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Cardiometabolic Recovery and Lactate Removal May Be Related to Muscular Adaptations

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Abstract

Introduction: *The removal of lactate could have relation with the anaerobic muscular adaptations.* ***Objective:*** *to measure the differences in cardiorespiratory recovery (CR) and blood lactate removal among young athletes with differences in non-lactic (NP) and lactic anaerobic power (LP) and fatigue index (FI).* ***Methods:*** *Sixteen swimmers from the Brazilian synchronized swimming team (2014) were divided into two groups GBP (n = 9) with lower NP, LP, and FI ($p<0.05$) than GAP (n=7). Both groups performed a four-minute routine at competitive intensity. Anaerobic power, maximal heart rate (HR) and blood lactate (BL) were determined before and at 1, 3 and 5*

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minutes after the routine. Student's t-test, and two-way ANOVA followed by Bonferroni was used both with a significance of 5%. ***Results:*** *The FI of the GBP was lower than that of the GAP (P <0.05). The NP of the GBP was higher than that of the GAP (P <0.05). The maximum HR of the GBP was equal to that of the GAP (P> 0.05). The GBP had better HR recovery than did the GAP (P <0.05). BL had its lowest levels after 1 and 5 minutes of recovery in the GBP when compared to the GAP (P <0.05).* ***Conclusions:*** *The GBP FI was lower than that of the GAP, while NP was higher, and CR was better in the GBP, indicating a relationship between a lower FI and higher NP and LP with CR and suggesting that muscular adaptations have an important influence on CR and BL removal.*

Keywords: Post-exercise Blood Lactate Removal. Heart Rate Recovery. Non-lactic Anaerobic Power. Lactic Anaerobic Power.

INTRODUCTION

The literature is consistent in affirming that various psychological, biological and performance variables are indicators of fatigue. Investigations have revealed that creatine kinase, lactate dehydrogenase, blood lactate, oxygen consumption and heart rate are associated with exercise intensity and fatigue. Furthermore, the time required to return to pre-exercise levels is considered an indicator of the recovery capacity that is linked to an athlete's physical fitness (Elias et al., 2013; Rider et al., 2014).

Heart rate variability (HRV) analysis is an established method used to quantify the extent of autonomic recovery from exercise (Michael et al., 2017). After completing a given exercise, a rapid decrease in parasympathetic cardiac activity to resting levels suggests a relative and physiological systemic recovery imposed by the workload (Cinaz et al., 2013) and the amount of time required for parasympathetic reactivation after exercise may be significantly influenced by several factors, including exercise intensity (Cunha et al., 2015) and cardiorespiratory fitness (Da Silva et al., 2014). Although many of the factors inherent to HRV have been frequently studied, studies specifically concerning the non-lactic and lactic anaerobic capacities and fatigue index have not yet been conducted.

Another important marker of metabolic activation provided by intense exercise is lactate (Hebisz et al., 2018). Many authors have shown that when the rate of ATP production by oxidative sources becomes insufficient, high rates of glycolytic or glycogenolytic ATP production are required, culminating in the production of pyruvate, a metabolite that can be reduced to lactate or oxidized to CO_2 or H_2O (Calì et al., 2019; Ferguson et al., 2018).

Thus, by increasing the intensity of exercise and muscle load, several tissues begin to produce more lactate and export it to the circulation. Simultaneously, the less active skeletal muscles, the heart, the liver, the renal cortex and the brain remove lactate from circulation, suggesting that this metabolite acts as an intermediary for transporting carbohydrates from cells and tissues with relatively low oxidative capacity to cells and tissues with high oxidative capacity (Bergersen, 2015; Weber et al., 2016). Therefore, it is well postulated that blood lactate concentration is the result of production and removal of this metabolite (Ferguson et al., 2018).

Lactate has been a focus of research on skeletal muscle metabolism and a central theme of the controversy over the relationships between lactate production, acidosis and fatigue, because it is probably a residual product; lactate is increasingly regarded as a source of fuel, continuously produced and metabolized in the organism in order to maintain energy homeostasis at adequate levels in an attempt to maintain cellular activity (van Hall et al., 2009).

A fact that somewhat contradicts what has been described in the literature up to the present moment is that high-intensity exercise can produce greater expression and translocation of MCT-4 (monocarboxylate transporter-four) (Luo et al., 2017). This adaptation may have implications for the export and import of lactate, because the MCTs is responsible for this transport; furthermore, high-intensity exercise, in addition to promoting adaptation related to lactic and non-lactic anaerobic resistance, is the stimulus for MCT-4 translocation and expression in muscles (Ideno et al., 2017).

