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Comparison of Cardiorespiratory and Hormonal Responses between Sustained Constant and Alternating Intensity Exercise

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Abstract

Background: Cardiorespiratory and hormonal responses were investigated during and after prolonged exercise of constant and alternating exercise intensity.

Methods: Ten healthy males underwent two main cycling exercise trials at the same overall power output, lasting one hour each. During the first trial, exercise intensity was constant at 70±5% VO_{2max}, while during the second trial, exercise intensity was alternated between 47±2% VO_{2max} for 40 s and 120% VO_{2max} for 20 s.

Results: Oxygen uptake (VO_2) and heart rate (HR) were higher in constant compared with alternating intensity exercise (VO_2: 32.5±6.6 vs. 29.8±5.9 ml/kg/min, $p<0.05$; HR: 152 ± 16 vs. 142 ± 15 b/min, $p<0.05$). Pulmonary ventilation, respiratory exchange ratio and blood lactate were similar in both trials. Plasma adrenaline and growth hormone during and 1 hour after exercise were similar in both trials, while nor-adrenaline was higher during constant intensity exercise ($p<0.05$). Significant time effects were found for all cardiorespiratory, lactate and hormonal parameters.

Conclusions: Constant and alternating intensity exercise of the same mean intensity and duration provoked similar changes in terms of stress and blood- lactate, while VO_2 and HR responses and nor-adrenaline concentration were higher when exercise intensity was constant, suggesting that constant exercise impose greater demand on the cardiovascular system.

Keywords: Adrenaline; Noradrenaline; Growth hormone; Blood-lactate

Introduction

Alternating intensity exercise consists of repeated periods of intense exercise followed by periods of less intense exercise. This type of exercise is used in many sports activities and it has the advantage that high intensity can be sustained for longer period of time than during constant exercise, depending on exercise protocols (ratio of exercise- rest, intensity [1,2]. Furthermore, it is well established that alternating intensity training improves performance of athletes and sedentary populations [1]. Comparison of the two exercise patterns are important, as both types are used in sports training in order to facilitate physiological adaptations to improve performance.

A few studies have examined the acute cardiorespiratory and metabolic response in intermittent exercise in comparison to constant exercise. Some of these showed that maximal oxygen uptake (VO_2), pulmonary ventilation (VE), respiratory exchange ratio (R), and heart rate (HR) did not differ between the two exercise protocols [3-5], or found lower values [6-8] or were higher compared to intermittent exercise [9].

Also, there are only a few studies that examined and compared hormonal changes in terms of stress response between constant and intermittent exercise. Catecholamines (adrenaline, nor-adrenaline) are known to regulate important cardiorespiratory and metabolic functions [10]. Nieman et al. [11], showed that adrenaline concentration was the same after both exercise regimes using a cycle ergometer. Moreover, growth hormone (GH) has been found to be either higher with intermittent exercise [12] or similar to constant [13].

Exercise at a high intensity results in an increase of VO_2 and blood lactate concentration in a non – sustainable way. Thus, it may be expected that the hormonal responses to alternating exercise would differ from those observed during constant exercise, even if mean intensity is similar. We hypothesized that alternating intensity exercise would evoke larger cardiorespiratory and hormonal responses than constant exercise, implying that alternating exercise is more stressful and demanding.

To the best of our knowledge, there is no other study that compared cardiorespiratory, stress responses and blood lactate concentration between the two types of exercise, when power output and exercise duration are equal. Thus, the purpose of this study was to compare the cardiorespiratory and hormonal response in constant and alternating intensity exercise of the same duration and average intensity.

Material and Methods

Participants

Ten healthy moderately trained young men volunteered for the study (age: 24.7±4.7 years, body mass: 78.5±8.9 kg, height: 180.8±6 cm, body fat: 9.1±3.1%. Prior to commencement, approval was obtained from the Institutional Ethical Committee and all experimental procedures

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conformed to the Declaration of Helsinki for experimentation with human participants. All participants were informed of all procedures and purposes of the study and gave their written informed consent.

