Acid-base balance during repeated cycling sprints in boys and men

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IT IS WELL ACCEPTED THAT ANAEROBIC glycolysis is lower in prepubertal children than in young adults during high-intensity exercise. In fact, some earlier studies showed that postexercise blood and muscle lactate concentration ([La]) was markedly lower in children compared with adults (10, 11, 16, 27). For instance, Hebestreit et al. (16) indicated that, after a 30-s “all-out” cycling task, postexercise blood [La] was 5.7 and 14.2 mmol/l in prepubertal boys and men, respectively. This was confirmed by some studies that showed that blood and muscle pH decreased slightly after exercise in children compared with adults’ values. Using phosphorus-nuclear magnetic resonance spectroscopy, after a graded exercise to exhaustion, it has been shown that intramuscular pH in the calf muscle of prepubertal children only decreased from 0.11 to 0.23 units, whereas the fall in pH represented 0.36–0.38 units in adults (33, 34). Furthermore, old studies showed that the decrease in blood pH was slightly smaller in 11- to 12-yr-old children (not lower than 7.34) than in adults (lower than 7.19) after maximal exercise (6, 15, 20). More recently, it has also been observed that, after a 30-s supramaximal exercise, venous blood pH only reached 7.32 in 10-yr-old children compared with 7.18 in 25-yr-old adults (16). Despite a lesser reliance on glycolytic energy pathways in children, these previous studies showed that blood pH was slightly modified, whereas [La] may increase highly in children (9). Therefore, according to these results, the relationship between [La] and pH may be different between children and young adults. We hypothesized that this smaller decrease in blood pH compared with the increase in [La] in children may result from a higher hydrogen ions (H+) buffering capacity by bicarbonate ions ([HCO3-]), Hb, and plasmatic proteins (total blood base) and/or from a different time course of regulation of the arterial partial pressure of carbon dioxide (PaCO2) by ventilation (Ve). To test this hypothesis, a repeated sprint exercise protocol, separated by short recovery intervals, was chosen because such protocol induces a high increase in [La] in children (19), as well as in adults (13), and children are often engaged in this type of activity (3).

Therefore, the aim of the present study was to investigate the acid-base balance during several repeated bouts of short-term, high-intensity cycling exercise separated by short recovery intervals in boys as well as in men.

METHODS

Subjects

Eleven 8- to 10-yr-old prepubertal boys and ten 19- to 21-yr-old men volunteered to participate in the study. All of the subjects were involved in different physical activities, such as ice hockey or swimming. Written informed consent was signed by each subject or his parents. The protocol was

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approved by the ethics committee of the Auvergne University.

Experimental Protocol

Design. Each subject attended the laboratory for two sessions. The time interval between the sessions was ≥8 h and ≤2 wk. The first visit was used to gather subjects’ physical characteristics and to habituate them to the subsequent testing procedure. During the second session, the subjects performed 10 short-term cycling sprints separated by 30-s recovery intervals. Each subject was instructed to refrain from intense physical exercise 48 h before the second visit.

Session I. During the first session, body mass (BM) and standing height were measured. Body fat (%) was estimated from tricipital and subscapular skinfold thicknesses using the equations of Slaughter et al. (31). Pubertal stage was determined according to pubic hair and gonadal development (32). The saddle height of the friction-loaded cycle ergometer (Ergomeca Sorem, Toulon, France) was adjusted to give optimal comfort to each subject and remained unchanged for the second session. The cycle ergometer was previously described in detail by Doré et al. (8). The subjects’ feet were strapped to the pedals to prevent them from slipping. The subjects performed a warming up that consisted of a 5-min submaximal cycling followed by two brief sprints (5 s) against a low-braking load. After 5-min rest, the subjects performed three sprints on the cycle ergometer against frictional forces of 0.245, 0.491, and 0.736 N/kg BM (corresponding applied loads: 25, 50, and 75 g/kg BM, respectively). The latter were applied in a randomized order. Each sprint was separated by at least 5 min of rest. These sprints allowed the researchers to familiarize the subjects with the cycle ergometer and to calculate the friction load against which the subjects had to perform the second session. In fact, velocity, force, and power values (averaged per half-pedal revolution) recorded during the acceleration phase of the three sprints were used to draw the individual force- and power-velocity relationships (2). Optimal values of friction force and velocity at which the highest power output is performed were determined from these relationships. After a 15-min rest, maximal oxygen consumption (VO2 max) was determined by direct method (CPX Medical Graphies, St. Paul, MN) using a graded cycling test. The initial power was 30 and 60–75 W for the boys and the men, respectively. The power was incremented by 15 W every 1 min for the boys and by 30 W every 2 min for the men. The pedaling rate was maintained at 60 rpm throughout the test. The exercise intensity was increased until exhaustion of the subject.

