FROM THE INSTITUTE OF OCCUPATIONAL HEALTH, HELSINKI

THE EFFECTS OF TRAINING ON HEART RATE

A »LONGITUDINAL» STUDY

by

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Training is known to lower the heart rate. Both the resting heart rate and the heart rate at a standard exercise become slower. This has been observed by comparing the heart rates of athletes and non-athletes, as well as in a few »longitudinal» studies, in which the heart rate of the same subjects has been observed during training (e.g. 6).

The maximum heart rate attainable during exercise is known to depend on age and sex (2). The maximum rate is claimed to be also dependent on physical fitness: it is less in athletes than in non-athletes (14). Other investigators have come to a contrary result; according to them, there is no difference between the maximum heart rates of trained and untrained subjects (12, 16, 19). In a longitudinal study (18) the maximum heart rate actually became slower during training.

In the present study, training of different intensities was used, and its effect on the resting, working and maximum heart rates was studied. The purpose was to find out what kind of quantitative relations may prevail between the intensity of training and the heart rates.

MATERIAL AND METHOD

The *subjects* were six male medical students, age from 20 to 23 years. One of them performed two training experiments, with an interval of five weeks. The subjects trained by *running* on a horizontal treadmill. The time run each day was constant, 30 minutes. Training occurred during 4 or 5 days a week, and each training experiment lasted 4 weeks.

The *working heart rate* (WR) was counted by using a stethoscope; the subject stepped off the treadmill for appr. 15 seconds, and a 10 sec. pulse count was taken. This was repeated every 10 minutes. Such a procedure is known to give a good approximation of the pulse rate during actual work (10, 17). The mean of the three counts is given as WR.

The aim was to keep the intensity of training constant during each training period. For this purpose, the *speed of running* was adjusted so that WR remained as close as possible to the predetermined level.

Each subject counted his *resting heart rate* (RR) every morning during the training period, in bed, before getting up.

The *maximum running heart rate* (MR) was determined at the beginning and at the end of each training period. The subjects ran at a submaximal speed until exhaustion, which with the speeds used was reached in 2 minutes or less; the heart rate was counted in the same way as in determining WR.

A chest roentgenogram was taken at the beginning and end of each training period, for determining the *heart volume* (22).

RESULTS

The results of the training experiments are shown in Table 1. A decrease of WR as effected by training appears in these experiments as an increase of the running speed. The intensity of training is expressed in two ways: (1) as WR, and (2) as $\frac{WR}{MR—RR} \times 100$; this expresses the WR as a percentage of the total range of pulse rates from rest to the maximum attainable by running, as calculated from the MR and RR at the start of training. The first value of RR was used as the beginning figure. For the

TABLE

SUMMARY OF THE RESULTS OF TRAINING EXPERIMENTS, IN THE ORDER OF INCREASING INTENSITY OF THE TRAINING.

WR = working heart rate, MR = maximum heart rate, RR = resting (morning) heart rate

Subject	Runing Speed km/hr			Mean WR	WR	MR			RR			Heart Size cc		
	Begin	End	Δ		MR-RR × 100	Begin	End	Δ	Begin	End	Δ	Begin	End	Δ
O.M. (1) ..	9	9	0	135	60	180	180	— 0	53	51	—2	560	585	+ 25
E.K.	9	9	0	136	60	192	186	— 6	52	48	—4	655	790	+135
K.L.	9	10	+1	137	60	192	174	—18	55	52	—3	525	780	+255
E.H.	11	13	+2	135	71	170	156	—14	52	46	—6	760	715	— 45[1]
O.M. (2) ..	11	13	+2	150	75	186	174	—12	55	50	—5	555	560	+ 5
O.K.	11	14	+3	160	75	192	186	— 6	58	55	—3	670	665	— 5
J. K.	11	14	+3	180	74	224	184	—40	52	48	—4	820	665	—155[1]

[1] Heart volume was measured from the orthodiagram only, using Bardeen's formula (5).

