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# Morning or evening training: effect on heart rate circadian rhythm

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**Abstract** Twenty male endurance athletes (aged 20–25 years) carried out 2-hour daily training sessions, every day from Monday to Friday, for an overall period of 4 weeks. Four different weekly training time table (09.00-11.00; 11.00-13.00; 16.00-18.00; 18.00-20.00 hours) were followed, changing the time slot each week. Each athlete trained, in turn, in each period. The fifth day of each week, heart rate was monitored for 24-28 hours. Statistical analysis employed the single and mean cosinor methods. The heart rate (HR) circadian rhythm was statistically significant ($p<0.05$) in all 4 training session time. The HR acrophase is progressively postponed during the afternoon: the heart rate acrophase for training done between 18.00 and 20.00 is delayed by approximately 3 hours compared to that of the training done between 09.00 and 11.00. Training done at different daily times synchronizes the HR circadian rhythm. Temporal programming of physical activity is a tool capable of modifying the temporal structure of physiological variables. This approach can be of great interest for coaches who plan training programs and it may benefit athletes when time zone adjustment is an issue, such as transferring to a different continent for a competitive event.

**Key words** Biological rhythm • Exercise • Performance • Heart rate

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## Introduction

Knowledge of the time course of variables tied to physiological modifications induced by physical exercise is important in sports. This is true both in the professional field, identifying the most favourable physiological moment to obtain the maximum result from performance, and for the amateur, allowing one to take full advantage of the benefits that physical activity produces for the body [1–7].

In different sports, physical performance is subject to circadian-type modifications [8–12]. For example, world records in sporting events are generally broken during the evening hours [1]. In fact, factors like joint flexibility, muscle strength and short-term high power output have their maximum expression in the afternoon hours [1].

Of particular interest is the evaluation of the circadian rhythm of heart rate (HR) [4, 13–15] in power and endurance disciplines, for the effect that physical exercise can have on the temporal HR trend. Studies in the 1970s on NASA astronauts [16] evaluated the effect of physical exercise on the time cycles of physiological variables, such as HR and other electrocardiogram parameters. At that time, studies investigated the effects of physical exercise, feasible in a spacecraft, on the circadian structure of the subjects and consequently on their well-being. More recently, attention has focused on obtaining different effects of physical activity on the circadian structure of subjects, according to the circadian span in which such activity was carried out [9, 17, 18].

To study periodic phenomena, we have to know the conditions of synchronization of the subject, then to collect and analyse the data appropriately [19–25]. Synchronizers are environmental factors with a periodic pattern which influence endogenous biological rhythms. These environmental factors are the metronome to which the endogenous periodicity of an organism adapts. Isolation from environmental factors, however, is not enough to suppress periodic phenomena. A delay of the main synchronizer may change parameters which characterize the biological rhythms [26]. Training could represent an important synchronizing factor that influences the circadian system and consequently athletic performance. We investigated the effects of physical exercise, done at different times of the day, on synchronization of HR circadian rhythm.

## Materials and methods

### Subjects and experimental design

The study was carried out on 20 male athletes, aged 20–25 years, all routinely practising endurance sports and training on a regular basis for about two hours daily. These athletes followed a program that foresaw 2-hour daily aerobic training sessions, every day from Monday to Friday, at fixed hours, for an overall period of 4 weeks. The athletes trained for 2 hours daily in one of four fixed training sessions time (09.00-11.00; 11.00-13.00; 16.00-18.00; 18.00-20.00 hours). In the 4-week span of the study, the subjects took turns weekly in all the training sessions, so that each athlete trained in all four of the time schedules.

The athletes followed the same aerobic training schedule. The two-hour training session included an initial warm up phase, a central block of exercises and a final phase of winding down. These subjects were allowed no further sporting activity outside the training session of the study. On the fifth day of each training week, heart rate (HR) was recorded for 24–28 hours using a heart rate monitor (Polar S810; Polar Electro, Kempele, Finland), taking measurements every 15 seconds; in this way, for each athlete we obtained 4 HR monitorings (24–28 hours), corresponding to each training period. The Polar monitor was previously used by the subjects several times to control their training. On the monitoring day, the daily training session was held as usual.