These statements support the notion that muscular fitness levels may be related to reduced blood lactate levels, while cardiorespiratory fitness is seen as being analogous to the velocity of decrease in heart rate, which is the hypothesis postulated in the present investigation. Thus, the objective of the present study is based

on the possibility that athletes with various levels of non-lactic and lactic power and fatigue indexes present various behaviors in terms of lactate removal and heart rate recovery curves.

MATERIALS AND METHODS

Volunteer Group

All 16 swimmers (17 ± 1.4 years old) from the Brazilian synchronized swimming team (2014) participated in the study at the beginning of the training season (January). The athletes were divided into two groups – GAP (n= 9) and GBP (n= 7) – based on their non-lactic and lactic anaerobic capacity. The athletes were instructed not to train the day before the test, to have their last meal up to three hours ahead of time, to avoid caffeine intake, to avoid medication, and to sleep at least 6 hours the night before. A brief history was taken to identify any possible exclusion factors. The volunteer characteristics are summarized in the Table 1. The volunteer group was compared about their basic characteristics by paired student t test with 5% of significance and non-differences were observed in the variables which allow to consider the group equal in regards the baseline data.

Table 1: Physical data and training experience of the volunteers.

Variables	GAP (n = 9)	GBP (n = 7)
Age (y)	18.8 ± 1.4	15.8 ± 1.6
Height (cm)	166.31 ± 4.3	162.0 ± 3.1
Body Mass	55.16 ± 4.2	55.28 ± 5.2
Body Mass Index	20.01 ± 3.3	21.06 ± 3.7
Training Time	9.5 ±1.6	7.9 ± 1.7

Note: Values are expressed as the mean ± SD.

Procedures

Exercise Protocol

The exercises were composed of a competitive routine at maximal intensity (see Fig 2A) with a duration of 4 minutes. Both exercise routine followed the same exercise choreography. Prior to the tests, heart rates and lactate levels were measured. Then, the routine was performed with heart rate monitoring in order to determine maximum heart rate. Finally, after 1, 3 and 5 minutes of recovery, heart rate

and blood samples were collected for later determination of blood lactate levels as summarized in figure 1.

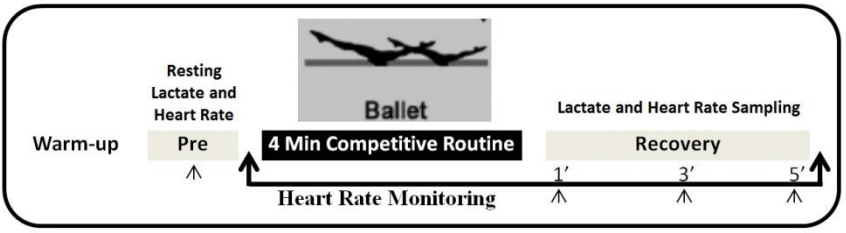

Figure 1: Exercise protocol and data collection.

Functional Capacity

The stress test was performed on a treadmill (ECAFIX), using Bruce's protocol. The Borg scale was adopted for a subjective measure of effort. The test was interrupted in the presence of symptoms that impeded its continuity (fatigue) and/or represented a risk to the evaluated individual. The exercise period was preceded by a period of adaptation and preparation of the athlete to the equipment, followed by five minutes of monitored active recovery (five km/h).

The air flow was measured with a pneumotachograph (Pt, MEDGRAFIC) coupled to a differential pressure transducer, near the capillary of the gas analyzer in order to collect a sample of inhaled and exhaled gases. The athlete, whose nose was sealed by a clip, was connected to the system for acquisition of ventilatory data through a mouthpiece. Flow signals and gaseous concentrations were sampled (Pentium III computer) at a rate of 1000 Hz. Cycle-to-cycle gas concentrations were sampled by the cardiorespiratory diagnostic system MEDGRAFIC, model VO2000. Respiratory flow and electrocardiographic signals (ECG - ECAFIX) were processed on a personal computer in real time.

The mean values of the maximum load reached during exercise of the last three respiratory cycles were computed to determine the results of the variables representative of the end of the exercise (peak). The following ventilatory variables were analyzed: ventilation minute (V_E, l.min^{-1} – BTPS), oxygen consumption (VO_{2peak}, l.min^{-1} – STPD), carbon dioxide production (VCO_{2peak}, l.min^{-1} – STPD), gas exchange ratio (R=VCO_{2peak}/VO_{2peak}) and ventilatory anaerobic threshold (LA, 1.min^{-1} – STPD).

