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## Heart Rate and Exercise Intensity During Sports Activities Practical Application

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### Summary

Variations in heart rate during exercise correlate with changes of exercise intensity and may be measured directly by radiotelemetry and continuous ECG recording. The heart rate can also be recorded in the memory of a microcomputer, which can be carried on the wrist as easily as a watch. The device has a transmitter and a receiver.

By recording the heart rate during a training session or a segment of training, and calculating the average of the heart rate and comparing this average to both the maximum heart rate of the individual and his heart rate at rest, the relative heart rate to the intensity of the work load (% maximum heart rate) can be calculated. These results are useful in planning optimal training intensities for both the healthy and rehabilitating athlete.

The use of target heart rate as a tool for exercise prescription is common. It represents the percentage difference between resting and maximum heart rate added to the resting heart rate. For calculating target heart rate there are also 2 other methods. The first represents the percentage of the maximum heart rate (%HR<sub>max</sub>) calculated from zero to peak heart rate. The second represents the heart rate at a specified percentage of maximum MET ( $\dot{V}O_{2max}$ ).

An appropriate individual heart rate for each level of an endurance performance is best

*in the blood and corresponding variations in the heart rate. From these results the running speed and heart rate corresponding to aerobic, partly anaerobic or strongly anaerobic running can be determined.*

*The %HR<sub>max</sub> values obtained by continuous ECG recording and telemetry have been used to measure the physical work load in alpine skiing. Alpine skiing has been recorded as exercise which improves general physical fitness and aerobic capacity. However, it has been found to increase more the anaerobic capacity than the aerobic capacity. This should be taken into consideration when planning the training of general physical fitness of alpine skiers.*

Heart rate monitoring is probably the most widely used method for exercise prescription of healthy adults and athletes. The variations in heart rate correlate with the variations in exercise intensity. Under submaximal load the heart rate of a healthy person increases linearly with the increase in oxygen uptake and exercise intensity. The exercise intensity of sports training and work can be estimated by measuring heart rate during normal training with various apparatus. The purpose of this article is to discuss heart rate follow-up methods such as telemeter, continuous ECG (Holter-monitoring) and microcomputer recording in athletes' training. The use of relative heart rate for follow-up of exercise intensity in various sports events based on our experiences will also be discussed.

### **1. Methods for Measuring Heart Rate During Physical Exercise**

#### **1.1 Radiotelemetry**

Variations in heart rate with exercise may be measured directly by radiotelemetry. A radiotelemeter consists of a radio transmitter connected to the subject by electrodes and a radio receiver of the signals, which may be connected to an ECG monitor, to a heart rate monitor and to an ECG recorder.

The ECG electrodes relay the activity of the atria and ventricles by means of radio signals from the transmitter connected to the electrodes. These signals are transmitted to the receiver and transformed into P-waves and to QRS-complexes relating to activity of the atria and ventricles. The signal.

istered by an ECG recorder connected to the telemeter.

The operating distance of a radiotelemeter varies with the surroundings during measurement and the type of meter. For indoor facilities with many walls, the measuring can normally be carried out from one room to another or along a corridor. For outdoor measurements the terrain has an effect on the operating distance. With a good telemeter it is possible to measure heart rate in a flat forested area for a distance of 1 to 1.5km. In an unforested terrain this distance may be as great as 3km. The distance can be increased by adding additional aerials to the receivers.

#### **1.2 Continuous ECG Recording**

Continuous ECG recording has been developed for studying arrhythmia and coronary diseases (Goldberger 1961). The ECG electrodes are connected to a lightweight recorder worn at the waist. Heart rate and ECG data are registered during the recording process on a tape which can be entered into and analysed with a computer (Hinkle et al. 1967).

By varying the analytical programmes, continuous ECG recording can be used to measure the physical work load of an active, healthy person. Each heart beat during the performance is registered. Analytical programmes can be applied to calculate the mean heart rate continuously for each minute (Karvonen et al. 1985c).

#### **1.3 Microcomputer**

The heart rate can also be recorded in the memory of a microcomputer, which can be carried on

The device has a transmitter and a receiver. The transmitter is worn on an electrode belt a little above the waist and transmits ECG signals caused by the heart beat into the receiver and into the memory of the microcomputer, where they can later be read (fig. 1). Aspects of the telemeter and continuous ECG recording have been combined in the microcomputer recording of heart rate. A transmitter connected to electrodes has a wireless contact to the memory of the microcomputer, where it can be analysed later as in Holter monitoring. Instead of a printed recording the heart rate is stored in the microcomputer memory. The results of the heart rate obtained from information fed to the microcomputer and that obtained from the ECG recorder for the same time period are well correlated for both rest periods and work periods (Karvonen et al. 1984).

