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Research Report

Human motor cortex oxygenation during exhaustive pinching task

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ABSTRACT

There are few observations of the activity of the bilateral motor cortex during prolonged exhaustive motor tasks. Knowing how the motor cortex modulates muscle fatigue or how information about fatigue affects motor cortex activities in healthy humans may help explain why fatigue is so prevalent in patients with neurological disorders. The purpose of the present study was to investigate the time course of oxygenation of the bilateral motor cortex during an exhaustive pinching task. Eight healthy, right-handed subjects participated in the study. Near-infrared spectroscopy over the bilateral motor cortex was used to measure the activity throughout the pinching task. Subjects performed a sustained 50–60% of maximal voluntary contraction until voluntary exhaustion was reached. After the start of the motor task, the contralateral motor cortex oxygenation increased significantly compared with the resting value ($P<0.05$). However, with the passage of time, it decreased significantly compared with the resting value ($P<0.05$). In addition, ipsilateral motor cortex oxygenation decreased significantly at voluntary exhaustion compared with the resting value ($P<0.05$). These results suggest an interaction between the bilateral motor cortices during motor tasks.

1. Introduction

When muscle fibers are repeatedly contracted, energy supplies are depleted and the muscles become fatigued. Physiological fatigue is characterized by exercise-induced loss of the power- and force-generating ability of muscle during or after exercise (Booth and Thomason, 1991; Nybo and Nielsen, 2001; Gandevia, 2001).

Several papers have examined the factors responsible for physiological fatigue that have determined the limits of exercise capacity. Numerous investigations have focused on the peripheral factors of physical fatigue (Backer et al., 1993; Fitts, 1994; McLester, 1997). Meanwhile, the influence of central fatigue on exercise capacity has received little scientific attention. It was shown that motor cortex inactivity and/or inhibition affects fatigue, using technical innovations for the measurement of brain activity (Gandevia et al., 1996).

Several experiments have demonstrated increases not only in the contralateral but also in the ipsilateral motor cortex in association with unilateral motor tasks (Hess et al., 1986; Muellbacker et al., 2000; Rossini et al., 1987; Stedman et al., 1998; Tinazzi and Zanett, 1998; Zwarts, 1992). However, bilateral motor cortex activity and hemodynamics during exercise to voluntary exhaustion have never been shown

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Abbreviations: NIRS, near-infrared spectroscopy; Hb, deoxyhemoglobin; HbO_2, oxyhemoglobin; MVC, maximal voluntary contraction; fMRI, functional magnetic resonance imaging; TMS, transcranial magnetic stimulation

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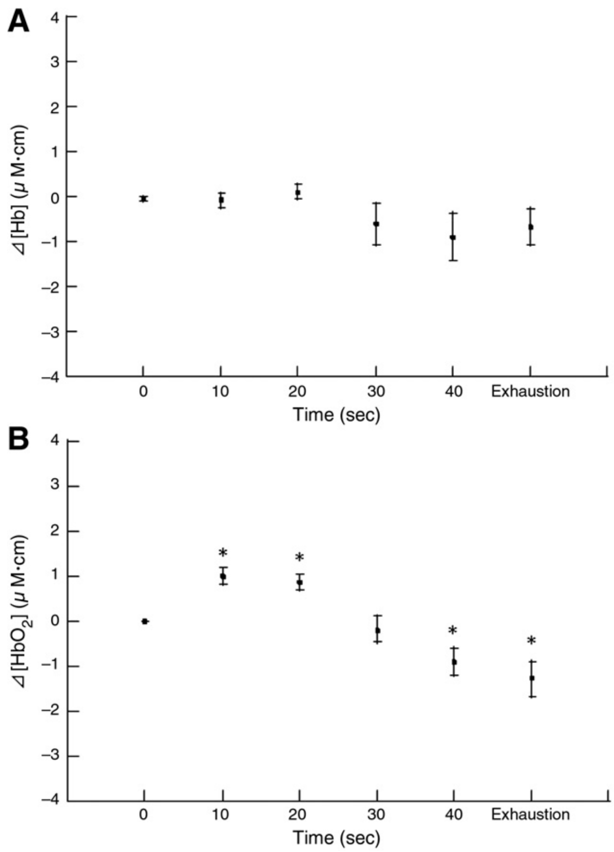