Identification of LA was done through a non-invasive method from the analysis of the ventilatory equivalent of oxygen (V_E/VO_2) and carbon dioxide (V_E/VCO_2), as previously described (Dickstein et al., 1989; Wasserman et al., 1990).

The gas analyzer was calibrated daily before beginning the tests with a calibration bullet (AGA – primary standard) with the following concentrations: 12.1% O_2, 5.0% CO_2 and 83.0% N_2.

Anaerobic Power

Non-lactic and lactic anaerobic power and the fatigue rate were determined by the Wingate test (Bar-Or, 1987) performed on a mechanical cycle ergometer (MONARK). This test preceded the ergospirometric test with an interval of at least 60 minutes between them. To compute the total revolution of the pedal and to calculate the power every five seconds, an optical sensor was coupled to the cycle ergometer managed by an acquisition program elaborated in Labview 6.0 (National Instruments, USA).

The load was determined by 0.075 $Kp.kg^{-1}$ of body mass as predicted in the Wingate test protocol. The test was preceded by a two-minute warm-up period and followed by an active three-minute recovery period with a 50-watt load. From the individual results, the following parameters were calculated: non-lactic anaerobic power by means of the absolute (or maximum) power peak (watts) and relative to body mass ($watts.kg^1$) and the lactic power or average (watts). The percentage of power decline (%) or rate of fatigue was obtained from the difference between the highest power and the lowest power achieved by the athlete during the 30 s test. The bicycle load was checked before starting the test.

Parameter calculations, descriptive statistics of the data and comparisons were performed using one-way ANOVA TWO WAY and the Bonferroni post-tests in the program "PrismStat 5.0" with a significance level of $p < 0.05$.

Ethical aspects

The evaluations were carried out in the Ergo-Spirometry Department of the Laboratory of Exercise Physiology of the School of Physical Education and Sports at the Federal University of Rio de Janeiro (SE-LABOFISE-EEFD-UFRJ). All participants were aware and signed a written consent form, including the procedures adopted and the

authorization of the volunteers to investigate the results found in the scientific study. The anonymity and privacy of the participants were preserved in the study. The Council of Ethics and Human Research of the Federal Institute of Education of Rondônia approved this investigation under CAAE number 44907715.2.00005653. All subjects gave their consent to participate.

RESULTS

The heart rate recovery and the lactate removal are faster in GAP

Heart rate recovered faster in the GAP group than in the GBP group after 3 or 5 minutes (p<0.05) (Fig. 2A) in field challenge, but in laboratory, although similar, in 1 minute is possible see difference (p<0.05) (Fig. 2C). Similar behavior was observed in regard the lactate removal that in field 1 and 5 minutes exhibit difference (p<0.05) (Fig. 2B), but, in laboratory the differences were found in 3 and 5 minutes (p<0.0001) (Fig. 2D). In addition, the heart rate recovery comparison among field and laboratorial investigation (Fig. 2A vs 2C), and the lactate removal (Fig. 2B vs 2D) did not displayed differences in their values comparing the correlated points (data showed in Supplementary File 1).

