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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 ($\%HR_{max}$) 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 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 results the running speed and heart rate corresponding to aerobic, partly anaerobic or strongly anaerobic running can be determined.*

The $\%HR_{max}$ 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, for subsequent analysis and measurement, are registered 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 wrist as easily as a watch (Säynäjäkangas 1983).

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

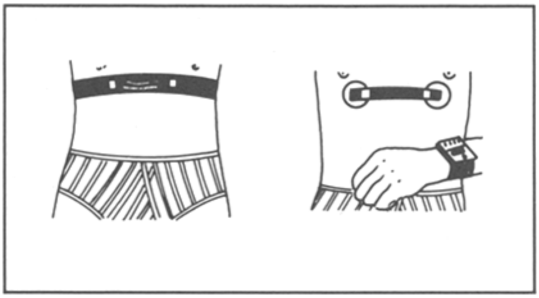

Fig. 1. The electrodes of the microcomputer used to measure heart rate are placed on the chest. The microcomputer displaying the heart rate is on the wrist.

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 ± 4 and 82 ± 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 equation:

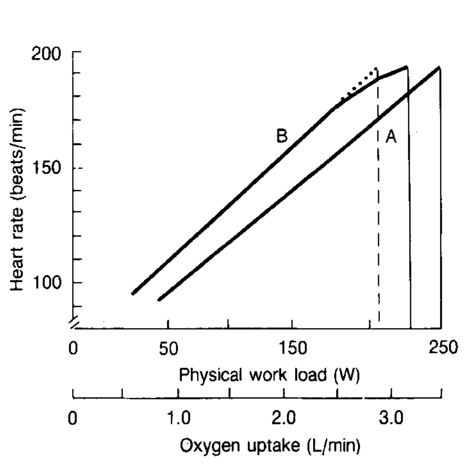

Fig. 2. Interrelation between heart rates (beats/min), physical work load (W) and oxygen uptake ($\dot{V}O_2$). The heart rate of person A increases linearly up to the maximum with physical work load and $\dot{V}O_2$. The $\dot{V}O_2$ of person B increases, on the other hand, even after the maximal heart 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 of the maximum heart rate calculated from zero to 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 average time per kilometre at maximal running 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).

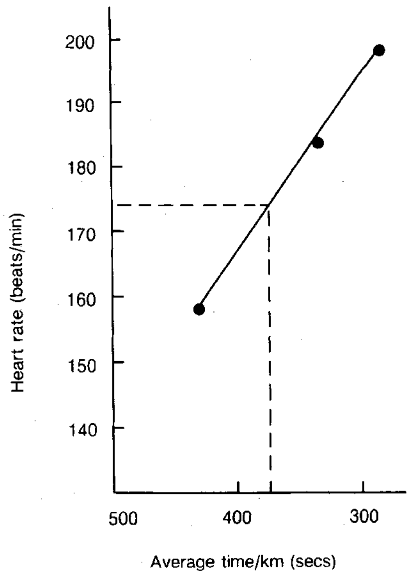

Fig. 3. The determination of average time per kilometre corresponding to the relative heart rate of 80% HR_{max}, indicating the physical work load.

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 results the running speed and heart rate corre-

