



Maximal heart rate on treadmill at different times

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ABSTRACT

The aim of this study was to compare the maximal heart rate (HRmax) in the Bruce test (TBruce) at different times of the day, since several measurements of the human performance present circadian variations which seem to follow the body temperature rhythm. Eleven male individuals, with 22.0 ± 1.6 years, physically active and from the intermediate chronotype were studied. The resting HR (HRres), maximal HR (HRmax), perceived exertion (PE) and time until exhaustion (TBruce) were observed. The Polar Vantage NV cardiofrequencymeter was used in order to measure the HR. The PE was obtained through the Borg's scale (6-20). The protocol by Bruce for treadmill was applied until exhaustion, at 6 different times: 9:00; 12:00; 15:00; 18:00; 21:00 and 24:00 hours. The results were submitted to the variance analysis for repeated measurements, followed by Tukey test ($p < 0.05$) and the Cosinor adjustment for identification of rhythmic patterns. There was significant difference between the HRres of the 15:00 and 24:00 h (67.2 ± 6.9 and 60.4 bpm) and in the HR max of the 12:00 and 24:00 hours (197.4 ± 7.9 and 191.3 ± 5.8 bpm). No difference was identified in the PE and in the TBruce. Rhythmicity was found in 1 individual in the HRres, 1 in the HRmax and 2 in the TBruce. It was concluded that in uncontrolled conditions, whenever daily activities are kept, both HRres and HRmax present lower indices around 24:00 hours, with no loss in the maximal aerobic performance and no PE alteration. These findings should be considered in the aerobic evaluation and in the exercises prescription at later times.

INTRODUCTION

Physiological functions as well as physical and psychological performance when studied concerning time, present rhythm in their behavior. The period of such oscillations may extend from seconds to years. Rhythms with periods of approximately 24 hours are called circadian rhythms and are expressed by oscillations of the physiological systems, mainly synchronized by the light/dark cycle and by the social interactions⁽¹⁻⁴⁾.

Several measurements of the human performance present circadian variations. These oscillations seem to follow the body temperature rhythm^(1,3,5-7). Body temperature is usually used as a rhythm marker, due to its easiness of measurement as well as its strong endogenous component. The minimal index in the temperature

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curve occurs during sleep, at about 4:00 h^(2,8). From this point, an increase which is more remarkable with one's waking, begins. After midday, there is a slight decrease, which is called "post-lunch dip", followed by new increase which leads to higher indices at about 18:00 h^(2,9). Considering the 24 hours of the day, there is a variation of about 0,5°C during the day^(1,4,7,10-11).

Similarly to the body temperature, the cardiac function also presents alterations according to the time of the day, being consistently lower at night, independently of the working load, with a difference of 5-10 bpm between the day and night. The heart rate (HR) in maximal physical exercise (HRmax) varies according to the day hour; nevertheless, with variation of lower breadth if compared with the resting HR⁽²⁻³⁾.

The HRmax has been the study objective of different researchers. Reilly and Books⁽¹²⁾ applied physical exercise in cycle ergometer at the times: 02:00, 06:00, 10:00, 14:00, 18:00 and 22:00 h and found significant circadian variation in the HRmax. Reilly *et al.*⁽¹³⁾ applied maximal test in cycle ergometer, at four times (03:00, 09:00, 15:00 and 21:00 h) and observed circadian rhythm in the HRmax as well. Conversely, again with the use of cycle ergometer, Cohen⁽¹⁴⁾ at the times: 04:00, 08:00, 12:00, 15:00, 18:00, 21:00 and 24:00 h and Deschenes *et al.*⁽¹⁵⁾ at 4 times (08:00, 12:00, 16:00 and 20:00 h) did not find significant differences between the different times.

The literature review shows that, in the studies of the HRmax, the maximal physical exercise in cycle ergometer has been used. This ergometer is not the most adequate for the study of the HRmax, once with its utilization, HRpeak of 5 to 10% lower than the ones obtained on treadmill is observed. Such fact is observed since in cycle ergometer the exhaustion in non-cyclists is caused by the occurrence of peripheral fatigue before the HRmax is reached⁽¹⁶⁾. Moreover, the studies results are not conclusive yet concerning the HRmax differences at different times of the day. Thus, the aim of this study was to compare the HRmax in the Bruce test performed at different times of the day.