Session II. The subjects performed a 6-min warm-up on the cycle ergometer at a power output leading heart rate to ~140–150 and 120–130 beats/min in the boys and the men, respectively. After a 5-min rest, the subjects performed 10 consecutive 10-s sprints separated by 30-s recovery intervals against a friction load corresponding to 50% optimal value of friction force for each subject. Before each sprint, the start position was standardized with the crank of the left leg located 45° forward of the top dead center. At the signal, the subjects were told to remain on the saddle and to pedal as fast as possible to reach maximal pedaling rate. Each subject was verbally encouraged throughout each sprint. During the resting periods, after each sprint, the subjects had to remain seated quietly on the cycle ergometer. Peak power (Wpeak) was calculated at each sprint, according to the method described by Doré et al. (8).

Blood Sampling

Capillary arterialized blood samples (150 μl) were drawn from the earlobe at rest and before the first and after the second, fourth, sixth, eighth, and tenth sprints to determine the time course of [H+] ([H+]1), [HCO3−] ([HCO3−]) and base excess (BE) concentrations ([BE]), and the PaCO2 (Fig. 1). Using a blood-gas analyzer (model IL Synthesis 1710, Instrumentation Laboratory), [H+] and PaCO2 values were measured immediately after collection. [HCO3−] values were calculated from the Henderson-Hasselbalch equation: [H+] = K−α [HCO3−]/αPaCO2)], where Kα is the effective dissociation constant for plasma weak acids and α is the solubility coefficient of CO2. At each sample, [BE] values were calculated from [HCO3−] and blood Hb concentration ([Hb]) according to the equation

\[ [BE] = \{(1 - 0.014[Hb]) \cdot ([HCO3−] - 24 + (1.43 \cdot [Hb]) + 7.7) \cdot (pH - 7.4) \]

[Hb] values were measured by an interfaced CO-oximeter. Additional capillary blood samples (10 μl) were collected at rest, before and after the first sprint, and after the third, fifth, seventh, ninth, and tenth sprints to measure the time course of [La]. Capillary tubes were frozen at −20°C. Blood [La] values were measured by an Analog GM7 GB analyzer (Analog Instruments, London, UK) using t-lactate O2 oxide reductase, which catalyzes oxidation of t-lactate to pyruvate and hydrogen peroxide. Given that [H+] and [La] sampling times were different, a [La] linear interpolation was performed between each sprint to correspond each [La] value with each [H+] value.

Gas Exchange

VE and carbon dioxide output (VCO2) were continuously measured breath by breath during the 10 sprint exercises using a CPX analyzer (Medical Graphies, St. Paul, MN). The breath-by-breath data were time interpolated, so that there was a data point every 1 s (1).

Statistical Analysis

All of the results are expressed as means ± SD. Differences between the two groups (the boys and the men) for anthropometric variables and VO2 max were tested using an unpaired Student t-test. Differences between the boys and the men for [La] and [H+] values over the 10 sprints were tested by a two-way ANOVA for repeated measures (interfactor:
RESULTS

Physical characteristics and VO2max of the subjects are described in Table 1. VO2max (ml-min⁻¹.kg body mass⁻¹) was not significantly different in the boys compared with the men.

