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THE EFFECT OF INHALING CONCENTRATED OXYGEN ON PERFORMANCE DURING REPEATED ANAEROBIC EXERCISE

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ABSTRACT: The objective of the pilot study was to test the effect of inhaling 99.5% oxygen on recovery. The source of concentrated oxygen was O-PUR (Oxyfit). Research subjects completed two thirty-second Wingate tests at an interval of ten minutes, and in the interval between the tests the subjects inhaled either oxygen or a placebo in random order. This procedure was then repeated. The pilot study revealed a significantly ($p<0.03$) smaller performance drop in the second Wingate test following the inhalation of 99.5% oxygen when compared with the placebo. The results of the study indicate that inhaling concentrated oxygen may have a positive effect on short-term recovery processes.

KEY WORDS: **concentrated oxygen, anaerobic capacity, Wingate test, recovery speed**

INTRODUCTION

For nearly a hundred years various ways of inhaling oxygen in higher concentrations have been used to treat respiratory and circulatory problems. Generally oxygen is used in a gaseous state in steel tanks. During the last twenty years the interrupted or short-term administration of oxygen to patients has been replaced by long-term and uninterrupted administration, which places significant demands on supervision, as it requires the constant presence of qualified persons. However, short-term application is also still used for respiratory and circulatory problems. In addition oxygen therapy is commonly used for acute oxygen deficiency, mostly in the provision of first aid (accidents, circulatory system disorders, mountain climbing, etc.).

The use of concentrated oxygen is not limited to therapy, and its potential to influence ability to work and performance has also been studied. During hyperoxic training (inhaling 90% to 100% oxygen during exercise) it is possible to increase the maximum intake of oxygen by approximately 10% [9]. Thanks to the increased supply of oxygen to the working muscles, the reduction in respiratory requirements and the lower heart rate during exertion, under normal conditions it is possible to increase the intensity of exertion during hyperoxic breathing. Symptoms of hyperventilation and the associated respiratory alkalosis (tachycardia, sweating, pins and needles, muscle spasms or shortened reflex times) have not been observed during the application of an increased concentration of oxygen. The inhalation of oxygen in higher concentrations leads to an increase in the arterial partial pressure of oxygen [16].

The results of a number of studies have confirmed the positive effects of using concentrated oxygen in sport [4, 13, 17, 20, 22, 23]. However, some studies have not confirmed any benefits for such usage [18], especially for medium to long periods of exertion, as well as for short periods of submaximal or maximal exertion [21, 26]. It has been demonstrated that the application of a hyperoxic

mix can have a positive effect immediately following activity lasting approximately two to three minutes, or it can speed up subsequent recovery and the return to default values thanks to the increased oxygen saturation of the blood and tissue, and lower anaerobiosis in the working muscles [19]. The one-off or repeated short-term application of oxygen or hyperoxic mixes has

a temporary effect: the increase in oxygen concentration in the tissue is temporary, but it can be used to speed up recovery during exertion of an intermittent character [19].

There has been extensive research on the influence of hyperoxia on the tolerance for physical activity, oxygen consumption during performance, oxidative metabolism, lactate response during and after exertion and the partial pressure of oxygen, as summarised in detail in an article by Astorino and Robergs [3]. Substantially less work has been published examining the influence of hyperoxia on recovery following physical exertion.

Portable canisters of concentrated oxygen for individual use were developed and introduced on the market primarily for therapeutic purposes [2]. Clinical studies of O-PUR (the source of concentrated oxygen) demonstrated that when patients with severe chronic obstructive lung diseases inhale oxygen from O-PUR canisters via a special mask, the partial pressure of oxygen in the blood increases in the short-term, on average from 70.7 mmHg to 95.8 mmHg. No negative side effects of inhalation have been observed. The results of studies from other research centres in Germany [16] reveal that it is possible to achieve high pO_2 increases by inhaling concentrated oxygen.

O-PUR has been tested for its ability to speed up post-exercise recovery following model anaerobic exercise (the thirty-second Wingate test), which was evaluated on the basis of the blood lactate concentration over twenty-five minutes under normoxia control conditions and with O-PUR inhalation (a 36-38% oxygen mix) in the fifth and fifteenth minutes of recovery [7].

