

# Relationships between rating of perceived exertion, heart rate and blood lactate during continuous and alternated-intensity cycling exercises

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**ABSTRACT:** This study aimed to: i) use Borg's scale of rating perceived exertion (RPE) in the prescription of cycling training exercises with alternated intensity (S); ii) determine the relationships between RPE and the indices of physiological strains, e.g. heart rate (HR) and blood lactate ([La]), measured during S compared to continuous exercises (C). HR, [La] and RPE were measured in 11 active men at the 5<sup>th</sup> and 10<sup>th</sup> minutes of cycling exercises. These exercises were performed with constant or varying intensity corresponding to average power outputs (APO) equal to 160 and 240 W. The protocols with varying intensity consisted of alternated short periods (10 s: S10, or 20 s: S20) of medium and high intensity (120-200 W for APO-160 W and 200-280 W for APO-240 W). During S exercises HR, [La] and RPE were significantly higher compared to C exercises. This effect was more pronounced when the duration of alternated-intensity bouts was longer (S20 versus S10 protocols). The relationships between HR, [La] and RPE (mean or individual data) were not significantly different for the different protocols. However, there was a shift in the relationship between RPE and HR measured at the 5<sup>th</sup> and 10<sup>th</sup> minutes of exercise ( $p < 0.001$ ). Moreover, in each protocol, there were significant differences in the individual values of HR or [La] corresponding to the same RPE. The relationships between HR, [La] and RPE were not different between C and S exercises. Individually determined RPE can be used in the prescription of training for both exercises.

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## INTRODUCTION

The evaluation of the aerobic capacity is generally performed by means of continuous incremental tests (laboratory or field tests) in order to measure variables such as maximal oxygen uptake and lactate thresholds, or maximal aerobic power (or speed). The relationships between Borg's rating of perceived exertion (RPE) and physiological exercise parameters such as heart rate (HR) and blood lactate concentration ([La]) were studied in a very large population (2,560 men and women) during incremental exercise tests on a treadmill or cycle ergometer [1]. In that large-scale study, RPE was strongly correlated with HR and [La] ( $r > 0.74$ ;  $p < 0.001$ ). For a long time, before the use of HR monitors, the prescription of exercise intensity was often based on RPE during testing and training. Nowadays, it is possible to measure and record HR by means of reliable and inexpensive HR monitors. Similarly, it is now possible to measure

lactate in the field using devices similar to those used for the control of blood glucose by diabetic patients. Nonetheless, the measurement of perceived exertion is still interesting because the RPE scale also predicts oxygen uptake ( $VO_2$ ) [2] and peak oxygen uptake ( $VO_{2peak}$ ) [3] or measures the psychological strain experienced during exercise, and it is likely that RPE is included by the adherence to an exercise programme [3–6]. In addition, RPE can be a tool to monitor intensity if a patient is on medication that alters the normal HR response to physical stress [7].

Intermittent or alternated-intensity exercises are often included in the sports training programme of athletes and sedentary subjects [8]. Similarly, exercise intensity varies during outdoor cycling [9]. These exercises can be characterized according to their average power output (APO), the ratio between exercise (E), recovery (R) phase

durations (E/R) and the amplitude (i.e., the difference between exercise and recovery intensities), expressed as a percentage of APO [10]. Field tests, which more closely replicate the characteristics of sport activities, have been proposed to assess the fitness of athletes and sedentary subjects. In these tests, alternated-intensity exercises consist of repeated periods of high and low intensity [11–15].

RPE is also used in the prescription of intermittent exercises [16]; e.g. RPE has been studied in self-pacing interval training with long phases (1–6 min) of exercise and recovery [17–21].

Similarly, the quantification of training loads using RPE has been proposed for basketball [22] and soccer [21,23–27]. Furthermore, the first study comparing RPE during continuous and intermittent exercises in a pathological population was proposed by Coquart *et al.* [28]. More recently, RPE has also been used by coronary heart disease (CHD) patients in two studies [29,30] comparing continuous exercise at 70% of the peak power output (PPO) in an incremental test and protocols of high-intensity interval exercise (HIIE) consisting of the repetition of phases (15 or 60 s) of exercise at 100% PPO interspersed by phases of passive or active recovery (50% PPO). In both studies, the CHD patients rated the HIIE with passive recovery and short intervals as their preferred ones mainly because RPE measured by the Borg scale was lower.