METHOD

Subjects – After being approved by the Ethics Committee of the Bandeirante University of São Paulo (protocol 011/2004), the experiment procedures for the participants' selection began. The sample consisted of 11 young male individuals. Besides that, they were Physical Education healthy students; not engaged in regular physical training programs with competitive aims and with intermediate chronotype; identified by the questionnaire on morning-evening profile by Horne and Östberg⁽¹⁷⁾, adapted to Brazil by Benedito-Silva *et al.*⁽¹⁸⁾. The individuals presented the following characteristics: age $22,0 \pm 1,6$ years, body weight $74,6 \pm 8,9$ kg, height $177,4 \pm 7,3$ cm, body mass index (BMI) $23,7 \pm 1,7$ kg/m² and body fat percentage $9,2 \pm 3,7\%$. The subjects signed the Free and Clarified Consent Form, presented the PAR-Q negative and

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did not make use of any medication that could alter the HR behavior.

Anthropometrical evaluation – An anthropometrical evaluation in which the body weight and height were identified through an anthropometrical scale (Filizola ID 1500) and stadiometers (Cardiomed) respectively, was conducted in order to characterize the individuals. The chest, abdomen and thigh skinfolds were measured (Lange adipometer). The fat percentage was estimated through the Jackson and Pollock equation⁽¹⁹⁾.

Preparation for the ergometric test conduction – The participants were instructed to keep their eating routine in the 24 h prior to the ergometric test; not to ingest food and alcoholic drinks which had caffeine in the 12 h prior to the test and not to ingest any food within the 3 h prior to the test. They were also asked not to perform physical activity additional to their academic routine on the day before the test. Concerning the dressing code, shorts, t-shirts and cotton socks were suggested. The participants wore the same shoes in all tests once there is evidence that the shoes type and model may influence on the running aerobic demand⁽²⁰⁻²¹⁾.

Ergometric test – Before the conduction of each ergometric test, the subjects remained laid on dorsal decubitus position for 30 min for registry of the HRres through a Polar Vantage NV cardiofrequency meter, beating after beating. The average of the final 10 min of the resting period was considered as HRres.

After a brief reminder on the recommendations to be followed by the individual concerning the test and the utilization of the perceived exertion scale (PE) by Borg 6-20⁽²²⁾, the Bruce test was conducted⁽²³⁾ on a multiprogram treadmill by Inbramed, model KT 10200 ATL. The HR was continuously registered through the Polar Vantage NV cardiofrequency meter. The HRmax was identified using the average of the last cardiac cycles prior to the test interruption. At the final 15 s of each stage, the participant was asked to report his PE.

The participants were verbally encouraged for motivation. As visual stimulus, a board was posted across from the treadmill with the highest duration time of the test (BruceT) obtained by the group up to the moment, that is, the group record, and the best time obtained by the individual in the previous tests, or his personal record.

The tests were conducted at six distinct times: 09:00, 12:00, 15:00, 18:00, 21:00 and 24:00 h. The tests were randomly organized and a minimum interval of 24 and maximum of 48 h between them was respected. The tests administration concerning the day of the week was not doubled, with the purpose to balance possible circaseptan influences according to Reilly and Brooks⁽¹²⁾. The individuals completed all the ergometric tests between 9 and 14 days. The room temperature in the laboratory varied between 19° and 23°C and the relative air humidity between 68% e 88%.

Statistical treatment – Descriptive statistics and variance analysis (ANOVA) of one factor for repeated measures were used, followed by the Tukey test ($p < 0,05$), with the aim to identify significant differences between the observed results at the different times. The Pearson correlation for the mean of the different times was calculated in order to identify the association between the variables. The Cosine, which is an analysis method of biological rhythms which consists of the adjustment of the cosine curve to the data, was applied for rhythm identification in the variables behavior. Besides that, it enables the description of time series of individuals through rhythm parameters estimated by the minimum squares method, identifying hence, parameters such as acrophase and mesor, for example. The Cosine method also verifies if the time series presents any kind of periodic recurrence, through a hypotheses test⁽²⁴⁾.

The Cosana program was used for rhythmic-metrical analysis of individual time series version 3.1. The BioEstat 3.0 and Statistica 6.0 statistical programs were used 6.0 for the data processing.