Experimental design

Each participant completed three preliminary tests for a) measurement of VO_{2max}, b)onset of blood lactate accumulation, and c) familiarization with the two main tests: I) constant and II) alternating intensity exercise protocol. These laboratory tests were conducted on five separate occasions. VO_{2max} and lactate threshold tests were conducted at least three days apart and no longer than a week. The two main tests were conducted one week apart in random order and took place at the same time of the day (at 6:00 am), so as to avoid alternations on performance because of circadian rhythm. Participants were fasted overnight and avoided exercise 2 days prior to the main tests. Also, they were asked to write down their food diary for the last 2 days before the first main test, and follow the same diet, so as to consume the same foods in both tests.

All tests (VO_{2max}, submaximal, Constant and Alternating intensity exercise) were conducted on the same modified, friction loaded cycle ergometer (Monark model, Sweden) in which a special alteration was made in order to run the alternating intensity exercise test. Specifically, a mechanical construction was affixed on the handles of the cycle ergometer and had the ability to change the workload of the cycle ergometer instantaneously with a flip of a switch. This operation was conducted manually by an assistant. Also, the cycle ergometer was equipped with a photocell, which monitored the velocity of the flywheel (122 black and white strips placed on the flywheel rim). The signal was amplified (Biopac Systems Inc) and stored on a computer. The calculation of power output was described elsewhere [14]. Shortly, Instantaneous flywheel velocity data were low pass filtered with a cut off frequency of Hz and flywheel acceleration was obtained by digital derivation. Flywheel inertia was calculated from deceleration measurements against different loads and power output was corrected for changes in kinetic energy of the flywheel. Values of power output and pedal rate were averaged over each pedal down stroke.

Protocol of VO_{2max} and onset of blood lactate accumulation

VO_{2max} was determined by continuous incremental cycling test to exhaustion with open circuit – spirometry (MedGraphics CPX/D, USA). The pedaling frequency was set at 70 rpm and was maintained throughout the test. VO_{2max} was defined as the highest VO_2 obtained in 30 seconds. Each participant was verbally encouraged to continue exercise until volitional exhaustion. The test was terminated when the participants met at least three of the following five criteria: a) a plateau in the VO_2 vs. exercise intensity relationship, which has been defined as an increase in VO_2 of less than 2ml/Kg/min with an increase in exercise intensity, b) R greater than 1.1, c) a final heart rate within 10 b/min of the age predicted maximum, d) participants fatigue and e) a rating of perceived exhaustion (RPE) of 19-20 on the Borg scale. Prior to each test, the gas analyzers were calibrated, using gases of known O_2 and CO_2 concentrations.

Maximal Power Output (POmax) was defined as the highest average power output during the last minute of the VO_{2max} protocol.

During the onset of blood lactate accumulation test (OBLA), each subject performed 5 submaximal sets using the cycle ergometer, which each lasting 5 minutes and the frequency was set at 70 rpm. The pedaling frequency was maintained through both tests, with the aid of a digital display adjusted to the bike. In addition, an assistant was verbally giving feedback to the participants, to either speed up, slow down, or maintain the pedaling frequency. At the end of each set, 20μl of blood was taken from the participant's fingertip and diluted with 200μl percloric acid and then stored at -20°C until the analysis was conducted. Determination of the OBLA (based on the 4mmole/l method) was obtained from non-linear plots of exercise intensity (power) against lactate concentration [15]. Four hours before each test participants were told to refrain from consuming food, coffee and alcohol.