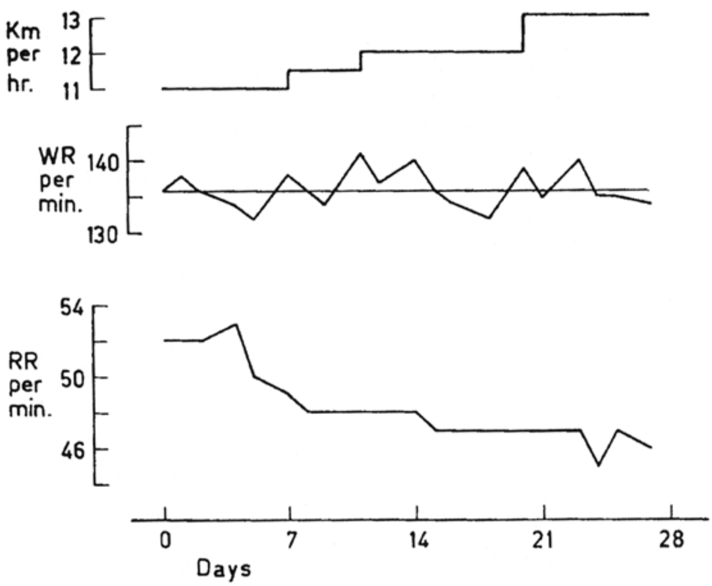

Fig. 1. — Speed of running (km per hr.), running heart rate (WR), and resting heart rate (RR) of subject E. H. during a training period. Running at the heart rate 136 per min. which was 71 per cent of the available range of heart rates at the beginning, produced a training effect which necessitated a progressive increase of the running speed.

ending figure the lowest pulse rate counted at least on two mornings was chosen; generally the lowest RR:s were observed at the end of the training period.

As an example, the results of an experiment are shown in detail in Fig. 1.

The results indicate that training in some experiments caused a decrease of WR which necessitated an increase of running speed, but in others no change of WR occurred. A decrease of WR was observable in those experiments in which running was fastest. If WR was used as an indicator of the intensity of training, the borderline between »effective» and »ineffective» training was not sharp. However, if the WR was expressed as a percentage of the range of pulse available, there appeared to be a critical limit at or slightly above the 60 per cent training level.

The MR decreased, in all but one of the experiments, but the decrease of MR apparently was not related to changes in WR or RR. The greatest fall, 40 beats per min., was observed in the subject who had the highest MR to start with.

The RR fell a few beats in every series. The extent of the decrease was not related to changes in WR or RR.

The roentgenological volumes of the heart showed both increases and decreases, with no clear relation to the intensity of training.

DISCUSSION

It is well known that training can cause a decrease of the WR, and several types of tests of »physical fitness» are based on counting the exercise or post-exercise heart rate. The work of Åstrand (2) and Ryhming (20) shows that there is a close correlation between the maximum oxygen uptake of a subject and his or her heart rate response to graded exercise, which correlation may be used as a basis for assessing the maximum oxygen uptake from the heart rate recorded during submaximal work; a nomogram for this purpose has been published (4).

The most interesting result of the present study is that considerable time and effort may be devoted to training at a work and heart rate level distinctly above those customary in medical studies, without the actual benefit of a measurable decrease of the WR. If the correlation between WR and maximum oxygen uptake is to be accepted also in this situation, the training has been without effect also on the latter. On the other hand, if training occurs at a more intense level, with pulse rates above 150 per min., or taxing at least 70 per cent of the available range of pulse rates, the training will cause a decrease of the WR.

These findings have an important bearing on the planning of athletic training. In order to cause an increase of the maximum oxygen uptake, training must be intense. Misguided philanthropism in the administration of athletic training programs may deprive them of one of their major effects.

In the physiological rationalisation of occupational work, normative limits have been defined, above which work is considered to be unduly heavy for the human organism. One of these norms is that in work done for a full working day, the heart rate ought not to rise above 125 or 130 per minute. In relatively short operations, heart rates of up to 150 are to be allowed (8).