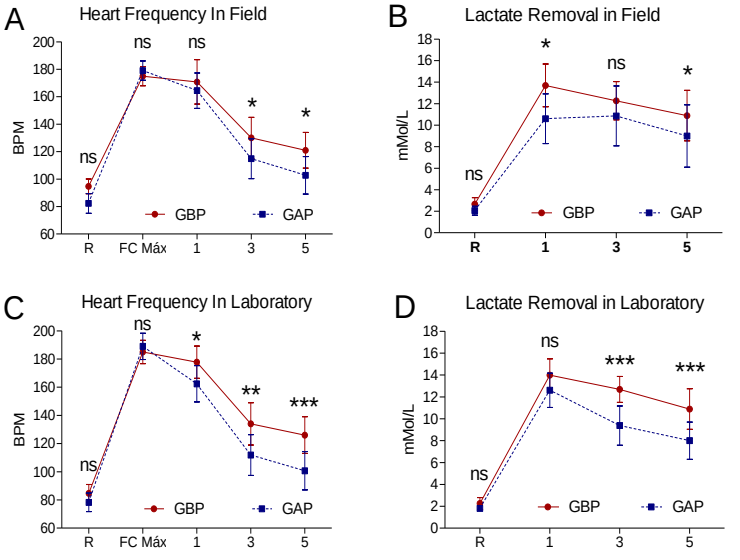

Figure 2: heart rate and lactate recovery curve. The two groups, GBP (n=9) and GAP (n=7), were submitted to a 4-minute routine on different days. **(A)** Comparison of heart rate between GBP and GAP before, during and after the 4-minute routine. **(B)** Comparison of lactate between GBP and GAP before, during and after the 4-minute routine. **(C)** Comparison of the Vo2, Vo2/kg peak, and the VE peak between GBP and GAP **(D)** Comparison of the R Peak, Vo2 and Vo2/Kg peak between GBP and GAP **(E)**. Comparison of the Fatigue Index, Non-lactic Anaerobic Power and Lactic Anaerobic Power between GBP and GAP (**A, B, C** and **D** ns = p> 0.05, *p <0.05). (**G** * = p <0.0001 GBP vs GAP).

The physical fitness did not display differences among GAP and GBP

In relation to functional capacities, there were no differences between the groups to all variables studied (p> 0.05) (Fig. 3A, 3B, 3C, 3D, 3E, and 3F) which suggest equal level of functional capacity.

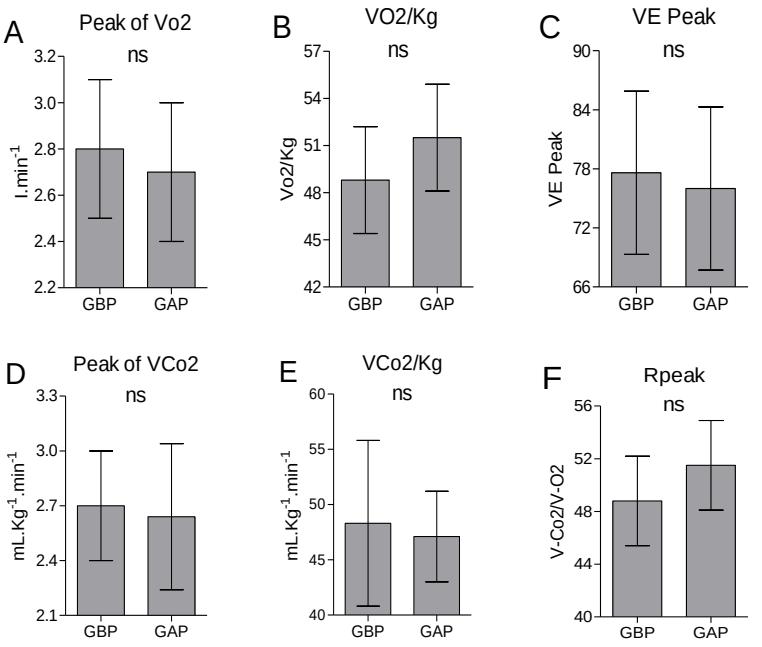

Figure 3: Functional capacity. The two groups, GBP (n=9) and GAP (n=7), were subjected at standard laboratorial tests to determinate the functional capacity. The ANOVA TWO WAY followed by Bonferroni's Post Hoc Test with 5% of significance was performed to determinate the difference between groups. **(A)** Peak of Vo2; **(B)** Vo2/Kg. **(C)**VE Peak; **(D)** Peak of VCo2; **(E)** VCo2/Kg; **(F)** Rpeak. (**A, B, C, D, E, F,** ns= p> 0.05).

The fatigue index, alactic power and the lactic power are best in the GAP

The fatigue index ($p< 0.05$) (Fig. 4A), non-lactic, and lactic anaerobic power showed differences between the groups ($p<0.0001$) (Fig. 4B and 4C).

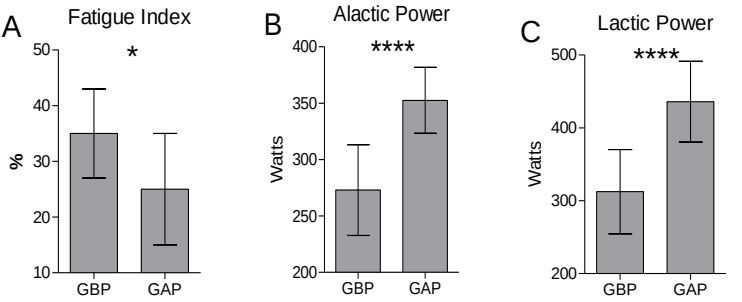

Figure 4: Fitness Performance. The two groups, GBP (n=9) and GAP (n=7), were subjected to a 4-minute routine at maximal intensity on different days. The ANOVA TWO WAY followed by Bonferroni's Post Hoc Test with 5% of significance was performed to determinate the difference between groups. **(A)** Fatigue Index; **(B)** Alactic Power; and **(C)** Lactic Power. (**A** *= $p<0.05$. **B** and C******** = $p<0.0001$ GAP vs GBP).