RESULTS

Table 1 shows that no statistically significant differences were observed among the different times in the BruceT and in the PE. Statistically significant difference was observed between the HRres in the 15:00 and 24:00 h times ($67,2 \pm 6,9$ and $60,4 \pm 6,4$ bpm) and in the HRmax in the 12:00 and 24:00 h times ($197,4 \pm 7,9$ and $191,3 \pm 5,8$ bpm). The individual HRmax curves and the arithmetic mean are presented in figures 1 and 2. In the Pearson correlation it was observed that the PE has independent behavior and that there is a positive correlation between HRres x HRmax ($r = 0,77$), HRmax x BruceT ($r = 0,78$) and FCres x BruceT ($r = 0,58$).

TABLE 1
Resting and maximal heart rate, Bruce time and perceived exertion at different times

Time	Resting HR (bpm)		Maximal HR (bpm)		Bruce Time (s)		Perceived exertion (Borg 6-20)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
9:00	64,6	8,1	195,7	7,1	876,6	42,0	18,8	0,8
12:00	64,9	7,8	197,4*	7,9	871,3	58,3	18,9	0,3
15:00	67,2*	6,9	196,0	7,8	867,5	50,3	18,8	0,6
18:00	63,7	9,7	194,0	6,4	871,9	64,8	18,8	0,6
21:00	61,7	5,3	194,9	7,8	869,5	52,8	18,9	0,3
24:00	60,4	6,4	191,3	5,8	851,7	52,1	18,8	0,4

* significant difference ($p < 0,05$) in relation to the indices obtained at the point of 24:00 h

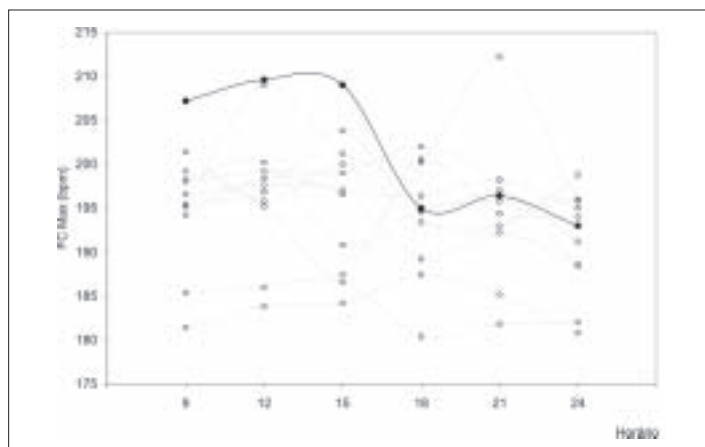


Figure 1 – Individual curves of the maximal heart rate, with attention to individual 5 whose data adjusted to the Cosine (—)

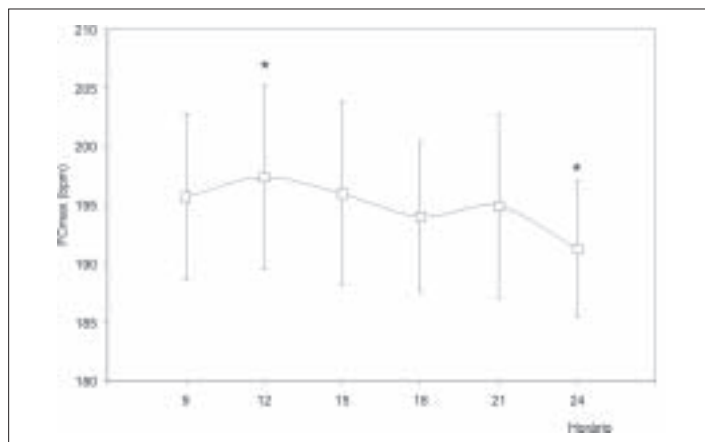


Figure 2 – Arithmetic mean and standard deviation of the maximal heart rate

* Significant difference $p < 0,05$

Concerning the data analysis, using the individual Cosine method for identification of the rhythmic patterns of the individuals in relation to the HRres, HRmax and BruceT, significant results were observed. They were as follows: for individual 3 in the HRres; for individual 5 in the HRmax and for individuals 1 and 2 in the BruceT. The Cosine was not significant in the remaining individuals (table 2).

TABLE 2
Individual Cosine results

Ind	Probability		
	HRres	HRmax	BruceT
1	0,792	0,885	0,042*
2	0,082	0,449	0,005*
3	0,010*	0,102	0,198
4	0,831	0,163	0,318
5	0,114	0,043*	0,084
6	0,591	0,166	0,361
7	0,291	0,281	0,795
8	0,696	0,710	0,409
9	0,292	0,462	0,052
10	0,496	0,371	0,095
11	0,558	0,086	0,942

* p < 0,05.