In the context of the aforementioned studies, this pilot study focused on whether it is possible to improve the performance of repeated short-term anaerobic exercise by inhaling 99.5% concentrated oxygen. O-PUR (distributed in the Czech Republic by Linde Gas under the brand name Oxyfit), a preparation containing gaseous oxygen in a 99.5% concentration, is made by the Swiss company Newpharm SA. Its exclusive importer to the Czech Republic, Linde Gas, recommends using the product principally to promote a swift return to normal rhythms after exertion, i.e. for faster recovery. According to the distributor the product also helps during and after sport, and can improve concentration, alleviate fatigue and reduce stress [27].

The relation between hyperoxia and recovery is based on the physiological principles of the energy for muscle contraction and relaxation. Following physical exertion beyond a particular individual critical limit, muscular weakness sooner or later appears [15] and can be determined in various ways (e.g. by the reduction in maximal power as a function of time during supramaximal exertion in the 30-second Wingate test [6]). The causes of muscular weakness are probably complex, but it seems that a significant factor is the level of phosphocreatine, which falls significantly once the individual critical limit has been exceeded, while the concentration of inorganic phosphate rises [14]. On entering the sarcoplasmic reticulum inorganic phosphate can – by means of the subsequent release of calcium cations – significantly influence subsequent muscle contraction [1]. Creatine is solely under aerobic conditions re-phosphorylated into high-energy phosphocreatine [8], accompanied by a reduction in inorganic phosphate. Hyperoxia can in this way accelerate recovery.

The objective of the study was to verify the effects of O-PUR on performance during exertion in sport. To this end an experimental model was devised where the preparation was inhaled at the recommended dosage between two repeated periods of anaerobic exercise, using the double-blind testing method.

A simple non-standardised supplementary questionnaire was used to assess the test subjects' feelings and technical aspects of the application of O-PUR.

The duration of the Wingate test (thirty seconds) corresponds approximately to the exertion of a player on the ice during one shift in an ice hockey match. The interval of ten minutes between two Wingate tests corresponds very closely to the intermission between periods, which is fifteen minutes according to the rules.

In the light of the above the following hypothesis was formulated: the inhalation of O-PUR will affect performance during repeated anaerobic exercise. The difference between performance achieved in the first and second Wingate test will be smaller when highly concentrated oxygen is inhaled rather than a placebo.

MATERIALS AND METHODS

Ice hockey was chosen as the model as it satisfies the criterion of repeated supramaximal exertion. The exertion model for laboratory conditions was chosen in order to replicate as closely as possible the real exertion in an ice hockey match, and represented a valid methodological objectification of short-term recovery processes.

Subjects: For the aforementioned reasons testing was conducted on volunteers (members of the Faculty of Physical Education and Sport ice hockey team, n=10) who compete in this sport. The subjects were aged 21.1±1.1 years, with a height of 182.5±4.5 cm and weight of 77.5±6.8 kg. On average the subjects have been involved in sport for approximately thirteen years. At the time of the study all were in good health, which was confirmed at the beginning of their yearly training cycle by means of a preventative athletic medical check-up. The test subjects were training as part of an annual training cycle, with seven to twelve hours per micro cycle after the end of season. Prior to the study all volunteers underwent a basic medical check-up.

The subjects had already been familiarised with the requirements and

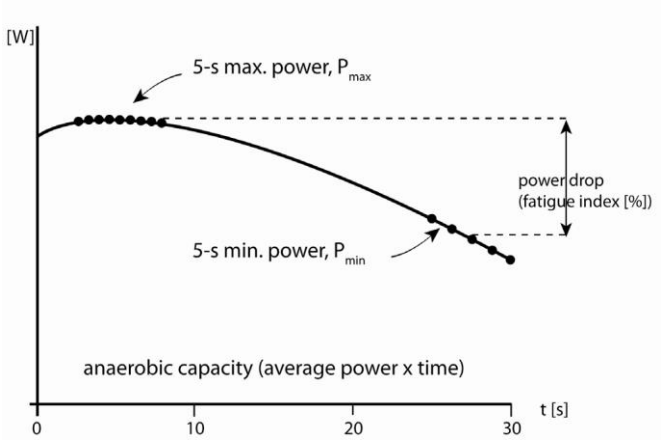

FIG 2. POWER IN THE COURSE OF THE WINGATE TEST

process of the Wingate test as part of their training check-up with their ice hockey club, or by means of practical instruction in the Faculty's laboratories.