#### 1.4 Experiences with the Use of These Methods

The telemeter is most useful in monitoring a single performance where rapid changes in heart rate are clearly observed. A negative factor is that it requires personal supervision at all times. Although rapid changes in the intensity of the work cannot be detected by a continuous ECG recording as easily as with a telemeter, the overall stress of the workout and changes between easy and strenuous periods can be clearly determined. With con-

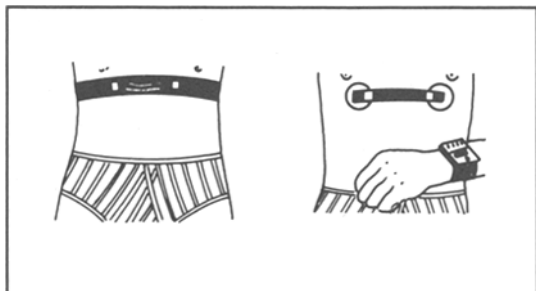


Fig. 1. The electrodes of the microcomputer used to measure heart rate are placed on the chest. The microcomputer display-

tinuous ECG and microcomputer recording personal supervision is not required since the heart rate is recorded on tape.

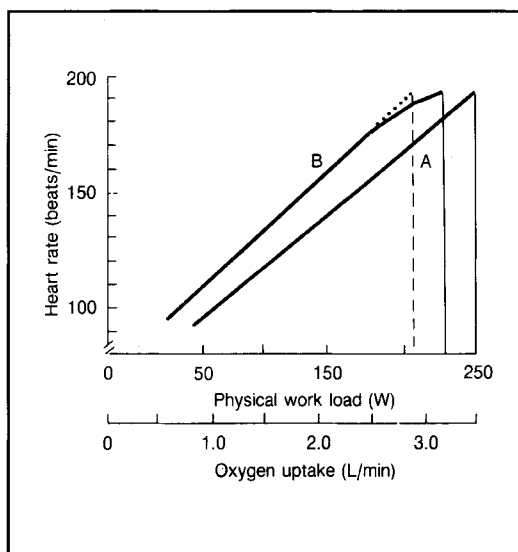
The telemeter can be used for follow-up of heart rate in short performances such as sprint, speed skiing and alpine skiing performances. Continuous ECG and microcomputer recording are most useful for endurance performances, i.e. skiing, endurance running or canoeing. Microcomputer recording is best for follow-up exercise intensity in recreational sport, because it is easy, accurate and rather cheap to use.

## 2. Relative Heart Rate

By recording the heart rate during a training session or a segment of training, and calculating the average of the heart rate and comparing this average to the maximum heart rate of the individual and at rest, the relative heart rate to the intensity of the workload ( $\%HR_{max}$ ) can be calculated. These results are useful in planning optimal training intensities for both the healthy and rehabilitating athlete. There is much research concerning the relationship of the heart rate, oxygen consumption and the intensity of exercise (Kamon & Kent 1972; Maritz et al. 1961; Nagel 1971; Verma et al. 1979).

According to Aunola et al. (1978) and Rosenblat (1967) the relative heart rate and relative oxygen uptake ( $\% \dot{V}O_{2max}$ ) are well correlated during light exercise. During strenuous endurance exercise at the anaerobic threshold of 4 mmol/L lactic acid concentration in capillary blood described by Jacobs et al. (1981) as onset of blood lactic acid accumulation (OBLA),  $\%HR_{max}$  of athletes has been  $87 \pm 4$  and  $82 \pm 5\%$  of  $\dot{V}O_{2max}$  (Karvonen 1983), quite similar values. Under maximum load the difference between values of  $\%HR_{max}$  and  $\% \dot{V}O_{2max}$  may be great because the oxygen uptake of some individuals under maximum load increases relatively more than the heart rate (fig 2).

Heart rate and  $\%HR_{max}$  indicate the relative work load in comparison with maximum load.  $\%HR_{max}$  can be calculated with the following equa-



**Fig. 2.** Interrelation between heart rates (beats/min), physical work load (W) and oxygen uptake ( $\dot{V}O_2$ ). The heart rate of person A increases linearly up to the maximum with physical work load and  $\dot{V}O_2$ . The  $\dot{V}O_2$  of person B increases, on the other hand, even after the maximal heart rate level (the points indicate the heart rate and the line, the increase in  $\dot{V}O_2$ ). With the maximal heart rate of 195 beats/min (person B) the estimated  $\dot{V}O_{2max}$  is 2.9 L/min, which is in reality 3.2 L/min (Åstrand & Rodahl 1970).

$$\%HR_{max} = \frac{HR_{work} - HR_{rest}}{HR_{max} - HR_{rest}}$$

Using this equation  $\%HR_{max}$ , indicating training intensity, approaches 100% under maximum load.

### 2.1 Heart Rate and Exercise Prescription

$\%HR_{max}$  has often been used to calculate the exercise intensities for athletes, for persons undergoing physical conditioning and in recreational sports. The use of target heart rate (see fig. 5 and the example) as a tool for exercise prescription (Karvonen et al. 1957; Karvonen 1975) is common. It represents the percentage difference between resting and maximum heart rate added to the resting heart rate.

For calculating target heart rate there are also 2 other methods. The first represents the percentage

peak heart rate. The second represents the heart rate at a specified percentage of maximum METs ( $\dot{V}O_{2max}$ ).

