1 **Title: CARDIOMETABOLIC RECOVERY AND LACTATE REMOVAL MAY BE RELATED TO**
2 **MUSCULAR ADAPTATIONS**

3

4 **Short Title: CARDIOMETABOLIC RECOVERY AND MUSCULAR ADAPTATIONS**

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38 Abstract

39 The aim of this study was to measure the differences in cardiorespiratory recovery (CR) and
 40 blood lactate removal among young athletes with differences in non-lactic (NP) and lactic
 41 anaerobic power (LP) and fatigue index (FI) but with the same degree of cardiorespiratory
 42 fitness. Sixteen swimmers from the Brazilian synchronized swimming team (2014) were
 43 divided into two groups GAP (Group High Power) (n = 9) , with NP, LP, and FI ($p < 0.05$)
 44 compared to GBP (Group Low Power) (n=7). Both groups performed a four-minute routine at
 45 competitive intensity. Anaerobic power, maximal heart rate (HR) and blood lactate (BL) were
 46 determined before and at 1, 3 and 5 minutes after the routine. Student's t-test was used to
 47 analyze the intergroup differences of NP, LP, FI, maximum and lactic HR, and two-way ANOVA
 48 followed by Bonferroni was used to analyze HR and BL at 1, 3 and 5 minutes after activity
 49 with a significance of 5%. The FI of the GBP group was lower than that of the GAP group (P
 50 < 0.05). The NP of the GBP group was higher than that of the GAP group ($P < 0.05$). The
 51 maximum HR of the GBP group was equal to that of the GAP group ($P > 0.05$). The GBP group
 52 had better HR recovery than did the GAP group ($P < 0.05$). BL had its lowest levels after 1 and
 53 5 minutes of recovery in the GBP group when compared to the GAP group ($P < 0.05$). The GBP
 54 group's FI was significantly lower than that of the GAP group, while NP was higher, and CR
 55 was better in the GBP group, indicating a relationship between a lower FI and higher NP and
 56 LP with CR and suggesting that muscular adaptations have an important influence on CR and
 57 BL removal.

58

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

61

62 Introduction

63 The literature is consistent in affirming that various psychological, biological and
64 performance variables are indicators of fatigue. Investigations have revealed that creatine
65 kinase, lactate dehydrogenase, blood lactate, oxygen consumption and heart rate are
66 associated with exercise intensity and fatigue. Furthermore, the time required to return to
67 pre-exercise levels is considered an indicator of the recovery capacity that is linked to an
68 athlete's physical fitness [1–4].

69 Heart rate variability (HRV) analysis is an established method used to quantify the extent of
70 autonomic recovery from exercise [5,6]. After completing a given exercise, a rapid decrease
71 in parasympathetic cardiac activity to resting levels suggests a relative and physiological
72 systemic recovery imposed by the workload [7,8] and the amount of time required for
73 parasympathetic reactivation after exercise may be significantly influenced by several factors,
74 including exercise intensity[9] and cardiorespiratory fitness [10,11]. Although many of the
75 factors inherent to HRV have been frequently studied, studies specifically concerning the
76 non-lactic and lactic anaerobic capacities and fatigue index have not yet been conducted.

77 Another important marker of metabolic activation provided by intense exercise is lactate.
78 Many authors have shown that when the rate of ATP production by oxidative sources
79 becomes insufficient, high rates of glycolytic or glycogenolytic ATP production are required,
80 culminating in the production of pyruvate, a metabolite that can be reduced to lactate or
81 oxidized to CO₂ or H₂O [12–15].

82 Thus, by increasing the intensity of exercise and muscle load, several tissues begin to
83 produce more lactate and export it to the circulation. Simultaneously, the less active skeletal

84 muscles, the heart, the liver, the renal cortex and the brain remove lactate from circulation,
85 suggesting that this metabolite acts as an intermediary for transporting carbohydrates from
86 cells and tissues with relatively low oxidative capacity to cells and tissues with high oxidative
87 capacity [16,17]. Therefore, it is well established that blood lactate concentration is the result
88 of production and removal of this metabolite.