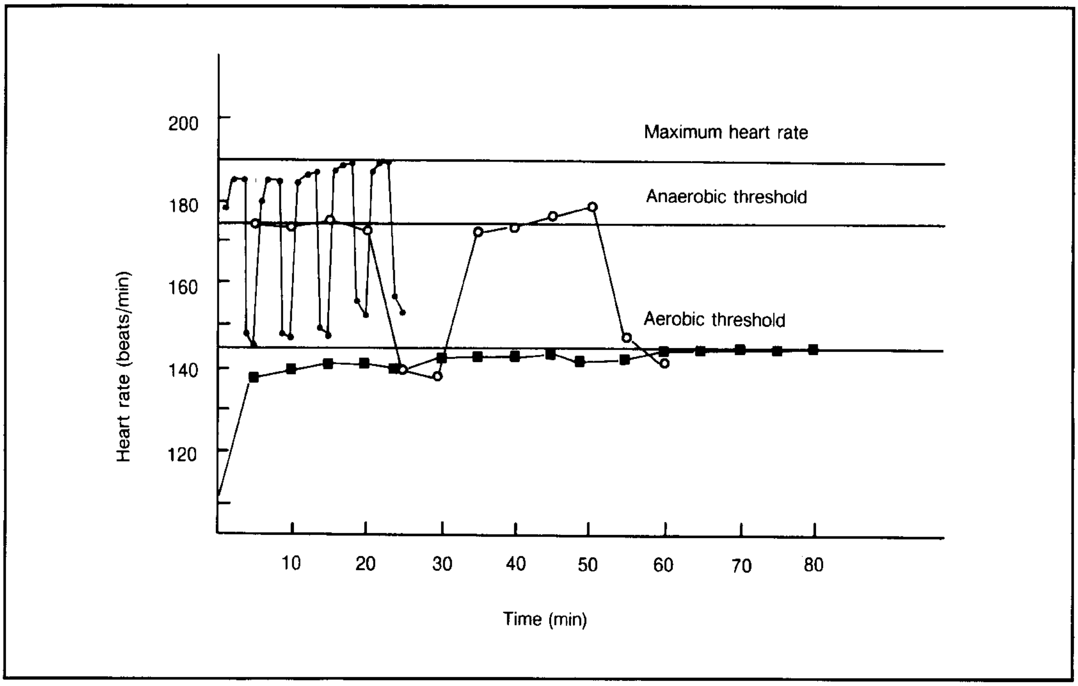

Fig. 4. Heart rate curves taken from typical long distance training. 20km run (■), 2 × 6km run with 10-minute recovery (○) and 5 × 1km run of 95% $\dot{V}O_{2max}$ with 2-minute recovery (●).

sponding to aerobic, partly anaerobic or strongly anaerobic running can be determined.

The upper limit for mainly aerobic running speed is the aerobic threshold of 4 mmol/L lactic acid concentration in capillary blood (Jacobs et al. 1981) which is normally 30 to 50 beats/min below the maximal heart rate for a long distance runner. The critical limit for partly anaerobic running, i.e. the anaerobic threshold, is generally 10 to 20 beats/min below the maximal heart rate.

At higher heart rates, running for longer than 2 minutes always causes some variations in pH levels. This is, however, necessary in order to increase the maximal aerobic capacity. The entire maximal aerobic capacity is in use when the heart rate is at its maximum.

An adult long distance runner in good physical condition is capable of running approximately 10 minutes at $\dot{V}O_{2max}$ and about 60 minutes at a speed corresponding to the anaerobic threshold.

Corresponding running speeds and heart rates can be estimated by running tests for distances of 3000m and 15 to 20km. During the shorter performance the heart rate reaches its maximum and during the longer the average heart rate is nearly that corresponding to the anaerobic threshold.

As heart rates corresponding to various levels of endurance performance are either determined in the laboratory or estimated in field tests, the effectiveness of daily endurance exercises can be controlled and, if necessary, corrected (see fig. 4).

3.3 Use of $\%HR_{max}$ in Cross-Country and Alpine Skiing

The physical workload during training is normally described with terms such as easy, medium and strenuous. Subjective feelings of exercise intensity are often misleading. This has been shown by using $\%HR_{max}$ in intensity measurements during training exercises (Karvonen et al. 1982). During snow-free periods the endurance training of skiers consists of walking, running and roller-skating.

The exercise intensity of walking depends on technical skills. This is why a skier's walking done at maximal speed has a lower physical workload than running at constant speed (Karvonen 1977, 1980). Young skiers' subjective estimates of the exercise intensity during their training are often inaccurate. Easy training at constant speed is done with an intensity of 60 to 70% of the maximum but medium training is often done with 90% of the maximum which is in fact already strenuous and exceeds the medium training level (Karvonen 1982). Rollerskiing and running at slow or medium speed correlate well with each other but in the maximal rollerskiing training the same physical work load is not reached as in maximal skiing, even if in rollerskiing the muscles of the upper body including the arms are used (Pekkarinen et al. 1984). This is often because of poor rollerskiing technique. Thus, running exercises are more effective in improving the aerobic capacity of skiers than rollerskiing.

The $\%HR_{max}$ values obtained by continuous ECG recording and telemetry have been used to measure the physical work load in alpine skiing (Karvonen et al. 1984; Rauhala & Karvonen 1984; Rauhala et al. 1987a,b). Alpine skiing utilises interval exercises with varying rest and load phases. The exercise intensity during downhill skiing is, in general, of short duration and, depending on the slope, radius of turns and on individual skills, quite intense. The energy production is mainly anaerobic, especially at the end of the performance. In downhill skiing on a slope of 600 metres in length and with a drop of 130 metres in height, with 1 run every 10 minutes during 2 hours, the total physical work load is approximately 55 to 57 $\%HR_{max}$ (Nagel 1971). The physical work load of each separate run may vary between 65 and 95% HR_{max} (fig. 5).