The study took place in September and October 2003. The subjects maintain a controlled way of living, with wake-up at 07.00 (±30 min) and bed time at 23.00 (±30 min); meals were at 08.00, 15.30 and 20.30 hours. The subjects kept a daily diary of their living habits, including the exact time of wake-up and rest, meals and other relevant day events. The athletes were controlled daily by a trainer.

### Statistical analysis

The data recorded at each (for every training sessions time) HR monitoring session (4 monitorings for each athlete) were averaged for time periods of 30 minutes. These data were then processed and analyzed excluding the HR data recorded during the training session and the 2-hour period following the training session. To evaluate HR circadian rhythmicity, the single cosinor method [21] was used. Using the least-squares statistical method, the single cosinor method identifies and evaluates the cosine mathematical function best fitting the data as a function of time. The function, $f(t) = M + A \cos(\omega t + \varphi)$, defines three parameters characteristic of each statistically significant rhythm: M, MESOR; A, amplitude; $\varphi$, acrophase. MESOR (midline estimating statistic of rhythm) approximates the arithmetical mean of the data for a 24-hour period, and amplitude is the measure of one half the extent of HR rhythmic variation in a cycle. Acrophase indicates, with its 95% confidence interval (CI), the time interval within which the highest values of HR are expected. The three parameters are usually indicated with the relevant 95% confidence intervals.

The HR rhythmometric parameters (MESOR, amplitude and acrophase), defined for each athlete in the 4 training sessions, were then processed with the average of population mean cosinor. This method, applied to the rhythmometric parameters of each subject's HR data, evaluates the HR rhythmometric characteristics of the population [21]. In this the HR population circadian characteristics in the 4 training sessions were determined and then compared using the Hotelling test [19]. The Hotelling test, a generalization in the multivariate field of Student's *t* test, allows testing the hypothesis that the distance between the mean vectors of two samples is nil.

## Results

All the 20 subjects that participated to the study trained in each session time, so, with this training program, the athletes have been followed for an overall period of 4 weeks. For every subject we collected 4 HR monitorings, one for each training session time; each of these monitorings included about 6.000 HR data. These data have been used to get a HR mean value every 30 minutes for every monitoring of the single subject, and then to get a HR mean value every 60 minutes for each group of monitorings with the same training session time (Fig. 1).

An accurate examination was made on the diaries data and on the HR data monitoring to confirm the congruence between the recorded heart rate data and the training program. 13 subjects was excluded from the study because they have not followed accurately the training protocol.

To exclude that the HR data recorded during the training session could cause an Acrophase dragging towards the training session time itself, we applied the analysis methodology to the heart rate monitorings stripped of the values recorded during the training session and during the 2 following hours.

Rhythmometric analyses, using the single cosinor method on the HR monitoring data of the single subjects revealed a statistically significant circadian rhythm (at least $p<0.05$) for all of the monitorings.

The population mean cosinor were calculated grouping the HR monitorings with the same training session time, obtaining, in this way, four groups of monitorings: one for each training session (09.00-11.00; 11.00-13.00; 16.00-18.00; 18.00-20.00). The population mean cosinor demonstrated a statistically significant circadian rhythm in all 4 groups of monitorings. Table 1 shows the parameters that characterize

