Hyperventilation reduces the decrease of power output in a repeated sprint training in cyclists

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**A R T I C L E   I N F O**

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**A B S T R A C T**

**Objective:** To evaluate the effect of hyperventilation during a repeated sprint training on a cycle ergometer.

**Method:** Seven cyclists performed two training sessions (10 maximal sprints of 10 s, with 60 s of rest), one with free ventilatory frequency and another one with hyperventilation (the participants breathed 60 cycles per minute during the last 30 s of recovery). Power, fatigue index and blood lactate concentration were analyzed.

**Results:** The lactate concentrations pre- and post-training did not differ between trainings. Regarding to the maximum absolute and relative power, no differences were found between sprints in the hyperventilation condition, however, the values obtained in the first four sprints were higher than the latter two (p < 0.05) in the normal condition. In relation to the mean absolute and relative power, differences were found between sprints in both conditions. In the hyperventilation condition the value of the first sprint was higher than the penultimate (p < 0.05), while in the normal condition, the value of the first sprint was greater than the last four (p < 0.05) and the value of the second sprint exceeded the last two ones (p < 0.05). For the fatigue index, both protocols showed differences from the first to the eighth sprint (p < 0.05).

**Conclusion:** Despite the absence of differences in lactate concentration between normal condition and hyperventilation condition, hyperventilation between efforts during a repeated sprint training could reduce the decrease in power output on a cycle ergometer.

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La hiperventilación reduce la disminución de potencia en un entrenamiento de sprints repetidos en ciclistas

**R E S U M E N**

**Objetivo:** Evaluar el efecto de la hiperventilación durante una sesión de entrenamiento con esfuerzos repetidos en cicloergómetro.

**Método:** Siete ciclistas realizaron dos entrenamientos (10 sprints máximos de 10 s con 60 s de recuperación), uno con frecuencia de respiración normal y otro con hiperventilación (los participantes respiraron a 60 ciclos por minuto durante los últimos 30 s de recuperación). Se analizaron la potencia, el índice de fatiga y la concentración sanguínea de lactato.

**Resultados:** La concentración de lactato pre y postentrenamiento no difirió entre los entrenamientos. En relación con los valores de potencia máxima absoluta y relativa, no se encontraron diferencias entre los sprints en la condición de hiperventilación; sin embargo, en la condición normal, los valores obtenidos en los cuatro primeros sprints fueron superiores a los dos últimos (p < 0.05). En relación con los valores de potencia media absoluta y relativa, se encontraron diferencias entre los sprints en las dos condiciones (p < 0.001). En la condición de hiperventilación, el valor del primer sprint fue superior al penúltimo.

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Introduction

The balance of acid–base status is maintained through protein, phosphate and bicarbonate buffers, with the assistance of renal and respiratory system, and its correct functioning is associated with efficient energy production. At rest or low intensity activities, the body maintains the pH in basic state; however, when performed high-intensity short-duration exercise, acidic environment is created in the muscular system (metabolic acidosis), generated by the dissociation of hydrogen (H+) ions.

Generally, training methods to increase the repeated sprint ability are applied considering high intensity efforts and short recovery time, which generate accumulation of hydrogen ions and hence the blood pH decrease. This methods are recognized as high intensity intermittent training (HIIT). This muscle acidic state inhibiting factor has been considered for operation of the glycolytic pathway. In addition, reducing the muscle contraction mechanism can also decrease performance, with reduction in the power production. For the maintenance of physical performance, some strategies are used to reverse the acidic environment created. Among the main ones, the ingestion of sodium bicarbonate and the realization of pre-effort hyperventilation, called respiratory alkalosis, are highlighted.

Hyperventilation is characterized as breathing in rhythm considered excessive for normal body needs, higher than 30 cycles per minute. This procedure may be used because the generated alkalosis is capable of modifying cellular pH, without the need for exogenous interventions, and accelerate the removal of CO₂, facilitating the buffering of the hydrogen ions. Thus, the metabolic alkalosis produced by hyperventilation would be able to increase the capacity of the anaerobic system. However, no studies investigated the effects of hyperventilation in mechanical and metabolic variables in HIIT.