Wpeak

In the boys, Wpeak remained unchanged during the 10 repeated sprints (sprint 1: 284 ± 50 W; sprint 10: 285 ± 46 W). In the men, Wpeak decreased significantly by 28.5% from the first sprint (1,122 ± 197 W) to the tenth sprint (798 ± 132 W) (P < 0.001).

Blood [La]

The time course of [La] during the 10 sprint exercises in the boys and the men is shown in Fig. 2. In the boys, [La] increased approximately fourfold from 1.9 ± 0.3 mmol/l at rest to 8.1 ± 2.3 mmol/l after the seventh sprint (P < 0.001) and then remained unchanged until the tenth sprint (8.5 ± 2.1 mmol/l). In the men, [La] progressively increased 11-fold from 1.3 ± 0.5 mmol/l at rest to 15.4 ± 2.0 mmol/l after the last sprint (P < 0.001). Blood [La] was slightly higher in the boys than in the men after the first sprint (P < 0.05) but became significantly lower in the boys from the third sprint to the end of the test. After the 10th sprint, [La] was twofold lower in the boys than in the men (P < 0.001).

Blood [H⁺]

The time course of blood pH during the 10 sprint exercises in the boys and the men is shown in Fig. 3. In the boys, blood [H⁺] significantly increased 1.2-fold from 37.9 ± 2.2 mmol/l (pH 7.42 ± 0.02) at rest to 44.3 ± 2.6 mmol/l (pH 7.35 ± 0.02) after the sixth sprint (P < 0.01) and remained unchanged until the tenth sprint (43.8 ± 1.3 mmol/l, pH 7.36 ± 0.01). In the men, blood [H⁺] progressively increased 1.7-fold from 38.6 ± 1.8 mmol/l (pH 7.41 ± 0.02) at rest to 66.9 ± 9.9 mmol/l (pH 7.18 ± 0.06) after the 10th sprint (P < 0.001). Blood [H⁺] was significantly lower in the boys than in the men after the second sprint (P < 0.05) and was 1.5-fold lower in the boys after the tenth sprint (P < 0.001).

Relationships among [La], [H⁺], [HCO3⁻], [BE], and PaCO2

Significant exponential relationships were found between [La] and [H⁺] over the 10 sprints in the boys (r = 0.66, P < 0.001) and the men (r = 0.92, P < 0.001). ANCOVA indicated that, for the same [La], blood [H⁺] was lower in the boys than in the men (P < 0.001) (Fig. 4). Furthermore, significant linear regressions were observed between [La] and [HCO3⁻], both in the boys (r = −0.72; P < 0.001) and the men (r = −0.93; P < 0.001). The ordinate and slope of the linear regressions.
were not significantly different between the two groups [ANCOVA, not significant (NS)] (Fig. 5). Similarly, inverse significant linear regressions were obtained between [La] and [BE], both in the boys \((r = -0.70; P < 0.001)\) and the men \((r = -0.96; P < 0.001)\). The ordinate and slope of the linear regressions were not significantly different between the boys and the men (ANCOVA, NS) (Fig. 6). Significant linear regressions were also found between the decrease in \([\text{HCO}_3^-]\) and \(\text{PaCO}_2\), both in the boys \((r = 0.90, P < 0.001)\) and the men \((r = 0.84, P < 0.001)\). The slope of these relationships was significantly greater in the boys compared with the men (ANCOVA, \(P < 0.001\)). For the same \([\text{HCO}_3^-]\), \(\text{PaCO}_2\) was lower in the boys than in the men (Fig. 7). Finally, significant inverse linear relationships were found between \([\text{H}^+]\) and \(\text{PaCO}_2\) in the boys \((r = -0.36; P < 0.05)\) and the men \((r = -0.64; P < 0.001)\). The slope of these relationships was significantly greater in the boys compared with the men (ANCOVA, \(P < 0.001\)). The time course of the \(\dot{V}\text{E}/\dot{V}\text{CO}_2\) ratio (\(\dot{V}\text{E}/\dot{V}\text{CO}_2\)) of both the boys and the men during the 10 sprints is presented in Fig. 9. \(\dot{V}\text{E}/\dot{V}\text{CO}_2\) was higher in the boys during the first five rest intervals and was then higher in the men during the last five sprints.

