H. Cardio-Respiratory Physiology

ELECTROCARDIOGRAPHIC CHANGES IN PERSONS WITH ACUTE HIGH ALTITUDE HYPOXIA (STUDIES IN A LOW PRESSURE CHAMBER)

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Introduction

There are individual differences in response to hypoxia due to lowered atmospheric pressure. An impaired adaptation to such hypoxia may lead in some to circulatory collapse and unconsciousness. If oxygen is not supplied in sufficient amount immediately sudden death in these cases may occur. This is of particular importance for pilots and Alpinists.

Using electrocardiographic criteria an attempt was made to establish a) which features of "resting" (initial) ECG may predict good or impaired tolerance of oxygen deficit, and b) which ECG changes, if any, caused by high altitude hypoxia correlate with good or impaired tolerance of such condition.

Material and methods

223 healthy glider pilots and parachutists, aged 17-29 years, were studied. The electrocardiograms were performed before and while in a hypobaric chamber where they were subjected to a low pressure corresponding to the altitude of 6.500 m. Usually five leads were taken: 3 standard limb leads and 2 precordial leads, V2 and V4 or V3 and V5, according to technical circumstances.

Results

In nearly half of the subjects some cyanosis was observed already at the altitude of 5000 m. In 53 cases (24%) a circulatory collapse with loss of consciousness occurred. In most cases the resting electrocardiograms, i.e. taken before experiment, showed characteristic features of well trained persons. Tall "vagotonic" T-waves were noted in 89 cases (40%). Significant bradycardia, less than 55 per min, was seen in 16 cases (7%). The most common abnormality was right axis deviation. Other abnormalities which deserve to be mentioned are: flat T-waves in 16 cases (8%), notching of the QRS complexes, delta-waves etc. in 16 cases (7%), partial right bundle branch block in 1 case, WPW syndrome in 1 case.

As compared with the resting electrocardiograms the typical change during the experiment was flattening of T-wave, sometimes with ST-depression, and acceleration of sinus rhythm. According to the degree of these "ischaemic" features, 4 types of ECG were distinguished: type I – with slight T-wave flattening, type II – with moderate T-wave flattening, type III – with significant T-wave flattening together with ST-depression, and type 0 – with no change observed.

The details are presented in the tables.

Table I

The distribution of the types of ECG taken during the experiment in the subjects studied.

<table>
<thead>
<tr>
<th>ECG type</th>
<th>with collapse</th>
<th>without collapse</th>
<th>Number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7 (64%)</td>
<td>4 (36%)</td>
<td>11</td>
</tr>
<tr>
<td>1</td>
<td>15 (30%)</td>
<td>36 (70%)</td>
<td>51</td>
</tr>
<tr>
<td>II</td>
<td>18 (14%)</td>
<td>115 (86%)</td>
<td>133</td>
</tr>
<tr>
<td>III</td>
<td>13 (46%)</td>
<td>15 (54%)</td>
<td>28</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>170</td>
<td>223</td>
</tr>
</tbody>
</table>

0 = with no change of ST-T
I = with slight flattening of T-waves
II = with moderate flattening of T-waves
III = with significant changes of ST-T

In isolated cases the electrocardiograms taken during high altitude hypoxia exhibited some abnormalities suggesting the existence of latent lesion of the myocardium. In this respect a few cases should be mentioned: one case with s-a block, one case with ventricular extrasystoles and 2 cases with pathologic elongation of QT interval.

Discussion

As can be seen in the table I the most favourable
The prevalence of resting ECG features in respect of the tolerance of high altitude hypoxia

<table>
<thead>
<tr>
<th>Feature</th>
<th>With collapse</th>
<th>Without collapse</th>
<th>Whole group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bradycardia</td>
<td>6</td>
<td>11%</td>
<td>16</td>
</tr>
<tr>
<td>“Vagotonic” T-waves</td>
<td>29</td>
<td>55%</td>
<td>89</td>
</tr>
<tr>
<td>Flat T-waves</td>
<td>5</td>
<td>9%</td>
<td>14</td>
</tr>
<tr>
<td>Alpha QRS &lt; 30°</td>
<td>4</td>
<td>8%</td>
<td>9</td>
</tr>
<tr>
<td>Notching of QRS complexes</td>
<td>7</td>
<td>13%</td>
<td>17</td>
</tr>
</tbody>
</table>

Table II

The data presented in the table II suggest that some features of resting ECG may have a prognostic value concerning the tolerance of oxygen deficit. Among them the features of circulatory hypervagotonia, especially an outstanding bradycardia, should be emphasized. This observation indicates that an excessive parasympathetic system tonus, considered commonly as an attribute of perfectly well trained sportsman, may in some cases impair the adaptation to high altitude hypoxia.

Conclusions

1. Some prediction of poor adaptation to hypoxia due to lowered atmospheric pressure can be made on basis of the resting electrocardiogram. The suggestive signs are: hypervagotonia (especially high degree bradycardia), flat T-waves, left axis deviation, and abnormalities of the intraventricular conduction system.

2. The most favourable form of electrocardiographic changes in a low atmospheric pressure conditions seems to be a moderate acceleration of sinus rhythm and a moderate flattening of T-waves.

3. In some cases the ECG taken in high altitude hypoxia may reveal existence of a latent myocardial lesion.

Fig. 1. Glider pilot, 20 years old, with good tolerance of high altitude hypoxia. Type II of ST-T changes. A = ECG before experiment. B = ECG at the height of 6,500 m.

Fig. 2. Glider pilot, 21 years old, with circulatory collapse during the experiment. Type III of ST-T changes. Heart rate increased from 75 to 130 per min.
Fig. 3. Parachutist, 18 years old, with circulatory collapse during the experiment. Type 0 of ST-T changes. Distinct ECG features of hypervagotonia.

Fig. 4. Glider pilot, 20 years old, with circulatory collapse during the experiment. An outstanding bradycardia in initial ECG (46/min).

