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Effects of the pedaling cadence on metabolic and cardiovascular responses during incremental and constant workload exercises in active individuals*

Benedito Sérgio Denadai, Vinícius Daniel de Araújo Ruas and Tiago Rezende Figueira

ABSTRACT

The main purpose of this study was to analyze the effect of the pedaling cadence (50 x 100 rpm) on the heart rate (HR) and the blood lactate response during incremental and constant workload exercises in active individuals. Nine active male individuals (20.9 ± 2.9 years old; 73.9 ± 6.5 kg; 1.79 ± 0.9 m) were submitted to two incremental tests, and to 6-8 constant workload tests to determine the intensity corresponding to the maximal steady state lactate ($MLSS_{intens}$) in both cadences. The maximal power (Pmax) attained during the incremental test, and the $MLSS_{intens}$ were significantly lower at 100 rpm (240.9 ± 12.6 W; 148.1 ± 154.W) compared to 50 rpm (263.9 ± 18.6 W; 186.1 ± 21.2 W), respectively. The HRmax did not change between cadences (50 rpm = 191.1 ± 8.8 bpm; 100 rpm = 192.6 ± 9.9 bpm). Regardless the cadence, the HRmax percentage (70, 80, 90, and 100%) determined the same lactate concentrations during the incremental test. However, when the intensity was expressed in Pmax percentage or in absolute power, the lactate and the HR values were always higher at highest cadences. The HR corresponding to $MLSS_{intens}$ was similar between cadences (50 rpm = 162.5 ± 9.1 bpm; 100 rpm = 160.4 ± 9.2 bpm). Based on these results, it can be conclude that regardless the cadence employed (50 x 100 rpm), the use of the HR to individualize the exercise intensity indicates similar blood lactate responses, and this relationship is also kept in the exercise of constant intensity performed at $MLSS_{intens}$. On the other hand, the use of the Pmax percentages depend on the cadence used, indicating different physiological responses to a same percentage.

Keywords: Heart rate. Lactate. Exercise intensity. Cadence. Cycling.

INTRODUCTION

The pedaling cadence is a variable in the cycling's motor pattern that has been known as influencing the performance and several physiological exercise responses to a given power output(1,2). A physiological variable that has been widely analyzed in function of the cadence is the efficiency (energetic cost for a given sub-maximal power output). Studies have verified that for a same cadence variation, it can be found an improvement in the delta efficiency (determined by the quotient between the energetic expenditure variation, and the variation of the power generated), thus worsen the gross efficiency (total energetic cost at a given power output)(3). The preferred cadence chosen by cyclists (80 to 100 rpm) generally is closest to the major neuromuscular efficiency (lower force application on the pedal, and to the lower electromyography fatigue)(4) and higher delta efficiency(5). However it surely is not the cadence of higher gross efficiency or the one indicating a lower energy expenditure if it would be kept without external resistance(6), and maybe non-trained individual will choose lower cadences with lower aerobic demand for a given power output(2). Other physiological responses, such as pulmonary ventilation, respiratory quotient, production of carbonic gas, muscular fiber recruitment, and blood lactate concentration ($[Lac]_{sang}$) seem to depend also on the pedaling cadence and the intensity chosen, in order to analyze such influence(3,7). So, the cadence to be evaluated, training or competition, has potential interference on physiological responses obtained, and on the performance itself.

Especially, the response to the blood lactate to the exercise has been quite used to prescribe the exercise intensity(8) and to establish the domain limits of the exercise's intensity (moderate, heavy, and severe)(9). Exercises with constant workload performed at intensities within a same domain present similar physiological response, such as stability of the $[Lac]_{sang}$, and the pH, whether it develops or not of the slow component of oxygen consumption, the attainment of the maximal oxygen consumption ($\dot{V}O_{2max}$) still in sub-maximal intensities, among others(9-11).

