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Original research

Effects of high vs. low cadence training on cyclists' brain cortical activity during exercise

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ABSTRACT

Objectives*:* As brain cortical activity depends on cadence, exercise at different pedaling frequencies could provide efficient stimuli for functional adaptations of the brain. Therefore, the purpose of the study was to investigate the effects of cadence-specific training on brain cortical activity as well as endurance performance.
Design*:* Randomized, controlled experimental trial in a repeated measure design.
Methods*:* Male ($n = 24$) and female ($n = 12$) cyclists were randomly assigned to either a high cadence group (HCT), a low cadence group (LCT) or a control group (CON) for a 4 week intervention period. All groups performed 4 h of basic endurance training per week. Additionally, HCT and LCT completed four cadence-specific 60 min sessions weekly. At baseline and after 4 weeks subjects performed an incremental test with spirometry as well as an interval session (constant load; varying cadences) with continuous recording of electroencephalographic (EEG) rhythms.
Results*:* In contrast to CON, HCT and LCT elicited similar improvements of maximal oxygen uptake and power at the individual anaerobic threshold. Additionally, there was a reduction of alpha-, beta- and overall-power spectral density in HCT, which was more pronounced at high cadences. Improvements of endurance performance were correlated with reductions of EEG spectral power at 90 and 120 rpm.
Conclusions*:* Whereas high and low cadence training elicit similar improvements in endurance performance, brain cortical activity is especially sensitive to high cadence training. Its reduction can be interpreted in the sense of the neural efficiency hypothesis and might as well influence the sensation of central fatigue positively.

1. Introduction

There has been considerable debate concerning the influence of brain function central mechanisms of fatigue and subsequent performance.[1] Due to difficulties of utilizing modern brain-imaging techniques while exercising, the number of studies is still limited. So far evidence has predominantly been generated with electroencephalographic (EEG) recordings, as in contrast to positron emission tomography (PET) or functional magnetic resonance imaging (fMRI), this technique does not require subjects to remain inactive. Although there is heterogeneity of study results, it has been repeatedly confirmed that brain cortical activity is highly influenced by the exercise protocol.[2] In this respect, studies have reported an increase in brain cortical activity with exercise intensity, indicating that a high central activation is necessary to maintain high loads.[3] Moreover, spectral power densities as well as frontal asymmetry follow an inverted U-shaped curve over exercise time.[4,5] Whereas the plateau was previously interpreted as phase of optimal performance, the decrease is known to be a symptom of central fatigue.[6] These findings confirm that in endurance competitions the maintenance of a high central activation is required to prevent the reduction of the power output and the termination of exercise resulting from central fatigue.

Abbreviations: CON, Control group; EEG, Electroencephalography, electroencephalogram; EMG, Electromyography; f, Female; fMRI, Functional magnetic resonance imaging; HCT, High cadence training group; LCT, Low cadence training group; m, Male; NIRS, Near-infrared spectroscopy; PET, Positron emission tomography; P_{IANS}, Power at the individual anaerobic threshold; rpm, Revolutions per minute; VO_{2MAX}, Maximal oxygen consumption.

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Despite the fact that a decrease of brain cortical activity clearly limits exercise performance, it has not been investigated whether or not endurance training elicits favorable changes in brain function during exercise. However, a cadence-specific training program might have the potential to directly modulate the brain's functional response, as the choice of movement frequency has a direct impact on brain function. In this respect, Hottenrott et al.[4] demonstrated that raising cadence to 120 rpm increased spectral EEG power in the alpha-, beta- and theta-band, whereas reductions in these bands were observed after a decrease of pedaling frequency to 60 rpm. This is further supported by Schumann and Seibt,[7] who also found brain cortical activity to be elevated with higher pedaling frequencies.

Although chronic effects of endurance training on brain cortical activity have not yet been investigated with a longitudinal design, the differences of resting EEG rhythms between athletes and untrained individuals indicate that brain function is sensitive to regular exercise.[8] Lardon and Polich[9] found spectral power to be less for exercise compared to the control group in the delta frequency range, but greater in all other bands. Similarly, Babiloni et al.[10] confirmed that a higher training status is associated with increased amplitude of resting state EEG rhythms especially in the Alpha-band, which reflect enhanced cortical neuronal synchronization. Apart from the resting EEG, subjects' physical fitness and motor skills are known to influence brain cortical activity during specific motor tasks. By differences of the dominant alpha rhythm, Del Percio et al.[11] showed that elite athletes are characterized by a reduced cortical activation during simple voluntary movement. Based on those cross-sectional findings, it is reasonable to suggest that endurance training elicits changes in brain function as well.

The aim of the present study was to investigate the effects of a short-term high and low cadence training on brain cortical activity during exercise as well as aerobic performance in cyclists. With regard to the results of Del Percio et al.[11] reductions of spectral EEG power were expected to occur predominantly at pedaling frequencies requiring a high level of brain cortical activity.