Procedure: The athletes underwent two laboratory test sessions separated by an interval of two to seven days. Each session included two Wingate tests, between which they inhaled either O-PUR (according to the manufacturer's instructions on the packaging) or a placebo in random order. The subjects inhaled O-PUR or the placebo from identical canisters using special masks. The canisters with O-PUR contained 99.5% oxygen, while the canisters with placebo were filled with ordinary air and were produced by the manufacturer for the purposes of this test. A double-blind test was designed in which neither the subjects nor the staff knew whether O-PUR or the placebo was being inhaled. Before each test all participants were given full instructions on proper inhalation. Only one newly-opened canister (8 litres, with either the placebo or O-PUR 99.5% concentrated oxygen) was used each day on which the subjects were tested.

Test structure: after warming up (five minutes) the test subject undertook a standard Wingate test lasting 30 seconds. In the fifth minute of recovery 20 microlitres of capillary blood were taken from the subject's fingertip to determine the peak blood lactate concentration using the SuperGL automated

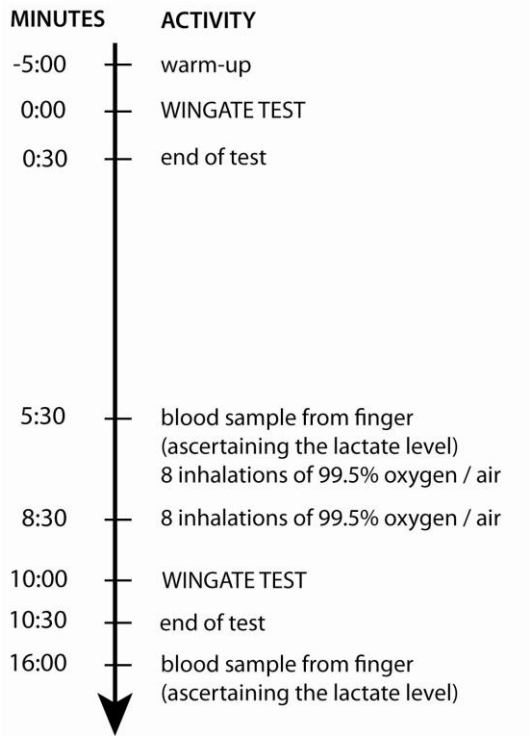

FIG 1. TEST STRUCTURE

analytic system (Dr. Muller, GmbH. Freital, Germany). At the same time O-PUR or the placebo was inhaled according to the manufacturer's instructions (eight inhalations, each lasting two seconds). A pause of three minutes followed, and then there was further inhalation of O-PUR or the placebo (again eight inhalations, each lasting two seconds) (Figure 1). The duration of the individual inhalations (two seconds) was estimated by the test subjects in accordance with the manufacturer's instructions. After a further one-minute break a second Wingate test was carried out (thirty seconds). A second blood sample was then taken to determine lactate levels, again five and half minutes after the start of the Wingate test. After the second Wingate test none of the test subjects performed a brief low-intensity warm-down session, preferring to rest on a bed.

Before the test all subjects were instructed on the necessity of working with maximum exertion from the very start, and that during the thirty seconds of pedalling it would not be possible to use any kind of strategy to distribute the workload. Before each test the position of the saddle was adjusted in line the subject's wishes and cycling habits, and the subject's feet were strapped to the pedals. The individual settings for the height and front-to-back position of the saddle were recorded and then used for all subsequent tests with the subject. The first test was preceded by five minutes of aerobic warm-up (with a load of 1.5 $W \cdot kg^{-1}$ of body weight) to induce central and peripheral activation in order to avoid localised muscle fatigue. A number of short sprints with maximal rotation frequency were included in the warm-up with the aim of preparing the subject for the test.

For each Wingate test a resistance load of 0.106 $W \cdot kg^{-1}$ was used, which corresponded – using the ergometer's calibration curves – to a load of 6 W kg^{-1} (for a frequency of 60 rpm). This resistance load was chosen on the basis of a previous series of pre-tests [12] and is in line with earlier studies of the optimal resistance load for trained male athletes [5, 24, 25]. The technique used by the test subjects was not prescribed in any way, and they were allowed to use whichever technique they considered optimal, e.g. standing up on the pedals, especially towards the end of the test. The reason for not placing restrictions on technique was that during such exertion we use our weight in accordance with our individual abilities [10].