Fig. 5. Parachutist, 22 years old, with circulatory collapse during the experiment. Frequent ventricular extrasystoles provoked by oxygen deficit.

Fig. 6. Glider pilot, 20 years old, with circulatory collapse during the experiment. Distinct notching of QRS complexes. S-A block in ECG taken at the height of 6,500 m.

Fig. 7. Glider pilot, 19 years old, with circulatory collapse during the experiment. Type III of ST-T changes. Distinct elongation of QT interval.

Fig. 8. Glider pilot, 19 years old, with relatively good tolerance of high altitude hypoxia. Wolff-Parkinson-White syndrome. In the ECG taken during the experiment a "concertina effect" can be seen.
THE INFLUENCE OF ATHLETIC TRAINING ON RESISTANCE
TO NON-SPECIFIC FUNCTIONAL EFFECTS

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It is well known that athletic training improves the ability to resist various nonspecific influences, those of temperature, acceleration, vibration, hypoxia, etc. The present examination was aimed at the study of peculiarities of adaptation of the cardiovascular system of athletes to such influences as bed rest for many days and prolonged water immersion. We have studied the ECG, the phase structure of the heart cycle, cardiac output, the regional vascular tonus, the arterial pressure, the blood and plasma volume, the haematocrit and some biochemical indices, at rest, during passive orthostatic tests and during standard and maximal muscular work. The changes in the analysed indices testify to deterioration of the functional state of circulation which reveals itself in the lowering of economy of the heart activity in rest and sharp deterioration of tolerance to orthostatic influences and muscle efforts.

During prolonged bed rest two stages of cardio-vascular adaptation to the lack of exercise occur. The changes in the circulation parameters during the first stage are advantageously connected with redistribution of fluid masses in the organism determined by the horizontal posture of the persons under the examination. In these conditions the decrease of blood volume, the increase of haematocrit, changes of ECG and dynamics of myocardial contractility are noted. After moderately expressed changes the phase of stabilisation comes during which the indices of ECG, phase structure of heart cycle and arterial pressure are practically unchanged. The duration of this stage of adaptation is approximately 25-30 days, and for nonathletes up to 20 days; for sick persons this stage in many cases is absent.

During the second stage of adaptation the changes of regulation which are characterised by the imbalance of vago-sympathetic interrelations are noted. Against a background of inhibitory activity, the sympatho-adrenal system and cholinergic and sympa-tho-inhibitory mechanisms' relative advantage of sympathetic influences is noticed. The changes of ECG appreciated as indices on myocardial lesions decrease. The analysis of the contractility of heart, phase changes and cardiac output, shows the increase of its contractile function and the decrease of its economy at rest. Changes of regional tonus of the arteries reflect definite disturbances of the regulation of peripheral circulation.

In conditions of water immersion, during the first 3 days, adaptive reactions which are expressed in considerable changes of circulation and hydro-electrolytic balance are noted.

In case of athletes out of training, a passive orthostatic test (head up) was accompanied by the fast tachycardia and considerable decrease of stroke volume, to 80%. In 2 cases out of 20 after bed rest and in 10 out of 33 — after water immersion orthostatic collapse was noted. Changes of orthostatic tolerance are connected with neural-humoral regulation disturbances, the decrease of blood volume and the increase of elasticity of venous walls.

The deterioration of physical exercise capacity was expressed in the shortage of run duration with constant velocity on the treadmill, until subjects under examination refused to continue the exercise; in the decrease of pulse cost of the dose work task, 10-minute pedalling on the veloergometer under constant value of the exercise; delay in restitution to the original indices, etc. The maximal value of extension time of minute volume (cardiac output) during the work after detrained effects was considerably decreased. Changes of physical work capacity are closely connected with duration of enforced rest and are mostly expressed after 40 days bed rest, being practically absent after 1 day water immersion. Running speed after bed rest and water immersion did not change in many cases. The direction of changes observed with athletes and untrained persons is, in general, equal. At the same time it is necessary to point out that training guarantees a certain protective effect with regard to the influence caused by prolonged bed rest and water immersion. If mobility is restricted for a comparatively short time it reveals itself in relatively small changes in the reactivity of the cardiovascular system and fast restitution to the initial indices. If the hypokinesis is long, 40 days or more, the shifts are pronounced much more strongly but at the same time recuperation occurs more rapidly than in untrained persons. The athletes under examination quickly recovered their physical work capacity and soon after the termination of the experiments described could achieve good athletic results.

The peculiarities of changes in the functional state of the cardiovascular system which developed in persons with different level of physical preparation allow us to assume that the character and degree of changes in the basal state and reactivity of circulation depend greatly
on the initial functional state of the regulator mechanisms which depends on the physical preparation of the persons under examination.

So, the most marked changes in pulse wave velocity along the vessels of the arm under the influence of the work tasks on the veloergometer are noted in sedentary subjects. The degree of change considerably increased after the 1 day water immersion. After 3 months physical training the expression of vessel tonus changes during the work as before but after immersion was considerably decreased.

The stability of the organism which permits to resist the influence of bed rest and the immersion of qualities characteristic of certain kind of sports is connected with the character of physical exercise which is predominant in the training schedule.

The runners retained a comparatively high degree of physical work capacity after noted effects. Even after 40 days bed rest they maintained a constant velocity on the treadmill for 2-3 times as long as nonathletes in normal conditions. Within 17 days of changing to an active mobile regime, before the beginning of training, athletes under examination recovered 40-60% of their initial physical work capacity.

Weight-lifters had less marked changes of orthostatic tolerance. After 40 days bed rest the changes of heart rate, stroke volume, velocity of blood output and blood pressure, weight-lifters had less increase of cardiac output than runners and subjects examined in other groups. It is possible to suppose that the saving of orthostatic tolerance of weight-lifters may be connected with the character of exercises which have a training influence on the venous side of the cardiovascular system.