The use of RPE in the prescription of alternated-intensity training exercises implicitly assumes that there are the same relationships between RPE and the indices of physiological strains (HR,  $\text{VO}_2$  and [La]) usually measured during continuous tests in a laboratory. A study was focused on the relationships between perceived exertion (6–20 Borg scale) and physiological variables during continuous and intermittent exercises [31].  $\text{VO}_2$ , ventilation, [La] and RPE were compared for cycling exercises: 4 continuous and 4 intermittent protocols corresponding to the same work output (about 59 kJ). This study showed that RPE,  $\text{VO}_2$ , ventilation, and [La] were significantly higher for intermittent exercises when compared to continuous exercises corresponding to the same average power output. Nonetheless, the relationships between RPE and HR or  $\text{VO}_2$  or [La] seemed to follow the same trends for continuous and intermittent exercises. However, the number of subjects in that study was very small (3 male subjects), which limited the statistical evaluation of this interesting pilot study.

In the present investigation, we studied the relationship between RPE, HR and [La] during constant and alternated-intensity exercises with short bouts (10 and 20 s) to verify whether the RPE collected during continuous tests could be used in the prescription of alternated-intensity training exercises with short phases.

## MATERIALS AND METHODS

### *Participants*

Eleven physical education students ( $23.90 \pm 1.9$  years;  $76.0 \pm 8.3$  kg;  $1.79 \pm 0.05$  m) participated in the present study. Most of them practised team sports and none of them were specialized in endurance training.

Each participant received thorough explanations about the protocol and gave written informed consent prior to any data collection. Before beginning the study, the participants were familiarized with constant and alternated-intensity exercises by performing short bouts of each protocol. The experimental protocol was approved by the Institutional Review Board of Nanterre University, and carried out according to the guidelines of the Declaration of Helsinki.

### *Material*

All the cycling exercises were performed on the same friction loaded ergometer (Monark 894E, Varberg, Sweden). RPE was determined using a French translated [32] Borg 6–20 point-category scale [34,35]. HR was recorded with a Sport-Tester (Polar RS400, Polar Electro Oy, Kempele, Finland). [La] was measured by a portable blood lactate analyser (Lactate Pro, Arkray, Tokyo, Japan). The lactate analyser was calibrated before each testing session and was used according to the manufacturer's guidelines. This [La] analyser has been reported to be reliable and valid [33].

### *Protocol*

In the first session, the participants performed an incremental cycling test until exhaustion at a constant pedal rate (80 rpm) to determine the peak aerobic power (PAP). This test began with 80 W. The power output was increased by 20 W every minute. The power output corresponding to the last step of this incremental test was considered as PAP. Two days after, the participants performed cycling exercises for 10 min at 160 (2kg\*80 rpm) or 240 W (3kg\*80 rpm). These 10 min exercise bouts were both performed at C or S intensities. Alternated intensities were set by adding or subtracting a 1 kg load: 120–200 W (1.5 kg \* 80 rpm and 2.5 kg \* 80 rpm) for 160 W or 200–280 W (2.5kg\*80 rpm and 3.5 kg\*80 rpm) for 240 W. For each alternated-intensity exercise (Figure 1), the intensity changed either every 10 s (S10 protocol) or every 20 s (S20 protocol). In summary, the subjects performed six tests in three sessions (two tests per day with one-hour rest between tests) in counter-balanced order for C, 10-s and 20-s protocols. The subjects began with 160 W intensity. In all sessions, the intervals between testing sessions were at least equal to 48 hours. Each test started with a warm-up cycling exercise of 5 minutes at 120 W followed by a passive recovery until HR decreased to <110 bpm.

It has been shown that HR was almost constant throughout the last minutes of intermittent exercises for protocols with short exercise and pause periods of equal durations (from 5 to 15 s) [10]. Moreover, the variations in HR were smaller than the variations in  $\text{VO}_2$  in these types of protocols [10]. Therefore, the only values of HR collected at the end of the 5<sup>th</sup> and 10<sup>th</sup> minutes are presented in the results section. RPE was estimated using the Borg 6–20 scale [34,35] at the 5th and 10th minutes of each exercise bout. Capillary blood samples ( $5 \mu\text{l}$ ) were collected from the fingertip for lactate concentration ( $\text{mmol} \cdot \text{l}^{-1}$ ) at rest, at the 5th and 10th minutes of each exercise protocol.