For the pause between the first and second Wingate tests, after dismounting from the ergometer the subject spent two minutes seated in a chair. The subject then spent the 3^{rd}-5^{th} minutes standing next to the back-up ergometer, and then pedalled on the back-up ergometer with low intensity from the 6^{th} to the 9^{th} minute. During the final minute the subject mounted the test ergometer and pedalled briefly.

During the test all subjects were given verbal motivation in an attempt to create a competitive atmosphere, as anaerobic tests frequently depend on the motivation of the test subject. During the test the heart rate was also recorded as a supplementary indicator [10].

The standard parameters of the test were based on the performance curve for individual rotations (Figure 2):

- Peak power, i.e. the highest power in the test during any five-second interval, measured in watts or relatively in watts per kilogram of body mass
- Minimum power, i.e. the lowest power in the test during any five- second interval, measured in watts or relatively in watts per kilogram of body mass
- Mean power, i.e. average power for the entire duration of the test, measured in watts or relatively in watts per kilogram of body mass
- Anaerobic capacity, the total work performed in the test, i.e. the product of average power and time, measured absolutely in kilojoules or relatively in joules per kilogram of body mass
- Power decrease or drop in power between Pmax and Pmin, expressed either absolutely in watts or relatively, as a percentage of maximum power, in a fatigue index
- Supplementary indicators for the test were the post-exercise blood lactate concentration and the post-exercise heart rate as approximate indicators of the effort exerted during the test

The values recorded for each individual Wingate test were processed to produce a detailed report. The results obtained in the Wingate test under experimental and control conditions, as well as the differences between the results of the first and second Wingate tests, were compared with a paired sample t-test.

A Monark 824E mechanical bicycle ergometer was used for the test. This ergometer is calibrated for short-term performance of up to 1500 W with a frequency of 160 rpm. The unit was equipped with a device to record rotations, linked to a computer. Specialised software enables rotations and current performance to be recorded, as well as providing evaluations of test parameters and the archiving of data.

Following the second test session the subjects completed a questionnaire that concerned their subjective feelings on inhaling from the canister. One of the aims of the questionnaire was to determine whether the subjects felt any change between the first and second day of testing, or any difference when inhaling the placebo and inhaling the 99.5% oxygen mixture. All subjects only completed the questionnaire after completing all their tests. At the time of completing the questionnaire it was not known to anyone which tests had been conducted with O-PUR and which with the placebo.

SPSS 15.1 software was used to analyse and process data. The results are presented as the mean and the standard deviation. To evaluate the significance of differences a parametric t-test was used for dependent samples and differences were evaluated with a significance level α=0.05 and the objective significance of differences was evaluated using the Hayes coefficient ω^2.

The entire study was conducted in accordance with the Declaration of Helsinki [28], and it was approved by the Ethics Committee of the Faculty of Physical Education and Sport at Charles University in Prague.

RESULTS

The average values for the first and second tests, i.e. after ten minutes of repeated Wingate tests, are presented in Table 1.

The results of both situations monitored, i.e. when oxygen (O-PUR) was inhaled and when the placebo was inhaled in the control, reveal that after ten minutes of recovery the test subjects were not able to achieve the same level of peak power, mean power, or minimum power as they had achieved in the first test. The decline in

performance between the first and second test, whether expressed absolutely or as a fatigue index, was similar in both tests, as was the effect of exertion on the heart rate. However, in the second test the concentration of lactate was always higher than in the first test.

TABLE 1. AVERAGE VALUES OF THE PARAMETERS FOR THE WINGATE TEST (MEAN ± SD) FOR THE FIRST AND SECOND TESTS WHEN OXYGEN WAS INHALED (O1, O2) AND WHEN THE PLACEBO WAS INHALED IN THE CONTROL (C1, C2)