Constant- alternating intensity protocol

The duration of each test was 1 hour with the same mean intensity at 105% of the OBLA for both protocols. Alternating intensity exercise was a continuous protocol in which there was no rest period and intensity fluctuated in a repeating pattern. The exercise protocol has been explained in detail previously [16]. Shortly, during constant exercise (CON), participants cycled at a power output corresponding to 105% of the OBLA (69.8±4.7% VO_{2max}). During alternating intensity exercise (ALT), 40 seconds of light exercise, (46.5±1.9% VO_{2max}), was alternated with 20 seconds intervals of hard cycling at 120% of VO_{2max}, so as the mean intensity (power output) was the same. The intensity of both protocols was based on pilot studies in which intensities corresponding from105% - 115% OBLA were tested. The intensity corresponding to 105% OBLA was chosen because all athletes could manage to exercise for at least 1 hour. Supramaximal intensity (120% of VO_{2max}) would recruit energy from both aerobic and anaerobic sources [17], suggesting different metabolic response between the two exercise protocols. Exercise intensity was calculated based on the equation of power (kg) against % of VO_2 in submaximal tests, and from the equation of time spent at 40´´ and 20´´ [(OBLA+ (5%of OBLA x OBLA)-(0.33*40%)]/0.66. The pedaling frequency was set at 70 rpm and maintained through both tests (both the slow and fast parts of the ALT exercise) with the aid of digital display adjusted to the bike. Furthermore, an assistant was verbally giving feedback to the participants.

Both protocols were conducted under the same environmental conditions (temperature of 20°C – 22°C, and relative humidity of 45-50%).

Measurements

Body composition: Percent of body fat was estimated by measuring skinfold thickness at four sites (biceps, triceps, suprailiac, subcapular) using a caliper [18].

Ventilatory parameters: VO_2, VE, and R were measured breath by breath. In both main trials (ALT and CON exercise) the ventilatory parameters were measured continuously during the first 10 minutes of the exercise and then continuously for the last 3 minutes of each of the remaining 10 minute intervals, until the completion of the exercise.

Lactate analysis (La): 20μl capillary blood from fingertips was collected at rest, 5, 10, 15, 20, 30, 40, 50 and 60 minutes for lactate concentration. The analysis of the lactate was made photometrically (Jenway, 3600, UK, [19]).

Heart rate was measured continuously throughout the tests with Polar (Sports Tester, Filand). Each test performed with the same HR monitor.

Borg scale: The subject perception of exertion during each test was referenced with 6-20 scale [15].

Venous blood sampling

Venous blood samples were drawn from an antecubital vein from each participant, in the sitting position, at the following times: prior to test, during the last seconds of 30 and 60 minutes of exercise and 1 hour after the end of exercise. Changes of plasma volume were calculated from Hemoglobin and Hematocrit according to Dill and Costil [20] equations.

Hormones

For Nor- adrenaline (NADR) and adrenaline (ADR) measurement, 2ml of blood for each hormone was collected into EDTA tubes and centrifuged and the plasma stored at -70°C until analysis. The concentration of each catecholamine was measured using the commercially available Elisa Kit (Biosource, Belgium, KAPL 10-200, KAPL 10-0100). The intra- and interassay coefficients of variation have been reported to be less than 5.2% and 7.0%, respectively

For Growth Hormone analysis (GH), serum was separated from whole blood by centrifugation at 1000 g for 10 min at room temperature, then, stored at -70˚C until analysis was conducted. The concentration of growth hormone was measured using the commercially available Elisa Kit (Biosource, Belgium, KAP1081). The intra- and interassay coefficients of variation have been reported to be less than 9.8% and 15%, respectively.

Hematocrit – Hemoglobin: were measured via routine methods (ABBOT, USA).

Statistical analysis

Data are presented as means and ±SD. Differences between the two conditions over time were analyzed using two-way ANOVA with repeated measures. In case a statistical significance was detected, a Tukey – Post Hoc Test was conducted for multiple comparisons. Statistical analysis was performed using Statistica V.8, the level of significance was set at $p<0.05$. Power analysis was conducted by commercial available software (G*Power 3.1, Germany), level was set at 0.8 level.

Results

Performance baseline characteristics of the subjects were: VO_{2max}: 47.9 ± 6.5 ml/kg/min, HRmax: 188 ± 12 b/min, maximal power (POmax): 267 ± 18 Watts and VO_2 at LT: 32.3±5.0 ml/kg/min. Mean PO for CON was 154 ± 17 Watts, (57.8±6.5% POmax), while mean PO for ALT was 158.8 ±20.5 Watts, (59.4± 7.8 % POmax). No difference was found between the two exercise protocols concerning PO, either in relative or absolute values, (p=0.12).