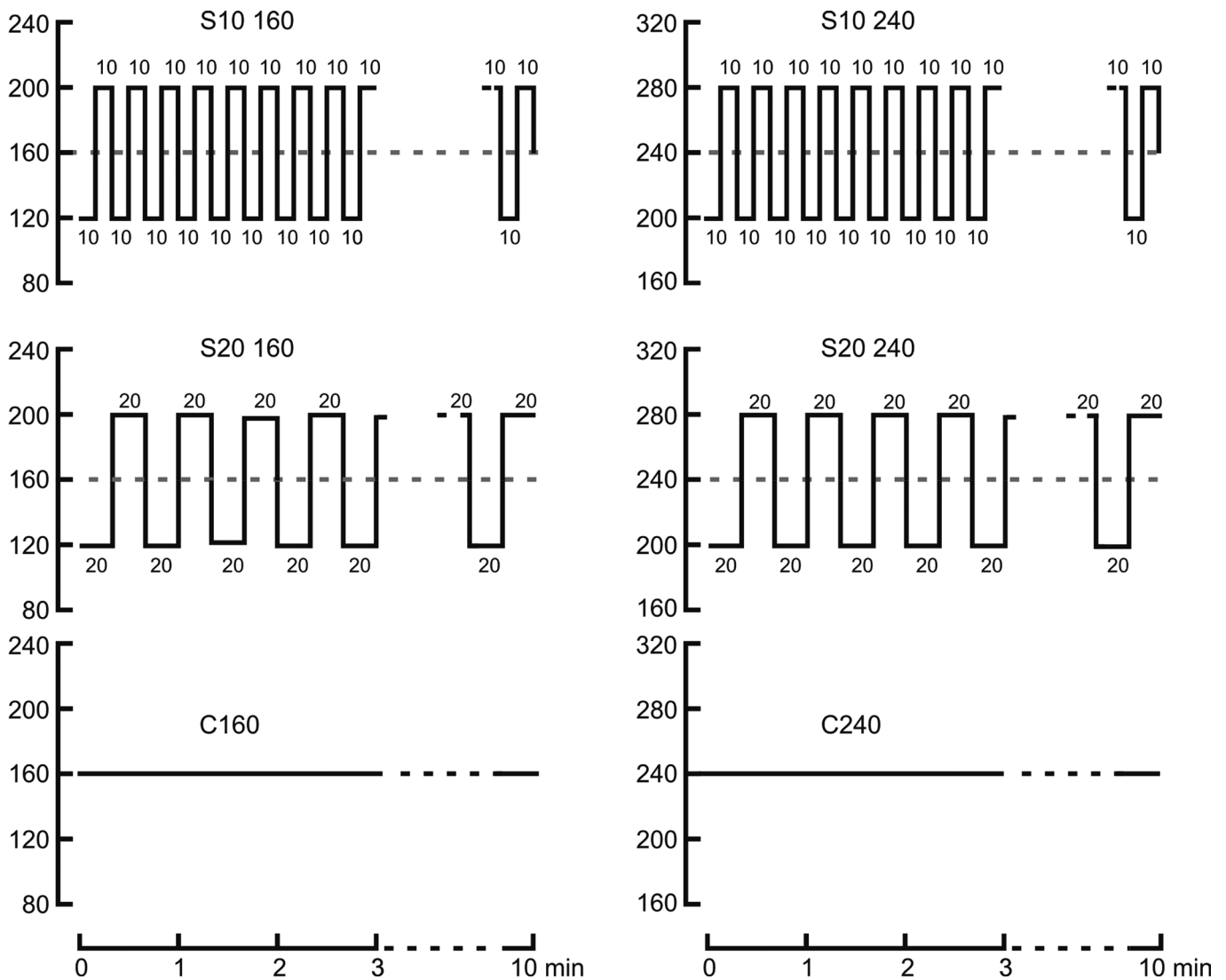


FIG. 1. Experimental protocol of constant (down), alternated-intensity S20 (middle) S10 (up) exercises at 160 W (left) and 240 W (right).

*Statistical analysis*

The normality of data was examined with the Shapiro-Wilk test. All data were presented as mean ± standard deviation (SD). Linear regression was used to determine the slope, intercept of the power, and the time model. Statistical comparisons over time were made using a one-way repeated measures analysis of variance (ANOVA). Post-hoc analyses were conducted using the Bonferroni test.

The effects of time (5 or 10<sup>th</sup> min) or APO (160 or 240 W) or protocol (C or S10+S20 for continuous and alternated-intensity) on the relationships between HR, [La] and RPE were also studied by multiple regressions including one or several dummy variables (D) equal to 0 (5<sup>th</sup> min or 160 W or C) or 1 (10<sup>th</sup> min or 240 W or S):

$$Y = aX + b + cD + dF$$

where F corresponded to the interaction between X and D (F = D\*X). When D was significant but not F, the relationships between X and Y were:

$$Y = aX + (b + c) \quad \text{for } D = 1$$

$$Y = aX + b \quad \text{for } D = 0$$

When both D and F were significant, the relationship between X and Y were:

$$Y = (a + d)X + (b + c) \quad \text{for } D = 1$$

$$Y = aX + b \quad \text{for } D = 0$$

Statistical significance was fixed at p<0.05.

