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Critical flicker frequency threshold increment after an exhausting exercise

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Abstract

The purpose of this study was to assess the effect of an incremental test to exhaustion on sensory sensitivity using critical flicker fusion (CFF) frequency. The CFF threshold measurements, tympanic temperature and heart rate were carried out, before and immediately after an incremental cycling test of maximal oxygen uptake. Deterioration in perceptual processes linked to fatigue phenomena were not observed in the present study. On contrary, results indicated that incremental exhausting exercise increases the sensory sensitivity threshold, thereby suggesting an exercise induced increase in cortical arousal. Furthermore, the absence of change on subjective judgment threshold suggests that change observed immediately after exercise was not linked to a more liberal response criterion by subjects. The CFF threshold protocols appear to be relevant to assess the effect of exercise on sensory sensitivity and cortical arousal.

Keywords: Cycling exercise, sensory sensitivity, tympanic temperature.

According to the literature, the influence of acute exercise on cognitive functioning differs as function of the exercise protocols employed (for a review see Tomporowski , 2003). Because the effect depends on the type and duration of exercise performed, Tomporowski (2003) distinguished among three types of exercise protocols. The first type induces fatigue through brief, exhausting[1] exercise (i.e., intense anaerobic exercise and incremental test to exhaustion with maximal oxygen uptake achievement). Intense anaerobic exercise seems not impair cognitive function. The second type involve brief, maximal and sub-maximal exercise protocols to induce arousal (i.e., short-duration aerobic and anaerobic exercise). At moderate intensities, improvements in cognitive performance were generally reported. The third type of protocols involve relatively long, sub-maximal exercise that lead to dehydration or/and energy substrates depletion (i.e., steady state aerobic exercise). Sub-maximal exercises seem decrease both information processing and memory functions.

Considered as an objective, quantitative and validated measure of alertness, the Critical Flicker Fusion (CFF) threshold is particularly interesting in sport and exercise psychology because this index can be used as a rating of central fatigue (e.g., Godefroy, Rousseu, Vercruyssen, Cremieux, & Brisswalter, 2002; Li, Jiao, Chen & Wang, 2004). In this framework, the central fatigue, associated with specific alterations in central nervous system (CNS) function, can cause a deterioration of mental performance. In many sports (e.g. team sports, fighting sports and racket sports), players must simultaneously handle both physiological and cognitive loads. A better understanding of the interaction between physiological and cognitive processes during exercise would be beneficial for practitioners to improve training procedures, competitive sport strategies and to anticipate the deleterious consequences of fatigue phenomena occurrence.

The CFF threshold measurement is already extensively used in psychopathology and psychopharmacology research (Ghozlan & Widlocher, 1993; Bobon, Lecoq, von Frenckell, Mormont, Lavergne, & Lottin, 1982) and to assess the effect of exercise on sensory processes (e.g., Davranche & Audiffren, 2004; Douchamp-Riboux, Heinz, & Douchamp, 1989; Godefroy et al., 2002). It is assumed in this research that an increase of CFF threshold is indicative of an increase in cortical arousal and sensory sensitivity. On contrary, a decrease of CFF threshold suggests a reduction of the efficiency of the system to process information (Li et al., 2004). In this framework, several studies have shown that physical exercise alters the

[1] Exhausting exercise is operationalized as exercise that ends when, despite encouragement, the subject is no longer able to maintain a constant power output.

CFF threshold (Davranche & Audiffren, 2004; Godefroy et al., 2002). However, the influence of exercise seems also differs as function of workload and duration of exercise employed. An increase in CFF threshold was reported immediately after a brief sub-maximal exercise (i.e., 20 minutes cycling at 50% of maximal aerobic power) (Davranche & Audiffren, 2004), whereas no effect was observed after a relatively long, sub-maximal exercise (i.e., rowing marathon race) (Douchamp-Riboux et al., 1989).

The effect of brief, exhausting exercise that induces the fatigue phenomenon, however, remains poorly understood. To our knowledge, only one study has assessed the influence of exhausting exercise protocols on sensory sensitivity using the CFF threshold (Godefroy et al., 2002). In their study, the authors have reported a decrease in CFF threshold after an incremental running test of maximal oxygen uptake ($\dot{V}O_{2max}$). This alteration was interpreted as indicating a decrement in perceptual response associated with the central nervous system fatigue. Because the CFF threshold is affected by non-sensory and sensory factors, the interpretation of the results must take into account two different parameters that are assumed to be independent. The first parameter is a relatively pure measure of sensory sensitivity. It can be assessed by calculating the mean of ascending and descending CFF threshold values (M_{tot}). The second parameter is a measure of the subjective criterion, which reflects the response criterion used by the subject (conservative or liberal). The subjective criterion can be estimated by calculating the mean difference between ascending and descending CFF threshold values (M_{di}) (Ghozlan & Widlocher, 1993). In the study of Godefroy et al. (2002), the effect of exercise on CFF threshold was only observed on M_{di} and no significant effect was observed on the classical M_{tot}. Because a conservative response criterion results in larger values of M_{di} than a liberal response criterion, CFF threshold changes observed by Godefroy et al. was likely due to a more liberal response criterion of the subjects than to the decrement of the sensory sensitivity.