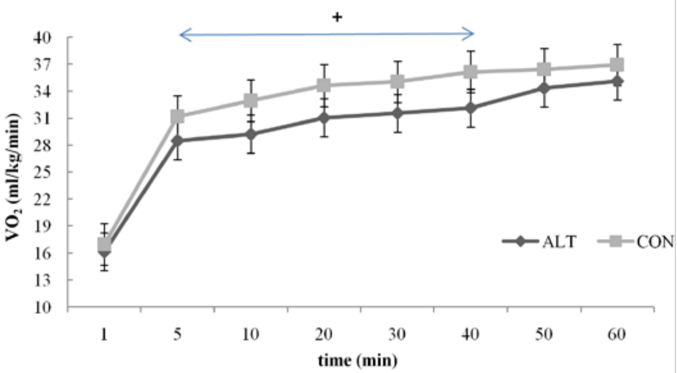
Cardiorespiratory and metabolic parameters

Oxygen uptake (VO_2) was affected by the type of exercise, with higher VO_2 in CON compared to ALT exercise, (32.5±6.6 vs. 29.8±5.9 ml/kg/min, $p<0.05$, see Figure 1). VO_2 was also, affected by the time ($p<0.01$, see Figure 1 and increased in both CON and ALT over time). Similarly, HR was overall higher in CON compared to ALT exercise, (152 ± 16 vs. 142 ± 15 b/min, see Figure 2). The type of exercise had no effect on VE (p=0.55, see Figure 3) or on the R value (p=0.42, see Figure 4). There was a drift in VO_2, HR and VE showing a gradual increase, while R showed a gradual decrease over time (Figures 1-4).

Changes in blood lactate concentration for CON and ALT are shown in Figure 5. Lactate concentration increased over time ($p<0.01$) in both exercise conditions, but there were no significant differences between the two protocols (p = 0.75).

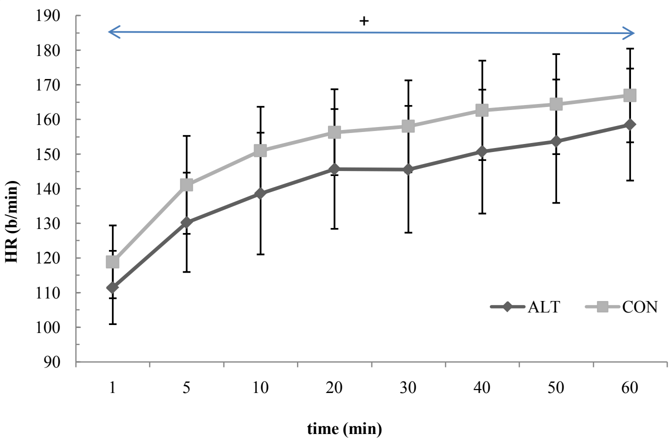
Hormonal parameters

There were no significant differences in plasma volume changes between CON and ALT from rest to the 30th minute (p= 0.11), from rest to the 60th minute of exercise (p = 0.33) and from rest to 1 hour post-exercise (p = 0.36). Table 1 shows the changes in hormone



+ significant difference between CON and ALT at 5, 10, 30, and 40 minutes ($p<0.05$).

Figure 1: Changes in VO_2 (mean ± SD) in constant and alternating intensity exercise.



+ significant difference between CON and ALT ($p<0.05$).

Figure 2: Changes in HR (mean ± SD) in constant and alternating intensity exercise.