DISCUSSION

The present study is the first in the literature to compare the cardiometabolic responses and lactate removal of elite athletes of synchronized swimming in terms of non-lactic anaerobic, lactic anaerobic power and fatigue index. To determine the physical characteristics of both groups, some measures of body composition, functional capacity and anaerobic power were conducted. It was shown that lactate removal was partly dependent on the time of recovery between stimulus sessions, and moderate correlations were observed between post-exercise blood lactate concentration, peak heart rate and perceived exertion (Lessard et al., 2013).

Nevertheless, the possible physiological mechanisms underlying these observations were not investigated, however, in an exercise of speculation of the mechanisms under the observations here displayed, is very possible that the relationship among the anaerobic muscle and lactate removal could be related to the expression of the monocarboxylate transporters (MCTs) on the muscle cell membrane that, probably will be more expressed in the muscle with higher if compared with lower anaerobic capacity. It is possible due to the

interaction with the needed adaptations to export the lactate produced in the final of the anaerobic step of the glucose degradation, that, the pyruvate need be converted in lactate to be exporter from the inner cell to outside (Holloszy & Coyle, 2016), that, perhaps, that demand induce the improvements in this metabolism key point due to the participation of this transporter in the lactate shuttle (Dong et al., 2017).

Additionally, in according the possible mechanisms that support the theory that suppose the monocarboxylate transporters-four (MCT-4) of the muscle membrane cell are overexpressed in muscle with more anaerobic adaptations, in comparison with muscles that have lower anaerobic power and fatigue resistance, Fransson *et al.*, (2018) affirm that within several adaptations in response to the intense training, the MCT-4 can be overexpressed until 61% in exercises of high intensity if compared with 31% in aerobic exercises before 4 weeks of training. These represents the exact adaptation that has been proposed here to swimmers which can support most fast lactate removal when more anaerobic muscle adaptations are observed. Moreover, a number of studies have found increased muscle GLUT4 content (Little et al. 2010), as well as resting muscle glycogen (Nordsborg et al. 2015), after high-intensity training protocols, even when not performed with trained athletes, displaying that these adaptations occur in untrained and trained subjects, which permit a good possibility of generalization of the present study.

The proposed here is that the muscle adaptations regarding the fatigue index can be related to lactate removal and heart hate recovery, not only related with the cardiorespiratory fitness which is the classic theory until this moment. In regard the literature, several studies have reporting that the blood lactate removal and heart rate recovery after exercise are dependent the cardiorespiratory capacity (Wiewelhove et al., 2018), moreover, data about the role of the muscle adaptations in both processes are unexplored and represents a literature gap. Here, the proposition is an addition on these mechanisms and not a replacement, but we are proposing that the knowledges here highlighted could add the classical theory.

It is well established in the literature that lower fatigue index and higher non-lactic and lactic anaerobic power are associated with higher level of exercise-related muscle adaptations. It has been proposed that aerobic training may improve the ability of muscle to

recover after anaerobic exercise, suggesting that an athlete with greater aerobic fitness will use fewer non-oxidative sources and thus will recover more quickly from exercise. Theoretically, an increase in aerobic fitness improves the recovery from anaerobic exercise. However, this phenomenon was not completely reproduced in the present study because the aerobic capacity of both groups was equal while the cardiometabolic recovery was different. This is reasonable because lactate removal could be linked to uptake by muscle and other tissues that use this substrate as an energy source specially during ketosis situation (George A. Brooks, 2018; Cox et al., 2016).

A synchronized swimming routine requires a high aerobic effort with fundamental anaerobic contributions to maintain high exercise levels during competition (Dos-Santos & de Mello, 2011; Yamamura et al., 1999). The data shown here demonstrate that the peaks of non-lactic and lactic anaerobic power have similar behavior in field and laboratory, which allow affirm that the brief interruption during the head submersion do not have significant effect on these variables, however, the fatigue index, alactic and lactic power showed differences between the groups.