	O1	O2	C1	C2
Peak power [W]	1 034 ± 95	1 009 ± 84	1 071 ± 118	1 024 ± 99
Peak power [W·kg^{-1}]	13.37 ± 0.88	13.05 ± 0.79	13.83 ± 1.07	13.26 ± 1.07
Minimum power [W]	634 ± 46	620 ± 84	644 ± 46	623 ± 74
Minimum power [W·kg^{-1}]	8.22 ± 0.59	8.01 ± 0.91	8.34 ± 0.54	8.05 ± 0.80
Mean power [W]	835 ± 62	808 ± 66	854 ± 68	805 ± 58
Mean power [W·kg^{-1}]	10.81 ± 0.59	10.46 ± 0.69	11.05 ± 0.53	10.44 ± 0.56
Anaerobic capacity [kJ]	25.05 ± 1.86	24.25 ± 1.97	25.62 ± 2.03	24.16 ± 1.71
Anaerobic capacity [J·kg^{-1}]	324 ± 18	314 ± 21	332 ± 16	313 ± 16
Power decrease [W]	400 ± 95	390 ± 105	427 ± 109	401 ± 118
Fatigue index [%]	38.21 ± 6.37	38.31 ± 8.73	39.30 ± 7.14	38.64 ± 9.22
Mean power/peak power ratio [%]	81.03 ± 4.92	80.30 ± 6.22	80.19 ± 5.06	79.06 ± 6.50
Revolutions [1]	53.72 ± 2.95	51.98 ± 3.34	54.90 ± 2.59	51.91 ± 2.64
Heart rate [min^{-1}]	175 ± 5	175 ± 7	177 ± 6	176 ± 7
Blood lactate [mmol·l^{-1}]	14.18 ± 1.97	16.40 ± 1.92	14.56 ± 1.88	17.01 ± 1.68

TABLE 2. AVERAGE VALUES FOR THE DIFFERENCES BETWEEN THE FIRST AND SECOND WINGATE TESTS (MEAN ± SD) WITH THE INHALATION OF OXYGEN (O1-O2) AND WITH THE INHALATION OF THE PLACEBO IN THE CONTROL (C1-C2)

	O1 – O2	C1 – C2	Statistical significance	Size of effect ω^2
Peak power [W]	24.45 ± 37.12	46.79 ± 43.70	n.s.	0.106
Peak power [W·kg^{-1}]	0.32 ± 0.50	0.57 ± 0.48	n.s.	0.104
Minimum power [W]	14.57 ± 50.52	20.53 ± 56.11	n.s.	0.062
Minimum power [W·kg^{-1}]	0.21 ± 0.65	0.29 ± 0.70	n.s.	0.066
Mean power [W]	27.09 ± 19.68	49.23 ± 29.18	$p < 0.03$	0.111
Mean power [W·kg^{-1}]	0.35 ± 0.27	0.61 ± 0.33	$p < 0.02$	0.111
Anaerobic capacity [kJ]	0.80 ± 0.59	1.46 ± 0.86	$p < 0.03$	0.111
Anaerobic capacity [J·kg^{-1}]	10.52 ± 7.70	18.86 ± 0.62	$p < 0.03$	0.111
Power decrease [W]	9.88 ± 72.56	26.28 ± 86.67	n.s.	0.084
Fatigue index [%]	-0.10 ± 5.96	0.66 ± 6.85	n.s.	0.060
Mean power/peak power ratio [%]	0.73 ± 3.24	1.13 ± 3.16	n.s.	0.065
Revolutions [1]	1.74 ± 1.26	2.99 ± 1.78	$p < 0.03$	0.111
Heart rate [min^{-1}]	0.20 ± 3.34	1.40 ± 4.41	n.s.	0.077
Blood lactate [mmol·l^{-1}]	-2.22 ± 1.34	-2.45 ± 1.45	n.s.	0.046

TABLE 3. RESULTS FROM THE NON-STANDARDISED QUESTIONNAIRE

question	O-PUR	placebo	don't know
In your opinion did you achieve better performance in the second Wingate test, following inhalation?	+	++++++++	+

Did you feel better following inhalation?	+	+++++++	++
In the pause between the tests, did you feel better during inhalation?	++++++	++	++

Table 2 reveals that on average the differences for maximum and minimum power following the second test tended to be smaller when 99.5% oxygen was inhaled than when air was inhaled in the control. However, the results display a substantial degree of variability and the differences were not statistically significant.

On the other hand mean power and/or anaerobic capacity expressing the total work performed in the entire test showed an almost 50% smaller decline when O-PUR was inhaled rather than the placebo in the control. A similar decline in the parameters was recorded for the total number of rotations in thirty seconds. This difference was statistically significant at a level of $p<0.02$ to $p<0.03$ for the individual parameters presented above (Tables 1 and 2).

The questions in the simple non-standardised questionnaire were aimed primarily at recording subjective feelings on the test and on the inhalation of O-PUR or the placebo. Table 3 summarises selected responses from the non-standardised questionnaire.