The normative limit for heart rate at continuous work is distinctly below those values at which a training effect on WR was obtained in the present series. According to experience from a number of occupations heart rates above 130 per minute are relatively rare in industry. The present tendency in industry is to more uniform work, and to an exclusion of physically heavy operations from the day's program. These factors make it obvious that occupational work, even relatively heavy physical work, rarely exerts a training effect on the heart, i.e. a decrease of the WR. If the worker wishes to increase his cardiovascular reserves — as expressed by the margin above the level of oxygen uptake required in his particular work — he has to take recourse to activities more intense than those offered by his occupation.

Running on a level course may not be the most practical and efficient means for an improvement of the WR and of the maximum oxygen uptake. In activities like skiing, in which larger groups of muscles participate, higher MR:s and maximum oxygen uptakes have been obtained than in running (9,23). Heart rates which in the present study proved sufficient to produce a training effect on the WR, are — according to the writers' experience — subjectively more easily attained by skiing than by running.

MR and RR decreased during training in all experiments, without evidence for the need of a similar critical limit in the intensity of training than with WR. Johnson and Brouha (14) report distinct differences in MR according to the state of training and physical fitness, in the same sense as those observed in the present study. Montoye, in a longitudinal study of changes in MR during a 12 weeks' training period, observed a mean decrease by 15 beats per min. in 50 subjects (18).

The factors governing the effects of training on the heart rate at rest and in work are multiple. The increase of the heart rate during work is understood probably occurring as a reflex response, in which the afferent stimuli come from the working muscles (1). It is reasonable to assume that the impulse drive from the muscles will become particularly intense when the conditions in the muscle become anaerobic. Training improves the blood supply of working muscles locally. Anaerobic conditions are not as easily produced in a trained muscle as in an untrained one. This reasoning is in line with the observation that the maximum pulse rates attained by running decreased during training: the afferent impulse drive from the trained muscles during maximum effort appears to have been less than at the beginning of training.

In work at a steady state, the muscles work under predominantly aerobic conditions. If anaerobiosis is important in determining the impulse drive from the muscles, as assumed above, training may be expected to have less effect on heart rates at »steady state» levels than in more intense work in which products of anaerobic metabolism pile up in the working muscles. This reasoning is in agreement with the present results, in which MR could decrease considerably, without a parallel change in WR. The WR probably depends relatively more on the condition of the heart and less on that of the peripheral muscles.

Previous experience has shown that among various indicators of exercise tolerance, the recovery of the heart rate after exercise is sensitively correlated with the amount and intensity of training (e.g. Karvonen: unpublished observations). The rate of recovery is used as a basis for several tests of cardiovascular fitness. At relatively low work intensities, at which the concentration of anaerobic metabolites in the circulating blood remains low, the rate of recovery probably depends on the local vascular conditions of the working muscles. At high intensities of exercise anaerobic metabolites, notably lactic acid, are present in blood at high concentrations. In such circumstances, the rate of recovery of the heart rate is an indication also of the adequacy of the cardiac output during work. In the present study the rate of recovery was not determined.

It is generally agreed that variations of RR are to a large extent irrelevant for cardiovascular fitness: adaptation to work is not strictly dependent on the type of adaptation to rest. The independence of RR from WR and MR is in agreement with such a conclusion.

Great individual differences certainly exist in the training process. The importance of individual differences is suggested e.g. by the irregular changes in the roentgenological volume of the heart in the present series. Although a pronounced positive statistical correlation prevails between maximum oxygen uptake, total blood volume and resting heart volume (2, 15), training of moderate intensity may in an individual subject lead to a change even in the opposite direction, as in the subjects E. H. and J. K.

The present study deals with only one of the variables in endurance training, the speed of running. The time of each training run, the frequency of the runs, and the total duration of the training period were kept constant. All these factors, and, moreover, the physical fitness of the subjects at the beginning of the training period may be important determinants of the results of training. The effects of each of these factors has to be ascertained separately. However, the rate of work rather than the total amount of it probably is the most important factor in training (7, 11, 13, 21).