Unlike other approaches used to relativize the intensity of the exercise, the lactate response has shown to be valid to indicate the exercise intensities that is similar both to active and trained individuals(12). But those indexes based on the lactate response, such as the anaerobic threshold (AT), when is expressed in absolute values (Watts) are clearly influenced by the pedal cadence(13). Alternative to the blood lactate measurement is the prescription or characterization of the exercise intensity related to the $\dot{V}O_{2max}$ percentage, the maximal heart rate (HRmax), and the maximal power output attained in an incremental test (Pmax). The potential effects of the cadence on the use of such indexes in the prescription and characterization of the exercise intensity is not still entirely understood, mainly on individuals with no cycling training.

Particularly, in the cycling practice in fitness centers, a strategy quite used to alter the exercise intensity is to change the pedaling cadence. As generally the equipment used does not have workload or power output indicator, the most frequent tool used to describe and control the exercise intensity is the HR. However, it is quite known the possible influences that the pedaling cadence may present on the HR and lactate response, particularly during the constant workload exercise. This information is potentially important when choosing the experimental protocol to evaluate the aerobic fitness, and mainly to use the HR to control the exercise intensity which is the most important component of the training overload, and consequently the adaptations that may be determined by the aerobic exercise. Thus, the purpose of this study was to analyze the effect of the pedaling cadence on the HR and blood lactate response during the incremental exercise and constant workload in individuals with no training in cycling.

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* Laboratory of Human Performance Evaluation – Unesp, Rio Claro – SP, Brazil.

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Correspondence to: B.S. Denadai, Laboratory of Human Performance Evaluation, IB – Unesp, Av. 24A, 1.515, Bela Vista – 13506-900 – Rio Claro, SP, Brazil. E-mail: bdenadai@rc.unesp.br

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MATERIALS AND METHODS

Individuals

Participated in this study nine active male individuals (20.9 ± 2.9 years; 73.9 ± 6.5 kg; 1.79 ± 0.9 m), with no previous experience in aerobic training in cycling. Each volunteer was informed on the procedures of the trial and its implications, and signed a consent term to participate in the study. The protocol was approved by the institution's Committee of Ethics in Research where the trial was accomplished (Protocol 2427).

Experimental procedures

Each volunteer initially performed randomly two incremental tests (50 and 100 rpm) in a mechanic braked-bicycle (*Monark*) where it was determined the AT and the Pmax. Next, it was performed also randomly two to four constant workload tests in each of the cadences (50 and 100 rpm) to determine the intensity corresponding to the maximal lactate steady state. The time interval between tests was at least 48 hours, with the whole protocol lasting 15-20 days. Individuals where guided to come to the test relaxed, fed and hydrated, and not to perform any previous intense exercise for the last 48 hours. Related to each individual, tests were accomplished at the same site and time of the day (± two hours).

Incremental test

Individuals were submitted to two incremental tests with initial workload of 83 W and increments of 33 W each three minutes, until volitional exhaustion. The HR was recorded at the end of each workload, and the blood sampling was collected at the last 20 seconds of each stage. The Pmax was defined as the higher intensity obtained in the incremental test, and which would be kept for at least one minute(14). The AT was determined through linear interpolation, using the fixed concentration of 3.5 mM of blood lactate(12).

Constant workload tests

First, all individuals were submitted to the AT intensity for 30 minutes or until volitional exhaustion. Whenever individuals reached the exhaustion before 30 minutes or presented a higher increase than one mM in the $[Lac]_{sang}$ between the 10th and the 30th minute, a new test was performed at the AT intensity – 16.5 W. If the blood lactate steady state still would not be found, the test was repeated once more at the AT intensity – 33 W. If during the AT intensity the individual presented a steady state of blood lactate, the test was repeated at the AT intensity + 16.5 W, and if there would be another steady state, the test was repeated at the AT intensity + 33W. It was collected in these tests the HR, and it was taken blood samples of the ear's lobe every fiftieth minutes, to perform the blood lactate analysis. The $MLSS_{intens}$ was defined as the higher workload at which the $[Lac]_{blood}$ did not increase more than one mM between the 10th and the 30th minute of the constant workload test(15). All these tests were accomplished at the cadence of 50 and 100 rpm.