**RESULTS**

*Effect of protocols on heart rate, lactate and perceived exertion*

PAP of the participants was 313.0 ± 11.0 W (range: 300 W - 330 W). The values of HR, [La] and RPE are presented in Table 1.

For the 5<sup>th</sup> minute at 160 W, the effects of protocols were significant for HR (F<sub>2,20</sub> = 18.06; p< 0.001), [La] (F<sub>2,20</sub>=7.79;

**TABLE 1:** Values (mean  $\pm$  SD) of HR, [La] and RPE at 160 W and 240 W for the three protocols (C, S10, S20).

	C	S10	S20	P (C vs S10)	P (S10 vs S20)	P (C vs S20)
<b>160 W</b>						
HR 5	142 $\pm$ 17	148 $\pm$ 16	154 $\pm$ 14	0.03	0.01	< 0.001
[La] 5	4.6 $\pm$ 1.4	5.2 $\pm$ 1.7	6.5 $\pm$ 2.8	0.67	0.05	0.003
RPE 5	11.5 $\pm$ 1.5	12.0 $\pm$ 1.3	12.7 $\pm$ 1.6	0.049	NS	0.009
HR 10	145 $\pm$ 18	152 $\pm$ 16	160 $\pm$ 15	< 0.001	< 0.001	< 0.001
[La] 10	5.8 $\pm$ 1.8	6.7 $\pm$ 1.4	7.9 $\pm$ 2.2	0.09	0.01	< 0.001
RPE 10	12.2 $\pm$ 1.3	13.4 $\pm$ 0.9	14.0 $\pm$ 1.4	0.03	NS	< 0.001
<b>240 W</b>						
HR 5	170 $\pm$ 12	170 $\pm$ 12	174 $\pm$ 14	NS	< 0.001	< 0.001
[La] 5	7.4 $\pm$ 3.0	8.6 $\pm$ 1.9	10.1 $\pm$ 2.8	NS	NS	0.003
RPE 5	14.7 $\pm$ 1.5	14.5 $\pm$ 1.6	14.8 $\pm$ 1.8	NS	NS	0.05
HR 10	177 $\pm$ 12	179 $\pm$ 12	183 $\pm$ 13	0.01	< 0.001	< 0.001
[La] 10	11.8 $\pm$ 1.7	13.5 $\pm$ 1.4	14.6 $\pm$ 1.8	0.002	0.04	< 0.001
RPE 10	16.5 $\pm$ 2.5	16.7 $\pm$ 2.3	17.6 $\pm$ 1.9	NS	0.007	< 0.001

Note: The significance levels for the differences between the protocols correspond to the results of the post-hoc tests of the two way ANOVA's (Time x Protocol) for 160 and 240 W. NS when  $P > 0.05$ .

$p=0.003$ ) and RPE ( $F_{2,20}=5.71$ ;  $p=0.02$ ). The same results were observed at the 10th minute of these exercises for HR ( $F_{2,20}=18.06$ ;  $p<0.001$ ), [La] ( $F_{2,20} = 14.32$ ;  $p<0.001$ ) and RPE ( $F_{2,20}=9.7$ ;  $p<0.001$ ).

The same results were observed at 240 W for HR ( $F_{2,20}=13.32$ ;  $p<0.001$  and  $F_{2,20}= 36.16$  at 5 and 10 min;  $p<0.001$ ) and [La] ( $F_{2,20}=7.29$ ;  $p=0.004$  at 5 min and  $F_{2,20}=22.65$ ;  $p<0.001$  at 10 min). However, the effect of protocols on RPE at 240 W was significant only at 10 min ( $F_{2,20}=11.12$ ;  $p<0.001$ ).

The results of the Bonferroni post-hoc tests were presented in Table 1. The values of HR, [La] and RPE were significantly higher in S20 at the 5th and 10th minutes.

#### *Relationships between RPE and HR*

The relationships between RPE and HR could be described by the same linear regression including all the exercises (160 and 240 W; 5<sup>th</sup> and 10<sup>th</sup> minutes):

$$\text{RPE} = - 0.998 + 0.0935 \text{ HR} \quad r=0.729; n = 132; p<0.001$$

Although one or several dummy variables corresponding to APO ( $D_1$ ), time ( $D_2$ ) and protocol ( $D_3$ ) were included in multiple regressions, the effects of  $D_1$  and  $D_2$  on RPE were always highly significant ( $p<0.001$ ). In contrast, the effects of  $D_3$  on the relationships between RPE and HR were not significant.