DISCUSSION

The subjects performed the sprints against a friction load corresponding to 50% of their optimal force, which allowed them to reach their optimal velocity and to produce their \(\dot{W}_{\text{peak}}\) during the sprints (8). This friction load represented the same workload relative to the maximal abilities of the boys and the men. This brak-

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**Fig. 4.** Relationships between the blood hydrogen ions concentration (\([\text{H}^+]\)) and [La] values during the 10 sprint exercises in the boys and the men. Blood [\(\text{H}^+\)] and [La] values measured before and after warm-up were not presented in the relationships.

**Fig. 5.** Relationships between the blood [HCO\(_3^-\)] and [La] values during the 10 sprint exercises in the boys and the men. Blood [HCO\(_3^-\)] and [La] values measured before and after warm-up were not presented in the relationships.

**Fig. 6.** Relationships between [BE] and [La] values during the 10 sprint exercises in the boys and the men. Blood [BE] and [La] values measured before and after warm-up were not presented in the relationships.

**Fig. 7.** Relationships between PaCO\(_2\) and blood [HCO\(_3^-\)] values during the 10 sprint exercises in the boys and the men. PaCO\(_2\) and [HCO\(_3^-\)] values measured before and after warm-up were not presented in the relationships.
ing load was 40 and 50 g/kg BM in the boys and the men, respectively. Furthermore, this friction load allowed all of the subjects to maintain the ten 10-s cycling sprints separated by 30-s recovery intervals.

The stressful nature of the present protocol was indicated by the dramatic increase in blood [La], in both the boys and the men. After the 10th sprint, [La] increased >8 and 15 mmol/l in the boys and the men, respectively. In the boys, postexercise [La] was higher than the values reported by Macek et al. (19) after 10 consecutive 10-s cycling sprints separated by 25-s recovery intervals in 13-yr-old boys (5.3 mmol/l). In the men, the increase in [La] was also higher than that reported by Gaitanos et al. (13) after 10 10-s cycling sprints separated by 30-s recovery intervals (12.6 mmol/l). Methodological differences in blood collection, [La] determination, and training status of the subjects may explain the small differences observed with previous studies. In the present study, [La] accumulation was markedly lower in the boys than in the men (Fig. 2). This result is in accordance with previous findings (11, 16, 27), which showed that maximal blood [La] is positively related to age. The underlying mechanisms of this diminished lactate response in children has still to be elucidated, but the pediatric literature suggests a muscle metabolic profile better equipped for oxidative than glycolytic energy turnover (5, 10, 14). The higher [La] in the men were associated with a higher metabolic acidosis in the blood as indicated by their lower blood pH and their higher decrease in BE (i.e., a higher amount of acidic ions appearing in the blood). In the boys, blood pH only decreased by 0.06 units, whereas, in the men, the fall represented 0.23 units (Fig. 3). Furthermore, changes in BE (delta BE from the rest to the last sprint) represented 7.3 and 15.8 mmol/l in the boys and the men, respectively. These results concur with those of previous studies, which showed that, whether determined by blood pH (4, 6, 15–17, 20) or BE (4, 6, 12, 15, 20, 22, 23, 26), the maximal acidosis reached by children is lower than that reached by adults.

In the men, the relationship between blood [H+] and [La] was curvilinear, which is in agreement with previous studies (23, 26) (Fig. 4). According to Medbo and Sejersted (23), the most important explanation for this nonlinearity is that HCO3- neutralize more efficiently at high pH (i.e., 7.42) than at low pH (i.e., 7.07). This suggestion is supported by the rather linear relationship found in the present study in the boys, in whom blood [H+] was continuously low during the 10 repeated 10-s cycling sprints (Fig. 4). Furthermore, according to Medbo and Sejersted, it is conceivable that the ventilatory regulation is more efficient, in relative terms, when pH approaches resting levels. As reported by Osnes and Hermansen (26) in men, it may be suggested, from Fig. 4, that measurements of blood [La] alone allow only a rough estimation of blood pH. In contrast, in the boys, given its low range, blood pH might be more precisely assessed from blood [La].

