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SHORT COMMUNICATION

EFFECT OF ENDURANCE TRAINING ON HYPOTHALAMIC SEROTONIN CONCENTRATION AND PERFORMANCE

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SUMMARY

1. Serotonin is a neurotransmitter that modulates several functions, such as food intake, energy expenditure, motor activity, mood and sleep. Acute exhaustive endurance exercise increases the synthesis, concentration and metabolism of serotonin in the brain. This phenomenon could be responsible for central fatigue after prolonged and exhaustive exercise. However, the effect of chronic exhaustive training on serotonin is not known. The present study was conducted to examine the effect of exhaustive endurance training on performance and serotonin concentrations in the hypothalamus of trained rats.

2. Rats were divided into three groups: sedentary rats (SED), moderately trained rats (MOD) and exhaustively trained rats (EXT), with an increase of 200% in the load carried during the final week of training.

3. Hypothalamic serotonin concentrations were similar between the SED and MOD groups, but were higher in the EXT group ($P < 0.05$). Performance was lower in the EXT group compared with the MOD group ($P < 0.05$).

4. Thus, the present study demonstrates that exhaustive training increases serotonin concentrations in the hypothalamus, together with decreased endurance performance after inadequate recovery time. However, the mechanism underlying these changes remains unknown.

Key words: endurance training, overtraining, serotonin.

INTRODUCTION

Serotonin (5-hydroxytryptamine; 5-HT) is a neurotransmitter that modulates several functions, including food intake, energy expenditure, motor activity, mood and sleep.[1,2] Acute exhaustive endurance exercise increases the synthesis, concentration and metabolism of serotonin in several brain regions. These changes could be responsible for the central fatigue observed after prolonged and exhaustive exercise.[1,3]

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Studies on the effect of endurance training on brain serotonin at rest are contradictory. Both increased and decreased serotonin concentrations have been shown in trained rats.[4] The physiological functions of serotonin in the brain include regulation of wakefulness and mood, motor neuron excitability and autonomic and endocrine functions, such as changes in the hypothalamic–pituitary–adrenal (HPA) axis that are indispensable for physical exercise performance. For this reason, increased serotonin concentrations in the hypothalamus could cause both chronic fatigue and poor performance. The present study was conducted to examine the effect of exhaustive endurance training on serotonin concentration in the hypothalamus and the performance of trained rats. Our hypothesis was that an increase in serotonin could be associated with a decrease in performance.

METHODS

Ethics

All protocols were authorised by the committee for Ethics in Animal Research of the Institute of Biomedical Science in agreement with the ethical principles for animal research adopted by the Brazilian College of Animal Experimentation.

Animals

Male Wistar rats, weighting 150–200 g at the beginning of the experiment, were obtained from the Biomedical Science Institute Animal House, University of São Paulo, São Paulo, Brazil. Rats were maintained under a constant 12 h light–dark cycle (lights on at 0700 hours) at 22 ± 2°C and 60 ± 5% humidity. Rats were kept in collective cages (five animals/cage) and received water and food *ad libitum.*

Groups and training protocol

Rats were divided into three groups as follows: (i) sedentary rats (SED) did not complete an exercise programme ($n = 10$); (ii) moderately trained rats (MOD) trained 1 h/day, 5 days/week for 6 weeks ($n = 20$); and (iii) exhaustive trained rats (EXT) trained 1 h/day for 5 weeks like MOD rats and, in the 6th week, trained for three 1 h sessions per day with 150 min of rest between each session ($n = 20$). During exercise bouts (60 min each), animals from the MOD and EXT groups swam with an extra load equivalent to 5.5% of their total bodyweight attached to the tail to enhance aerobic training.[5] Twenty-four hours after the last exercise, 10 animals from the MOD and EXT groups were submitted to an exhaustive performance test, whereas the other animals were killed by decapitation. The training was realised in individual water tanks, 100 cm deep and with a water surface area of approximately 1200 cm^2.

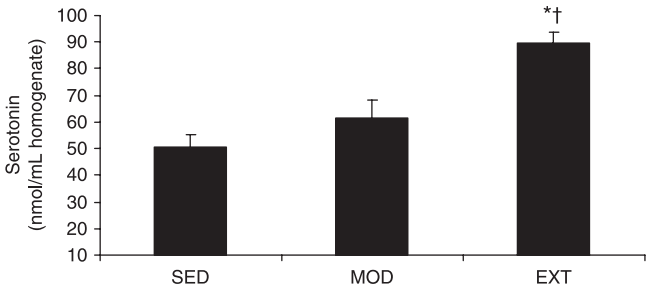

Fig. 1 Serotonin concentrations in the hypothalamus of rats from the sedentary group (SED; $n = 10$), the moderately trained group (MOD; $n = 10$) and the exhaustive trained group (EXT; $n = 10$). Data are the mean±SEM. $^{*}P < 0.05$ compared with the SED group; $^{\dagger}P < 0.05$ compared with the MOD group.

