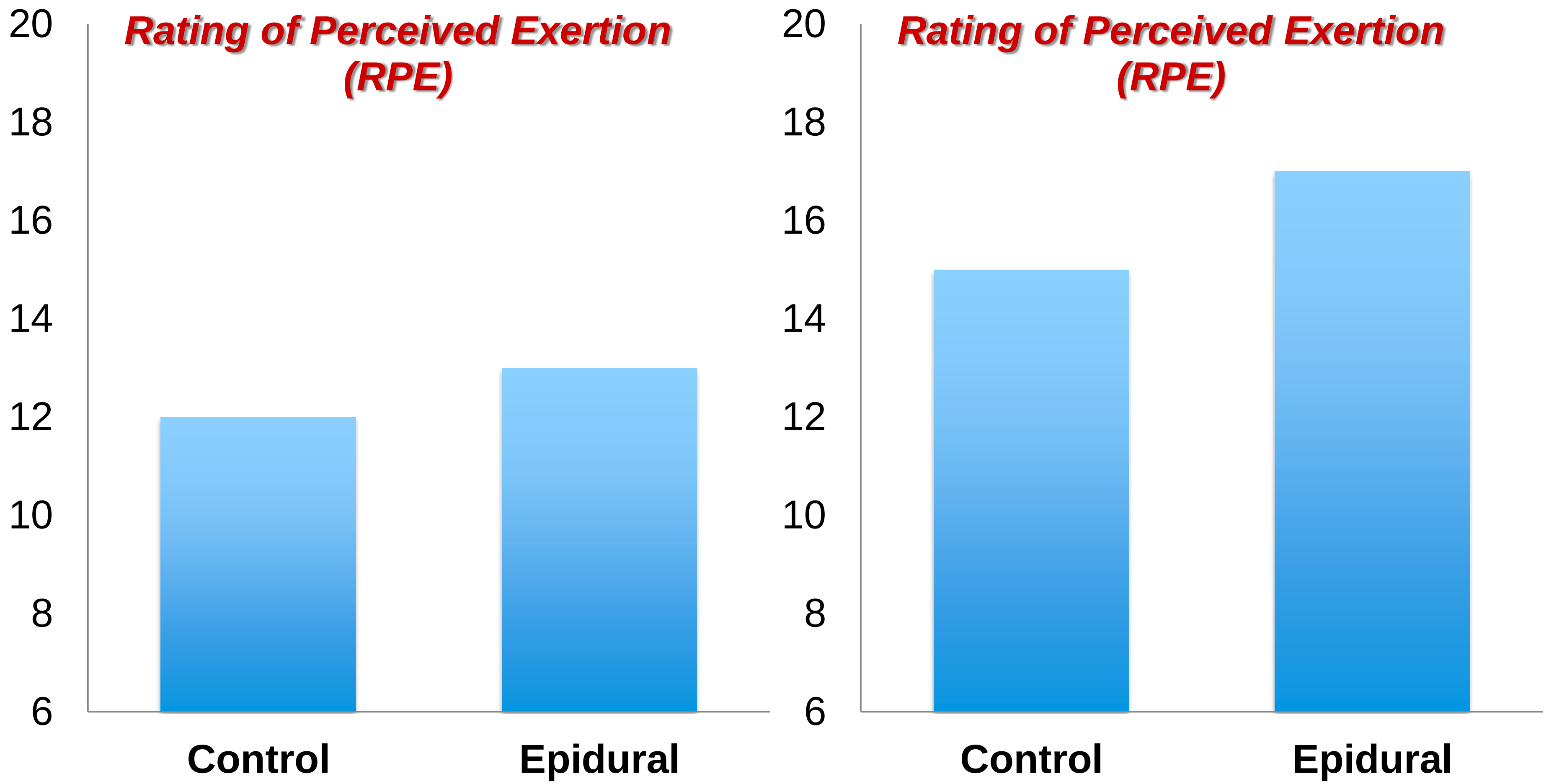
Afferent Feedback and Perception of Effort



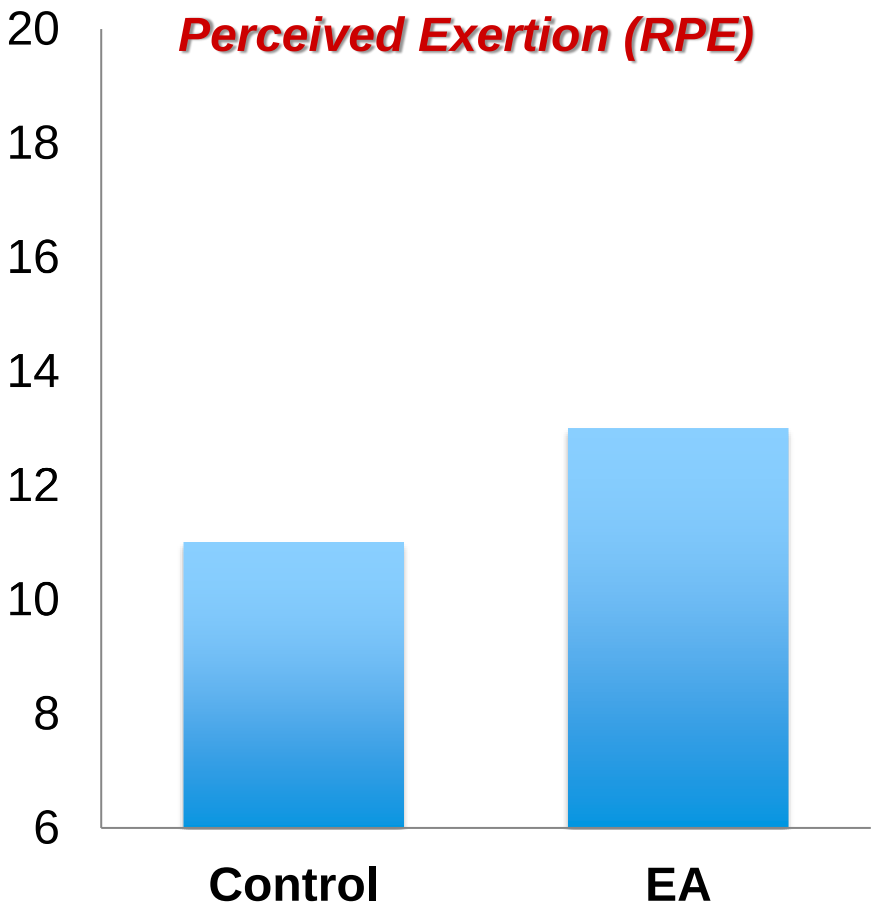
Normoxia (20.9% oxygen)