Measurement of the blood lactate and heart rate

It was taken 25 ml of arterial blood of the ear's lobe without hyperemia to determine the blood lactate. The blood was immediately transferred to 1.5ml polyethylene micro tubes with cover (type Eppendorff), having 50 ml of 1% NaF, which was kept in ice. The measurement of the lactate concentration was performed through an electrochemical analyzer (YSL 2300 STAT). The HR was monitored through a frequency-meter (*Polar Vantage NV*).

Comparisons of the HR and $[Lac]_{blood}$ values during the incremental exercise performed at two cadences

The effect of cadences on the HR during the incremental exercise was analyzed expressing the values obtained from such variable related to the absolute power output, and the Pmax percentage. Likewise, the blood lactate concentration was analyzed related to the absolute power output, the Pmax percentage and the HRmax percentage.

Statistical analysis

Data was expressed as mean ± DP. Data was analyzed by the *t* Student test for repeated data. It was adopted a significance level of $p \leq 0.05$ in every test.

RESULTS

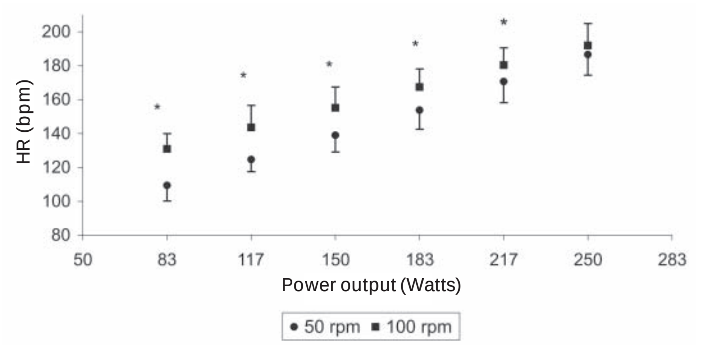
The Pmax, HRmax, $MLSS_{intens}$, and the percentage of $MLSS_{intens}$ related to the Pmax (%$MLSS_{intens}$), HR in the $MLSS_{intens}$ (MLSS-HR) and the percentage of MLSS-HR related to the HRmax (%MLSS-FC) are expressed in the table 1. There was no significant difference of the HRmax, MLSS-HR and %MLSS-HR between both cadences analyzed. The Pmax, $MLSS_{intens}$ and %$MLSS_{intens}$ values were significantly lower at 100 rpm.

TABLE 1

Mean ± SD values of the maximal power output (Pmax) and of the maximal heart rate (HRmax) attained during incremental test, the intensity corresponding to the maximal steady state of the lactate expressed in absolute ($MLSS_{intens}$) and related to the Pmax (%$MLSS_{intens}$) values, and heart rate in the MLSS intensity expressed in absolute (MLSS – HR) and related to the maximal heart rate (%MLSS-HR) values. N = 9

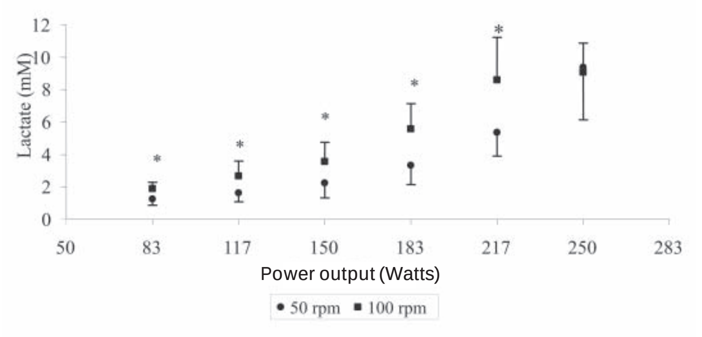
	Pmax (W)	HRmax (bpm)	$MLSS_{intens}$ (W)	% $MLSS_{intens}$	MLSS – HR (bpm)	%MLSS–HR
50 rpm	263.9 ± 18.6	191.1 ± 8.8	186.1 ± 21.2	70.7 ± 6.2	162.5 ± 9.1	85.4 ± 6.3
100 rpm	240.9 ± 12.6*	192.6 ± 9.9	148.1 ± 15.4*	61.6 ± 5.7*	160.4 ± 9.2	83.6 ± 4.2

* $p \leq 0.05$ related to 50 rpm.