The results of the present study have some value for applied physiology, clinical and sports medicine, and can also be used for a scientific explanation of the process of training.

POST-EXERCISE VENTILATORY CHANGES IN NORMAL SUBJECTS AND ASTHMATICS

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ABSTRACT

Chest auscultation, and serial maximum ventilatory function tests were carried out on twelve healthy non-smokers, eight healthy cigarette smokers, and five asthmatics, before, during and after moderately heavy treadmill exercise.

During the exercise, asthmatics, as well as non-asthmatics, showed increased maximum flow rates.

Significant post-exercise bronchoconstriction was exhibited by the healthy smokers, and eight of the healthy non-smokers, who developed rhonchi and depressed maximum midexpiratory flow rates in the post-exercise period. The greatest flow rate reductions were found 9-11 minutes after exercise in healthy and asthmatic subjects. Rhonchi were heard in the non-asthmatic subjects in the period 5-11 minutes post-exercise. The mean drop in maximum flow rates post-exercise was less in the non-asthmatics than the asthmatics.

Acknowledgements

This work was supported by a grant from the Ontario Tuberculosis Association. We are indebted to Professor T. Wonnacott for statistical help, and Mrs. M. Lawrence for editorial advice.
THE EFFECTS OF A SUSTAINED TRAINING PROGRAMME OF BREATH-HOLD SWIMMING ON SELECTED PHYSIOLOGICAL PARAMETERS AND SWIMMING PERFORMANCE

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Introduction

Coaches can be intuitively aware of the physiological benefits of a particular training technique long before these benefits are analyzed by researchers. Thus in studying breath-hold swimming a type of work was being examined that has for some time been used in the training programmes of some leading swimming coaches, though it has yet to be written up in the literature.

The respiratory problems which confront the swimmer, are more acute than those of the track athlete, in that the swimmer must make maximum use of a limited amount of ventilation, whereas the track athlete has unrestricted access to the atmospheric air.

Work by Magel and Faulkner (6) has shown that swimmers compensate for their restricted ventilation by maintaining a high rate of oxygen extraction; pulmonary ventilations for a given oxygen uptake being routinely 30% less swimming front crawl than running.

Thus all prone swimming is a type of breath-control work, and the ability of the swimmer to extract and use oxygen from a limited intake of atmospheric air and to make use of anaerobic energy sources is vital.

Methods

Swimming performance was standardized by use of a swimming ergometer (2) which enabled the work-load of swimmers to be fixed, and legitimate comparisons to be made between swimmers, and between pre- and post-test data. Twenty eight subjects were used, all of them leading age-group swimmers from Santa Clara Swim Club.

The selection of age-group swimmers offered a number of advantages. The group chosen had no previous experience with no-breath swimming and their strong competitive background ensured maximum effort in the various testing activities. The comparative lack of sophistication of the subjects prevented them from anticipating outcomes and creating a ‘Hawthorne Effect’. All subjects were coached by the experimenter both prior to, and during the experiment, which overcame one of the major problems in research work concerned with top athletic performance, namely, the disinclination of athletes to make serious modification of their training programme for the benefit of a researcher.

All subjects performed identical pre-tests, and the data obtained from these tests was used to divide them into Control and Experimental groups on a matched pairs basis. The independent variable in the training was the inclusion of no-breath swimming in the daily practice of the Experimental Group, while the Control Group covered a like distance using regular breathing. The training period extended over eight weeks during which 44 training sessions took place.

The tests on the swimming ergometer were designed to provide information concerning the O2 uptake and CO2 output in the swimmer for, (1) a maximum breath-hold swim, and (2) a standardized 2 minute swim with regular breathing, during which the volume of expired air was also recorded. Further testing at Stanford Hospital measured the haematocrit and vital capacity of each subject.

The final statistical analysis was performed on the means of differences between pre and post-tests in the two groups, the type of analysis being a ‘t’ test for means with unequal variances as described by Dixon and Massey.

Results

Perhaps the most important finding was that the Experimental Group showed a significant improvement in competitive performance. The differences between a subject’s best time prior to, and at the completion of, the training period were analyzed for 100 metre swims in the 3 prone competitive strokes. The Experimental Group was found to average half a second faster per event than the Control Group, which is important in a sport where victory and defeat are often separated by one hundredths of a second. The improvement of the Experimental Group was significant at the 0.05 level of confidence.

Maximum Breath-hold Swim

The initial expiration on completion of the swim was collected and analyzed to determine the partial pressures of oxygen and carbon dioxide. As the study was designed to show the responses of swimmers to the inclusion of no-breath swimming in their training programme, it was reassuring that the Experimental
Group did indeed develop a facility in this activity. In the post-test the mean time of the Experimental Group was more than 10 seconds longer than that of the Control Group (Table I). Despite reports of increased tolerance of hypercapnia in swimmers involved in breath-holding work (8), the PACO\textsubscript{2} of the Experimental Group was not significantly different from that of the Control Group after the post-test swim. However, there was a significant increase in hypoxia in the Experimental Group who were able to use a considerably larger percentage of their inspired O\textsubscript{2} (Table I).

Laboratory testing revealed that the Experimental Group increased their vital capacity by 0.22 l during the training period this compared with an increase of 0.21 l of the Control Group during the same period and was significant at the 0.1 level of confidence.

**Standardized Swim with Normal Breathing**

Expired air was collected, its volume measured and the partial pressures of C\textsubscript{0}2 and O\textsubscript{2} analyzed. The test was designed to show if any changes in ventilation or O\textsubscript{2} uptake occurred as a result of the breath-control training. Both Control and Experimental Groups reflected a considerable decrease in V\textsubscript{E} when performing the post-test. However, the difference between the groups was not significant. The data relating to V\textsubscript{O}2 were undoubtedly influenced by the decrease in ventilation of all subjects, but the mean decrease in V\textsubscript{O}2 of the Experimental Group was significant at the 0.05 level of confidence. No significant differences between groups were evident in their respective respiratory quotients.