89 Lactate has been a focus of research on skeletal muscle metabolism and a central theme of
90 the controversy over the relationships between lactate production, acidosis and fatigue,
91 because it is probably a residual product; lactate is increasingly regarded as a source of fuel,
92 continuously produced and metabolized in the organism in order to maintain energy
93 homeostasis at adequate levels in an attempt to maintain cellular activity [12,16,18].

94 A fact that somewhat contradicts what has been described in the literature up to the present
95 moment is that high-intensity exercise can produce greater expression and translocation of
96 MCT-4 (monocarboxylate transporter) [19,20]. This adaptation may have implications for the
97 export and import of lactate, because the plasma membrane is responsible for this transport;
98 furthermore, high-intensity exercise, in addition to promoting adaptation related to lactic
99 and non-lactic anaerobic resistance, is the stimulus for MCT-4 translocation and expression in
100 muscles [21,22].

101 These statements support the notion that muscular fitness levels may be related to reduced
102 blood lactate levels, while cardiorespiratory fitness is seen as being analogous to the velocity
103 of decrease in heart rate, which is the hypothesis postulated in the present investigation.
104 Thus, the objective of the present study is based on the possibility that athletes with various
105 levels of non-lactic and lactic power and fatigue indexes present various behaviors in terms
106 of lactate removal and heart rate recovery curves.

107

108

109 **Materials and Methods**

110 **Volunteer Group**

111 All 16 swimmers (17 ± 1.4 years old) from the Brazilian synchronized swimming team (2014)
 112 participated in the study at the beginning of the training season (January). The athletes were
 113 divided into two groups – GAP ($n=9$) and GBP ($n=7$) – based on their non-lactic and lactic
 114 anaerobic capacity. The athletes were instructed not to train the day before the test, to have
 115 their last meal up to three hours ahead of time, to avoid caffeine intake, to avoid medication,
 116 and to sleep at least 6 hours the night before. A brief history was taken to identify any
 117 possible exclusion factors. The volunteer characteristics are summarized in the Table 1.

118 **Table 1:** physical data and training experience of the volunteers

Variables	GAP ($n=9$)	GBP ($n=7$)
Age (years)	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

119 Values are expressed as the mean $\pm$ SD.

120

121 **Procedures**

122 **Exercise Protocol**

123 The exercises were composed of a competitive routine with a duration of 4 minutes at
 124 maximum competitive intensity. Prior to the tests, heart rates and lactate levels were
 125 measured. Then, the competitive routine was performed with heart rate monitoring in order
 126 to determine maximum heart rate. Finally, after 1, 3 and 5 minutes of recovery, heart rate
 127 and blood samples were collected for later determination of blood lactate levels as
 128 summarized in figure 1.

129 **Figure 1:** exercise protocol and data collection.

130 **Functional Capacity**

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

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

145 The mean values of the maximum load reached during exercise of the last three respiratory
146 cycles were computed in order to determine the results of the variables representative of the
147 end of the exercise (peak). The following ventilatory variables were analyzed: ventilation
148 minute (V_E , $\text{l} \cdot \text{min}^{-1}$ – BTPS), oxygen consumption ($\text{VO}_{2\text{peak}}$, $\text{l} \cdot \text{min}^{-1}$ – STPD), carbon dioxide
149 production ($\text{VCO}_{2\text{peak}}$, $\text{l} \cdot \text{min}^{-1}$ – STPD), gas exchange ratio ($R = \text{VCO}_{2\text{peak}} / \text{VO}_{2\text{peak}}$) and ventilatory
150 anaerobic threshold (LA, $\text{l} \cdot \text{min}^{-1}$ – STPD).

151 Identification of LA was done through a non-invasive method from the analysis of the
152 ventilatory equivalent of oxygen (V_E/VO_2) and carbon dioxide (V_E/VCO_2), as previously
153 described [23,24].

154 The gas analyzer was calibrated daily before beginning the tests with a calibration bullet
155 (AGA – primary standard) with the following concentrations: 12.1% O₂, 5.0% CO₂ and 83.0%
156 N₂.

157 **Anaerobic Power**

158 Non-lactic and lactic anaerobic power and the fatigue rate were determined by the Wingate
159 test [25] performed on a mechanical cycle ergometer (MONARK). This test preceded the
160 ergospirometric test with an interval of at least 60 minutes between them. To compute the
161 total revolution of the pedal and to calculate the power every five seconds, an optical sensor
162 was coupled to the cycle ergometer managed by an acquisition program elaborated in
163 Labview 6.0 (National Instruments, USA).