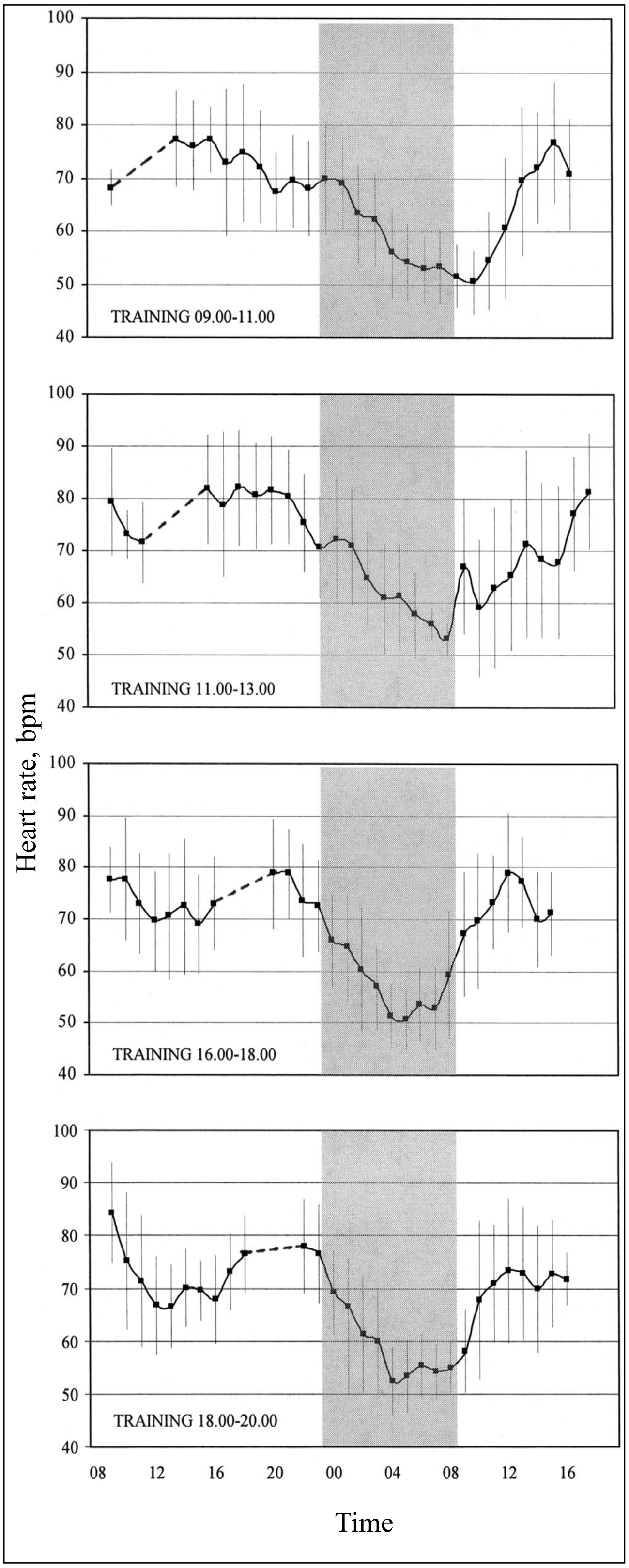


**Fig. 1** Mean heart rate (HR) values, calculated hourly over 24–28 hours for 7 athletes on the fifth day of training at 4 different training sessions. The broken line represents the HR data recorded during the training sessions and the following 2 hours, excluded from the statistical analysis. The grey band represents the night rest

**Table 1** Rhythmometric analysis (population mean cosinor) on the monitorings in relation to the 4 training sessions (09.00-11.00, 11.00-13.00, 16.00-18.00, 18.00-20.00)

| Training session time | *p* | MESOR (±s.e.) | Amplitude (95% CL) | Acrophase[c] (95% CL) |
|---|---|---|---|---|
| 09.00-11.00 | <0.001 | 66 (±2.3) | 11 (7-16) | 14.55 (13.32-17.12) |
| 11.00-13.00 | <0.001 | 70 (±2.3) | 13 (9-19) | 16.55 (14.40-19.24) |
| 16.00-18.00 | <0.01 | 69 (±2.7) | 11 (8-15) | 16.53 (15.44-18.28) |
| 18.00-20.00 | <0.01 | 68 (±1.7) | 8 (1-18) | 18.08 (13.00-21.00) |

the circadian rhythm, for each group of monitorings in the different experimental conditions. Also by naked eye is evident that MESORS and Amplitudes are similar in all experimental conditions:. the HR mean values in the 24 hours for all the subjects ranges from 66 to 70 beats/minute, and the oscillations in the 24 hours have a range of about 8-13 beats/min.

