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# Aerobic fitness influences cerebral oxygenation response to maximal exercise in healthy subjects

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ABSTRACT

The study examined whether the aerobic fitness level modifies the cerebral oxygenation response to incremental ramp exercise, and more specifically the decline in cerebral oxygenation from heavy exercise up to maximal intensities. 11 untrained ($\dot{V}_{O_{2max}}$ 47.3 ± 4.0 mL min$^{-1}$ kg$^{-1}$) and 13 endurance-trained ($\dot{V}_{O_{2max}}$ 61.2 ± 8.0 mL min$^{-1}$ kg$^{-1}$) healthy men performed a maximal ramp cycle exercise. Left prefrontal cortex oxygenation ($\Delta HbO_2$) was monitored by near-infrared spectroscopy. A cerebral oxygenation threshold decline ($Th_{COx}$) during exercise was determined. $Th_{Cox}$ occurred in all subjects but for higher $\dot{V}_{O_2}$ (mL min$^{-1}$ kg$^{-1}$) in endurance-trained than in untrained subjects ($P < 0.01$). At submaximal exercise intensity corresponding to $Th_{COx}$, $\Delta HbO_2$ was higher in endurance-trained than in untrained subjects ($P < 0.05$). $\dot{V}_{O_2}$ at $Th_{Cox}$ was related to $\dot{V}_{O_2}$ at respiratory compensation point ($n = 24$, $r = 0.93$, $P < 0.001$) and to $\dot{V}_{O_{2max}}$ ($n = 24$, $r = 0.92$, $P < 0.001$). These findings indicate that above the respiratory compensation point the prefrontal $O_2$ demand exceeds the supply in untrained and in endurance-trained subjects. In addition, the occurrence of $Th_{COx}$ was delayed to higher absolute exercise intensities in endurance-trained in relation with their higher $\dot{V}_{O_{2max}}$ than untrained men. These results demonstrated that aerobic fitness influences cerebral oxygenation during exercise.



## 1. Introduction

The origin of exercise performance limitation is still under debate. Maximal oxygen uptake ($\dot{V}_{O_{2max}}$) is considered to be one of the most important indicators of aerobic fitness (Wagner, 1996). $\dot{V}_{O_{2max}}$ is classically determined using exercise testing with 1 to 3 min of increasing step by step workload increments, or by a more progressive design with a slight workload increase every 1 to 5 s. This last protocol is named the 'ramp exercise'. Numerous studies show that $\dot{V}_{O_{2max}}$ and the maximal mechanical power output ($\dot{W}_{max}$) achieved during these tests are essentially limited by $O_2$ delivery to muscle (Basset and Howley, 2000). Recent researches have proposed that exercise-induced cerebral impairments may also contribute to maximal exercise performance: several investigations using near-infrared spectroscopy (NIRS) to evaluate the prefrontal cortex haemodynamic have reported a decrease in cerebral oxygenation at heavy exercise intensities above the respiratory compensation threshold (e.g. Bhambhani et al., 2007; Oussaidene et al., 2013; Rupp and Perrey, 2008; Subudhi et al., 2007, 2008). This drop in cerebral oxygenation at heavy exercise up to maximal intensities implies a reduced $O_2$ supply relative to demand. The cerebral oxygenation decrease might reflect a reduction in central motor command (Rupp and Perrey, 2008; Subudhi et al., 2007). Previous studies have proposed that reduced $O_2$ availability in the brain might influence central nervous system motor output and constitutes a signal leading to limiting exercise (Amann et al., 2007; Rasmussen et al., 2010; Subudhi et al., 2007–2009; Vogiatzis et al., 2011). In agreement, several studies have provided support that cerebral oxygenation is a pivotal contributing factor to limiting maximal exercise capacity in hypoxia condition (e.g. Subudhi et al., 2007, 2008; Vogiatzis

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et al., 2011). However, the involvement of cerebral oxygenation in exercise limitation under normoxia is still debated because even if cerebral oxygenation decreases at heavy exercise, it remains above the resting level (Subudhi et al., 2007, 2011). New findings, using $O_2$ supplementation, support the involvement of cerebral oxygenation as a limiting factor in maximal ramp exercise in a normal $O_2$ environment (Oussaidene et al., 2013). The authors suggested that a cerebral oxygenation decline threshold may have a significant role in the maximal performance during this type of exercise.

It is well recognized that endurance-trained athletes show high aerobic fitness and, more specifically, $\dot{V}_{O_{2max}}$ in comparison to other sports or untrained subjects. The high $\dot{V}_{O_{2max}}$ in endurance-trained athletes is mainly due to the increase in maximal cardiac output and in tissular $O_2$ supply induced by endurance training (Basset and Howley, 2000; Wagner, 1996). This increase in maximal cardiac output could also increase cerebral blood flow and consequently increase cerebral oxygenation during exercise by endurance athletes compared to untrained subjects. In support, some studies in animals or humans suggest that cerebral blood flow is enhanced by aerobic fitness (Ainslie et al., 2008) and, consequently, it may enhance cerebral oxygenation. In addition, it has been well known for a long time that endurance-trained subjects present a respiratory compensation threshold at higher exercise intensities than untrained subjects. Therefore, with increasing aerobic fitness in subjects, cerebral oxygenation threshold decline may occur for increasing exercise intensities if hypocapnia is a major factor in cerebral deoxygenation during exercise (Bhambhani et al., 2007) in endurance-trained as well as in untrained subjects.