Hypoxia (11.5% oxygen)

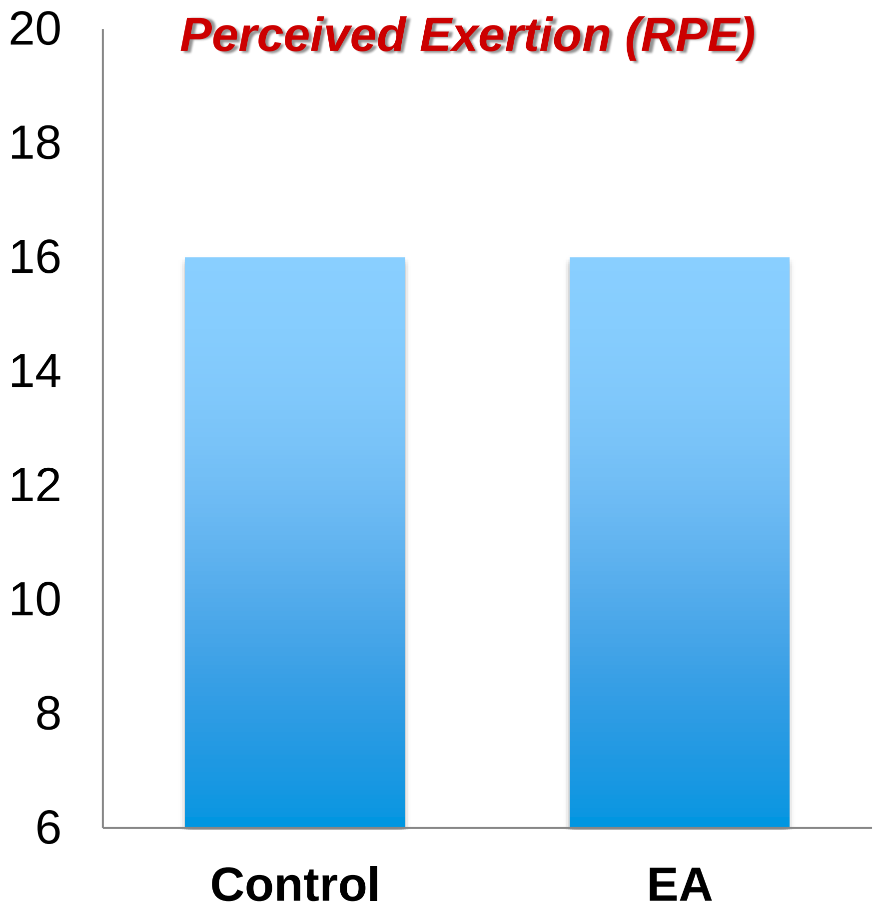
(Kjaer et al. 1999)

Peripheral/Metabolic Sources of Afferent Feedback

5 min of isometric one leg extension at same absolute force (10% of initial MVC = 21 ± 2 Nm)



2 min of isometric one leg extension at same relative force (30% of current MVC)



Mitchell et al. (1989)