Considering the importance of improving the repeated-sprint ability in sports with intermittent actions, the strategies to improve the recovery process avoiding large decreases in performance show essential role in maximizing the training results. Thus, the present study aimed to evaluate the effect of hyperventilation during the HIIT on the blood lactate, the fatigue index and the power production.

Method

Subjects

The participants were seven amateur cyclists from Brazil. They met the following inclusion criteria: 1) male, 2) between 18 and 40 years; 3) not being a smoker or drug addict, 4) is not using any type of medication or have respiratory and/or medically diagnosed heart problems. The descriptive data of the subjects are in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass (kg)</td>
<td>66.2 ± 3.2</td>
</tr>
<tr>
<td>Age (years)</td>
<td>24.7 ± 5.8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.2 ± 4.0</td>
</tr>
<tr>
<td>Years of training</td>
<td>3.0 ± 1.5</td>
</tr>
<tr>
<td>Training sessions peer week</td>
<td>4.4 ± 0.9</td>
</tr>
</tbody>
</table>

SD = standard deviation.
Table 2  
Maximum (panel A) and mean (panel B) absolute power production and fatigue index in intermittent protocols, with hyperventilation or normal condition.

<table>
<thead>
<tr>
<th></th>
<th>Hyperventilation</th>
<th>Normal</th>
<th>Hyperventilation</th>
<th>Normal</th>
<th>Hyperventilation</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum absolute power (W)</td>
<td>864.8 ± 78.7</td>
<td>850.7 ± 78.1</td>
<td>836.6 ± 73.5</td>
<td>818.8 ± 72.5</td>
<td>794.4 ± 63.4</td>
<td>777.5 ± 100.5</td>
</tr>
<tr>
<td>Mean absolute power (W)</td>
<td>720.9 ± 87.5*</td>
<td>666.6 ± 55.3</td>
<td>643.4 ± 73.0</td>
<td>628.5 ± 60.9</td>
<td>608.9 ± 56.4</td>
<td>580.8 ± 62.1</td>
</tr>
<tr>
<td>Fatigue index (%)</td>
<td>16.2 ± 3.1</td>
<td>17.9 ± 3.1</td>
<td>25.5 ± 5.0</td>
<td>26.4 ± 6.7</td>
<td>25.6 ± 4.8</td>
<td>23.4 ± 5.6</td>
</tr>
</tbody>
</table>

1 Statistically different from sprint 7 (*p < 0.05).  
2 Statistically different from sprint 8 (*p < 0.05).  
3 Statistically different from sprint 9 (*p < 0.05).  
4 Statistically different from sprint 10 (*p < 0.05).  

To determine the sample size, it was considered the result from a previous study, which found a difference of 0.05 in pH after the tenth (last) sprint between experimental (hyperventilation) and normal conditions, with a standard deviation difference of 0.025.6 Considering 0.8 as observed power and p < 0.01 as significant level, it would be needed five subjects, but seven were recruited, anticipating a loss of until two subjects.

All subjects involved cycled more than four days per week, and were familiarized with the training procedures. They signed informed consent (approved by ethics committee – 004/2012).

Experimental design

The participants attended to the laboratory in two days, separated by at least 48 h. They were asked to: 1) not consume caffeine or stimulants in 3 h preceding sessions; 2) do not drink alcoholic beverages for 24 h prior; 3) avoid physical activity in the 12 h prior; 4) perform light meal, but rich in carbohydrates 2 h before; and 5) consume 500 mL of water 30 min prior the procedures.6 Additionally, the procedures were conducted at the same daytime in all sessions.

The participants performed a warm-up protocol with 5 min of cycling, with free cadence, and a short sprint at the last 5 s of each minute. After remained three minutes at rest on the exercise bike (BIOTEC2100, CEFISE® Brazil), the subjects started the HIIT protocol. Blood lactate [LAC] samples were collected before warm-up, after warm-up, and post exercise.