A different situation appears for the Achrophase: the clock time, in which higher HR values fall, shifts from 14.55 (for training session time 09.00-11.00) to 18.08 (for training session time 18.00-20.00). It means a delay of at least 3 hours of the heart rate circadian pattern for subjects that train in the late afternoon compared with those that train in the morning.

The Hotelling test, applied to compare the rhythmometric parameters of the four different experimental conditions, showed no differences for MESORS and amplitudes, but a statistically significant difference in acrophases for all group combinations, except in the comparison between monitorings done in the training sessions 11.00-13.00 vs. 16.00-18.00 and 16.00-18.00 vs. 18.00-20.00.

The temporal distribution of acrophases (Fig. 2) shows, for each training session, the number of monitorings with acrophases that fall within the indicated time band. This analysis clearly shows the shift in acrophase obtained from the first to the last training session.

## Discussion

This study suggests that a training program carried out at different times of the day can modulate the circadian rhythm of the heart rate (HR). This modulation determined, for the late afternoon training session (18.00-20.00), a shift in acrophase of about 3 hours with respect to training done in the morning (09.00-11.00). This acrophase shift is not affected by the HR data recorded during the training sessions, as the statistical analysis was made without such values. Therefore, the HR circadian rhythm can modify the acrophase, depending on the time of day in which physical exercise is carried out, i.e. training acts as an entraining

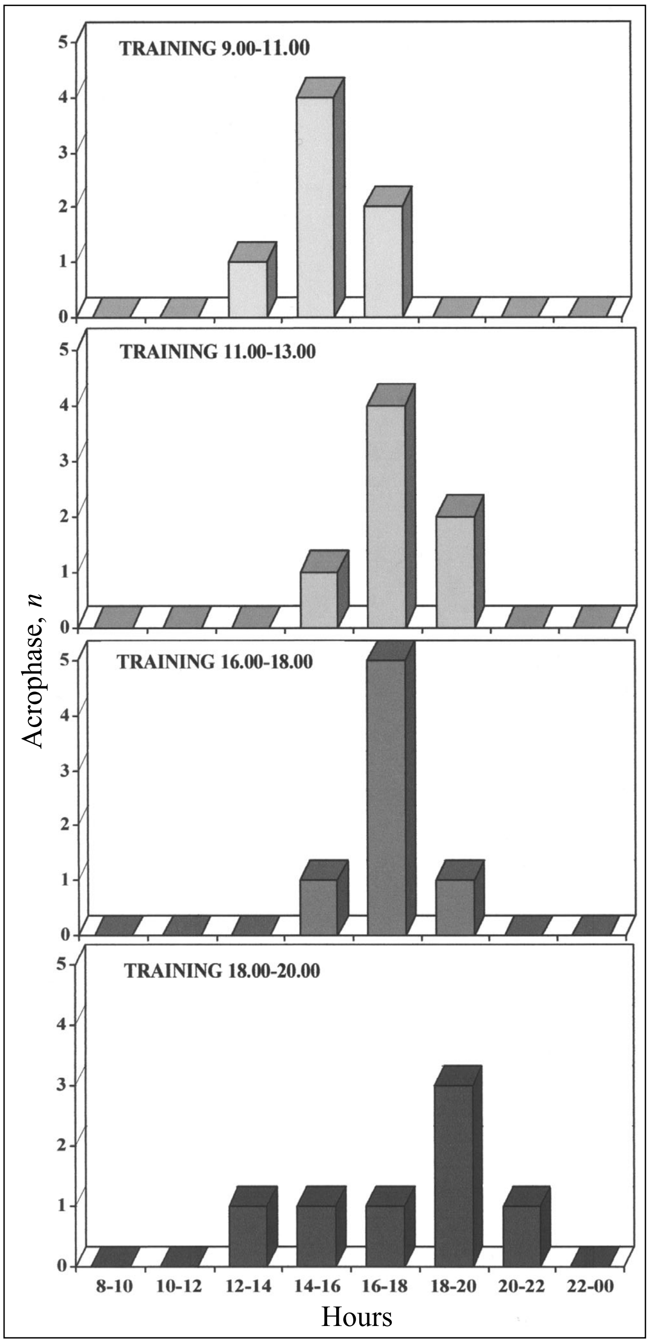


**Fig. 2** Temporal distribution of acrophases. The abcissa shows the grouped 2-hour time-bands, the ordinate the number of monitorings with acrophase that falls within the indicated timeband. The acrophases of the earlier morning training session time (09.00-11.00) falls mainly in the mid-afternoon hours (12.00-18.00), those of the late morning (11.00-13.00) and those of the earlier afternoon training session time take place between 14.00 and 20.00, while the achrophases of the late afternoon training session time (18.00-20.00) shift to later in the evening