**Discussion**

The improvement of the Experimental Group in the breath-hold swim can be attributed in part to the sophistication which they developed in their hyperventilation techniques. This enabled them to begin their swims at a low PACO\textsubscript{2}, and therefore a longer period of time elapsed before there was sufficient C\textsubscript{0}2 build-up to act on the respiratory centre and cause a termination of apnoea.

Other factors probably contributed to the increased facility of the Experimental Group in breath-hold swimming. Mostyn et al. (7) have noted the ability of champion swimmers to continue to transfer oxygen across the lungs despite low levels of alveolar oxygen. This ability seems to have been developed to a high degree by some of the Experimental Group. Despite a high build-up of C\textsubscript{0}2, two subjects were able to continue to take up oxygen until their partial pressure of alveolar oxygen (with an estimated correction factor for the dead space contamination of the expired sample) was 35 mm Hg. or less.

The significant increase in vital capacity may well have been a factor in increasing the duration of breath-hold swimming as it provided a greater initial volume of oxygen and conceivably a greater area for gas exchange, which could be particularly effective if coupled with the increased diffusing capacity in swimmers reported by Mostyn and others (7).

In the standardized swim with regular breathing the size and unanimity of the drop in ventilation suggests that it was not a training effect as a result of breath-hold swimming and that other factors were involved. The size of the decrease indicates that there was a conscious effort on the part of the subjects to breathe less. However, the significant decrease in O\textsubscript{2} uptake of the Experimental Group compared with the Control Group cannot be satisfactorily explained in terms of the slight difference in V\textsubscript{E} between the two groups. Factors which may have contributed to the lower O\textsubscript{2} uptake of the Experimental subjects are an increased stroke efficiency as a result of repeated attempts to conserve oxygen on breath-hold swims, and possibly an increase in anaerobic metabolism. The decrease in ventilation and O\textsubscript{2} uptake of both groups in the post-test confirms the work of previous researchers that there is a high energy cost to breathing in prone swimming (4).

As all prone swimming is a type of breath-control work, and as long breath-hold swims are but an extreme form of this activity, it was reasonable to anticipate that some of the adaptive changes which took place in swimmers as a result of no-breath swimming would also be reflected in the Control Group. Thus both groups showed improvement with respect to competitive time, duration of breath-holding capacity, ventilatory cost and O\textsubscript{2} cost of the standardized ergometer swim and the level of hypoxia attained in the no-breath swim. However, the significant improvement in competitive performance of the Experimental Group suggests that breath-hold swimming produces desirable training effects beyond those obtained in normal practice.

Further analysis will be required to isolate those variables which resulted in the improvement of breath-hold swimmers. An increased inspiratory capacity, particularly if coupled with the change in the diffusion component of the alveolar membrane, could be a major factor. Possibly breath-hold swimming leads to changes in technique and a more efficient stroke, though this explanation seems improbable. Other factors which must be considered are, beneficial changes in enzymatic
and acid-base parameters in response to hypoxia, now being studied by E. W. Banister. (1)

Breath-hold swimming adds a new and apparently effective dimension to the preparation of competitive swimmers. Like all forms of training it must be administered carefully with adequate safety precautions. (No underwater swimming and no excessive hyperventilation.) The apnoeic work appears to accelerate those physiological adaptations associated with successful competitive swimmers, and as such merits further careful study.

TABLE 1

Summary of the Mean Values Achieved by Each Group on the Testing Activities

<table>
<thead>
<tr>
<th>TEST DESCRIPTION</th>
<th>EXPERIMENTAL</th>
<th>CONTROL</th>
<th>Significance of Improvement of Experimental Group Compared with Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean of Pre-Test</td>
<td>Mean of Post-Test</td>
<td>Mean of Differences</td>
<td>Mean of Pre-Test</td>
</tr>
<tr>
<td>1. Time of Breath-hold swim in seconds</td>
<td>35.69</td>
<td>49.42</td>
<td>13.73</td>
</tr>
<tr>
<td>2. Percentage of O₂ in expired air (Initial Expiration including Dead Space)</td>
<td>12.35</td>
<td>9.44</td>
<td>2.91</td>
</tr>
<tr>
<td>3. Percentage of CO₂ in Expired Air (Initial Expiration Including Dead Space)</td>
<td>4.29</td>
<td>4.54</td>
<td>0.25</td>
</tr>
<tr>
<td>4. Vital capacity in Litres</td>
<td>3.38</td>
<td>3.60</td>
<td>0.22</td>
</tr>
<tr>
<td>5. Haematocrit</td>
<td>40.93</td>
<td>41.43</td>
<td>0.50</td>
</tr>
<tr>
<td>6. ( V_E ) for 2 Minute Swim in Litres</td>
<td>28.04</td>
<td>19.11</td>
<td>8.93</td>
</tr>
<tr>
<td>7. ( V_O_2 ) for 2 Minute Swim in Litres</td>
<td>1.26</td>
<td>1.07</td>
<td>0.19</td>
</tr>
<tr>
<td>8. Total improvement in swimming time in the 3 competitive prone strokes (Seconds)</td>
<td>4.71</td>
<td>3.16</td>
<td>0.05</td>
</tr>
</tbody>
</table>

REFERENCES


PHYSIOLOGICAL RESPONSES OF ATHLETES DURING INTERVAL TRAINING

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ABSTRACT

Subjects and Methods

Thirteen distance runners (800 to 1,500 metres), submitted to a regular interval training are examined. The working speed is determined according to their time on 200 metres. It varies from 22 to 26 Km/hour. The run lasts 30 seconds, while the relative rest consists in a one minute walk at 4 Km/hour. Ten athletes perform 20 repetitions, three others perform 15 times. Ventilation, \( O_2 \) uptake, and heart rate are registered for each subject. \( O_2 \) pulse and \( V_{O_2} \) are also calculated.