For the data collected at the 5<sup>th</sup> and 10<sup>th</sup> minutes, the relationships between individual values of RPE and HR were almost paral-

lel and significantly different. Indeed, the multiple regression including a single dummy variable ( $D_2$ ) corresponding to time was:

$$\text{RPE} = - 0.81 + 0.089 \text{ HR} + 1.13 D_2 \\ R = 0.763; n = 132; p<0.001 \text{ for HR and } D_2$$

This effect of time on the RPE-HR relationship was confirmed by the relationships between the mean values of HR and RPE measured at the 5th and 10th minutes (Figure 2 B):

$$\text{RPE} = - 6.84 + 0.127 \text{ HR} + 0.89 D_2 \\ R = 0.995; n = 12; p<0.001 \text{ for HR and } D_2$$

When computed separately, the linear RPE-HR regressions corresponding to the mean values at the 5<sup>th</sup> and 10<sup>th</sup> minutes were:

$$\text{RPE}_{5\text{min}} = - 4.85 + 0.114 \text{ HR}_{5\text{min}} \quad r = 0.996; n = 6; p<0.001 \\ \text{RPE}_{10\text{min}} = - 7.33 + 0.135 \text{ HR}_{10\text{min}} \quad r = 0.997; n = 6; p<0.001$$

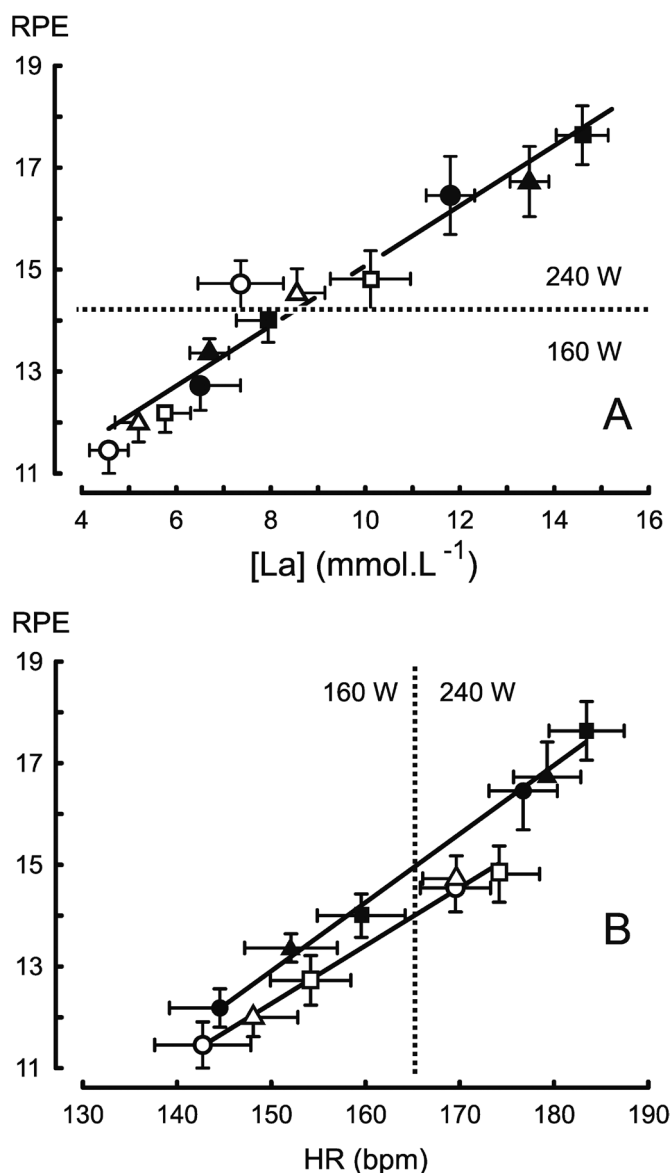
#### *Relationships between RPE and [La]*

The relationship between the individual values of RPE and [La] for all the exercises is presented below.