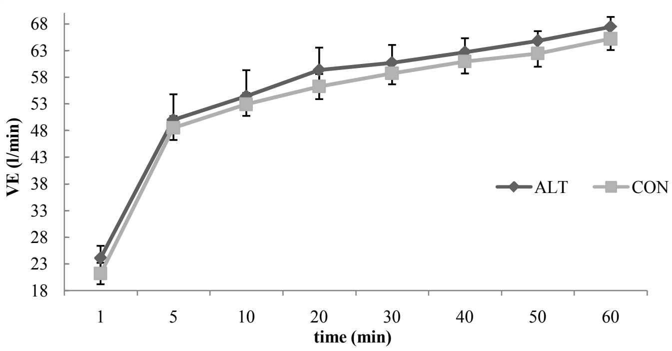


Figure 3: Changes in VE (mean ± SD) in constant and alternating intensity exercise.

concentration in CON and ALT. There was no difference between CON and ALT in the changes of ADR (p=0.22), and GH (p=0.80), but there were significant main effects for time (p<0.01). ADR and GH increased at 30 and 60 minute of exercise and returned to the resting values 1 hour post exercise (Table 1). Changes in NADR concentration were affected by the type (p=0.05) of exercise and by time (p<0.01) with values in CON being higher than values in ALT. The NADR concentration was increased from rest over time and returned to resting value 1 hour post exercise (Table 1). For all 3 hormones examined, higher values were observed at the 30th and 60th min of exercise in comparison to rest (p≤ 0.01), but no differences were observed between rest and 1 hour post exercise (p> 0.05). For NADR and GH there were also significant difference between the 30th and 60th min of exercise (p≤ 0.05).

In relation to type of exercise and the interaction of 'time by type', power analysis showed that sample size is not a confounding factor (ADR: 0.22; 0.12, GH: 0.06; 0.05, VE: 0.05; 0.25, for type and 'time by type' respectively). This was not the case for La concentration (power: 0.06 for time, 0.56 for time by type) and R (power: 0.12 for type, 0.54 for time by type), for which, power analysis showed that some differences in time by type interaction could be found increasing the sample size.

Borg Scale: We found no differences between the two exercise protocols concerning the type and the time (p=0.35, and p=0.30 accordingly, see Figure 6).

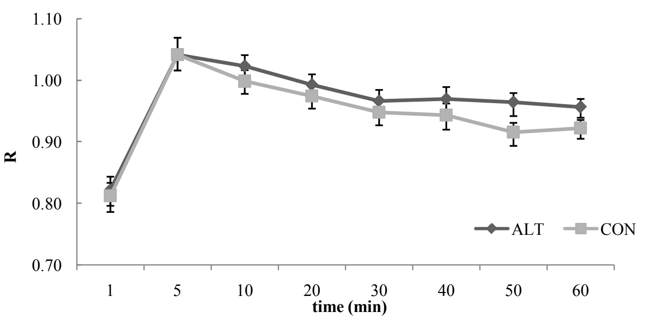


Figure 4: Changes in R (mean ± SD) in constant and alternating intensity exercise.

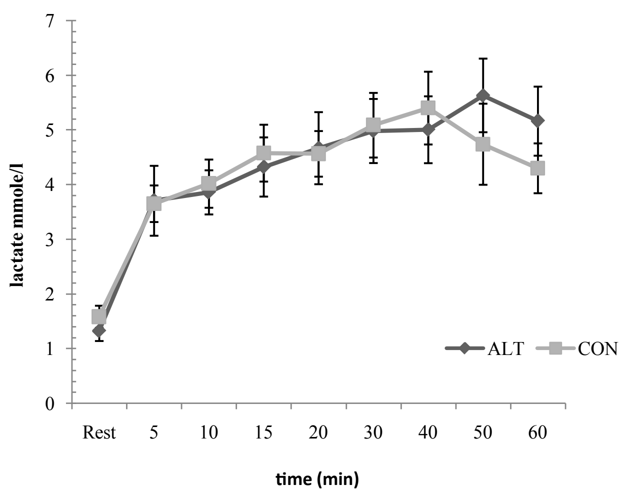


Figure 5: Changes in blood lactate concentration (mean ± SD) in constant and alternating intensity exercise.