Results

1. During the 30 second runs, none of the athletes reaches the maximal values expected for well trained subjects.

2. During the one minute relative rest periods, the values differ from those registered during the 4 Km/hour steady state.

3. The statistical analysis shows that the heart rate is the most affected parameter. It is modified by the number of repetitions during the runs as well as during the rest periods.

4. During brief and intense efforts, there appear to be diversified behaviours in the heart rate, ventilation and maximum \( O_2 \) uptake.

Conclusion

The choice of a single parameter as an index of interval training seems to cover only a small portion of the problem and has to be completed on times by a deeper investigation, especially when one of the components of training is modified. (Speed, intensity, resting times . . .).
LABORATORY ASSESSMENT OF PERFORMANCE CAPACITY OF OARSMEN

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ABSTRACT

There is a need towards norms for specific anthropometrical and functional parameters as a means of selection and assessing performance potential of oarsmen.

In this perspective we measured in our laboratory a group of Belgian first class oarsmen using ergometers and a battery of morphological and functional tests. The results of our study emphasised the informative value of different parameters in assessing the performance capacity of oarsmen.

Anthropometrical data points to the fact that height and muscular development are reliable parameters as selection criteria in rowing. From a comparative review of different data in literature it seems reasonable to consider a minimum height of 180.0 cm. as an objective criterion.

Maximal oxygen intake can be considered as the most objective test in assessing maximal performance capacity. This parameter, however, should be expressed in terms of unit of bodyweight. A minimum of 60 ml/min./kg is in our opinion a criterion for an excellent functional performance capacity.

It is, however, obvious that both parameters are insufficient to give conclusive information concerning the physical performance potentials of oarsmen. There are too many other factors which can influence maximal performance. Their significance must, therefore, be interpreted in this perspective.

Introduction

There is a trend towards objective measurement as a means of selection and assessing performance potential of athletes in any particular sport.

Our laboratory was interested in the specific anthropometrical and physiological factors limiting performance in rowing. During 1969 we measured for this purpose the physical working capacity of 19 successful Belgian oarsmen, using a battery of morphological, functional and strength tests.

The following morphological indexes were measured: height, weight, sitting height, leg length, vital capacity and percentage of body fat. Strength tests consisted in isometric muscle strength measurement with the Hettinger dynamometer.

Maximal exercise test with increasing load was performed on a bicycle ergometer, using an open circuit system. The following parameters were recorded: oxygen intake, carbon dioxide output, oxygen pulse, heart frequency and respiratory adaptation. Before and after the ergocycle test an electrocardiogram recording was made.

Finally we also measured the heart volume in recumbent position according to the method of Mushoff & Reindell.

The anthropometrical data and the results for strength tests are listed in table I.

| TABLE I |
| ANTROPOMETRICAL DATA AND SCORES FOR STRENGTH TESTS |
| (mean value = $\bar{X}$; standard deviation = $s$; coefficient of variation = $V$ %) |
| | $\bar{X}$ | $s$ | $V$ % |
| Anthropometry |
| Height (cm) | 182.2 | 5.2 | 2.8 |
| Weight (Kgr) | 79.8 | 5.6 | 7.0 |
| Leg length (cm) | 90.3 | 2.9 | 3.2 |
| Sitting Height (cm) | 91.9 | 4.1 | 4.4 |
| Bodyfat content (%) | 16.8 | 3.1 | 18.7 |
| Isometric strength |
| Forearm flexion (Kgr) | 36.8 | 4.5 | 12.3 |
| Forearm extension (Kgr) | 25.6 | 5.1 | 19.9 |
| Knee extension (Kgr) | 70.4 | 9.5 | 13.5 |
| Knee flexion (Kgr) | 39.4 | 5.0 | 12.8 |
| Trunk flexion (Kgr) | 56.9 | 9.7 | 17.1 |
| Trunk extension (Kgr) | 170.3 | 21.1 | 12.4 |
Height and weight of Belgian oarsmen exceed largely the average values of the adult male population in Belgium. The mean height of our athletes is 182.2 cm with a weight of 79.8 Kgr, whereas the norms for the same age group amount to 174.5 cm and 65.2 Kgr.

Five athletes measured less than 180.0 cm in height and only one between them achieved international successes in races.

The anthropometrical data of our study support the existence of a relationship between physique and performance in sport at the international level. Height and muscular development are the limiting factors in performance of oarsmen. This fact becomes more evident by comparative study of statistics at different Olympic games and the anthropometrical data of successful foreign crews (Table III).

It is obvious that Belgian athletes show a lack in size and weight as compared with successful foreign oarsmen. These factors partly explain the frustration of our athletes in international competitions.

Our statistics indicate that from the morphological point of view a minimum height of 180.0 cm can be considered as a reasonable criterion for selection.

Muscle strength and development is also a determinant factor in rowing. However we are not in possession of reliable statistics of random population and foreign crews. Comparative data of athletes of various physical activities indicate however that oarsmen belong to the groups with high strength scores.

The data of the various physiological indices are listed in Table III.

Functional data supply evidence of various adaptations of the organism to intensive training. Firstly we emphasize the high values for maximal oxygen intake. The average exceeds by a large amount the norms for the untrained adult male population of the same age. Comparative statistics of athletes in any sport indicate that oarsmen belong to the groups with the highest degree of physical fitness. Since maximal oxygen intake is however directly related to body weight, this index must be expressed for preference in terms of unit of body weight.

Three subjects obtained scores between 40 & 50 ml/min./Kgr; 10 athletes had a score between 50 & 60 ml and only 6 athletes of the group obtained a value more than 60 ml/min./Kgr.

The cardio-vascular adaptation expressed by oxygen pulse and heart equivalent was efficient. Heart-volume was also enlarged.

The average respiratory minute volume for maximal work was 128.5 l/min. Only two athletes exceeded 150 l/min. Both obtained also the best results for maximal oxygen intake.