$$\text{RPE} = 10.2 + 0.469 [\text{La}] \quad r = 0.697; n = 132; p<0.001$$

The regression between the mean values of RPE and [La] (Figure 2A) was as follows:

$$\text{RPE} = 9.18 + 0.59 [\text{La}] \quad r = 0.971; n = 12; p<0.001$$



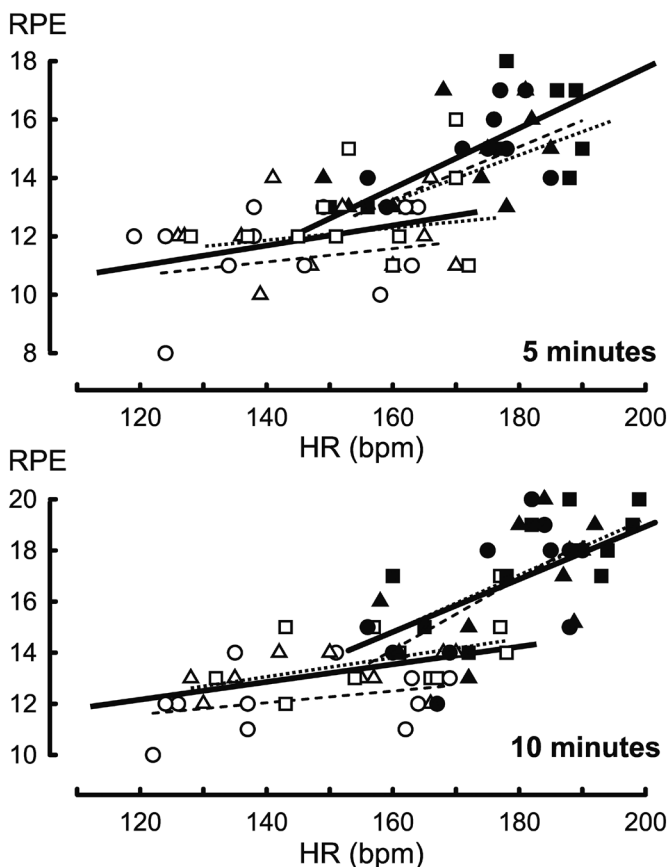
**FIG. 2.** Relationships between the average values (SE) of blood lactate [La] and HR, collected at the 5<sup>th</sup> (empty symbols) and 10<sup>th</sup> (black symbols) minutes of cycling exercises corresponding to continuous (circles), S1 (triangles) and S2 (squares) protocols for cycling exercises at 160 and 240 W.

The relationships between the individual values of RPE and [La] at the 5<sup>th</sup> and 10<sup>th</sup> minutes were:

$$\begin{aligned} \text{RPE}_{5\text{min}} &= 11.172 + 0.313 [\text{La}] & r &= 0.455, n = 66; p < 0.001 \\ \text{RPE}_{10\text{min}} &= 9.689 + 0.535 [\text{La}] & r &= 0.769, n = 66; p < 0.001 \end{aligned}$$

## DISCUSSION

Compared to the data for continuous exercises, the values of HR at 160 and 240 W were significantly higher during alternated-intensity exercises (S10 and S20). In agreement with the results of Edwards et al. [31], lower mechanical efficiency in alternated-intensity exercise could explain this higher HR in protocols S10 and S20. Furthermore,



**FIG. 3.** Relationships between the individual values of heart rate (HR) and rate of perceived exertion (RPE) measured at the 5<sup>th</sup> (top) and 10<sup>th</sup> (bottom) minutes of cycling exercises corresponding to continuous (circles), S1 (triangles) and S2 (squares) protocols at 160 W (empty symbols) and 240 W (black symbols). The thick continuous lines correspond to the multiple regressions including the APO (D<sub>1</sub>) and time (D<sub>2</sub>) dummy variables. Dashed lines: regression between RPE and HR for continuous protocols at 160 or 240 W. Dotted lines: regression between RPE and HR for alternated-intensity protocols (S1+S2) at 160 or 240 W.

lower mechanical efficiency for intermittent and alternated-intensity protocols was, in fact, observed by Guiraud et al. [30] (see appendix B).

The possibility of lower mechanical efficiency in alternated-intensity or intermittent exercises was questioned in the review by Saltin et al. [10]. Indeed, according to Pedersen's unpublished data presented in Figure 2 of the paper by Saltin et al. [10], the VO<sub>2</sub> during alternated-intensity exercises with the same APO as during continuous cycling exercises was slightly higher at 180 W, only. Similarly, the mechanical efficiency of intermittent work was within the same range and only slightly lower than that found in continuous work in