The condition order was determined randomly and in both – control (NC) and with hyperventilation (HC), the subjects performed 10 sprints of 10 s, in all-out fashion, with a load of 7.5% of body mass applied in the bike, separated by 60 s of recovery between them.5 The HC session included hyperventilation in the last 30 s of recovery, when the subjects performed voluntary hyperventilation in a frequency higher than 60 cycles per minute, controlled by a metronome.6 In another session (NC), the protocol was exactly the same; but without hyperventilation between sprints when the subjects performed free ventilation.

The maximum and mean power in absolute values (W) and relative to body mass (W/kg), as well as the fatigue index (in percentage) were recorded by specific software (Ergometric 6.0, CEFISE® Brazil). Samples of blood lactate, 30 µL extracted from earlobe, were immediately analyzed in Yellow Springs™ lactimeter, model 2300.

Statistical analysis

Data are presented as mean (±standard deviation (sd)). The normality of data was tested using the Shapiro–Wilks test. Mauchly’s sphericity test was conducted and Greenhouse–Geisser correction was employed when necessary. Two-factor analysis of variance (condition [HC or NC] and time) with repeated measures on time factor was conducted. For the power output and fatigue index values, differences between moments were located with Bonferroni post hoc test. The mean power produced in the both training session was compared with paired t test. Statistical significance was set at p < 0.05.

Results

The results of the absolute power production are shown in Table 2, and the relative values are in Fig 1. In both is showed the absence of differences between conditions for absolute and relative maximum power (respectively F1,6 = 1.24, p = 0.30 and F1,6 = 1.35; p = 0.28), as well as the absolute and relative mean power (respectively F1,6 = 0.46, p = 0.52 and F1,6 = 0.71, p = 0.43) and fatigue index (F1,6 = 0.19; p = 0.67). However, differences have been reported between sprints performed in the same conditions (Table 2 and Fig. 1), in absolute and relative maximum power (respectively F3,54 = 8.78, p < 0.001 and F3,54 = 8.02, p < 0.001); absolute and relative mean power (F3,54 = 9.52, p < 0.001 and F3,54 = 10.35; p < 0.001, respectively), and the fatigue index (F3,54 = 3.43; p = 0.002). Also, there are no interactions in all the variables related to the power production.

For the mean values of all sprints performed (Table 2), no differences were found for absolute and relative maximum power (t = 1.11, p = 0.30 and t = 1.16, p = 0.29, respectively), absolute and relative mean power (t = 0.68, p = 0.52 and t = 0.84, p = 0.43, respectively) and fatigue index (t = 0.44, p = 0.67).

The [LAC] pre warm-up was 0.99 ± 0.20 mmol/L and 1.08 ± 0.19 mmol/L in the NC and HC conditions, respectively, in the post-exercise moment the [LAC] reached 14.85 ± 3.2 mmol/L in the NC and 13.9 ± 4.0 mmol/L in the HC, with no differences between conditions (F1,6 = 0.64, p = 0.45). However, was found statistically significant differences between moments (F1,6 = 111.18, p = 0.001) with no significant interactions.

Discussion

The main finding of this study was the attenuation of the decrease in power production over the repeated sprints using
hyperventilation between efforts in high-intensity interval training, despite the absence of differences in the [LAC] values. Thus, as much as the chronic effects of hyperventilation have been recently investigated,\textsuperscript{14} our study confirms the acute effectiveness of this feature to maintain the performance during a HIIT session.\textsuperscript{6}

The ergogenic effects generated by hyperventilation can be explained by the supply of renewable energy and especially the continuous supply of glycolytic source,\textsuperscript{14} since the fall of intracellular pH affects the reaction of phosphocreatine-fructose kinase, impairing the resynthesis process of phosphocreatine.\textsuperscript{12} However, as there was no measurement of intracellular pH in the present investigation, this idea is speculative, and further research should consider the assessment of this variable. However, it was found previously that this procedure increased significantly the blood pH,\textsuperscript{6} which reinforces our hypothesis.