In the present study, the GAP had heart rate and lactate curve response behaviors different from those observed in the GBP group, although the maximum heart rate was equal in both groups. The GAP group showed a lower lactate peak than did the GBP group. Another important fact is that the non-lactic anaerobic power, lactic anaerobic power and the fatigue index differed between the two groups, even though VO_2 and VCO_2 were equal. These data contradict a part of the literature that states that aerobic capacity improves recovery after intense exercise, a finding that was not seen in the present investigation.

Other investigations have pointed to several possible explanations for the effect of aerobic conditioning on recovery. Freguson *et al.*, (2018); Macinnis & Gibala, (2017) pointed to the increase in the number and size of mitochondria in metabolic recovery which give us the logic notion that the aerobic adaptations are related with the lactate shuttle. However, the increased myoglobin content and blood volume together would be implicated in the transport of O_2 to the muscle during high-intensity exercise, and consequently, there would be a decrease in recovery time, since this would also help to remove the accumulated lactate more quickly (Kanda et al., 2013;

Tomlin & Wenger, 2001). Our work did not counteract this theory, only add other components to the heart recovery and lactate removal suggesting that more than one mechanism is involved in this process, which is perfectly plausible.

These data explain the higher velocity in cardiometabolic recovery, however, the described here demonstrate a clear difference in lactate removal between the groups in field, and in laboratory though both exhibit equal V_E peak, $V_{O2\ Peak}$, $V_{O2\ Peak/body\ mass}$ and peak heart rate, suggesting that the aerobic capacity of these athletes is unrelated to metabolic recovery after maximal intensity exercise in this group.

A number of studies displayed the use of lactate by other muscles and tissues, since anaerobic metabolism after a few minutes of intense exercise may activate lactate uptake and use it as an important energy source during intense exercise by modifying the kinetics of the use of glucose in the presence of lactate (G A Brooks, 2007; Weber et al., 2016). However, unfortunately, almost all studies investigating differences in lactate responses depend on blood lactate measurements that reflect muscle lactate alone, providing indirect evidence of lactate accumulation and removal (Chatel et al., 2016).

These data, taken together, suggest that the adaptations that led to differences in lactate responses, but not in heart rate, were linked to the muscular system in greater magnitude than to the cardiorespiratory system, since the ventilatory capacities between the groups ($V_{E\ Peak}$, $V_{O2\ Peak}$, $V_{O2\ Peak/body\ mass}$, $V_{CO2\ Peak}$, $V_{CO2\ Peak/body\ mass}$) were the same. Therefore, it appears that the cardiorespiratory adaptations of both groups reached the same levels, suggesting that the observed difference was related to adaptations of the muscles required during the exercise routine.

A study conducted by Otsuki *et al.*, (2007) demonstrated differences in cardiac recovery rates between athletes trained in endurance and strength. This study may have its results extrapolated to the data found here, because the non-lactic and lactic anaerobic power and the fatigue index between the two groups showed differences, a fact that is usually evident among people who are trained or not in exercises and strength. However, studies that demonstrate differences in heart rate between groups that have differences in non-lactic and lactic anaerobic power and the fatigue index are scarce, limiting the discussion of the present study.

Among the limitations found in the present study is the need for a population with greater diversity than the one tested here and in previous studies; for example, diversity in terms of age, BMI and health status is the next logical step in order to refine the interpretation of the data described here. There is also a scarcity of data regarding metabolic and cardiac recovery in elite athletes with the same level of aerobic conditioning for comparison between our findings and those of other authors.

Finally, lactate removal and HR characteristics showed differences between the groups, with the best performance and the group with the lowest fatigue index, although cardiorespiratory fitness, demonstrated by the maximum HR reached, and the measure of pulmonary capacity and O_2 uptake were equal between the two groups as in field as in laboratorial challenge. These data suggest that muscular adaptations may have an important role in the behavior of cardiometabolic recovery and lactate removal.

CONCLUSION

Therefore, an intense neuromuscular training could help in recovery, especially in sports in which there is more than one match or challenge on the same day, or when various stimulus in a sequence are needed in sports like soccer which the player, sometimes, need perform more than on sprint in a short time between then, and, perhaps, several times during the match. This knowledge could be important for the improvement of the performance in sports with the characteristics of several trials during the competition.

As a practical application, this paper challenges the idea that only the cardiovascular adaptations are related to recovery after an exercise training session, and high-intensity muscle training that lead to anaerobic adaptations as best fatigue index and anaerobic power could have an important hole on lactate metabolism during and after intense exercise which allow suggest that the high intensity strength training may represent an advantage to the sportive performance of sports with aerobic metabolism predominance.

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