* $p \leq 0,05$ related to 50 rpm

Fig. 1 – Mean ± SD values of heart rate (HR) related to the absolute power output attained in the incremental test performed at 50 and 100 rpm. N = 9.

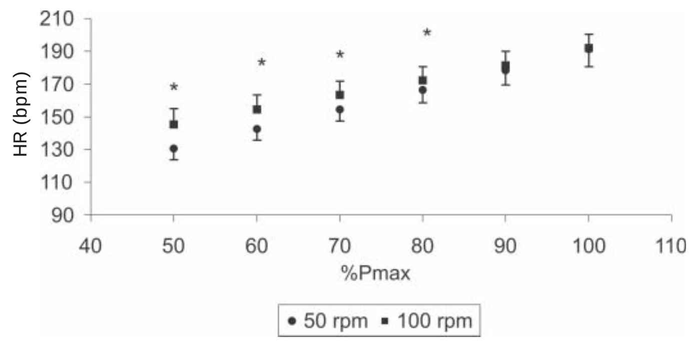


* $p \leq 0,05$ related to 50 rpm

Fig. 2 – Mean ± SD values of the blood lactate concentration in function of the absolute power output attained during the incremental test performed at 50 and 100 rpm. N = 9.

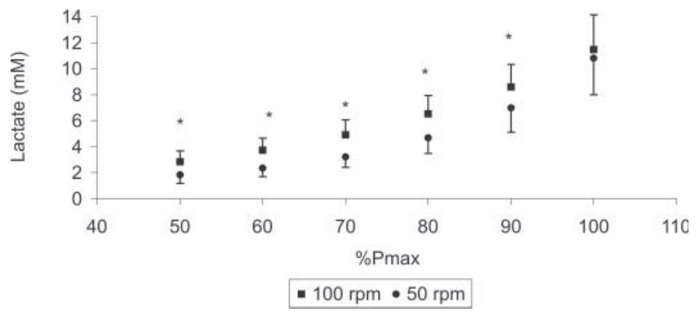
The HR and $[Lac]_{blood}$ values in function of the absolute power output attained in the incremental test performed at 50 and 100 rpm are expressed in figures 1 and 2. It is observed that there is no significant difference between cadences only in the last stage analyzed both to HR and $[Lac]_{blood}$.

The HR and $[Lac]_{blood}$ values attained in the incremental test are also expressed in function of the Pmax percentages (50, 60, 70, 80, 90 and 100%) to both cadences shown in figures 3 and 4. As the HR, there was no difference between cadences only at 90 and 100% Pmax. As to $[Lac]_{blood}$, there was no difference between cadences only at 100% Pmax.



* $p \leq 0{,}05$ related to 50 rpm

Fig. 3 *– Mean ± SD values of the heart rate (HR) in function of the maximal power output percentage (%Pmax) attained during the incremental test performed at 50 e 100 rpm. N = 9.*



* $p \leq 0{,}05$ related to 50 rpm

Fig. 4 *– Mean ± SD values of the blood lactate concentration in function of the maximal power output percentage (%Pmax) attained during the incremental test performed at 50 and 100 rpm. N = 9.*

When the $[Lac]_{blood}$ attained in the incremental test is expressed in function of the HRmax percentages (70, 80, 90 and 100%), it was verified no significant difference between none of these points compared to both cadences (figure 5).

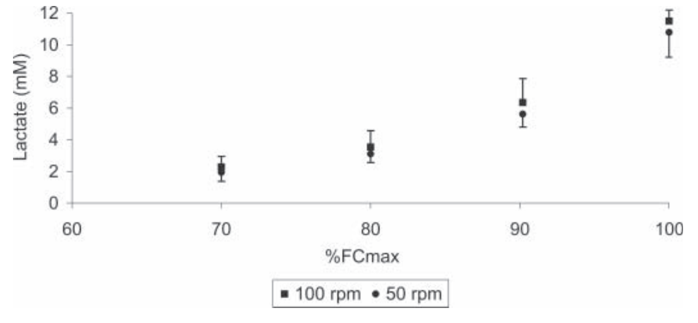


Fig. 5 *– Mean ± SD values of the blood lactate concentration in function of the maximal heart rate percentage (%HRmax) attained during the incremental test performed at 50 and 100 rpm. N = 9.*