agent that forces the HR circadian rhythm to assume a new synchronization. Physical exercise is one of the most important factors able to modulate the autonomous system. In fact physical exercise supplies an important stimulation to the orthosympathetic system, with the aim of ensuring the physiological adaptation necessary to sustain physical activity. Such stimulation is proportional to the intensity of physical exertion and muscular mass. Therefore, not only physical exercise as such, but also the time of day in which it is carried out, is an important determinant in regulating the equilibrium of the autonomous nervous system.

Callard et al. [27] demonstrated that MESOR and amplitude are altered by protracted training like continuous training for over 24 hours (with 20-min breaks): they showed an increase in both the average HR and the amplitude of the rhythm. Our analysis of 24-h HR data, deprived of the training session HR data, did not show any modification in either MESOR or amplitude of the oscillation. As a function of the training session time, there is a progressive delay of the acrophase that is, however, less evident in the two central training sessions (11.00-13.00, 16.00-18.00), which have almost superimposable acrophases.

This significant acrophase delay ($p$<0.05, Hotelling test) is evident between the morning training session (09.00-11.00), with acrophase at 14.55, and the late afternoon training session (18.00-20.00), with acrophase at 18.08 (Table 1, Fig. 2). At first, these data seem not to be in agreement with Reilly and Brookes' findings [10], according to which the circadian rhythm of post-training heart rate (measured after physical exercise on 6 days separated into 6 different time points) has an acrophase superimposable on that of resting HR. Nevertheless, in the present study, physical exercise was understood, and was therefore used as such, as a HR circadian rhythm synchronizing element; in this way, it is not a single training session but the training repetition, according to a constant and fixed time-table, that acts on the HR acrophase. Moreover, also heart rate variability (HRV), when monitored in conditions of normal daily activity, is characterized by a circadian rhythm with acrophase in the afternoon, but when measured during physical exercise shows modification of the acrophase [17, 18].

In sedentary subjects monitored for heart rate, body temperature, blood pressure and several urinary and blood variables, the temporal circadian structure was practically stable week by week [28].

The evident HR acrophase delay, for training carried out in the evening, modifies the temporal structure that can certainly have an important outcome in the evaluation of an individual's characteristics with regard to changing or not the training times. Indeed by delaying training to the late afternoon or the evening, athletes are able to synchronize their bodies to a delayed activity-rest program, by up to several hours with respect to normal habits. It is important to keep training to as stable a time schedule as possible, as changing times can lead to variations in the rhythm of biological variables, which can lead to variations in the rhythm of performance [2]. In the event of a competition involving transfer to another continent in a different time zone, modifications to the training session times during preparation in the home country could lead to a lengthening of the activity state towards the evening hours that, once the transfer has taken place, will coincide with the local competition time. In this way training is used both as a means of improving physical performance and as an element to synchronize heart rate.

Having higher HR values that fall in the evening rather than in the afternoon could predispose the body to a more prolonged state of activity-evening awakeness with the postponement of the night-time rest period and also a delay in awakening the next morning. Therefore, if athletes can use training to synchronize their temporal structures with their activity needs, the subjects that practise a sporting activity for their own physical well-being must to be aware that physical activity in the late afternoon lengthens the activity phase, and, consequently, possibly delays the sleeping phase.

In conclusion, temporal programming of physical activity is a tool capable of modifying the temporal structure of physiological variables. This approach can be of great interest for coaches who plan training programs and it may benefit athletes when time zone adjustment is an issue, such as transferring to a different continent for a competitive event.

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