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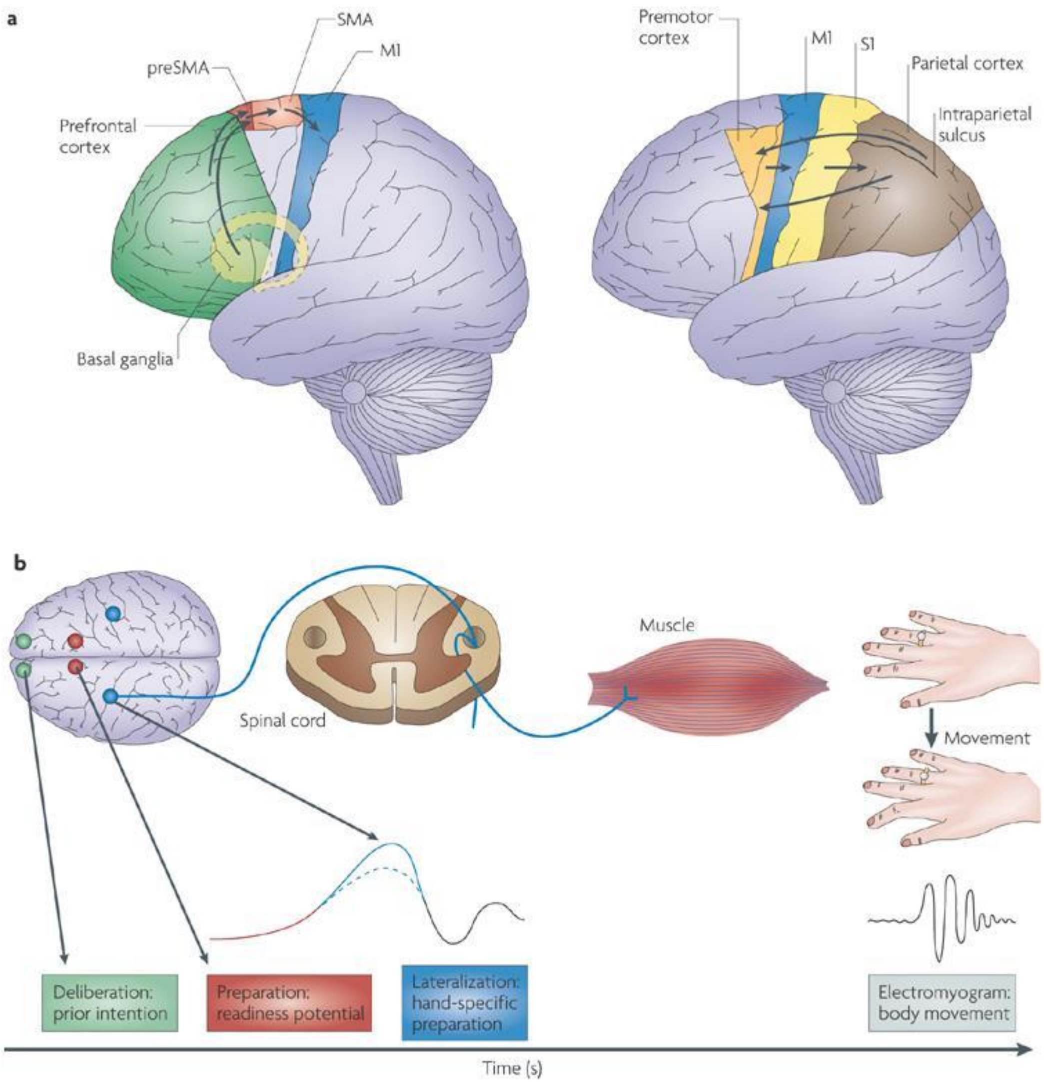
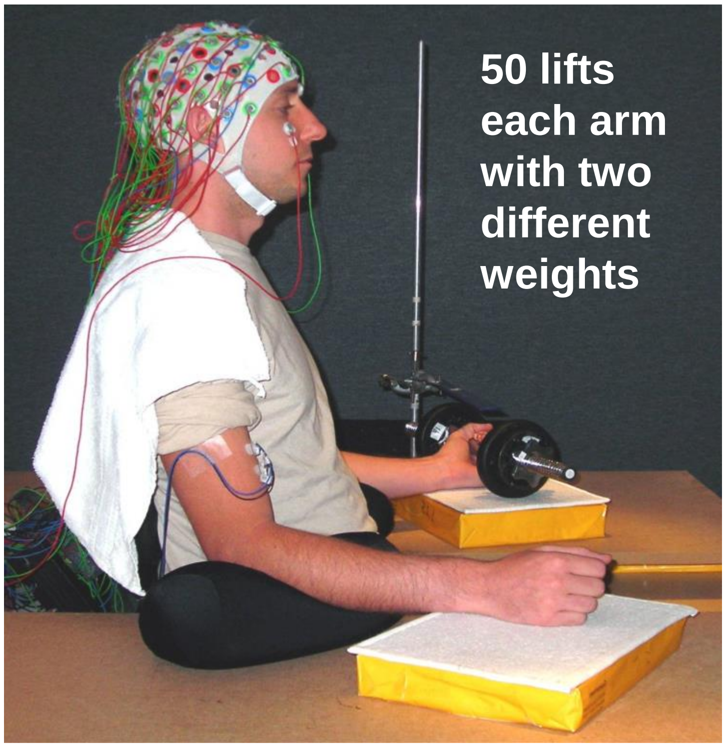
Motor-Related Cortical Potentials

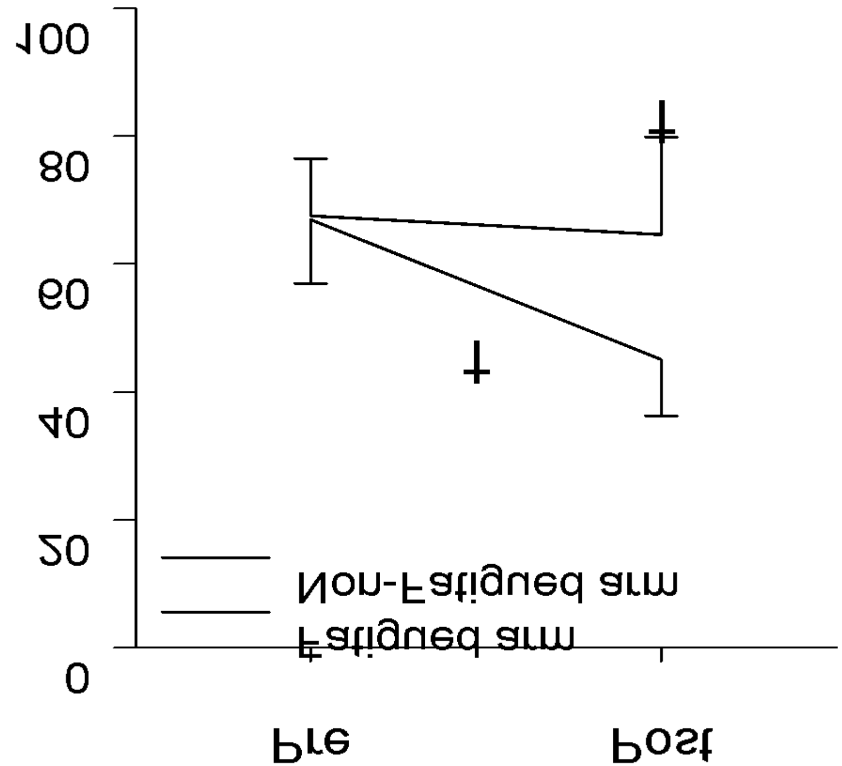


Nature Reviews | Neuroscience

Electroencephalography (EEG)

Central Command and Perception of Effort





Left. Experimental set-up. *Right.* Strength loss after fatiguing protocol. † significant paired difference.