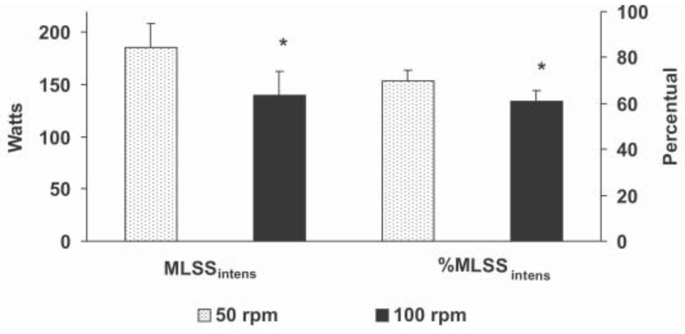
DISCUSSION

The main purpose of this study was to analyze the effect of the pedaling cadence on the HR and the blood lactate response during incremental and constant workload exercises in individuals with no cycling training. The most important result found in our study was that during the incremental exercise, the $[Lac]_{blood}$ expressed in function of the HRmax percentage (70, 80, 90 and 100%) and the HR corresponding to $MLSS_{intens}$ are independent from the cadence analyzed. It is important to point out that such behavior occurred despite the cadence has modified the expressed HR in function of the power output (absolute and %Pmax) during the incremental exercise, and the power output (absolute and %Pmax) corresponding to the $MLSS_{intens}$.

Changes in the HR presented in function of the cadence of a given absolute sub-maximal power output (figure 1) was previously reported(3), and, possibly, it is related to differences in the aerobic demand ($\dot{V}O_2$), since other hemodynamic changing (stroke volume and cardiac output) also occur as a way to sustain to such increasing in the energy demand that occurs in higher cadences(16). Confirming this hypothesis, Chavarren *et al.*(3) verified that the HR values for a given $\dot{V}O_2$ during the incremental exercise are independent from the cadence employed. Interestingly, differences in the HR during the incremental exercise continue appearing even when comparisons are made in function of the Pmax percentages (figure 3). Such behavior probably occurs due to the lower effect of the cadence on the maximal index (Pmax = 8%) than the submaximal index ($MLSS_{intens}$ = 20%) (table 1), also shown by Woolford *et al.*(13). These effects that the intensity analyzed has on the physiological changes found in function of the manipulation of the cadence are already well known to the gross and delta efficiencies which increase according to the intensity increment for a given cadence(3,7). That means, the higher the absolute power output attained in the bicycle, the lower the cadence influence on the physiological indexes analyzed.

As occurs to the HR, both in absolute and relative (%Pmax) power output, the $[Lac]_{blood}$ (figures 2 and 4) was dependant on the cadence analyzed. The same behavior was found during the constant workload exercise, where the power output corresponding to the $MLSS_{intens}$ also expressed in absolute and relative values was lower at 100 rpm. But when the intensity analyzed is close to the Pmax, the lactate values trend to reach the maximal values, and do not show to be dependant of the cadence (figures 1, 2, 3, and 4). The mechanisms that determine such differences in the $[Lac]_{blood}$ are not well understood up to this moment. The recruitment pattern of the muscular fibers that is already quite known to be influenced by the cadence, maybe can be set apart due to the fact that the higher recruitment of the type II muscular fibers that potentially would propitiate higher concentrations of lactate would occur at lower cadences(17). On the other hand, the hemodynamic changing, mainly the increased intramuscular blood flow caused by the increase in the cadence(16) has potential effect on the lactate release by active muscles(19). So, the $[Lac]_{blood}$ would rise in function of the faster transportation between the production site (muscle), and the analysis site (vasculature), and this does not necessarily means a higher rate of the lactate formation. However, this would explain only part of differences, because although $MLSS_{intens}$ is determined by exercises with enough duration to promote the balance in the concentration gradient between sites, it was also significantly changed by the cadence employed. With this, it can be hypothesized that the increase in the $[Lac]_{blood}$ would be simply connected to the increasing demand of energy, having the blood lactate values for a given $\dot{V}O_2$ not probably influenced by the pedaling cadence. Such hypothesis can be partially based on the Woolford *et al.*(13) data, who verified that the AT expressed in $\dot{V}O_2max$ percentage is not dependant from the cadence analyzed.