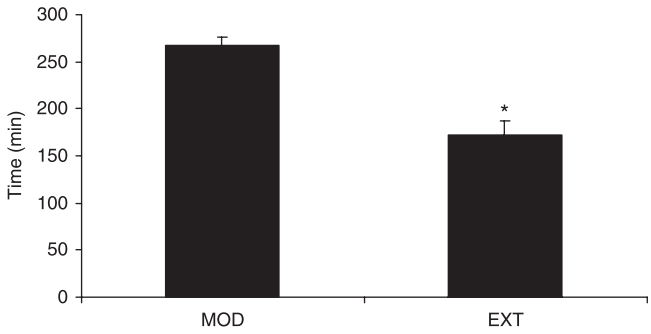

Fig. 2 Results of the exhaustive performance test in the moderately trained group (MOD; $n = 10$) and the exhaustive trained group (EXT; $n = 10$). Data are the mean±SEM. $^{*}P < 0.05$ compared with the MOD group.

Water temperature was maintained at 33 ± 1°C and during the scheduled training and all exercise bouts were performed at the same time each day.

Serotonin measurement

After rats had been killed, their brains were removed and the hypothalamus was dissected, weighed and frozen in liquid nitrogen. Samples (100 mg) were homogenized in 1.0 mL solution containing 0.2 mol/L $HClO_4$ and 0.5 mmol/L ascorbic acid. The homogenate was centrifuged at 17 000 *g* for 15 min at 4°C. Serotonin concentrations in the resulting filtered supernatant were assayed by HPLC, as described by Pawlak *et al*.[6] Results are expressed in nmol/mL homogenate.

Exhaustive performance test

In the exhaustive performance test, rats from the MOD and EXT groups were exercised to exhaustion. The rats swam with an extra load equivalent to 5.5% total bodyweight attached to the tail, similar to the training period. Exhaustion was determined and the test stopped when at least two of the following criteria were met: (i) an inability to swim in water for at least 10 consecutive seconds; (ii) loss of normal motor pattern; and (iii) lack of motion when rats were returned to their cage. The moment when the test was stopped was determined by two experienced scientists blinded to the experimental groups.

Statistical analysis

All results are presented as the mean±SEM. Data were evaluated using the Prisma V program (GraphPad Software, San Diego, CA, USA). Statistical differences were determined by two-way ANOVA and Tukey's post hoc test, with significance set at $P < 0.05$.

RESULTS

Figure 1 shows serotonin concentrations in the hypothalamus of rats from each of the three groups. Twenty-four hours after the last exercise bout, serotonin concentrations were similar in the SED and MOD groups (50.4 ± 4.9 and 61.6 ± 7.6 nmol/mL homogenate, respectively), whereas serotonin concentrations were higher in the EXT group (89.4 ± 6.4 nmol/mL homogenate). Figure 2 shows the time to exhaustion for trained animals. Performance was lower in the EXT group compared with the MOD group (172 ± 15 *vs* 268 ± 10 min, respectively).

DISCUSSION

The aim of the present study was to investigate the effect of exhaustive endurance training on serotonin concentrations in the hypothalamus, as well as on performance, in trained rats. Our hypothesis was that the increase in serotonin may be associated with impaired endurance performance. In fact, our results show that after an exhaustive training programme with an insufficient recovery period, hypothalamic serotonin concentrations increased. Moreover, this change was associated with decreased performance in the EXT group.

Previous studies have demonstrated that during acute exercise serotonin levels increase in several areas of the brain, including the hypothalamus and brain stem.[1,3] Despite earlier studies that suggested an increase in serotonin concentration during overtraining in athletes,[7,8] the effect of exhaustive training on serotonin levels at rest was not known. An increase in serotonin concentrations is associated with many changes present during chronic fatigue and overtraining, such as lethargy, acceleration of the onset of fatigue, impairment of the HPA axis response to stress, changes in mood, depression and sleep disorders. In contrast, low serotonin favours improved performance through the maintenance of motivation and arousal.[8–10] In the present study, serotonin levels were similar between the SED and MOD groups, demonstrating that 24 h rest after exercise is sufficient for serotonin recovery. However, serotonin concentrations were higher in the hypothalamus of EXT rats, which were subjected to several exercise sessions each day. This result supports the hypothesis that exhaustive training with inadequate recovery could increase serotonin levels in the hypothalamus, even during subsequent rest.

Athletes submitted to an exhaustive training programme followed by insufficient rest time are able to start normal exercise at normal intensity; however, they are not able to complete the exercise as they normally would.[8] The results of the present study demonstrate that animals from the EXT group reached exhaustion more quickly than animals submitted to moderate training (MOD). As proposed earlier,[2,7,8] it is possible that increased hypothalamic serotonin concentrations may contribute to poor performance during periods of excessive training.

In conclusion, the present study is the first to show that an exhaustive training programme with insufficient recovery promotes increased serotonin concentrations in the hypothalamus and that this change is associated with decreased endurance. Additional studies are needed to understand the mechanisms responsible for the observed increases in serotonin and to determine whether and how this neurotransmitter impairs performance.

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