Variable	Rest	30'	60'	120'	P
Adrenaline (ng/ml)					
Alternating Intensity	0.03±0.03	0.14±0.07	0.20±0.08	0.05±0.03	<0.01;0.23
Constant Intensity	0.03±0.01	0.14±0.05	0.17±0.10	0.04±0.04	
Nor-Adrenaline (ng/ml)					
Alternating Intensity	0.62±0.48	1.98±1.30	3.30±1.65	0.84±0.57	<0.01;0.05
Constant Intensity	0.79±0.28	3.03±1.05	3.70±2.06	1.21±0.76	
Growth Hormone (ng/ml)					
Alternating Intensity	0.38±0.34	3.62±3.13	7.83±4.34	0.77±0.57	<0.01;0.80
Constant Intensity	0.34±0.37	3.47±3.80	7.50±6.40	0.69±0.81	

The first p value represents the time effect; the second p value represents the type (continuous versus intermittent) x time interaction

Table 1: Plasma catecholamines and serum growth hormone changes (mean ± SD) before, 30 and 60 min of exercise and 1 hour after the end of exercise (ALT-CON).

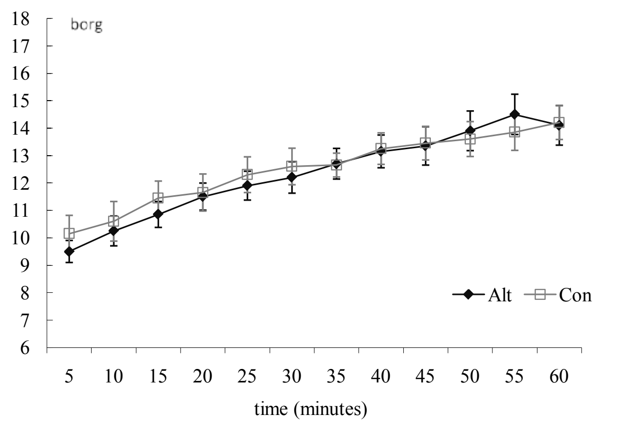


Figure 6: Changes in Borg Scale (mean ± SD) in constant and alternating intensity exercise .

Discussion

The main finding of the present study was that during sustained exercise slightly above the lactate threshold, VO_2, HR and NADR were higher in the CON compared with the ALT condition. In contrast, large fluctuations of exercise intensity (power corresponding to 47%-120% VO_{2max}) did not alter the time course of VE and R value, lactate, ADR and GH concentration from that observed in the CON exercise protocol (power corresponding to 70% VO_{2max}).

Our data differed from the findings of Essen et al. [3,4], who found that cycling for 60 minutes continuously or with alternating intensity (15 sec work – 15 sec rest) with identical average power output and mean intensity corresponding to 50-55% of VO_{2max}, resulted in similar cardiorespiratory response. Also, differed from other studies, who found that R and blood lactate concentration were higher in intermittent compared to continuous exercise, while there were no differences in HR response [21,22]. In these protocols, exercise either lasted 30 minutes with mean intensity corresponding to 90% of the Lactate Threshold, or they cycled for 1 hour to 78% of VO_{2max}, In addition, other investigators showed that interval running (1- to 60 sec work altered with 20 to 120 sec rest) caused lower lactate concentration compared to running continuously to exhaustion with the same amount of work [23], or found no difference on lactate concentration and VO_2 when constant and alternating intensity exercise performed with the same power output corresponding to 90% of critical power and to 75 Watt [24,25].

The controversial results between the previous studies and our study are possibly due to methodological differences in exercise protocol depending on the purpose of each study. There were differences in exercise protocols concerning the type of exercise, cycling vs running, the overall intensity, fluctuating from 50% to 120% of VO_{2max}, exercise duration and ratio of intense exercise and rest/or lower impact exercise. Another explanation could be the different substrate utilization between the studies. Essen et al. [3,4] found that lipid metabolism was higher in intermittent exercise compared to constant. Others [26,27] showed that fat oxidation was 3 times lower in intermittent exercise compared to continuous submaximal exercise, despite similar overall VO_2, when running at 70% of VO_{2max}. Earlier studies, mentioned that ATP- CP and oxygen bound to myoglobin were used predominately in intermittent exercise compared to constant with the same workload [6,7,23].