2. Methods

Male ($n = 24$) and female ($n = 12$) cyclists [average values for age: 27 ± 3 years; body mass: 71.8 ± 8.5 kg; height: 176.9 ± 7.1 cm; VO_{2MAX}: 52.6 ± 6.0 ml min^{-1} kg^{-1}; relative P_{MAX}: 4.31 ± 0.50 W/kg; P_{MAX}: 310.2 ± 57.5 W] were recruited from local sports clubs. Eligible subjects had to fulfill the following inclusion criteria: non-smokers and at least 4 h cycling training per week within the last 6 months. Prior to the study, cyclists' preferred cadence was 88 ± 4 rpm. A preliminary screening process, including ECG and a personal anamnesis, was employed to establish that subjects were free of health problems. The participants provided written, informed consent. The study was approved by the local ethics committee.

Recruited subjects were randomly assigned to either a high cadence training (HCT, $n = 12$), a low cadence training (LCT, $n = 12$) or a basic endurance training (CON, $n = 12$). The compositions of the groups were gender balanced. While cyclists in CON weekly performed 4 h of basic endurance training to maintain their aerobic performance, HCT and LCT additionally completed 4 h of cadence-specific exercise on indoor cycles. At baseline and after 4 weeks of training subjects' aerobic performance was assessed with an incremental ergometer test. On a separate day brain cortical activity was recorded at rest and during exercise.

Subjects completed pre- and post-tests at the same time and day of the week. Environmental temperature (20 °C), fluid intake and nutrition were standardized. By using 24 h recall protocols, cyclists' nutrition was similar between pre- and post-tests. Subjects were instructed to have their final meal 90 min before testing and refrain from consuming caffeine in any form. Following the assessment of body composition (Tanita, BC-545 Inner Scan, Germany), subjects performed an incremental exercise test (increment: 25 W/3 min) on a cycle ergometer to determine their maximal oxygen uptake (VO_{2MAX}: highest value achieved over a 30 s period) using spirometry (Cortex Medical, Metamaxx 3b, Germany). At rest and after each increment lactate concentration was measured with the enzymatic-amperometric method in 10 μl blood taken from an ear lobe. Collected data were processed with WinLactat 3.1 (Mesics, Germany). The individual anaerobic threshold was defined as the lowest quotient of lactate·power^{-1} + 1.5 mmol l^{-1}.

Three–five days after the assessment of aerobic performance subjects' brain cortical activity was recorded under the following conditions: (1) resting state (sitting on the cycle ergometer with 1 min eyes closed/1 min eyes open) and (2) during interval exercise. The exercise test included a 10 min warm-up, followed by three series of 3 min intervals at different cadences (60, 90 and 120 rpm) and 3 min cool-down. During the test the workload was held constant at 100% P_{IANS}. The test set-up was identical to Hottenrott et al.[4]

For the EEG recordings, 32 Ag/AgCl electrodes were mounted to the subjects head with a flexible, breathable EEG cap (ActiCap, BrainVision, Germany) and arranged according to the international 10:20 system.[12] Occipital and temporal electrodes were deactivated, as exercise is known to provoke muscle artifacts at these electrode sites.[4] FCz was used as reference and AFz as ground. The active EEG electrodes were filled with SuperVisc gel (EasyCap GmbH, Germany) to reduce impedances below 10 KΩ. The EEG data were amplified using the QuickAmp system (BrainVision, Germany), sampled at 512 Hz and recorded with Vision Recorder (BrainVision, Germany).

Collected data were processed with BrainVision Analyzer 2.0 (Germany). After a reduction of the sampling rate to 256 Hz, high- and low-pass filters were applied so that a frequency range from 3.0 to 40 Hz remained for analysis (time constant 0.0318 s; 24 dB/octave). The last 60 s during warm-up, intervals and cool-down were selected for analysis. A systematic protocol was used to detect artifacts automatically with thresholds.[13] Within artefact-free epochs five consecutive segments were selected. These were individually transformed to power spectra using a Hanning window (20%), subject to Fast Fourier Transform and then averaged. Subsequently, the mean activity in the theta- (4.5–7.49 Hz), alpha- (7.5–12.49 Hz), beta- (12.5–32 Hz) and overall spectrum (4.5–32 Hz) were exported and normalized to the average power of the same frequency band during the recordings at rest (eyes open). To present brain cortical activity at 60, 90 and 120 rpm, spectral power was averaged over three intervals of identical cadence.

The EEG application and data processing procedures followed a standardized protocol, which has been shown to provide a 4 week test-retest reliability of brain cortical activity during exercise for the relative alpha-, beta-, theta- and overall-power averaged across the scalp at 60, 90 and 120 rpm.[13]

All groups performed 4 h of unsupervised basic endurance training with individual heart rate targets (70–80% P_{IANS}) per week. HCT and LCT also engaged in four 60 min sessions of supervised cadence-specific exercise weekly. This compromised two interval sessions and two rides at constant speed. The training protocols of HCT and LCT were identical in intensity, frequency and duration. The interval sessions included six to eight 3 min bouts of high intensity at 120 to 140 rpm in HCT and 60 rpm in LCT followed by 3 min active rest. The constant rides were designed to allow cyclists the maintenance of either high (HCT) or low cadences (LCT) at a submaximal intensity over 45 min. During training intensity was controlled by establishing heart rate targets at the equivalent percentages of the