### TABLE II
**COMPARATIVE TABLE OF ANTHROPOMETRICAL DATA**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number (n)</td>
<td>19</td>
<td>120</td>
<td>4</td>
<td>6</td>
<td>357</td>
</tr>
<tr>
<td>Age (y)</td>
<td>23.3</td>
<td>24</td>
<td>23.2</td>
<td>24.7</td>
<td>25.0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>182.2</td>
<td>188.5</td>
<td>191.0</td>
<td>186.0</td>
<td>187.0</td>
</tr>
<tr>
<td>Weight (Kgr)</td>
<td>79.8</td>
<td>86</td>
<td>95.6</td>
<td>85.2</td>
<td>82.2</td>
</tr>
</tbody>
</table>

### TABLE III
**FUNCTIONAL DATA**

(mean value = $\overline{x}$; standard deviation = $s$; coefficient of variation = $V\%$

<table>
<thead>
<tr>
<th></th>
<th>$\overline{x}$</th>
<th>$s$</th>
<th>$V%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart frequency at rest</td>
<td>68</td>
<td>10</td>
<td>15.6</td>
</tr>
<tr>
<td>Blood pressure in recumbent position (mm Hg)</td>
<td>139/84</td>
<td>8/7</td>
<td>6.1 – 7.9</td>
</tr>
<tr>
<td>Vital capacity (ml BTPS)</td>
<td>6040</td>
<td>621</td>
<td>10.3</td>
</tr>
<tr>
<td>Maximal oxygen intake (ml/min. STPD)</td>
<td>4627</td>
<td>608</td>
<td>13.1</td>
</tr>
<tr>
<td>Maximal oxygen intake/body weight (ml/min./Kg STPD)</td>
<td>58.0</td>
<td>7.7</td>
<td>13.3</td>
</tr>
<tr>
<td>Maximal oxygen pulse</td>
<td>25.7</td>
<td>2.5</td>
<td>9.8</td>
</tr>
<tr>
<td>Maximal respiration Min. Vol. (l/min. BTPS)</td>
<td>126.7</td>
<td>24.3</td>
<td>19.2</td>
</tr>
<tr>
<td>Heart volume (ml)</td>
<td>999</td>
<td>140</td>
<td>14.0</td>
</tr>
<tr>
<td>Heart volume/body weight (ml)</td>
<td>12.4</td>
<td>1.7</td>
<td>13.7</td>
</tr>
<tr>
<td>Heart equivalent</td>
<td>38.9</td>
<td>5.6</td>
<td>14.5</td>
</tr>
</tbody>
</table>
In the following table (Table IV) our data were compared with statistics of successful foreign oarsmen.

The absolute data are in favour of foreign athletes; however, expressed in terms of unit of body weight the differences are inconsiderable.

Data from this comparative study point to the fact that from the physiological point of view a minimum score of 60 ml/min./Kg must be considered as an objective criterion for an excellent functional performance capacity.

It is however obvious that both morphological and physiological indices are insufficient to give conclusive information concerning the physical performance capacity of oarsmen. There are too many other factors which can influence maximal performance. Their significance must therefore be interpreted from this angle.

### Table IV

**Comparative Table of Functional Data**

<table>
<thead>
<tr>
<th></th>
<th>Belgian athletes</th>
<th>Coxed four W-Germany 1964</th>
<th>Olympic Golden Medallist 1968</th>
<th>Oarsmen Yugoslavia via 1966</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart volume (ml)</td>
<td>999</td>
<td>1099</td>
<td>1036</td>
<td>1148</td>
</tr>
<tr>
<td>Heart volume/body weight (ml/Kg)</td>
<td>12.5</td>
<td>11.5</td>
<td>11.9</td>
<td>13.9</td>
</tr>
<tr>
<td>Maximum oxygen intake (ml/min.)</td>
<td>4627</td>
<td>5900</td>
<td>–</td>
<td>5003</td>
</tr>
<tr>
<td>Maximum oxygen intake body weight (ml/min./Kg)</td>
<td>58.0</td>
<td>61.8</td>
<td>–</td>
<td>58.7</td>
</tr>
<tr>
<td>Maximal oxygen pulse</td>
<td>25.7</td>
<td>36.5</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Maximal respiration min. vol. (l/min.)</td>
<td>126.7</td>
<td>124.0</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

**Oxygen Consumption During Rowing: Implications for Training**

R. A. SCHWARTZ, M.D.

1100 Sixth Street, S.W. 704, Washington, D.C. 20024, U.S.A.

**Abstract**

There are few studies in the literature dealing with the energy cost of rowing. The commonly cited values are estimates of caloric cost. Only one study to our knowledge deals directly with oxygen consumption.

In an effort to help fill this gap in our knowledge of this sport, twenty-four lightweight oarsmen at Cornell University were studied. Measurements of oxygen consumption were made during two submaximal and an all out three minute row in a stationary indoor rowing tank. Fifteen of the subjects were tested one week later on a treadmill at similar submaximal and maximal efforts.

The results showed no significant differences in oxygen consumption at submaximal levels. However, the average oxygen consumption of the maximal treadmill run (66.1 mg./kg.) was significantly higher than that of the all-out row. This is attributed to the fact that the dynamics of the rowing tank prevenit a maximum cardiovascular effort. Muscle fatigue becomes the limiting factor even in the stronger oarsmen. Intra-group comparisons supported this assumption.

These findings are in keeping with those of Ishika and others which indicate that muscle power is perhaps more important to success in rowing than cardiovascular endurance.
LABORATORY AND TELEMETRIC OUTDOOR TRAINING TESTS TO MEASURE THE EFFICIENCY OF THE CIRCULATORY SYSTEM OF SPORTSMEN

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Dept. of Sports Medicine, Institute for Research in Physical Culture, Warsaw, Poland

ABSTRACT

The investigation of haemodynamic reactions with simultaneous measurements of the oxygen consumption is one of the most accurate methods for the determination of the efficiency of the circulatory system. Nevertheless, the method has certain shortcomings, particularly when it is used during the natural motoric activity of man. Appliances for collecting the expired air, indispensable for the measurement of oxygen consumption are rather cumbersome and inconvenient in use. This is why under field conditions the evaluation of the efficiency of the circulatory system is carried out mainly on the basis of relatively simple telemetric measurements of the function of the heart.