De Morree et al. Psychophysiology 2012; 49(9): 1242-1253

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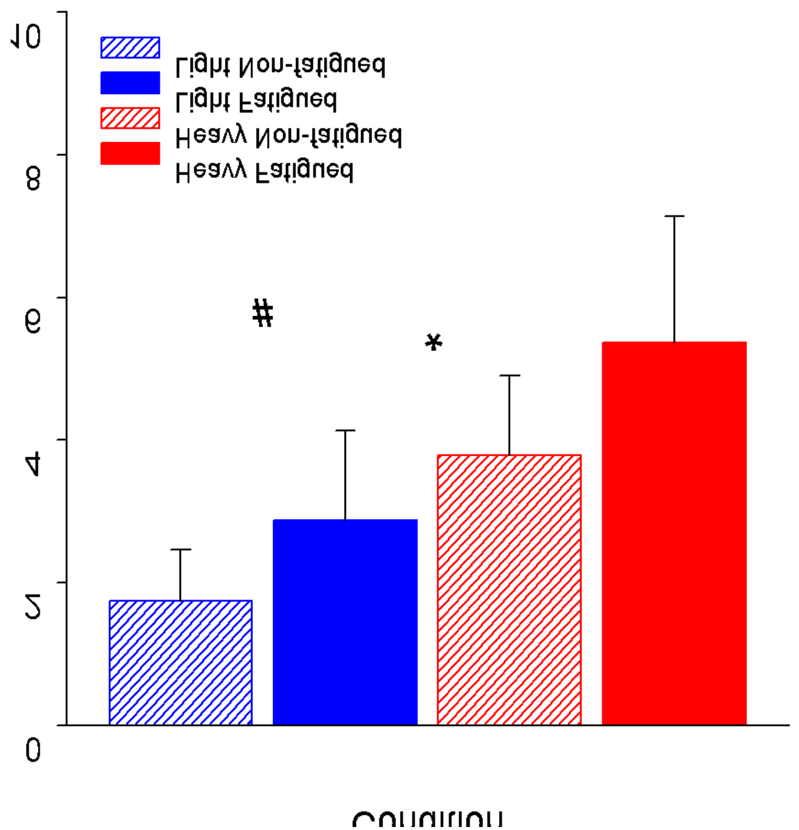
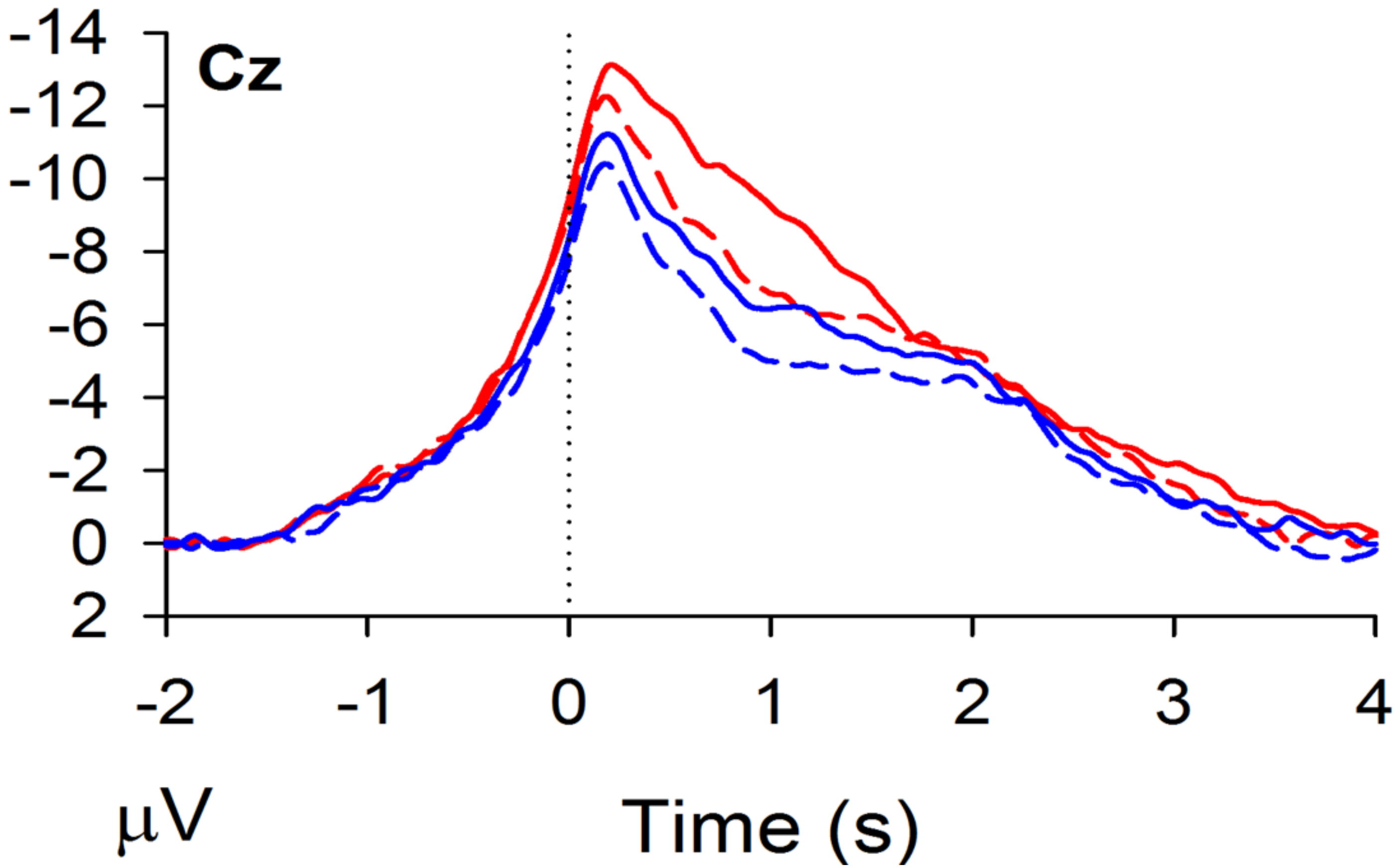
Central Command and Perception of Effort



Rating of perceived effort for all four weightlifting conditions. Data are presented as means ± standard deviations. # Significant main effect of fatigue ($p < 0.001$), * significant main effect of weight ($p < 0.001$).

Central Command and Perception of Effort



Movement-related cortical potentials at five electrodes for the four weightlifting conditions over time. contra is contralateral to the movement and ipsi is ipsilateral to the movement. Time 0 s is EMG onset.