To our knowledge, there has been no direct comparison of exercise cerebral oxygenation between endurance-trained and untrained subjects. There are few data reported in the meta-analysis of the literature by Rooks et al. (2010), which suggests lower cerebral oxygenation during moderate to intense exercise and higher cerebral oxygenation during heavy to maximal exercise in trained than in untrained subjects. However, this meta-analysis included studies with varied ages of subjects and varied NIRS cerebral oxygenation parameters, which depend on the type of NIRS devices. In order to clarify the effect of training status and aerobic fitness on the cerebral oxygenation response to exercise it is necessary to compare untrained to endurance-trained subjects.

The purpose of the present investigation was to compare the cerebral oxygenation response to ramp cycle exercise between untrained and endurance-trained men in order to determine the influence of aerobic fitness status. We hypothesized, first that cerebral oxygenation may be higher in endurance-trained than in untrained subjects, and second that cerebral oxygenation threshold decline may occur at higher exercise intensity in endurance-trained athletes than in untrained subjects, related to a higher respiratory compensation threshold in the former.

## 2. Materials and methods

### 2.1. Subjects

Eleven healthy men, untrained (UNT) in physical endurance activities (sport leisure ≤3 h/week; age, 24 ± 6 years; height, 179.7 ± 4.9 cm; body mass, 77.2 ± 6.1 kg,) and 13 endurance-trained subjects (TR) who practised cycling and triathlon (endurance activities >8 h/week; age, 26 ± 5 years; height, 178.5 ± 5.8 cm; body mass, 70 ± 6 kg) volunteered to participate in this study. All subjects were non-smokers and free of known chronic cardiac, respiratory, metabolic or neurological disease. All subjects were informed of the nature of the investigation, and consecutively gave written informed consent. The study was approved by the local Ethics Committee.

### 2.2. Experimental design

Subjects came to the laboratory at least 2 h after their last meal. They were instructed to refrain from caffeine or alcohol and to avoid practising strenuous exercise for at least 24 h prior to the test. After a familiarization with the device, the subjects performed a maximal cycle ramp exercise which was immediately followed by 10 min of recovery period and a supramaximal cycle exercise until exhaustion.

#### 2.2.1. Ramp cycle exercise test

Following a resting period of 5 min sitting on a cycle ergometer (Excalibur Sport, Lode BV, Medical Technology, Netherlands), the subjects performed a ramp cycle exercise. The exercise began with a 3-min warm-up period at 60 W for UNT or 100 W for TR subjects. Then, exercise workload was increased following a ramp of 1 W every 3 s (20 W min$^{-1}$) until exhaustion. The mean duration of exercise was 12.2 ± 1.0 min for UNT and 12.7 ± 1.2 min for TR. Subjects were to remain upright while maintaining a pedalling rate of 70 rpm. They were verbally encouraged until the end of the exercise.

$\dot{V}_{O_{2max}}$ was considered to have been achieved when three of the five following criteria were obtained: (1) a plateau of $\dot{V}_{O_2}$ (increase <100 mL min$^{-1}$ over 1 min of exercise) in spite of increasing workload; (2) a respiratory exchange ratio > 1.1; (3) a heart rate ($H_R$) > 90% of the theoretical maximal heart rate (208 − 0.7 × age) (Tanaka et al., 2001); (4) a rate of perceived exertion (RPE) score ≥19; and (5) subjects were unable to maintain pedalling cadency at 70 rpm despite verbal encouragement. All the subjects achieved at least three of these criteria. $\dot{W}_{max}$ corresponded to the highest power output.

#### 2.2.2. Supramaximal test

Because the validity of secondary criteria for establishing maximal $O_2$ uptake is controversial (Poole et al., 2008), the subjects performed a supramaximal test in order to obtain additional evidence of $\dot{V}_{O_{2max}}$ achievement during the ramp exercise test (Scharhag-Rosenberger et al., 2011). The subjects performed the supramaximal test consecutively to the ramp test after 10 min of recovery period (2 min active recovery +8 min passive recovery) seated on the cycle ergometer. It began with 1 min at 50% of $\dot{W}_{max}$ and continued at 105% of $\dot{W}_{max}$ until voluntary exhaustion.

### 2.3. Cardiopulmonary measurements

During the cycle ramp and supramaximal tests, pulmonary gas exchanges were measured continuously with a breath-by-breath system (Ergocard®, Medisoft, Belgium). Before each test, the analysers were calibrated with known reference gases (16% $O_2$ and 4% $CO_2$). The subjects breathed through a mask with low dead space connected to a pneumotachograph. The pneumotachograph was calibrated with a 3 L syringe. Room temperature was set at 21.0 ± 1.0 °C with a relative humidity of 47.0 ± 10.0% and barometric pressure of 755.0 ± 4.0 mmHg.

The expired volume of air was continuously sampled for analysis by the system. Mean values of gas exchange variables were recorded and averaged every 15 s: minute ventilation ($\dot{V}_E$), $\dot{V}_{O_2}$, expired $CO_2$ ($\dot{V}_{CO_2}$), ventilatory equivalents for $O_2$ ($\dot{V}_E/\dot{V}_{O_2}$) and $CO_2$ ($\dot{V}_E/\dot{V}_{CO_2}$), respiratory exchange ratio (RER), end-tidal $O_2$ pressure ($P_{ET_{O_2}}$) and end-tidal $CO_2$ pressure ($P_{ET_{CO_2}}$). $H_R$ was continuously recorded with a 12-lead electrocardiogram (Medcard®, Medisoft). A scale of perceived exertion – 15 levels between 6 and 20 associated with verbal information (Borg, 1970) – was presented to the subjects at the end of each minute of the ramp exercise. Arterial haemoglobin $O_2$ saturation ($S_{PO_2}$) was estimated by pulse oximetry