Fig. 1 – Changes in the contralateral motor cortex from resting values in (A) deoxyhemoglobin concentration ([Hb]) and (B) oxyhemoglobin concentration ([HbO$_2$]) during a pinching motor task. Values are the mean ± SE. Asterisks show significant differences compared with the resting value, *P*< 0.05.

directly by data from the brain. Previous studies have proposed that bilateral motor activity occurs during motor tasks, using pioneering approaches (Ghacibeh et al., 2007; Liu et al., 2002, 2003). However, these experiments did not examine the activity and hemodynamics of the bilateral motor cortices during a continuous motor task to voluntary exhaustion.

Near-infrared spectroscopy (NIRS) allows non-invasive monitoring of regional changes in cortical tissue oxygenation in response to various stimuli (Colier et al., 1999; Kleinschmidt et al., 1996; Mehagnol-Schipper et al., 2000; Obrig et al., 1996, 2000), detecting changes in oxy-(HbO$_2$) and deoxyhemoglobin (Hb) with high temporal resolution. The NIRS method is based on absorption changes that depend on changes in the concentration of HbO$_2$ and Hb in the tissue under investigation. With NIRS, it is possible to determine bilateral motor cortex oxygenation during sustained static exercise to voluntary exhaustion and oxygenation at the exact moment of voluntary exhaustion.

In the present study, we examined bilateral motor cortex oxygenation during a static sustained motor task performed until voluntary exhaustion was reached, demonstrating the interaction between contralateral and ipsilateral motor cortex oxygenation changes. In addition, we examined the time course of oxygenation of the bilateral motor cortices during the unilateral exhaustive motor task, including that at voluntary exhaustion.

2. Results

The mean maximal voluntary contraction (MVC) was 8.45 ± 1.61 kg. The value of 50% MVC was 4.23 ± 0.18 kg. The time to voluntary exhaustion from the start of the motor task was 66.8 ± 13.60 s.

2.1. *Contralateral (left-side) motor cortex oxygenation*

The oxygenation kinetics of the contralateral motor cortex during the motor task is described in Fig. 1 and Table 1. The contralateral [HbO$_2$] changed significantly during exercise (F = 13.616, P < 0.0001). [HbO$_2$] was significantly increased at 10 s (T = −6.202, P = 0.0004) and 20 s (T = −5.807, P = 0.0007) after the start of the motor task compared with the resting value. In all subjects, contralateral [HbO$_2$] was increased at 10 and 20 s after the start of the motor task compared with the resting value. [HbO$_2$] was significantly decreased, however, at 40 s (T = 2.983, P = 0.00204) and at voluntary exhaustion (T = 3.301, P = 0.0131) compared with the resting value. In six of eight subjects, contralateral [HbO$_2$] was decreased at 40 s after the start of the motor task and was decreased at exhaustion compared with the resting value in all subjects.

Contralateral [Hb] did not change significantly throughout the motor task (F = 1.496, P = 0.2118). In six of eight subjects, contralateral [Hb] was decreased at exhaustion compared with the resting value.

Table 1 – The changes of [HbO$_2$] and [Hb] from resting value after the start of motor task

	Ipsilateral motor cortex		Contralateral motor cortex	
	Δ[HbO$_2$]	Δ[Hb]	Δ[HbO$_2$]	Δ[Hb]
0 s	0.020 ± 0.008	−0.028 ± 0.075	0.002 ± 0.001	−0.043 ± 0.132
10 s	0.299 ± 0.651	0.098 ± 541	1.009 ± 0.459*	−0.077 ± 0.415
20 s	−0.173 ± 0.462	−0.260 ± 0.412	0.857 ± 0.417*	0.106 ± 0.429
30 s	−0.972 ± 1.613	−0.556 ± 0.404*	−0816 ± 0.799	−0.610 ± 1.260
40 s	−1.726 ± 1.398*	−0.781 ± 0.374*	−0.892 ± 0847*	−0.882 ± 1.426
Exhaustion	−2.647 ± 1.308*	−0.966 ± 0.619*	−10276 ± 1.096*	−0.662 ± 1.139

Results are mean number ± SD. Asterisks show significant differences compared with the resting value, P < 0.05.