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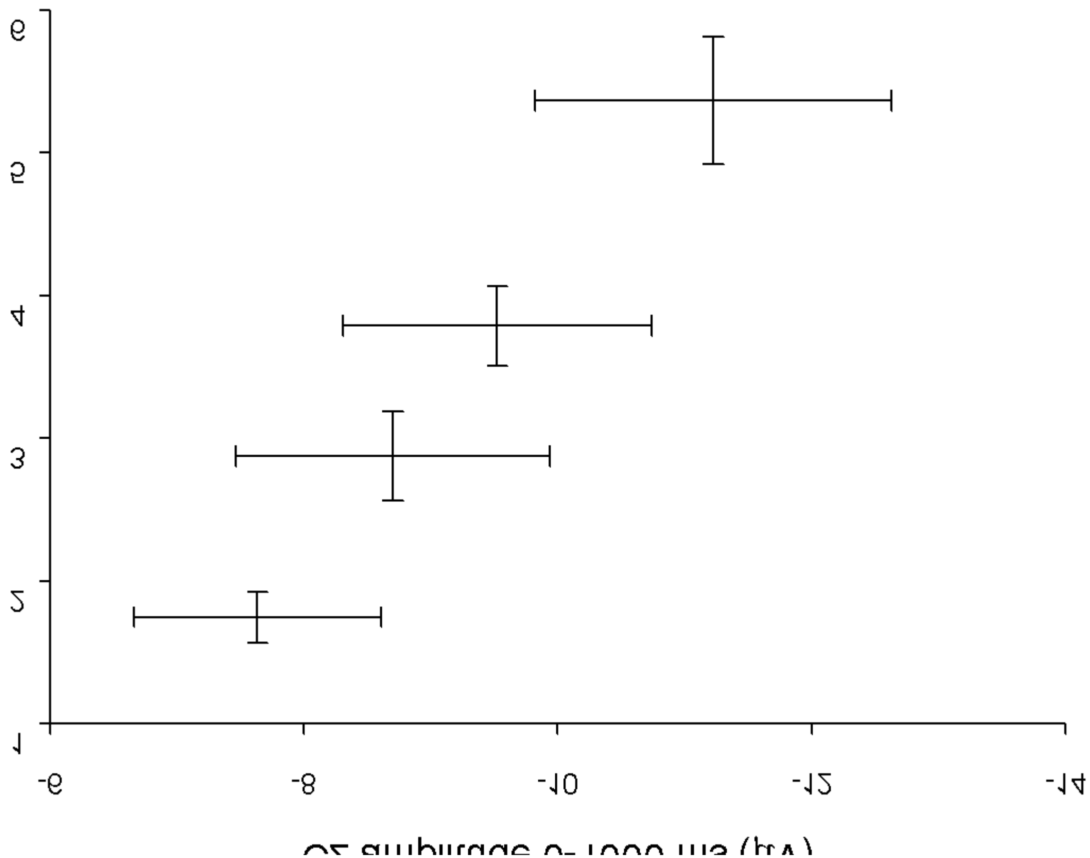
Central Command and Perception of Effort



Within-subject correlation between rating of perceived effort and average Cz amplitude during the first 1000 ms of movement. Each data point represents the means ± standard errors for one of the four conditions. The correlation coefficient was $r_{(14)} = -0.64$ ($p < 0.001$).

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PRACTICAL APPLICATIONS OF THE PSYCHOBIOLOGICAL MODEL:

- **Reduce mentally draining activities before and during competitions**
- **Psychobiological monitoring of training**
- **Psychological interventions:**
  a) Conscious
  b) Non-conscious
- **Psychoactive Substances:**
  a) Nutrition
  b) Drugs
- **Brain Endurance Training (BET)**
- **Brain Stimulation**

Use (legal) psychostimulants

Brain Stimulation (TMS/tDCS)

NEUROSCIENCE

Performance boost paves way for 'brain doping'

Electrical stimulation seems to boost endurance in preliminary studies.

BY SARA REARDON

Elite ski jumpers rely on extreme balance and power to descend the steep slopes that allow them to reach up to 100 kilometres per hour. But the US Ski and Snowboard Association (USSA) is seeking to give its elite athletes an edge by training a different muscle: the mind.

Working with Halo Neuroscience in San Francisco, California, the sports group is testing whether stimulating the brain with electricity can improve the performance of ski jumpers by making it easier for them to hone their skills. Other research suggests that targeted brain stimulation can reduce an athlete's ability to perceive fatigue[1]. Such technologies could aid recovery from injury or let athletes try 'brain doping' to gain a competitive advantage.

