HOSTED BY
ELSEVIER
CrossMark
Available online at www.sciencedirect.com
ScienceDirect
Journal of Sport and Health Science 4 (2015) 24–29
www.jshs.org.cn

Review

Transcranial magnetic stimulation probes the excitability of the primary motor cortex: A framework to account for the facilitating effects of acute whole-body exercise on motor processes

Karen Davranche [a,*], John Temesi [b], Samuel Verges [c,d], Thierry Hasbroucq [e]

[a] Aix Marseille Université, CNRS, LPC UMR 7290, FR 3C FR 3512, 13331 Marseille cedex 3, France
[b] Human Performance Laboratory, Faculty of Kinesiology, University of Calgary, Calgary T2N 1N4, Canada
[c] HP2 Laboratory, Grenoble Alpes University, Grenoble, France
[d] U1042, INSERM, Grenoble, France
[e] Aix Marseille Université, CNRS, LNC UMR 7291, FR 3C FR 3512, 13331 Marseille cedex 3, France

Received 22 July 2014; revised 10 September 2014; accepted 29 September 2014
Available online 23 December 2014

Abstract

The effects of exercise on decision-making performance have been studied using a wide variety of cognitive tasks and exercise interventions. Although the current literature supports a beneficial influence of acute exercise on cognitive performance, the mechanisms underlying this phenomenon have not yet been elucidated. We review studies that used single-pulse transcranial magnetic stimulation (TMS) to probe the excitability of motor structures during whole-body exercise and present a framework to account for the facilitating effects of acute exercise on motor processes. Recent results suggest that, even in the absence of fatigue, the increase in corticospinal excitability classically reported during submaximal and exhausting exercises may be accompanied by a reduction in intracortical inhibition. We propose that reduced intracortical inhibition elicits an adaptive central mechanism that counteracts the progressive reduction in muscle responsiveness caused by peripheral fatigue. Such a reduction would render the motor cortex more sensitive to upstream influences, thus causing increased corticospinal excitability. Furthermore, reduction of intracortical inhibition may account for the more efficient descending drive and for the improvement of reaction time performance during exercise. The adaptive modulation in intracortical inhibition could be implemented through a general increase in reticular activation that would further account for enhanced sensory sensitivity.

Keywords: Corticospinal excitability; Exercise-cognitive function interaction; Intracortical inhibition; Transcranial magnetic stimulation

1. Introduction

The effects of exercise on decision-making performance have been studied using a wide variety of cognitive tasks in conjunction with exercise interventions inducing a range of physiological changes in core temperature, blood glucose concentration, and muscle/cerebral oxygenation. The current literature supports a beneficial influence of acute exercise on cognitive performance.[1–3] However, the mechanisms underlying this phenomenon have not yet been elucidated. In this paper, we review studies that used single-pulse transcranial magnetic stimulation (TMS) to probe the excitability of motor structures during whole-body exercise. We present a framework that accounts for the facilitating effects of acute exercise on motor processes during cognitive tasks.

2. Acute bout of exercise and cognitive function

Cognitive facilitation is more consistently observed during moderate acute exercise and usually disappears at higher exercise intensities. Several authors claim that above a certain

* Corresponding author.
E-mail address: karen.davranche@univ-amu.fr (K. Davranche).
Peer review under responsibility of Shanghai University of Sport.

http://dx.doi.org/10.1016/j.jshs.2014.09.001

level of physical stress, exercise disrupts cognitive functioning,[4,5] suggesting that intensity and duration are determining factors in the acute exercise—cognition relationship.[6] According to the transient hypofrontality theory,[7] strenuous exercise causes extensive activation of motor and sensory systems that contribute to the recruitment of motor units, sensory input integration, and regulation of the autonomic systems. Due to limited cognitive resources available, this huge solicitation induces competition for resources which alters cerebral oxygenation and renders the frontal lobes hypoactive.