The results of the present study highlight that, for a given [La], [H+] was significantly less during repeated sprint exercises in the boys than in the men (Fig. 4). Two assumptions may explain this relatively small increase in blood [H+] in the boys. First, because it has been shown that intense exercise and lactic acidosis induce a muscle H+ release independent of lactate release (22), the release of H+ from the men’s muscles should be higher compared with that from the boys’, whereas the release of lactate might be similar. Second, PaCO2 might be regulated at a lower level by VE in the boys compared with the men.

The first hypothesis is not relevant, because the results of the present study indicate that, for a given [La], the concentrations of BE and HCO3- are similar in the boys compared with the men (Figs. 5 and 6). Even if the production of H+ and lactate in children’s muscles is lower than in that of adults’ during intense exercise (10, 18, 34), it seems reasonable to assume that the amount of H+ in the muscle should be similar in children compared with adults for the same production of lactate. It was suggested that the intracellular buffering capacity represented by the total muscle pro-

Fig. 8. Relationships between PaCO2 and blood [H+] values during the 10 sprint exercises in the boys and the men. PaCO2 and [H+] values measured before and after warm-up were not presented in the relationships.

Fig. 9. Time course of ventilation (VE)-to-carbon dioxide output (VCO2) ratio (VE/VCO2) during the 10 sprint exercises separated by 30-s recovery intervals, in both the boys and the men.
tein mass (myofibrillar and sarcoplasmic) might be proportional to the production of lactate (30). Therefore, the amount of $H^+$ that entered the circulation from the muscle was similar between the two populations, and the blood buffering of $H^+$ (for the same blood $[La^+]$) was identical between the boys and the men.

On the other hand, the second hypothesis tries to explain the smaller drop in blood $pH$ in the boys because $P_{aco_2}$ was lower in the boys than in the men for a given $[HCO_3^-]$ (Fig. 7). In other words, according to the Henderson-Hasselbalch equation, the $[HCO_3^-]/[H^+]$ ratio was higher in the boys compared with the men. Similarly, for a given blood $[HCO_3^-]$, $P_{aco_2}$ was lower in the boys compared with the men (Fig. 8). A higher relative $Ve$ in the boys would explain their lower $P_{aco_2}$ during the first five rest intervals because the results of the present study show that $Ve/VCO_2$ was higher in the boys compared with the men. However, the men hyperventilated more during the last five sprints because their $Ve/VCO_2$ was higher than that of the boys (Fig. 9). In the men, the gradual increase in $Ve/VCO_2$ during the 10 sprints may be explained by the fact that $[La^+]$ progressively increased (Fig. 2). In the boys, $Ve/VCO_2$ and $[La^+]$ reached a steady state during the last five sprints. These results are in agreement with previous studies that showed that $Ve$ or effective alveolar $Ve$ to eliminate a given amount of $CO_2$ was greater in younger children than in older subjects from rest to supramaximal exercise (1) and during incremental exercise (7, 21, 24, 25, 28, 29). Little information is available to explain this higher relative $Ve$ in children. Nevertheless, it has been suggested that age-related differences in ventilatory responses to exercise may reflect variations in neural respiratory drive, lung mechanics, or both (see Ref. 29 for review).

In conclusion, the results of the present study show that, during repeated sprints, children regulate their blood $[H^+]$ better than adults do. This finding may be explained by the fact that they ventilate more than adults during the first rest intervals to exhale a given amount of carbon dioxide, which allows them to regulate their $P_{aco_2}$ to a lower level. In other words, the ventilatory regulation related to the change in acid-base balance induced by lactic acidosis is more important in boys compared with men during the first rest intervals.

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