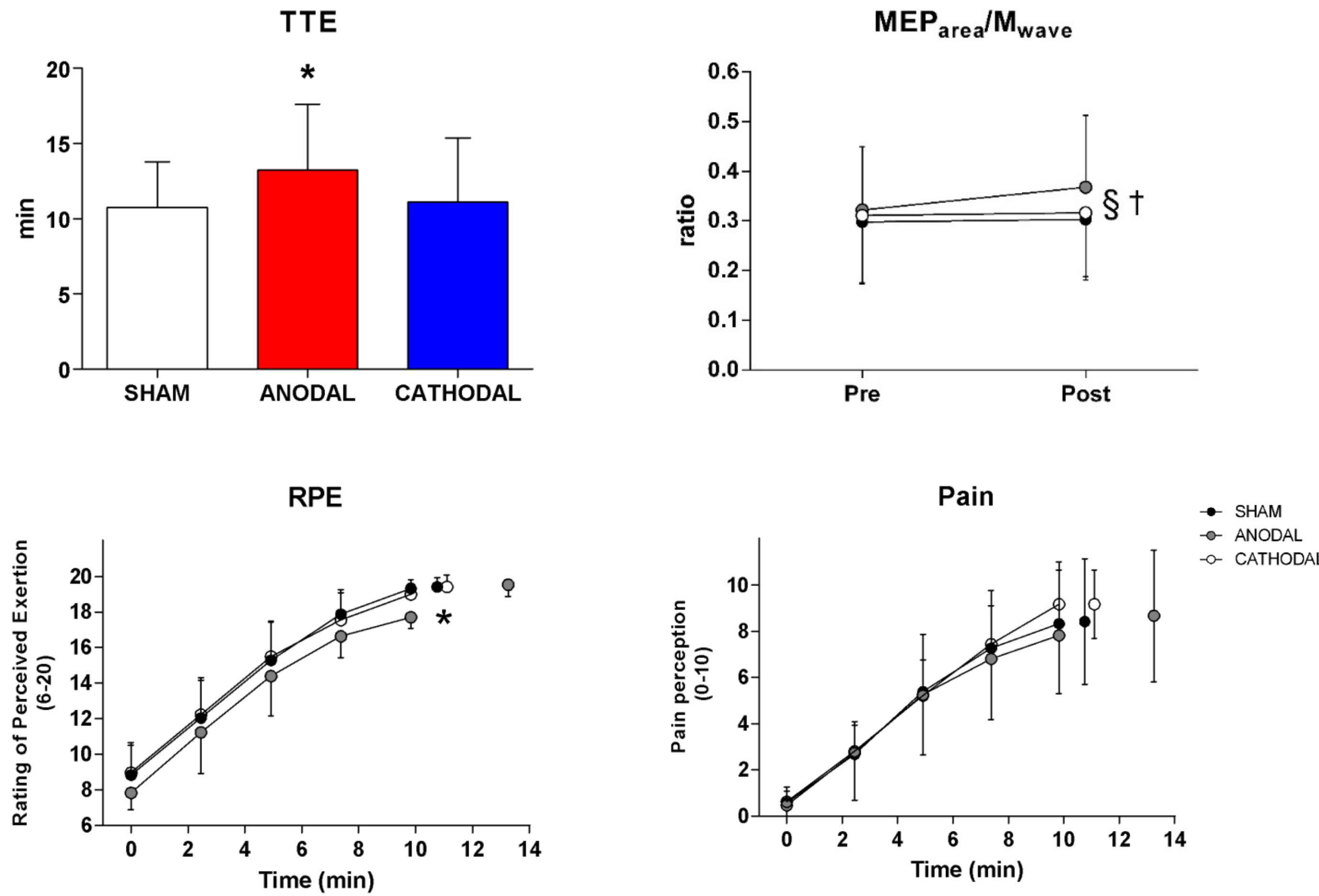
Yet many scientists question whether brain stimulation is as effective as its proponents claim, pointing out that studies have looked at only small groups of people. "They're cool findings, but who knows what they mean," says cognitive psychologist Jared Horvath at the University of Melbourne in Australia.

The USSA is working with Halo to judge the efficacy of a device that delivers electricity to the motor cortex, an area of the brain that controls physical skills. The company claims that the stimulation helps the brain to build new connections as it learns a skill. It tested its device in an unpublished study of seven elite Nordic ski jumpers, including Olympic athletes.

Four times per week, for two weeks, the skiers practised jumping onto an unstable platform. Four athletes received transcranial direct-current stimulation (tDCS) as they trained; the other three received a sham procedure. The ▶

Brain Stimulation (TMS/tDCS)

10 min tDCS stimulation of both primary motor cortexes prior exercise



23% improvement in cycling time to exhaustion

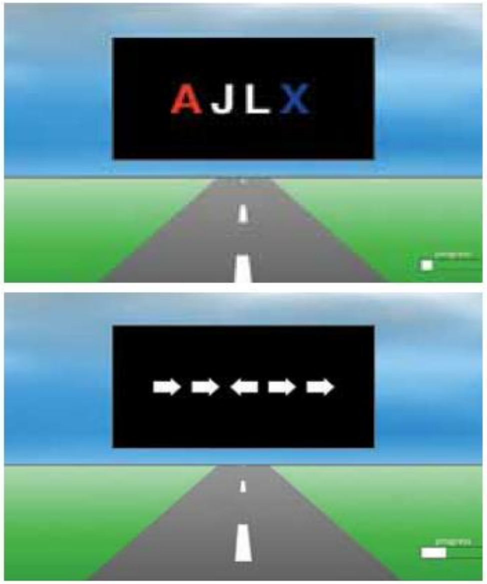
Angius et al. (2017)

Brain Endurance Training (BET)

Mentally Fatiguing Tasks

AX-Continuous Performance Task

Flanker Task

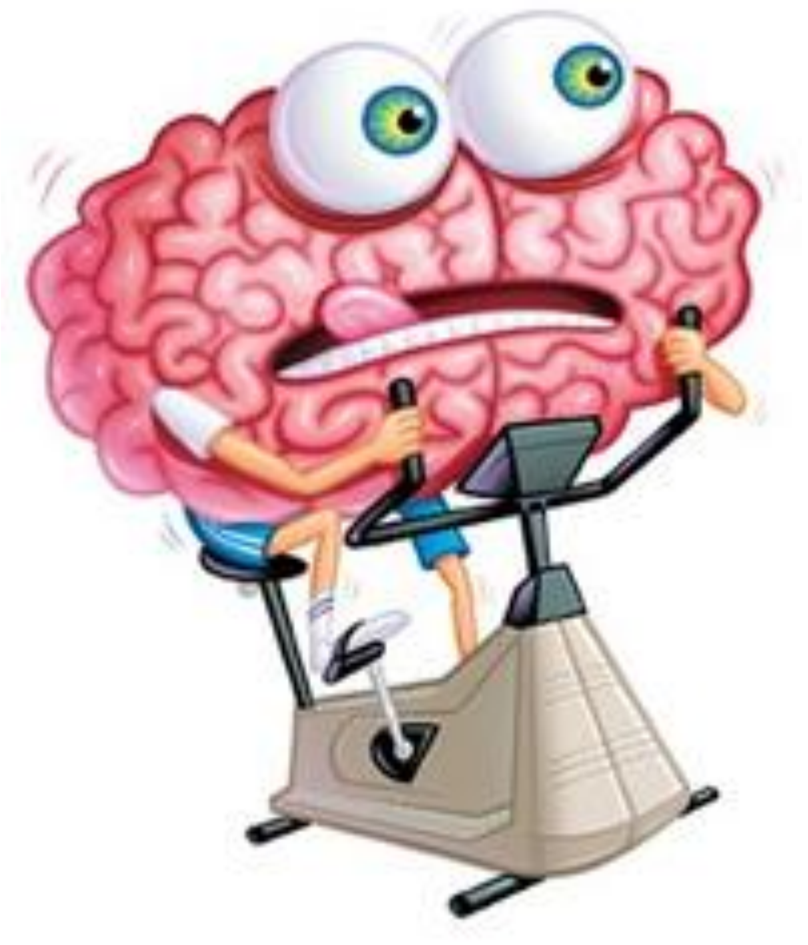


RUNNERSWORLD.COM 73

Hypotheses

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**



METHODS

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

Variable	BET Group (n = 17)	Control Group (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

METHODS

"I tried out a researcher's new brain training protocol, and it wasn't easy."