According to these results, the aim of the present study was to examine the effect of an incremental cycling test to exhaustion on sensory sensitivity and the subjective criterion using CFF threshold measurement. If a physical exercise leading to exhaustion induces a transitory CNS fatigue, a decrease in sensory sensitivity criterion of CFF threshold (M_{tot}) should be observed. Alternatively, if this type of exercise induces an increase in cortical arousal and sensory sensitivity, an increase in CFF threshold (M_{tot}) should be observed. Furthermore, if CFF threshold change observed after exercise was associated with the internal subjective judgment, a change in subjective criterion (M_{di}) should also be observed. If the subjective criterion is conservative, a greater value of M_{di} (related to a more cautious strategy) should be

observed. Alternatively, if the subjective criterion is liberal, a smaller value of M_{di} (related to a more risky strategy) should be observed.

Method

Participants

Seven males, aged 22 ± 3 years, volunteered to take part in the experiment. They participated in regular physical activity and had normal vision. Informed consent was obtained from the participants.

Maximal exercise test

The participants performed incremental cycling maximal exercise test on an electrically braked stationary cycle ergometer (Ergoline 800S). After a 5-minute warm-up period, the workload was increased by 25 W every minute until exhaustion. The pedaling rate was kept at 60 rpm. Participants were verbally encouraged to achieve their maximal level. The subject breathed through a facemask (Hans Rudolph). Expired gas flows were measured using a pneumotachograph (Type 3 Hans Rudolph) and analyzed breath-by-breath using an automated system (Medi Soft, Exp'air 1.26). Oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), expiratory flow ($\dot{V}E$), and other classical respiratory parameters were monitored continuously and averaged every 15 seconds. A four-lead electrocardiogram recorded heart rate continuously. All participants achieved $\dot{V}O_2max$ as defined by the following criteria: 1) an inability to continue cycling despite encouragement; 2) an observed plateau in $\dot{V}O_2$ kinetic despite an increase in workload; 3) a respiratory exchange ratio ($\dot{V}CO_2/\dot{V}O_2$) greater than 1.15; and 4) attainment of age predicted maximum HR.

Critical Flicker Fusion

The CFF measurements were carried out, before and immediately after exercise. Participants were seated in front of a viewing chamber (Campden Instruments, 12021*C), constructed to control extraneous factors that might distort CFF values. Two light-emitting diodes (58 cd/m2) were presented simultaneously in the viewing chamber: one for the left eye and one for the right eye. The stimuli are separated by 2.75 cm (center to center) with a stimulus to eye distance of 15 cm and a viewing angle of 1.9 degree. The inside of the viewing chamber is painted flat black to minimize reflection.

The flicker frequency increment (1 Hz/sec) changed in two different ways: either it increased (from 0 to 100 Hz) until the subject perceived fusion, or decreased (from 100 to 0

Hz) until flicker was detected. After a fovea binocular fixation, participants were required to respond by pressing a button upon identification of the visual flicker (descending frequency) and the fusion (ascending frequency) thresholds. Before the experiment, subjects performed as many practice trials as necessary to familiarize with the exigencies of the CFF test. Then, three ascending and three descending trials were performed alternatively. The CFF test lasted approximately 3-4 minutes. The average of the six values, representing the classical sensory sensitivity criterion (M_{tot}), was calculated for each subject. In addition, the mean ascending and descending threshold difference (Δ = fa – fd) was individually calculated to assess the subjective judgment criterion (M_{di}).

Tympanic temperature

Tympanic temperature reflecting deep brain temperature was recorded before and after exercise (Thermoscan, Braun). Four measures were taken successively in the same ear and the average of the 4 values was calculated.

Data analysis

A Student *t* test, one sample two-tailed, was used to analyze each of the following measures: heart rate, tympanic temperature, M_{tot} and M_{di} CFF threshold values. Alpha was established at 0.05 for all analyses. The effect sizes of exercise on the M_{tot} and M_{di} CFF threshold values were estimated using Cohen's *d*.

Results

Student *t* test revealed that heart rate was significantly higher after exercise than before, 186 ± 5 versus 78 ± 14 bmp.min^{-1}; t_6 = -19.18, $p < .05$. Concerning the tympanic temperature, the data of one subject were lost because of data acquisition failure and hence, the number of subjects was reduced to 6 subjects. After exercise, an increase in tympanic temperature was observed, 37.5 ± 0.5 °C versus 36.7 ± 0.4 °C, t_5 = -4.2, $p < .05$. Participants' descriptive data and cardiovascular exercise history are reported in Table 1.

Table 1. Anthropometrical and physiological characteristics of subjects (N = 7).