DISCUSSION

The number of individuals of this experiment was compatible with studies previously conducted by other researchers⁽¹²⁻¹⁵⁾. The age group was also supported by the literature with the option for young, healthy and physically active individuals^(12-15,25-29), which contributed for the decrease of the age factor influence in the results⁽³⁰⁻³⁴⁾. Only individuals with intermediary chronotype were included in the sample in order to avoid that subjects of the morning chronotype would obtain better results in the morning, and evening ones at later times. Such procedure was not observed in other studies⁽¹²⁻¹⁵⁾.

The treadmill was chosen as ergometer, once according to the study by Araujo *et al.*⁽²⁸⁾ in which the HRmax obtained on treadmill, cycle ergometer and ergometer of the upper limbs was compared, the treadmill was the most recommended ergometer for the observation of the highest indices of HR. Similar results were found by Scolfaro *et al.*⁽²⁶⁾, Hermansen and Saltin⁽³⁵⁾ and Hermansen *et al.*⁽³⁶⁾. The Bruce protocol for progressive ergometric test on treadmill was chosen due to its good reputation on the scientific community, which is used in the physical evaluation of healthy individuals, athletes⁽³⁷⁾ and cardiopatic patients⁽³⁸⁾.

The choice of the times for the conduction of the ergometric tests had as basis the moments of the day at which the population generally performs a physical activity. The non-inclusion of times during very early morning had the purpose not to increase the sleep disturbance of the participants. The tests were randomly organized in order to decrease the possibility of the learning effect during the 6-tests series performance⁽³⁹⁾. The minimum interval of 24:00 h between the ergometric tests was suitable, not being reported any complaint on the individuals behalf concerning fatigue or discomfort. Drust *et al.*⁽⁴⁰⁾ highlight the difficulty of consecutive tests performance in humans due to fatigue.

It would be interesting to have the participants confined in the laboratory with the purpose to increase the degree of control on the subjects routine. Such measure was not taken for technical limitations; therefore, it is not possible to guarantee that the individuals followed the recommendations provided by the researcher. On the other hand, it increases the external validation, once the individuals were inserted in their routine expressing their daily rhythms without interference of forced desynchronization by a constant routine performed in laboratory.

It was found a statistically significant difference (p < 0,05) in the HRres between the 15:00 and 24:00 h points. These findings follow the same trend of the ones found by Reilly and Brooks⁽¹²⁾ who reported the highest index of HRres at 14:00 h, and, from that point on, observed the decrease of this variable until the lowest index was found at 02:00 h, that is, during the early morning hours. Nevertheless, Cohen⁽¹⁴⁾ found significant differences between the highest and lowest indices of the HRres between the 18:00 and 04:00 h points, respectively, with Faria and Drummond⁽²⁷⁾ reporting similar results. Millar-Craig *et al.*⁽⁴¹⁾ found the highest indices at 13:00 h, with progressive decrease until the minimum indices at 04:00 h.

The literature presents papers that did not identify difference in the HRres, such as the study by Deschenes *et al.*⁽¹⁵⁾ who observed the physiological responses at the 08:00, 12:00, 16:00 and 20:00 h points. The present study found significant decrease in the HRres at the 24:00 h point, demonstrating the beginning of the decrease of this variable. According to the literature previously mentioned, the minimum index would be observed between 02:00 and 04:00 h. Nonetheless the methodological outlining of this research did not enable such fact occurrence.

A significant difference was observed in relation to the HRmax between the 12:00 and 24:00 h points, with no identification of any other difference among the remaining times. These findings are within the time interval in which Winget *et al.*⁽¹⁾ reported the possible occurrence of the HRpeak during physical exercise, so that this interval may vary between 07:00 and 22:00 h. Studies conducted by Reilly and Brooks⁽¹²⁾ and Reilly *et al.*⁽¹³⁾ showed a time pattern in the Hrmx with higher indices being observed in the light phase of the light-dark cycle.