On the other hand, the relationship between HR and the blood lactate response both during the incremental (figure 5) and the rectangular exercise (figures 6 and 7) are not significantly influenced by cadences analyzed in our study. As previously indicated, the HR x $\dot{V}O_2$ relationship is not modified as well[13], reinforcing that the validity of the HR to select certain sub-maximal intensities of the exercise (< $\dot{V}O_2$max) in cycling is independent of the pedaling cadence. Thus, when the purpose to determine the HR in the incremental test is to find certain %$\dot{V}O_2$max, as proposed by several regressions[20] or certain lactate concentrations, it does not appear to be necessary choose a specific pedaling cadence by the time of the elaboration of the protocol. Likewise, the control of the intensity during the rectangular exercise prescribed based on the MLSS$_{intens}$ can be performed through the HR response corresponding to such intensity, even when changing the pedaling cadences.



* $p \leq 0,05$ related to 50 rpm

Fig. 6 *– Mean ± SD values of the intensity corresponding to the maximal lactate steady state expressed in absolute (MLSS$_{intens}$) and relative values at Pmax (%MLSS$_{intens}$) determined during constant workload exercise performed at 50 and 100 rpm. N = 9.*

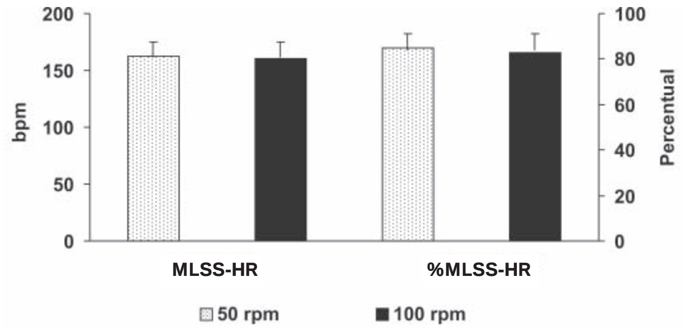


Fig. 7 *– Mean ± SD values of the heart rate at the intensity of the maximal lactate steady state expressed in absolute (MLSS – HR) and relative values at maximal cardiac rate (%MLSS – HR) determined during the constant workload exercise performed at 50 and 100 rpm. N = 9.*

Although it was not the purpose of this study, it is interesting to analyze the MLSS – HR and %MLSS – HR values found here, since the determination of the lactate response to prescribe the intensity of the exercise is still restrained to some laboratories. Our HR values (MLSS – HR = 161 bpm; %MLSS – HR = 84%) are quite close to that found in other study (MLSS – HR = 163 bpm; %MLSS – HR = 87%) performed at our lab with individuals having the same physical characteristics, and with training status quite similar to that analyzed in this study (unpublished data). With this, upon the impossibility to perform the direct determination of the lactate response, it is suggested that the prescription of the aerobic training intensity in cycling based on the MLSS$_{intens}$ may be done from the HRmax percentage found here (75 to 90% HRmax). The MLSS$_{intens}$ has been considered the upper threshold to prescribe the aerobic training, particularly the performed continuously by sedentary/active individuals. However, it should be noticed that besides of the individual variability, these percentages should be used by individuals that have the same features as our voluntaries, since the %MLSS – HR depends on the aerobic fitness of individuals[21].

Finally, it is necessary to remind also the limitations that the use of the HR has to the controlling of the endurance exercise, such as the cardiovascular deviation, and the daily variations[22,23].

CONCLUSION

Based on the results found, it can be concluded that regardless the cadence employed (50 x 100 rpm), the use of the HR to relativize the exercise intensity indicates similar responses of the blood lactate both in the incremental and in the constant workload exercise performed at the MLSS$_{intens}$.

On the other hand, the use of the Pmax percentages present dependence of the cadence used, indicating different physiological responses for a same percentage.

All the authors declared there is not any potential conflict of interests regarding this article.

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