DISCUSSION

The results convincingly demonstrate that the inhalation of 99.5% oxygen positively affects performance in the given model arrangement, which in our trial differed from previous models of exercise and recovery [21, 26] that had not established any benefits from concentrated oxygen for short-term recovery processes. In the literature only one previous similarly-designed study was found that demonstrated an improvement in maximum anaerobic capacity in the order of 3-6% after inhaling concentrated oxygen [6]. However, the design of that study would appear to be irrelevant to the present investigation.

The above results from the Wingate tests (peak power, mean power, minimum power, AnC, FI, HR, and blood lactate concentration) significantly exceed the values for those who participate in sport on a recreational basis, and correspond more to the values for professional ice hockey players [11, 12], although the results for professionals are approximately ten percent higher. Regardless of the absolute values of the results achieved, which depend on the test subjects' physical condition and professional ability, the deciding factor in judging the effectiveness of the application of concentrated oxygen is performance in the second model exercise. In the chosen model of repeated high-intensity anaerobic thirty-second exertion with a ten-minute rest interval, this criterion was the reduction in the decline in performance in the second anaerobic test.

Some of the results achieved were not statistically significant, but analysis demonstrated modest differences in favour of the effects of O-PUR. A study conducted with a larger sample could help confirm this.

The chosen exercise model represented the situation that typically occurs in ice hockey matches, one of exertion repeated after incomplete (or insufficient) recovery. The true course of a match is of course generally influenced by a variety of technical and tactical factors.

The reliability of the parameters derived from the Wingate test is relatively high – the coefficient of correlation between the first and second tests was 0.91–0.93 [25]. The classic thirty-second Wingate test has been criticised by some authors on the grounds that thirty seconds is too short a time for the full utilisation of anaerobic glycolysis, and accordingly there has been discussion of a longer time frame for the test, as the highest concentration of lactate can be attained in anaerobic tests lasting approximately sixty seconds [5]. On the other hand with the extending of the exertion period the share of oxidative energy production also increases. In the thirty-second test this makes up only approximately fifteen percent, but as the exertion period is extended it increases more markedly than the rate of lactate production. In longer tests the influence of the psyche and "fainting" (i.e. strategies to distribute exertion over the course of the test) are more pronounced, and moreover the value of maximum anaerobic power is reduced and the fatigue index cannot be reliably evaluated. For this reason the majority of research centres currently recommend retaining the classic period of thirty seconds, which allows both maximum anaerobic power and anaerobic capacity to be determined reliably. A longer period would also significantly affect the course of recovery, which would not correspond to lineswitching in ice hockey matches.

A question remains over how long O-PUR remains effective. According to our subjective opinion and sources in the literature that cover the inhalation of oxygen in general [21, 26] that period is anywhere between tens of seconds to a maximum of several minutes, due to the limited capacity of tissue to bind a non-physiologically increased amount of oxygen. A study [21] using two five-minute exercises separated by four-minute breaks did not show any marked differences in the kinetics of ventilation or in the heart rate dependent on hyperoxia, normoxia or a combination of the two.

The number of inhalations (presses of the cap via the special plastic mask) from the canister during one application was consistent with the importer's instructions (i.e. eight times). It was not possible to quantify the duration of each individual inhalation,

but the test subjects were instructed that each inhalation should last two seconds.

The need to use a questionnaire was not flagged until after the first set of tests, and in consequence the test subjects only completed it after the second set of tests. In view of that fact the questions were aimed primarily at comparing the test subject's feelings on the inhalation of O-PUR or the placebo.

The main contribution made by the non-standardised questionnaire was the finding that the majority of test subjects recognised a difference between inhaling O-PUR and the placebo, despite the fact that they had no way of knowing whether they were inhaling highly concentrated oxygen or the placebo.

Before introducing the inhalation of concentrated oxygen as standard practice in sport it would be appropriate to verify the positive results of this study on a larger sample.

CONCLUSIONS

The study demonstrated a significant difference in mechanical performance between inhaling the placebo and inhaling O-PUR before a second supramaximal exercise, in favour of O-PUR.

The hypothesis formulated in the objective of this paper was confirmed.

On the basis of the results recorded, it can be stated that inhaling O-PUR in the interval between two periods of supramaximal anaerobic exertion lessens the reduction in mechanical performance in the second brief high-intensity exercise.

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