The method of training used in the present study makes it possible to keep the training physiologically constant, at a predetermined heart rate level, and to gauge simultaneously the effect of training on an important component of exercise tolerance, the maximum oxygen uptake, from the adjustments of speed necessary for keeping the WR constant. A further advantage of the method is that the results are quite independent of the motivation of the subjects, since training occurs and all essential observations are made at the level of submaximal effort.

SUMMARY

Six young male subjects trained by running on treadmill half an hour daily, 4 to 5 times a week, over a period of 4 weeks; one of the subjects did two training periods. The speed of the treadmill was adjusted so that the working heart rate (WR) remained at a predetermined level throughout the training period.

Training by running at a relatively high speed, and consequently with a high heart rate, caused a decrease of the WR, which was counteracted by further increasing the speed of running. However, running at a slow speed and thus with a low heart rate did not produce any decrease of the WR. It was concluded that the heart rate during training has to be more than 60 per cent of the available range from rest to the maximum attainable by running — or above appr. 140 per minute — in order to produce a decrease of the WR. A decrease of the WR is understood to indicate an increase of the maximum oxygen uptake. Training by running at lower speeds and pulse rates may nevertheless cause a decrease of the resting heart rate (RR) and of the maximum heart rate (MR) attainable by running. Changes of RR, MR and WR were largerly independent of each other; those of RR and MR also from the intensity of the training.

The bearing of the results on athletic training and on occupational work is discussed.

REFERENCES

1. Asmussen, E., and Nielsen, M.: Physiol. Rev. 1955:*35:*778.
2. Åstrand, P.-O.: Experimental studies of physical working capacity in relation to sex and age. Copenhagen 1952.
3. Åstrand, P.-O.: Physiol. Rev. 1956:*36:*307.
4. Åstrand, P.-O., and Ryhming, I.: J. appl. Physiol. 1954:*7:*218.
5. Bardeen, C. R.: Amer. J. Anat. 1918:*23:*423.
6. Christensen, E. H.: Arbeitsphysiol. 1931:*4:*453.
7. Christensen, E. H.: Arbeitsphysiol. 1931:*4:*470.
8. Christensen, E. H.: In Ergonomics Society Symposium on Fatigue. Pp. 93—108. London 1953.
9. Christensen, E. H., and Högberg, P.: Arbeitsphysiol. 1950:*14:*292.
10. Cotton, F. S., and Dill, D. B.: Amer. J. Physiol. 1935:*111:*554.
11. De Lorme, J.: J. Bone Jt Surg. New Ser 27, 1945:*43:*645.
12. Dill, D. B., and Brouha, L.: Travail hum. 1937:*5:*3. Ref. by Åstrand (3).

13. EDWARDS, H. T., BROUHA, L., and JOHNSON, R. E.: Travail hum. 1940:*8*:1. Ref. by ÅSTRAND (3).
14. JOHNSON, R. E., and BROUHA, L.: Rev. Canad. Biol. 1942:*1*:171.
15. KJELLBERG, S. R., RUDHE, U., and SJÖSTRAND, T.: Acta physiol. scand. 1949:*19*:152.
16. KNEHR, C. A., DILL, D. B., and NEUFELD, W.: Amer. J. Physiol. 1942:*136*:148.
17. LUNDGREN, N.: Acta physiol. scand. 1946:*13*:41.
18. MONTOYE, H. J.: Research Quarterly 1953:*4*:453.
19. ROBINSON, S., EDWARDS, H. T. and DILL, D. B.: Science 1937:*85*:409.
20. RYHMING, I.: Arbeitsphysiol. 1954:*15*:235.
21. SIEBERT, W. W.: Z. klin. Med. 1929:*109*:350.
22. STRANDQUIST, M.: Acta radiol. ,Stockh. 1935:*16*:304.
23. TAYLOR, H. L., BUSKIRK, E., and HENSCHEL, A.: J. appl. Physiol. 1955:*8*:73.