the early studies by Chrestensen *et al.* [36] and Astrand *et al.* [37]. For example, the  $\text{VO}_2$  uptakes corresponding to the same APO (180 W) were equal to  $2.44 \text{ L} \cdot \text{min}^{-1}$  for continuous exercise and  $2.60 \text{ L} \cdot \text{min}^{-1}$  for 30 s-30 s intermittent exercise [37], that is, 6% lower mechanical efficiency, only. The reduction of mechanical efficiency during alternated-intensity or intermittent exercises could be partly explained by the recruitment of the fast muscle fibres that increases at high percentages of PPO. Indeed, the maximum mechanical efficiency is lower when measured in the isolated fibres of fast muscles. For example, the maximum mechanical efficiency was 0.333 for the fast muscles (extensor digitorum longus, EDL) and 0.425 for the slow muscles (soleus) in the mouse [38]. The subjects of the early studies by Christensen *et al.* [23] and Astrand *et al.* [37] were endurance athletes. The participants of the present study were not specialized in endurance exercises but practised team sports, and their proportions of fast muscle fibres were probably higher. Therefore, a greater effect of the alternated protocol on  $\text{VO}_2$ , HR and RPE would be expected if efficiency depends on muscle fibre proportion. However, the effect of muscle-fibre type on mechanical efficiency during cycling exercises is debatable [39–46].

In the present study, all the relationships between RPE and HR were stronger than the relationships between RPE and [La] in contrast with the results of a large-scale study on incremental exercise tests [1] ( $r = 0.83$  for [La] and  $r = 0.74$  for HR). For the short lasting exercises (10 min) in the present study, the effect of time on the HR-RPE relationship corresponded to higher values of RPE for a given HR: the difference in RPE was 1.13 according to the multiple regressions with the dummy variable  $D_2$ . Similarly, according to the RPE-HR relationships corresponding to the mean values (Figure 2 B), the difference in RPE at the 10<sup>th</sup> minute was 0.57 and 1.09 for 145 and 170 bpm, respectively. It would be interesting to study the effect of time on the RPE-HR relationships beyond 10 min in continuous and alternated-intensity protocols. In long-lasting continuous cycling exercises up to exhaustion [47], there were drifts in HR and RPE. The slopes of the RPE-time or HR-time relationships from the beginning to exhaustion depended on the exercise intensity. Unfortunately, the effect of time on the relationship between HR and RPE for the different exercise protocols was not studied in this previous paper. In contrast with the RPE-HR relationship, the same regression could describe the relationship between the mean values of RPE and [La] at the 5<sup>th</sup> and 10<sup>th</sup> minute (Figure 2A). However, there was a significant effect of time for the multiple regressions corresponding to the individual values of RPE, [La] and dummy variables  $D_1$  and  $D_2$ . Moreover, the relation between individual values of RPE and [La] was weak. At the 10<sup>th</sup> minute, RPE differences higher than 5 were observed for the same value of [La]. Similarly, differences of around 5 in the Borg CR 10 scale were observed for the same blood lactate in the study by Dantas *et al.* [48] It is likely that muscle lactate concentration is one of the main factors determining RPE, but the value of [La] also depends on capillarity and monocarboxylic acid transporters in muscle. Löllgen *et al.* [49] reported

that subjects with similar [La] could have a large difference in muscle lactate levels, which could explain the large differences in RPE for the same values of [La] for the same protocols and APOs at the 5<sup>th</sup> and 10<sup>th</sup> minutes. The relationship between RPE and [La] is probably not stronger for exercise protocols longer than 10 min. Indeed, an uncoupling of RPE and blood [La] is generally observed during long lasting exercises because [La] often decreases beyond the 30<sup>th</sup> minute whereas HR and RPE continue to increase.

In agreement with the study by Edwards *et al.* [31], the relationships between RPE and [La] (Figure 2A) or HR (Figure 2B and Figure 3) were not statistically different for continuous and alternated-intensity protocols. These results suggested that RPE can be used in the prescription of training for both continuous and alternated-intensity exercises.

## CONCLUSIONS

The values of HR, [La] and RPE measured during alternated-intensity exercises were higher than those measured during constant-intensity exercise with the same APO. This effect was more pronounced when the duration of exercise periods of alternated-intensity protocols was longer (S20 versus S10). However, the relationships between HR, [La] and RPE were not significantly different between continuous and alternated-intensity protocols. Individually determined RPE can be used in the prescription of training for both continuous and alternated-intensity exercises.