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

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

175 Ethical aspects

176 The evaluations were carried out in the Ergo-Spirometry Department of the Laboratory of
177 Exercise Physiology of the School of Physical Education and Sports at the Federal University
178 of Rio de Janeiro (SE-LABOFISE-EEFD-UFRJ).

179 All participants were aware and signed a written consent form, including the procedures
180 adopted and the authorization of the volunteers to investigate the results found in the
181 scientific study. The anonymity and privacy of the participants were preserved in the study.
182 The Council of Ethics and Human Research of the Federal Institute of Education of Rondônia
183 approved this investigation under CAAE number 44907715.2.00005653. All subjects gave
184 their consent to participate.

185

186 Results

187 Heart rate recovered faster in the GBP group than in the GAP group ($P < 0.05$) (Fig. 2A); a
188 similar phenomenon was observed regarding the behavior of lactate ($P < 0.05$) (Fig. 2B). In
189 relation to physical fitness and respiratory capacities, there were no differences between the
190 groups ($P > 0.05$) (Fig. 2C and 2D); however, the fatigue index, lactic and non-lactic anaerobic
191 power showed substantial differences between the groups ($P < 0.0001$) (Fig. 2E).

192 **Figure 2: heart rate and lactate recovery curve.** The two groups, GBP ($n=9$) and GAP ($n=7$),
193 were subjected to a 4-minute routine on different days. **(A)** Comparison of heart rates
194 between the GBP and GAP groups before, during and after the 4-minute routine. **(B)**
195 Comparison of lactate between the GBP and GAP groups before, during and after the 4-
196 minute routine. **(C)** Comparison of the $\dot{V}O_2$, $\dot{V}O_2/\text{kg}$ peak, and the $\dot{V}_E$ peak between the GBP
197 and GAP groups. **(D)** Comparison of the R Peak, $\dot{V}O_2$ and $\dot{V}O_2/\text{kg}$ peak between the GBP and

198 GAP groups. **(E)**. Comparison of the Fatigue Index, Non-lactic Anaerobic Power and Lactic
199 Anaerobic Power between the GBP and GAP groups (**A, B, C** and **D** ns = $p > 0.05$, $*p < 0.05$). (**G**
200 $* = p < 0.0001$ GBP vs GAP).

201

202 Discussion

203 The present study is the first in the literature to compare the cardiometabolic responses of
204 elite athletes of synchronized swimming in terms of non-lactic anaerobic, lactic anaerobic
205 power and fatigue index. To determine the physical characteristics of both groups, some
206 measures of body composition, functional capacity and anaerobic power were conducted.
207 Recently, it was shown that lactate removal was partly dependent on the time of recovery
208 between stimulus sessions, and moderate correlations were observed between post-exercise
209 blood lactate concentration, peak heart rate and perceived exertion [26]. Nevertheless, the
210 possible physiological mechanisms underlying these observations were not described. Here,
211 we propose that the muscle adaptations regarding the fatigue index can be related to lactate
212 removal and heart rate recovery.

213 It is well established in the literature that lower fatigue index and higher non-lactic and lactic
214 anaerobic power are associated with higher level of exercise-related muscle adaptations.

215 It has been proposed that aerobic training may improve the ability of muscle to recover after
216 anaerobic exercise, suggesting that an athlete with greater aerobic fitness will use fewer non-
217 oxidative sources and thus will recover more quickly from exercise. Theoretically, an increase
218 in aerobic fitness improves the recovery from anaerobic exercise. However, this phenomenon
219 was not completely reproduced in the present study because the aerobic capacity of both
220 groups was equal while the cardiometabolic recovery was different. This is reasonable

221 because lactate removal could be linked to uptake by muscle and other tissues that use this
222 substrate as an energy source [12,27].

223 A synchronized swimming routine requires a high aerobic effort with fundamental anaerobic
224 contributions to maintain adequate exercise levels during competition [28,29]. The data
225 shown here demonstrate that the peaks of non-lactic and lactic anaerobic power have the
226 same behavior, but the fatigue index was the only factor directly related to physical fitness
227 that showed differences between the groups.