Alpine skiing has been regarded 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 (Karvonen et al. 1985a,b,c).

4. Conclusions

Heart rate measurements with a telemeter, continuous ECG (Holter monitoring) or microcomputer recording are widely used for estimation of exercise intensity during normal outdoor training, because these apparatus are easy to use and they allow a subject to make his exercises freely during follow-up period. In determination of target heart rate and $\%HR_{max}$ there are differences between different methods. The method representing the percentage of the maximum heart rate calculated from zero to peak heart rate gives lower heart rate values at the same exercise intensity than the method of Karvonen and METs.

The use of target heart rate and $\%HR_{max}$ is appropriate for follow-up of exercise intensity in training of endurance athletes, in recreational sport and in rehabilitation after sicknesses.

The exercise intensity determined by $\%HR_{max}$ may differ from the one determined by $\%\dot{V}O_{2max}$. During strenuous endurance exercise at the aerobic threshold of 4 mmol/L lactic acid, the $\%HR_{max}$ of athletes determined by the method of Karvonen or METs corresponds well to the $\%\dot{V}O_{2max}$. 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.

Coaches and athletes who control training and exercise intensity by heart rate measurements should avoid testing in each training session, as it may also be disruptive for the athlete. These tools are most useful as a check, when an athlete's physical performance capacity is expected to change or a coach wants to control the effect of training in normal circumstances. Currently the heart rate measurements are almost the only common methods for estimation of the exercise intensity. In the future, when ambulatory oxygen uptake testing methods are better developed heart rate measure-

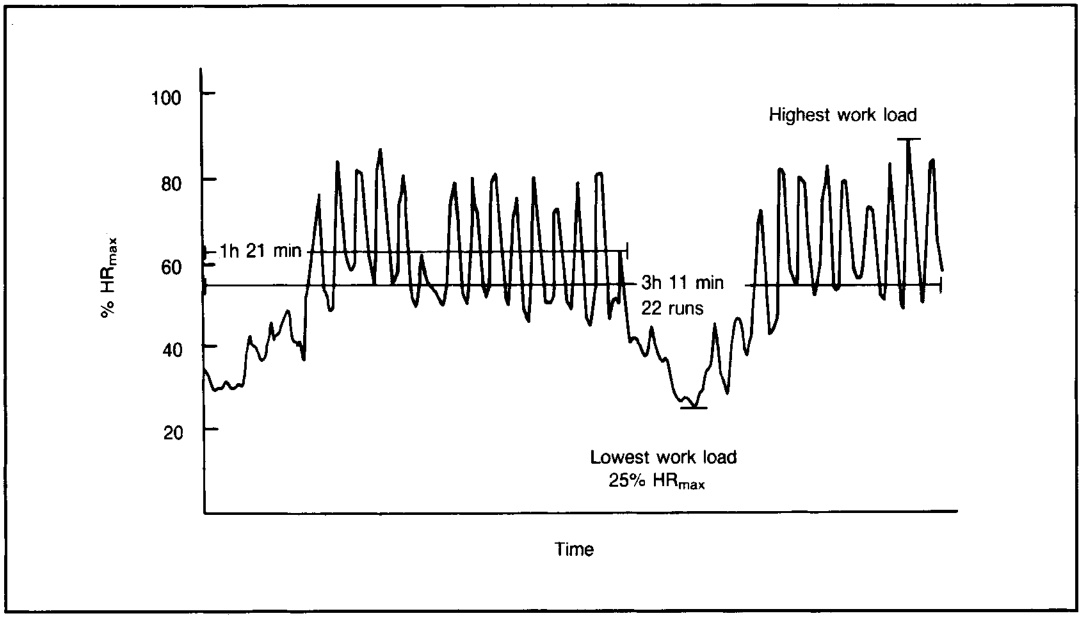

Fig. 5. Variations in the relative heart rate (%HR_{max}) of a subject during 3 hours and 11 minutes of slalom training. For the first 1h 21min the mean exercise intensity was 63% HR_{max} and for 3h 11min 55% HR_{max}.

ments will have less importance, especially in top sports.

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