All 3 techniques are acceptable for use in determining the target heart rate or exercise intensities or both. In comparison Pollock et al. (1979) has shown that the target heart rate calculated by the percentage of heart rate maximum method was approximately 25 to 13 beats/min lower than that calculated by the other 2 methods (the method of Karvonen and METs) at 70 and 85% of maximum, respectively. The recommendations for exercise prescription designed for the general population are an intensity of 60 to 90% of maximum heart rate (the method of Karvonen) and duration of 15 to 60 minutes (continuous) 3 to 5 days per week (American College of Sports Medicine 1978). These recommendations are not designed for endurance athletes or persons in poor health. However, according to Roitman et al. (1978) these means of calculating an exercise prescription for athletes may be below the ideal training heart rate.

Since the resting heart rate increases with increasing age, whereas the maximal heart rate decreases,  $\%HR_{max}$  is a better indicator of exercise intensity than heart rate alone because the effect of age and other individual factors is minimal.

### 2.2 Use of Relative Heart Rate in Training

Relative heart rate is a method to estimate the exercise intensity during outdoor endurance training. Running speed during training is increased in stages. The average time per kilometre corresponding to the speed at each stage is calculated (time/km) and simultaneously the heart rates corresponding to each stage and to the average time per kilometre is measured by the telemeter. The  $\%HR_{max}$  indicating the intensity of running speed for each stage is calculated when the heart rate at rest and the maximal heart rate are known (Karvonen 1975, 1976a,b).

For example, the heart rate of an endurance runner at rest ( $HR_{rest}$ ) is 80 beats/min and the maximal heart rate ( $HR_{max}$ ) is 198 beats/min. The

speed in normal training circumstances is 286 seconds and the heart rate 198 beats/min. During running at constant speed on medium exercise intensity the average time per kilometre is 333 seconds and the heart rate 184 beats/min.

During walking in the same training circumstances the average time is 429 seconds and the heart rate 159 beats/min. In order to determine the heart rate and the speed at which one has to run so that the physical work load in training would correspond to 80%  $HR_{max}$ , the corresponding heart rate ( $HR_{work}$ , i.e. target heart rate) is calculated with the following equation:

$$HR_{work} = (HR_{max} - HR_{rest}) \times \%HR_{max} + HR_{rest}$$

where the  $HR_{work}$  will be 174 beats/min. The average time per kilometre corresponding to this heart rate is obtained from figure 3 and is 370 seconds.

Soviet scientists have used this method to measure the physical work load in ski training (Mihalev 1983).

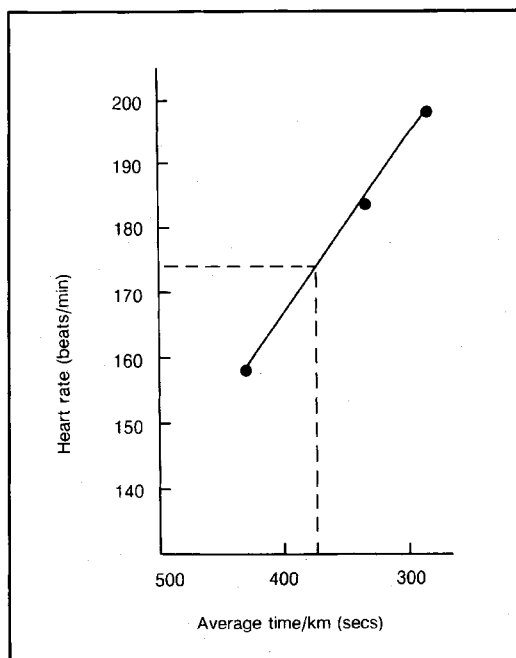


Fig. 3. The determination of average time per kilometre corresponding to the relative heart rate of 80%  $HR_{max}$ , indicating

### 3. Use of Heart Rate in Controlling Individual Endurance Training

In most sports events endurance is one of the factors affecting performance. In events where endurance is not the most decisive factor, the endurance factor in training is usually called 'general conditioning'. Relative heart rates are useful indicators of the effectiveness of general conditioning.

In sports where endurance is the most decisive factor and where the competition performance mostly depends on the development of endurance, the control of the effectiveness of endurance training is of utmost importance.

#### 3.1 Control of the Effectiveness of Training for the Long Distance Runner

As speed in long distance running increases to maximum endurance running speed, the production of aerobic energy increases linearly with the increase in running speed until maximum speed is approached, when the oxygen uptake begins to increase at a greater rate than the running speed.

The production of anaerobic energy also increases with increased running speed and causes variations in pH levels as the anaerobic threshold of 4 mmol/L (Jacobs et al. 1981) is reached. As the long distance runner exceeds the running speed corresponding to the anaerobic threshold and approaches the maximal oxygen uptake the heart rate no longer accurately indicates the real responses to training.

#### 3.2 Determination of an Appropriate Heart Rate

An appropriate individual heart rate for each level of an endurance performance is best determined in the laboratory. This is carried out by increasing the speed of the runner in stages on a treadmill and by measuring the oxygen uptake, the lactic acid concentration in the blood and corresponding variations in the heart rate. From these

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