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

235 Other investigations have pointed to several possible explanations for the effect of aerobic
236 conditioning on recovery. Holloszy [30] pointed to the increase in the number and size of
237 mitochondria in metabolic recovery. However, the increased myoglobin content and blood
238 volume together would be implicated in the transport of O_2 to the muscle during high-
239 intensity exercise, and consequently, there would be a decrease in recovery time, since this
240 would also help to remove the accumulated lactate more quickly [31,32].

241 These data explain the higher velocity in cardiometabolic recovery, However, the data
242 described here demonstrate a clear difference in lactate removal between the groups though
243 both exhibit equal V_E peak, V_{O2} Peak, V_{O2} Peak/body mass and peak heart rate, suggesting that the

244 aerobic capacity of these athletes is unrelated to metabolic recovery after maximal intensity
245 exercise.

246 This difference may be related to the use of lactate by other muscles and tissues, since
247 anaerobic metabolism after a few minutes of intense exercise may activate lactate uptake
248 and use it as an important energy source during intense exercise by modifying the kinetics of
249 the use of glucose in the presence of lactate[15]. However, unfortunately, almost all studies
250 investigating differences in lactate responses depend on blood lactate measurements that
251 reflect muscle lactate alone, providing indirect evidence of lactate accumulation and
252 removal. Other authors did not find evidence that associated the aerobic capacity with
253 greater speed of lactate removal, corroborating the findings of the present study [32–34].

254 These data, taken together, suggest that the adaptations that led to differences in lactate
255 responses, but not in heart rate, were linked to the muscular system in greater magnitude
256 than to the cardiorespiratory system, since the ventilatory capacities between the groups (V_E
257 Peak, $\dot{V}O_2$ Peak, $\dot{V}O_2$ Peak/body mass, $\dot{V}CO_2$ Peak, $\dot{V}CO_2$ Peak/body mass) were the same. Therefore, it appears
258 that the cardiorespiratory adaptations of both groups reached the same levels, suggesting
259 that the observed difference was related to adaptations of the muscles required during the
260 exercise routine, although explaining the mechanism that is linked to what was observed
261 here was not the focus of the present investigation.

262 A study conducted by Otsuki et al. [35] demonstrated differences in cardiac recovery rates
263 between athletes trained in endurance and strength. This study may have its results
264 extrapolated to the data found here, because the non-lactic and lactic anaerobic power and
265 the fatigue index between the two groups showed differences, a fact that is usually evident
266 among people who are trained or not in exercises and strength. However, studies that
267 demonstrate differences in heart rate between groups that have differences in non-lactic and

268 lactic anaerobic power and the fatigue index are scarce, limiting the discussion of the present
269 study.

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

276 **Conclusions**

277 Lactate removal and HR characteristics showed differences between the groups, with the
278 best performance and the group with the lowest fatigue index, although cardiorespiratory
279 fitness, demonstrated by the maximum HR reached, and the measure of pulmonary capacity
280 and O₂ uptake were equal between the two groups. These data suggest that muscular
281 adaptations may have a critical role in the behavior of cardiometabolic recovery, in contrast
282 to the findings in the literature that focused on muscle metabolism in exercise.

283 **Practical Applications**

284 This paper challenges the idea that only the cardiovascular training is related to recovery
285 after an exercise training session. Therefore, an intense neuromuscular training could help in
286 recovery, especially in sports in which there is more than one competition on the same day.
287 This may be applicable to athletes in sports with fundamentally aerobic components. This
288 knowledge could be crucial for improving performance during the several trials during the
289 competition day.

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293

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THE CARDIOMETABOLIC RECOVERY MAY BE RELATED TO MUSCULAR ADAPTATIONS

Figure 1: exercise protocol and data collection.

CARDIOMETABOLIC RECOVERY AND LACTATE REMOVAL MAY BE RELATIONSHIP TO MUSCULAR ADAPTATIONS

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 V_E 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).

CARDIOMETABOLIC RECOVERY AND LACTATE REMOVAL MAY BE RELATIONSHIP TO MUSCULAR ADAPTATIONS

Variables	GAP (n=9)	GBP (n=7)
Age (years)	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
Values are expressed as mean ± SD.		

Table 1: volunteer group characterization.