However, deficits in prefrontal-dependent cognitive tasks are not always observed. McMorris et al.[8] failed to observe a deterioration in cognitive control, a crucial element in decision-making, despite very high exercise-induced physiological stress (i.e., 80% of maximal aerobic power (MAP)) while Davranche and Pichon[9] reported enhanced sensory sensitivity after an incremental exercise test to task failure. The effect of acute exercise on the cognitive tasks used in these studies (e.g., reaction time (RT), visual discrimination) may result from the activation of the reticular-activating system.[4] The increased arousal, that is induced by enhanced activity of the noradrenergic and dopaminergic systems, permits sustained physical exercise by massively recruiting motor units and activating the autonomic and endocrine systems. By improving early sensory sensibility and motor process efficiency, the reticular-activating system is probably also responsible for shortening motor times and enhancing sensory sensitivity.

3. A chronometric and electromyographic approach to assess the effect of exercise on RT

Mental chronometry is the most widespread method used to assess the effects of exercise on cognitive processes. The paradigm of mental chronometry is based on the notion that cognitive processes can be assessed by measuring the time required for information processing. Indeed, a number of inferences can be made using the measure of RT. RT corresponds to the time that elapses between the onset of a stimulus and the occurrence of an overt response. The mental chronometry method consists of measuring RT in different conditions and, when all other factors are equal, RT differences are used to make inferences regarding the influence of the different conditions on cognitive processing. Electrophysiological techniques (e.g., single neuron activity, electrical and magnetic stimulation, electroencephalography, magnetoencephalography) can also be used in conjunction with RT measures to make inferences based on observations of physiological changes. The general principle is to combine electrophysiological and mental chronometry techniques in order to record indices related to the nature and organization of the cognitive processes. For example, the locus of the effect of an experimental factor can be addressed using fractionated RT with respect to the changes in electrophysiological activity.[10] The electromyographic (EMG) activity of the response agonists allows such a fractioning. The time interval between the onset of the response signal and the onset of EMG activity is termed "premotor time", while the time interval between the onset of EMG activity and the onset of the required motor response is termed "motor time".

The combination of electrophysiological and mental chronometry techniques has been used to study the effects of exercise on cognitive function. Two RT experiments, one using a choice RT test and the other one using a simple RT task, were carried out and the EMG activity of the response agonist muscle involved in the task was recorded during exercise.[11] With this paradigm, Davranche et al.[12,13] showed that RT facilitation is mostly due to a shortening in the duration of the motor time (i.e., motor processes involved in response execution). Based on indirect arguments relative to the steepness of the rectified EMG burst during exercise, the authors suggested that the corticospinal command provides a more efficient descending drive while exercising than at rest. This improvement could be due to changes in the excitability of corticofugal neurons and/or cortical neurons projecting directly or oligosynaptically onto these cells. One way to directly assess changes in corticospinal tract excitability induced by exercise is to use single-pulse TMS to assess the excitability of motor cortical structures during whole-body exercise.

4. TMS of the motor cortex reveals neural activation and suppression

TMS is a non-invasive, safe and relatively painless technique to investigate the motor cortex by producing a magnetic field that elicits an electrical current in the brain. The delivery of single- or paired-pulse TMS is often used to characterize alterations in central motor pathways. When the muscles are tonically contracted, TMS of the cortical zones that control these muscles evokes two events in the ongoing EMG. First, due to the direct and transynaptic recruitment of corticospinal neurons, TMS causes a synchronous discharge of the motoneuronal pool reflected by the motor-evoked potential (MEP).[14] The MEP is followed by a silent period (SP) in the ongoing tonic EMG activity. While the initial part of the SP is a direct consequence of the MEP (refractory period of neurons involved in the MEP, pause in spindle firing, or Renshaw inhibition), the latter part results from the recruitment of inhibitory gamma-aminobutyric acid (GABA)-ergic interneurons within the motor cortex.[14—18] When the stimulus intensity is constant, variations in MEP amplitude reflect changes in the excitability of the corticospinal tract while changes in SP duration reflect intracortical inhibitory influences projecting onto this pathway.

Using single-pulse TMS of the primary motor cortex to stimulate the agonist muscle involved in an RT task, Davranche et al.[19] and Tandonnet et al.[20] investigated the neural mechanisms of temporal preparation. Through SP duration and MEP amplitude measures, TMS was used to investigate corticospinal tract excitability and intracortical inhibitory influences before (during the foreperiod) and during the RT interval. The TMS intensity was set at 105% the minimum