With the use of this method, in connection with difficulties of a technical nature, the quantity of information on the reactions taking place in the coronary heart system is considerably limited. Because, however, a close connection and far-reaching correlations are noted in the behaviour of the individual parameters and values characterizing the functional condition of the circulatory system the application of telemetric methods assumes an ever growing importance.

Our studies on the effort capacity of the circulatory system consisted of two parts. Part one consisted in the determination of the oxygen consumption and observation of the reactions of the heart during bicycle ergometer tests under varying loads. Part two consisted in the telemetric measurements of the circulatory system during natural motor activity. By carrying out a comparative analysis of the reactions of the organism under normal loads and during natural physical exercises we attempted the determination of the actual level of the capacity of the circulatory system of the subjects.

Introduction

The evaluation of the effort capacity of the circulatory system under laboratory conditions does not offer any great difficulties as a rule. Broad complex examinations carried out usually on the basis of the measurement of energy cost during various functional tests with a standard sub-maximum or maximum physical load permit a rather thorough analysis of both the general condition and the specific fitness of the subjects for their chosen sports.

The investigation of haemodynamic reactions with simultaneous measurements of the oxygen consumption is one of the most accurate methods for the determination of the efficiency of the circulatory system. Nevertheless, the method has certain shortcomings particularly when it is used during the natural motoric activity of man. Appliances for collecting the expired air, indispensable for the measurement of oxygen consumption are rather cumbersome and inconvenient in use. This is why under field conditions of physical exercises or sport performance the evaluation of the efficiency of the circulatory system is carried out mainly on the basis of relatively simple parameters characterizing the function of the heart. Apart from the measurements of blood pressure and the frequency of heart contractions, checked either by touch of carphones, ever more frequently under field conditions the method of the registration of the functional currents of the heart in the form of an electrocardiograph curve. Worth particular attention is the method of continuous electrocardiography which supplies objective information on changes taking place in the function of the heart in the course of the entire physical effort.

Two methods of collecting material during tests of this type are used: in one of them the subject carries a registering apparatus equipped with a magnetic tape which registers changes in the function of the organism (Roskamm, Reindell (12), Kuzin (9) et al., Weidemann (15), in the other one information on the changes is transmitted by radio with the help of a suitable transmitter (telemetric tests) (Bellet (2), Hanson, Tobakin (4), Rozenblat (13), Kozinski (5, 6, 7, 8), Stolz (14), Minarovjeh (10) et al.).

In view of the fact that in both cases the subject carries the apparatus on himself the quantity of the information collected is limited. This is due first of all to the still considerable technical difficulties connected with the construction of sufficiently small, light and reliable transmitters or registering devices. Because, however, a close connection and far-reaching correlations are noted during physical efforts between
the individual haemodynamic parameters and respiratory parameters, such as the heart frequency, contraction and minute volume of the heart, ventilation, oxygen intake, etc., the investigation of the functional currents of the heart during physical activity assumes an ever increasing importance.

Our studies of the effort capacity of the circulatory system were carried out on 184 sportsmen aged from 12 to 31. Table I contains a list of the subjects in the individual sports disciplines. The studies consisted of two parts.

Part one consisted of bicycle ergometer tests with loads from 1 to 4 watts per 1 kg of body weight. In the majority of subjects we determined oxygen intake and ejection of carbon dioxide with the help of a Spirolit II apparatus.

<table>
<thead>
<tr>
<th>Type of sport</th>
<th>Number of subjects</th>
<th>Age mean</th>
<th>Age in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skiing</td>
<td>65</td>
<td>19-31</td>
<td>23.1</td>
</tr>
<tr>
<td>Kayak paddling</td>
<td>34</td>
<td>14-25</td>
<td>19.8</td>
</tr>
<tr>
<td>Basketball</td>
<td>29</td>
<td>12-20</td>
<td>15.5</td>
</tr>
<tr>
<td>Judo</td>
<td>17</td>
<td>19-25</td>
<td>21.3</td>
</tr>
<tr>
<td>Wrestling</td>
<td>14</td>
<td>22-31</td>
<td>25.3</td>
</tr>
<tr>
<td>Cycling</td>
<td>10</td>
<td>19-25</td>
<td>22.1</td>
</tr>
<tr>
<td>Marksmanship</td>
<td>8</td>
<td>20-23</td>
<td>21.7</td>
</tr>
<tr>
<td>Gymnastics</td>
<td>5</td>
<td>19-22</td>
<td>21.4</td>
</tr>
<tr>
<td>Total</td>
<td>184</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

We registered at the same time in a continuous manner the electrocardiograph curve before, during, and after the tests.

The second part of the studies was based on the telemetric measurement of the circulatory system during natural motor activity of the subjects. We used, as in our earlier studies (Kozinski 5, 6, 7, 8), a modified single-channel teleelectrocardiograph TEK 1. A continuous registration of the electrocardiograph curves was carried out throughout the whole of the experiments.

By carrying out a comparative analysis of the reaction of the organism during standard work on a bicycle ergometer and during natural physical exercises we tried to assess the actual effort capacity of the circulatory system of the subjects.

An analysis of the results of the bicycle ergometer tests showed that with loads of 1 and 2 watts per 1 kg of body weight the acceleration of the frequency of heart contractions was relatively slight. In the majority of subjects the pulse rate with a 2-watt load did not exceed 120-142-heartbeats per minute (an average of 128.5) (Table II). This constituted an acceleration of the work of the heart by 39.5 to 89.3% in comparison with the values at rest. Oxygen intake in the final phase of the work did not exceed 1550-2180 ml/min. (STPD).