The absolute and relative maximum power generated during the repeated sprints demonstrated differences only when they were made without the use of pre-exercise hyperventilation, and the power generated in the first four efforts was statistically higher than in the last two efforts. This may have occurred because hyperventilation accelerates the removal of $\text{H}^+$ ions, while maintaining the internal environment less acidic,\textsuperscript{9} being able to postpone the process failure excitation/contraction and therefore maintain power production for a longer period of time.\textsuperscript{5,15} In this context, a previous study showed lower tendency to decrease the maximum power output over repeated sprints with hyperventilation.\textsuperscript{6}

With respect to the absolute (W) and relative (W/kg) mean power, we found decrease in both conditions; however, the realization of hyperventilation appeared to slow the decline in the average power. In this sense, the difference was only recorded from the first to the penultimate sprint in the hyperventilation condition, while the normal condition, already the first sprint was significantly different compared to the last four efforts (7th, 8th, 9th, 10th sprint), and the second sprint was statistically superior to the last two sprints (9th and 10th). This may be a result of increased activity of the respiratory muscles and trunk, which would assist in the recovery and retard the onset of central fatigue – a phenomenon called “Sethenov” – which attenuates the performance decrease.\textsuperscript{16,17} These data corroborate those found by Sakamoto et al.,\textsuperscript{5} which found higher mean power, from the sixth sprint with the hyperventilation protocol.

In this study no differences were recorded in blood lactate values between conditions, and in both there was a statistically significant increase. These data corroborate those found by Sakamoto et al.,\textsuperscript{5} in which trained athletes underwent the same protocol yielded approximately 15 mmol/L, highlighting an high actuation of glycolytic pathway.\textsuperscript{18} Additionally, this can be explained by the respiratory muscles and trunk are active during recovery in the protocol with hyperventilation, capturing and reusing part of the formed lactate.\textsuperscript{19} A previous study evaluated the effect of hyperventilation in removing post-exercise 45 s all-out lactate, and found no difference between groups (hyperventilation or control) in the time required for this value (post-exercise) was reduced to a half.\textsuperscript{13} This result demonstrates that, apparently, hyperventilation performed in a short period could not modify the blood lactate concentration.

Our results indicate that hyperventilation was not able to generate preparatory effect to achieve the proposed series of repeated sprints, because of the conditions differences were recorded for the amounts related to power. However, the hyperventilation condition allowed maintenance of indices related to the power of the first to the last sprint, whereas in the condition without hyperventilation the first four sprints are significantly different from the latter two. Thus, we can hypothesize that, according to the trend observed in series with more efforts may be differences and that further studies should explore this hypothesis with higher amount of repeated sprints.

As limitations, we highlight the absence of measures for the intracellular pH of the subjects; however, other studies with a similar protocol showed the same behaviour in this variable.\textsuperscript{6,20} It is suggested that further studies investigate the acute effect of hyperventilation in series with more than ten sprints, as well as the chronic effect of this technique in training programmes over successive weeks.

Professionals could use the results of this study to comprehend the effects of induced alkalosis in repeated-sprint training in cyclists and to apply this procedure in their routines. In our sample, the subjects were able to complete the training protocols without the reduction in power production and without any problems such as dizziness, vertigo or headache during or after training. Therefore, 30 s of hyperventilation before high-intensity sprints may be a beneficial tool to improve performance in training for cyclists.
It could be concluded that hyperventilation held between intermittent efforts was effective to mitigate the performance decrease over successive bouts of high intensity intermittent training. These results indicate that this technique can be used to maximize profits deriving training for allowing the intensity of effort is maintained for a longer period of time.

**Ethical disclosures**

**Protection of human and animal subjects.** The authors declare that the procedures followed were in accordance with the regulations of the relevant clinical research ethics committee and with those of the Code of Ethics of the World Medical Association (Declaration of Helsinki).

**Confidentiality of data.** The authors declare that they have followed the protocols of their work center on the publication of patient data.

**Right to privacy and informed consent.** The authors have obtained the written informed consent of the patients or subjects mentioned in the article. The corresponding author is in possession of this document.

**Conflicts of interest**

The authors have no conflicts of interest to declare.

**References**