Reilly⁽³⁾ raises issues about the difficulties of exposing individuals to the maximal progressive physical exercise, especially concerning their reluctance on performing the physical tests at the night times. Another difficulty to be considered is the so called plateau effect of physiological ability found in these kinds of evaluations, which is characterized by lower variations in a maximal physical exercise situation. Therefore, the fact that many studies do not report a circadian variation is not surprising. This is the case of the study by Wojtczak-Jaroszowa and Banaszkiwicz⁽⁴²⁾ who did not observe differences between the indices obtained between 09:00 and 13:00 h compared with the ones obtained between 01:00 and 05:00 h; or as the study by Cohen⁽¹⁴⁾ who did not observe differences among the 04:00, 08:00, 12:00, 15:00 18:00, 21:00 and 24:00 h points. Such result differs from the ones found in the present study.

Confronting the findings of the present study with papers whose methodological outlinings were close, one could observe a similarity in the results as the ones showed by Deschenes *et al.*⁽¹⁵⁾ who did not find statistically significant difference between the 08:00, 12:00, 16:00 and 20:00 h points. Another study that can add to this idea is the one by Reilly *et al.*⁽¹³⁾ who did not find statistically significant differences among the 09:00, 15:00 and 21:00 h points, but observed a significant decrease in the HRmax at the 3:00 h point when compared with the 9:00, 15:00 and 21:00 h, though. Such result allows us to speculate on the beginning of the decrease of the HRmax at the 24:00 h point, as found in the present study. One may speculate that the cause of this decrease may be explained by the light-dark cycle, since in the dark phase of this cycle a body temperature decrease which presents a remarkable circadian pattern occurs.

A correlation between the HRres and the HRmax was observed, that is, they tend to vary in the same direction. However, the HRres behaved with a higher variation (6,8 bpm between the highest and lowest indices) when compared with the HRmax (5,9 bpm), confirming the study by Cohen Muehl⁽⁴³⁾ that reports a lower variation in the HR when in physical exercise situation. Showing that the HRmax is a phenomenon of reduced intraindividual variation, and

according to Winget *et al.*⁽¹⁾ such discrepancy in the found results in the previously mentioned research, in having or not a variation in the HRmax, may be related with this lower variability with the physical exercise intensity increase. Atkinson and Reilly⁽⁸⁾ attribute this lack of consensus concerning the possible circadian rhythm detection to a plateau effect of the physiological ability reached in the maximal ergometric test.

Concerning the BruceT, no statistically significant difference was found among the observed times. Such result is shared by studies that used a cycle ergometer^(13,15,44). Conversely, Baxter and Reilly⁽⁴⁵⁾ reported the influence of the time of the day in swimmers performance. This report agrees with the results found by Rodahl *et al.*⁽⁴⁶⁾ who observed better swimming performance in the afternoon comparing with the tests performed in the morning, hence raising the issue that the kind of physical exercise, the test's characteristics as well as the environment may affect the observation of the performance variation or time of the test in relation to the time of the day.

Concerning the PE, no statistically significant difference was observed among the studied times, nor correlation with the other variables of the study. This result finds support in the studies by Deschenes *et al.*⁽¹⁵⁾ and Reilly *et al.*⁽¹³⁾ who did not identify difference in the PE, under maximal physical exercise condition. The literature reports a variation in the PE in submaximal physical exercises, in which higher indices were found in the PE Borg's scale in the tests performed at the early morning times^(27,47). Results close to the 19 category in the PE Borg's scale suggest the compromising of the participants in dedicating their most in the ergometric test at all times; they show as well, the relevance to set a goal to be reached. In our case, the goal was the posting of the individuals tests times across from the treadmill, so that the participant could be more stimulated to increase his motivation degree.

Analyses through the individual Cosine method were performed with the purpose to observe the rhythmic patterns of the HRres, HRmax and BruceT variables. These analyses pointed to few individuals with significant rhythmic pattern. These results should be observed with concerns, since the data collection was conducted at distinct days to the utilization of maximal physical exercise which hampered the collection of more than one point at the same day. Such situation resulted in the making of a fictitious day for the analysis conduction, making a higher degree of trustworthiness of the Cosine results impossible.

Few individuals presented a significant adjustment according to the Cosine analysis, a fact that does not allow deeper inferences on these individuals' rhythmicity. Nonetheless, what was evident in the observation of the results was the decrease in the physiological variables HRres and HRmax in the dark phase of the light/dark cycle. Such behavior demonstrates the power of this cycle as synchronizer of the biological rhythms of these individuals.

As a conclusion, one may suggest that in non-controlled conditions, when the daily activities are kept, the HRres and the HRmax present lower indices at around 24:00 h, without loss in the maximal aerobic performance or PE alteration. These findings should be considered in the aerobic evaluation and the exercise prescription at later times.

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

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