Alex Hutchinson
Sweat Science Blog
Runner's World
September 17, 2013

Cycling exercise for 60 min at 65% VO2max, three times a week for 12 weeks, with and without BET

METHODS

Experimental Treatment

Both groups trained on a cycle ergometer for 60 min at 65% VO2max, three times a week for 12 weeks.

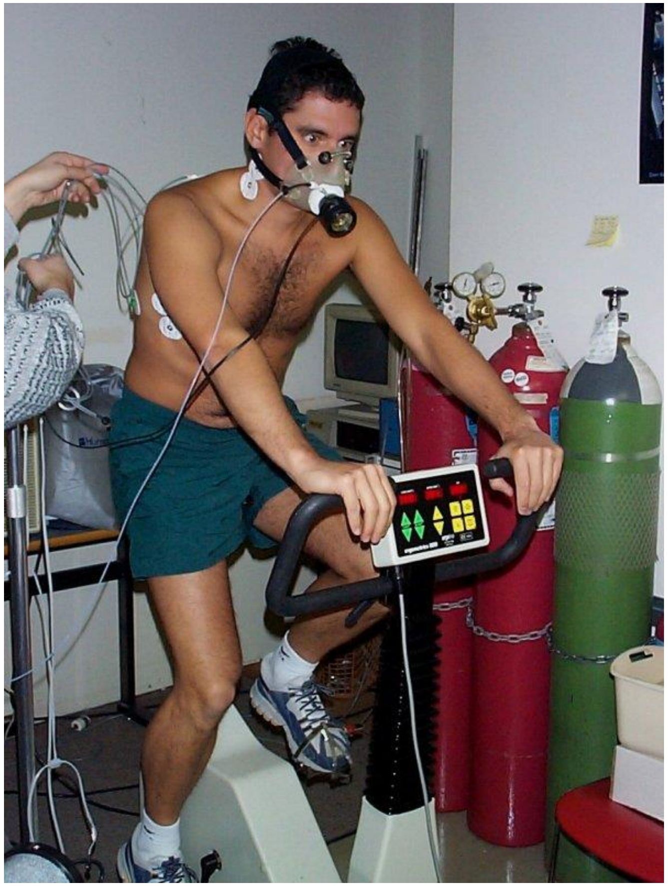
Whilst cycling, the BET group performed a mentally fatiguing task on a computer (60 min of the AX-CPT task).

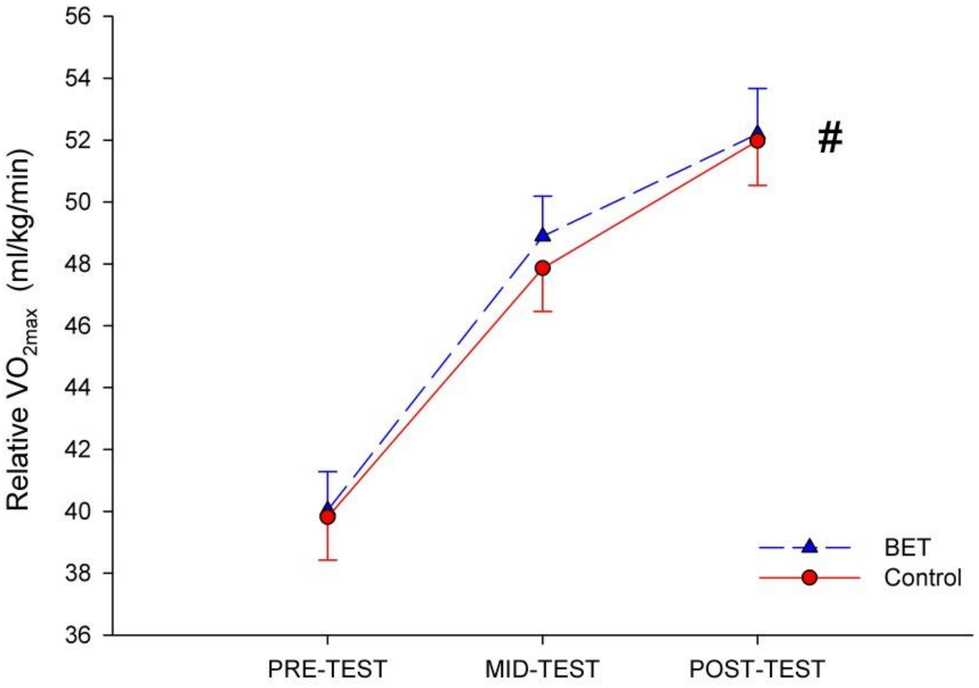
The control group was not involved in any mentally fatiguing task whilst cycling.