## APPENDIX A

Interesting unpublished data of a study by Pedersen on the alternated-intensity exercises were presented in a review by Saltin *et al.* [10] on the intermittent exercise. In Pedersen's study, continuous exercises were compared with alternated exercises with the same APO (60, 120, 150 and 180 W) and different amplitudes. Unfortunately, the protocols were not detailed and the results were presented in several figures, only. The value of the ratio E/R was 1 in all the alternated-intensity protocols and the durations of E were 15 or 120 s. According to Figure 13 [10], the total duration of the different protocols was 12 min. The values of RPE at the end of the different protocols are presented in the same figure for all the continuous and alternated-intensity exercises with medium or 'large' amplitudes. 'Large' amplitude probably corresponded to 75% APO (Figure 13 [10]). Medium amplitude was not specified but probably corresponded to 50% APO ( $\pm 25\%$  APO).

In spite of the lack of details about the protocols, these data are interesting because this study is probably the only one that has compared the effects of the amplitude and duration of E and P on RPE during continuous and alternated-intensity exercises. The main results of the paper by Saltin *et al.* [10] were as follows:

1. The perceived exertion in alternated-intensity exercise scores higher on the Borg scale than continuous exercise at the same APO;

- For APO between 60 and 180 W, the difference in the RPE between continuous exercise and various combinations of intermittent exercise can be from 1-2 (low APO) up to 4-5 points (high APO);
- The amplitude is one factor of the difference: the larger the amplitude, the more marked is the difference in RPE;
- The duration of E also plays a role, the longest E resulting in the highest RPE;
- for the short-period intermittent exercise the RPE, HR and RPE-VO<sub>2</sub> relationships are virtually the same as in continuous exercise;
- The same holds for the long-period alternated-intensity exercises with an amplitude of  $\pm 25\%$  APO;
- On the other hand, in the long-period intermittent work with larger amplitudes, a certain average HR or VO<sub>2</sub> was accompanied by higher RPE scores.
- In long-period intermittent exercise with rather wide amplitude, [La] concentrations were markedly elevated, suggesting that this could be an additive factor explaining the higher RPE scores.

The values of RPE corresponding to 160 W at the end of continuous and 15 s-15 s alternated-intensity exercises with medium and large amplitudes can be estimated by interpolation of the data corresponding to 150 and 180 W in Pedersen's study (Figure 12 in the paper by Saltin et al. [10]). The estimated values of RPE at 160 W in Pedersen' studies were 12.75, 13.4 and 14 for continuous exercise, 15 s-15 s with low amplitude and 15 s-15 s with large amplitude, respectively. In the present study, the values of RPE were 12.2 for continuous protocol and 13.7 for S15 (average of S10 and S20).

### APPENDIX B

In the first study, Guiraud et al. [29] compared intermittent and alternated-intensity protocols. In the intermittent protocols, power output was equal to 100 and 0% PPO during the exercise and recovery phases, respectively. In alternated-intensity protocols, power output was equal to 100 and 50% PPO during the exercise and recovery phases, respectively. Each participant performed 2 intermit-

tent exercises: one with exercise and recovery phases lasting 15 s (protocol A) and the other one with phases lasting 120 s (protocol C). They also performed alternated-intensity exercises with phases lasting 15 s (protocol B) and 120 s (protocol D). The total duration of all the protocols was 10 min. The values of RPE were lower at the end of short lasting phase protocols for intermittent (15 versus 17 for protocols A and C) as well as alternated-intensity exercises (17 versus 18 for protocol C and D). The difference in RPE between protocols A and B was probably the result of a lower APO in intermittent protocols. Indeed, APO was equal to 50% PPO for intermittent protocols and 67% for alternated-intensity protocols.

A lower mechanical efficiency for intermittent and alternated protocols was observed in the next study by Guiraud et al. [30]. In a pilot study, 18 CHD patients performed two exercises of 10 min composed of repeated phases of 15 s at 100% of peak power output (PPO) interspersed by 15 s of either active (50% of PPO, alternated-intensity protocol) or passive recovery (0% of PPO, intermittent protocol). They observed that mean VO<sub>2</sub> during passive recovery represented 77  $\pm$  8% of mean VO<sub>2</sub> during active recovery. In the study following this pilot study, VO<sub>2</sub> (1773  $\pm$  589 L  $\cdot$  min<sup>-1</sup>) during continuous exercise at 70% PPO in CHD patients was 10% higher than VO<sub>2</sub> (1604  $\pm$  468 L  $\cdot$  min<sup>-1</sup>) measured during an intermittent protocol (15 s at 100% PPO and 15 s passive recovery). However, the APO of the intermittent protocol was equal to 50% PPO (100/2) and, consequently, the APO of the continuous protocol was 40% higher (70/50). Therefore, the mechanical efficiency (APO/VO<sub>2</sub>) of the intermittent protocol was, in fact, 21% lower than that of the continuous protocol.

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