Energy production through ATP-CP system is unlikely to be the main source of energy in ALT exercise, since 40 seconds of low intensity exercise alternated with 20 seconds of supramaximal exercise may not be enough for complete resynthesization of ATP-CP in ALT [24]. VE for exercise intensities above LT is stimulated by metabolic acidosis resulting in lactate accumulation [28]. We found no difference in lactate concentration between the two types of exercise, explaining why VE didn't differ and suggesting that ALT intensity exercise could not place greater stress on anaerobic energy systems than CON exercise. Possibly, the lower intensity during ALT exercise stimulated lactate removal and as a result metabolic acidosis was avoided [29]. R values, fluctuating between 0.9 and 1, didn't differ between the two exercise protocols, suggesting that in both protocols energy was supplied by carbohydrate. In intense and non steady state exercise there is an underestimation of fat oxidation with Indirect Calorimetry [30]. Since, we didn't measure carbohydrate, fat oxidation and ATP-CP system only speculations we could made. More studies need to be conducted in order to examine the energy source in two exercise regimes. The greater VO_2 in CON exercise could not be explained by environmental condition and water supply during exercises, because both were kept constant in both studies. The variations in VO_2 and HR response between the two types of exercise could be explained by the different kinetics. Morris et al. [8], showed that the slower kinetics of HR and VO_2 in alternating exercise caused lower VO_2, VE and HR values compared to constant exercise. Probably, the lower values in VO_2 and HR response in AL compared to CON may reflect a delay on kinetics from light to supramaximal exercise. On the contrary, Dorado et al. [31], mentioned that active recovery (20% of VO_{2max}) between high intensity intermittent cycling for two minutes and corresponding to 120% of VO_{2max} caused greater contribution of aerobic metabolism due to faster VO_2 kinetics. Our results differ from Dorado et al. [31], because in our protocol the alternating intensity exercise was longer, lasting 1 hour and the alterations between 40´´ of light exercise with only 20´´ of intense exercise may not be enough for changes in VO_2 kinetics.

The higher HR and NADR response in CON exercise suggests greater demand on the cardiovascular system compared to ALT. Despite the significant difference between the two protocols concerning the NADR concentration, more studies need to be conducted in order to examine the NADR response because of the large standard deviation in ALT values at the 30th minute of exercise.

We found that the concentration of ADR and GH did not differ between the two exercise protocols. Our results are in line with the study of Nieman et al. [11], who examined 2 hours cycling at 64% of Wattmax continuously or with 3 minutes rest interspersed every 10 minutes. They showed that the concentration of cortisol and ADR was the same either in constant or alternating intensity cycling. The concentration of GH in intermittent exercise was higher [12], or there was no difference [13] when compared to constant. The differences may be attributed to different exercise protocol. In one study the duration of exercise was 20 minutes, while in the other was 40 minutes, and the intensity was set at 150 watt and 45% of the minimum load which elicit VO_{2max} accordingly (shorter duration and different exercise intensity).

ADR and NADR regulate cardiovascular and metabolic functions, and their blood levels reflect sympatho-adrenal activity [10]. Adrenaline level is supposed to represent emotional stress, while NADR reflects physical stress [32]. The fact that we found no differences in ADR concentration between the two types of exercise maybe explained by the rate of perceived exertion, ALT and CON exercise had similar RPE, indicating that subjects when exercising at the same average intensity did not perceive ALT as more or less stressful. So, the concentration of ADR, GH, and Cortisol [16] did not seem to be influenced by the type of exercise when mean intensity and duration are similar.

Limitations

These results could not be applied in different exercise protocols, (different ratio of intense – light exercise, duration and mean intensity) in which the stress and cardiorespiratory demand could be different.

Conclusions

Our study showed that VO_2 HR response and NADR concentration was higher in CON exercise compared to ALT exercise of the same average intensity and duration, suggesting that CON exercise evoke greater demand on the cardiovascular system. On the other hand, stress hormones, (ADR and GH concentration) did not differ between the two exercise protocols, implying that both protocols are equally stressful. These findings could be applied in designing exercise training programs in various sports and disciplines.

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