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)

Results: VO_{2max} Test





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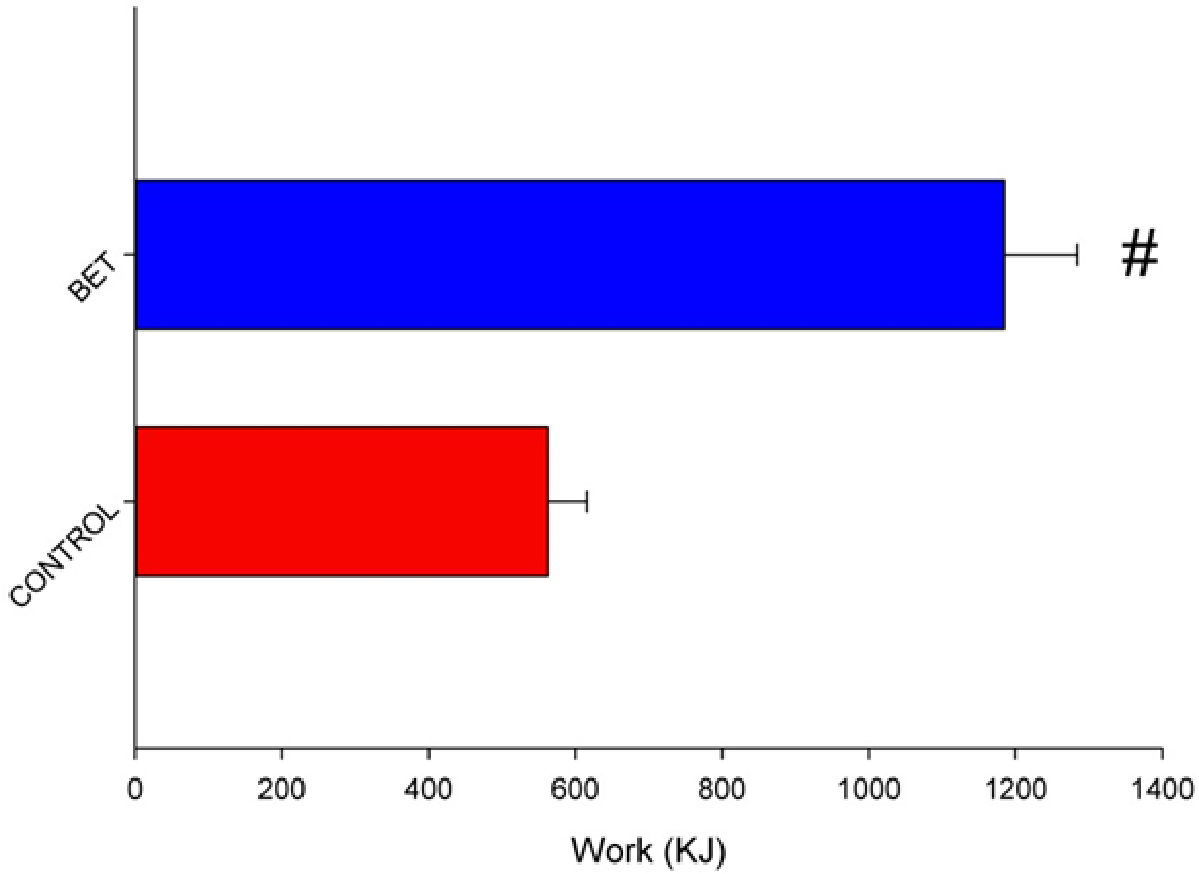
Results: Time to Exhaustion Test



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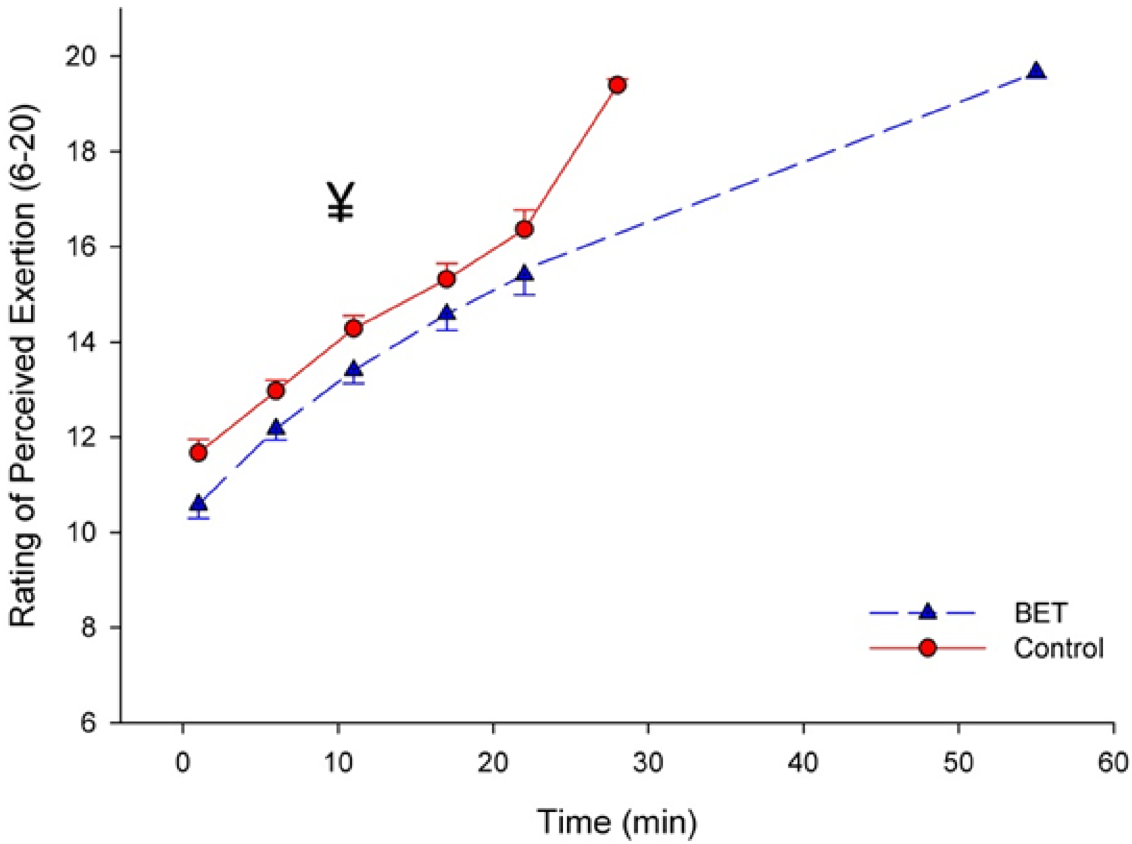
Results: Time to Exhaustion Test



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Brain Endurance Training in the field

Auditory Tasks via Smartphone App

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