Variable	**Mean ± SD**
Age (yrs)	22 ± 3
Height (cm)	178 ± 7
Weight (kg)	72 ± 9
$\dot{V}O_{2MAX}$ ($ml.min^{-1}.kg^{-1}$)	54 ± 11
$P\dot{V}O_{2MAX}$ (W)	339 ± 54
HR_{MAX} ($bmp.min^{-1}$)	186 ± 6
RQ_{MAX}	1.23 ± 0.1
$\dot{V}E_{MAX}$ ($l.min^{-1}$)	142 ± 19

Note. $\dot{V}O_{2MAX}$, maximal oxygen uptake; $P\dot{V}O_{2MAX}$, power at maximal oxygen uptake; HR_{MAX}, maximal heart rate; RQ_{MAX}, maximal respiratory quotient; $\dot{V}E_{MAX}$, maximal minute ventilation.

A effect of exercise was observed on M_{tot} (t_6 = -8.84, p ‹ .05, d = 0.65). After exercise, an increase of M_{tot} CFF threshold was shown (from 34.8 ± 3.1 Hz to 36.7 ± 2.7 Hz). No significant effect of exercise was observed on M_{di} (-2.7 ± 3.4 Hz versus –1.3 ± 4 Hz; t_6 = -0.95, p = 0.38, d = 0.37). Change in CFF threshold was only observed on sensory sensitivity (average of the ascending and descending thresholds, M_{tot}) and no significant effect was observed on the subjective criterion (difference between the ascending and descending thresholds, M_{di}) (Figure 1).

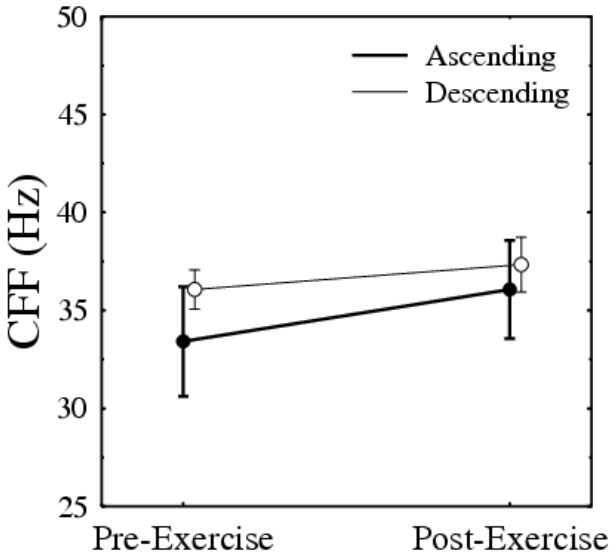

Figure 1. Pre-Exercise and Post-Exercise ascending (thick line) and descending (thin line) critical flicker frequency (CFF) thresholds. Points represent the mean CFF thresholds; vertical lines depict confidence interval for the mean.

Discussion

The aim of the present study was to evaluate the effect of an incremental maximal test on the CFF threshold and to investigate the respective role of this type of exercise on sensory sensitivity and response criterion. Results show that change in CFF threshold was only observed in sensory sensitivity. No significant effect was observed on the subjective criterion.

Contrary to Godefroy et al.' (2002) observations, the deleterious effect of fatigue phenomenon induced by exhausting exercise was not observed on perceptual response during brief maximal exercise. Instead, incremental cycling to exhaustion increased the M_{tot} CFF threshold values, thereby suggesting that exercise instead induces an increase in cortical arousal and sensory sensitivity. The absence of change on M_{di} CFF threshold values suggests that change observed immediately after exercise was not linked to the more liberal response criterion of the subjects. The difference between our results and those reported by Godefroy et al. may also have been due to differences in apparatus and design. According to Bobon et al. (1982), several variables could alter CFF threshold on top of the non-sensory variables. Thus, the use of CFF threshold protocols necessitates some important methodological prerequisites to obtain reliable, valid and sensitive data (i.e., led intensity, incremental frequency, visual angle, fovea fixation). Furthermore, the interpretation of the CFF threshold change must take into account both sensory sensitivity and the response criterion.

In the present study, the absence of effect of fatigue on perceptual response could be linked to the nature of the fatigue induced by exercise protocol. Because, a brief exhausting cycling test was used, the induced fatigue was probably more a peripheral than a central nervous system fatigue phenomenon. It seems, therefore, that the fatigue phenomenon responsible for the cessation of the exercise cannot be evaluated by using CFF threshold.

The increase of body temperature during exercise may be a plausible explanation of the increase in the CFF threshold. However, to date it is not known if this observation reflects a casual relationship. An increase in CFF threshold has been previously observed in normal subjects when the temperature of body increases from 0.5°C (Accornero, De Vito, Rotunno, Perugino, & Manfredi, 2003). In the present study, the increase in temperature seems not to be important enough to induce transitory central nervous system fatigue. Only the attainment of a high core temperature has been shown to induce central fatigue (i.e. reduction of central nervous drive to the muscle). In laboratory settings, trained participants become exhausted when they reach a core temperature of 40°C (Nielsen & Nybo, 2003).

In conclusion, we observed that a maximal exercise test produced an increase in CFF values suggesting an exertion related enhancement of sensory sensibility and cortical arousal. Further work is necessary to study the causal relation between the core temperature and cognitive function during exercise.

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