Table II

<table>
<thead>
<tr>
<th>Specification</th>
<th>Variation zone and mean values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate frequency per min. before effort</td>
<td>65 – 88</td>
</tr>
<tr>
<td>Maximum heart rate frequency per min. during effort</td>
<td>120 – 142</td>
</tr>
<tr>
<td>Increase of the heart rate in %</td>
<td>139.5 – 189.3%</td>
</tr>
<tr>
<td>as compared with its value at rest</td>
<td>163.6%</td>
</tr>
<tr>
<td>VO₂/min. in ml (STPD)</td>
<td>1550 – 2180</td>
</tr>
</tbody>
</table>

With a load of 4 watts per 1 kg of body weight the reaction of the circulatory system in all subjects was significant. The acceleration set in early, (Table III). In the final phase of effort which amounted in subjects in various sports disciplines to from 65,350 J to 195,000 J (6661 – 19877 kpm) the frequency of heart contractions increased on the average to 179.2/min. (173-192/min.). This constituted an acceleration of heart rate of from 105.9 to 174.2% in comparison with the values before the test. The contraction pressure was measured immediately after the test and amounted to from 155 to 210 mm Hg (an average of 170.2 mm Hg). It was often impossible to determine the value of the expansion pressure. In a considerable part of our subjects we found the so-called “phenomenon of unending tone”. Maximum oxygen intake per 1 minute (VO₂ max) amounted in the final phase of the work to an average of 3,710.3 ml (STPD) (2,920-5050). This means that a single heart contraction used from 15.8 to 26.3 ml of oxygen (an average of 20.7 ml). With a load smaller than 2 watts per 1 kg of body weight this index amounted to 14.1 ml. The value of the index depends among other things on the heart ejection volume, pulse rate and oxygen intake. If this increases with increased loads we draw usually the conclusion that the work of the circulatory system in a given subject is more economical. In well-trained subjects who have a high
capacity organism, this index is considerably higher than in untrained individuals.

Table III

*Behaviour of heart rate frequency and oxygen intake during bicycle ergometer tests under a load of 4 watts per 1 kg of body weight*

<table>
<thead>
<tr>
<th>Specification</th>
<th>Variation zone and mean values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall value of the work performed</td>
<td>65,350 – 195,000 J</td>
</tr>
<tr>
<td>Heart rate frequency per min. before effort</td>
<td>66 – 90 76.2</td>
</tr>
<tr>
<td>Maximum heart rate frequency per min. during effort</td>
<td>173 – 192 179.2</td>
</tr>
<tr>
<td>Increase of the heart rate frequency as compared with its value at rest in %</td>
<td>205.9 – 274.2% 235.1%</td>
</tr>
<tr>
<td>( \dot{V}_O_2 ) /min. in ml (STPD)</td>
<td>2,920 – 5,050 3,710.3</td>
</tr>
<tr>
<td>( O_2 )/heart rate in ml</td>
<td>15.8 – 26.3 20.7</td>
</tr>
</tbody>
</table>

The volume of the maximum oxygen consumption per minute and the reactions of the circulatory system during tests on a bicycle ergometer are consistent with the results obtained by numerous other authors such as Brouha (3), Reindell (11), Adolph (1) et al., and indicate that the majority of our subjects performed heavy work and were characterized by a high efficiency of the circulatory system.

An analysis of the results of the telemetric tests showed that circulatory system reactions during most natural training efforts are usually highly differentiated and variable. One notes great changes in the frequency of heart rate, depending first of all on the character and intensity of physical effort. This permits a general conclusion that almost every training fulfills to a greater or smaller extent conditions of interval training. Besides periods of moderate heart rate we noted often pulse accelerations considerably exceeding accelerations registered during bicycle ergometer tests under a maximum load. In many cases the pulse rate reached the value of 182-211 heartbeats per minute (Table IV). Also the overall time period during which the pulse rate remained on a high level of over 150 heartbeats, which according to many authors may be a manifestation of a heavy physical load (Brouha (3), Reindell (11), et al.), was not infrequently much longer during training than during bicycle ergometer tests under heavy load. In canoeists, for example, in spite of the fact that the duration of the ergometer test was nearly 64% longer than the test on water, the period during which the pulse rate exceeded 150 heartbeats per minute was nearly 3

Table IV

*Comparison of the reaction of the organism of kayak paddlers during bicycle ergometer tests under a load of 4 watts per 1 kg of body weight and during special efficiency tests on a water track (100 m plus 500 m)*

<table>
<thead>
<tr>
<th>Specification</th>
<th>Bicycle test</th>
<th>Water track test</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of work</td>
<td>( \bar{x} ) 4 min. 40.1 sec.</td>
<td>( \bar{x} ) 2 min 51.1 sec.</td>
<td>63.7% (163.7%) Longer during Bicycle test</td>
</tr>
<tr>
<td>Volume of work performed</td>
<td>( \bar{x} ) 79,123 J</td>
<td>( \bar{x} ) 8069.5 kpm</td>
<td></td>
</tr>
<tr>
<td>( \dot{V}_O_2 ) max/min. in ml (STPD)</td>
<td>( \bar{x} ) 3,204 (2920-3630)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart rate frequency during work maximum values per minute</td>
<td>( \bar{x} ) 181.3 (180-186)</td>
<td>( \bar{x} ) 194.5 (189-211)</td>
<td>Heart rate on track 7.2% faster (107.2%)</td>
</tr>
<tr>
<td>Heart rate frequency mean values for the overall work per minute</td>
<td>( \bar{x} ) 165.2 (132-186)</td>
<td>( \bar{x} ) 186.6 (171-211)</td>
<td>Heart rate on track 12.9% faster (112.9%)</td>
</tr>
<tr>
<td>Time during which heart rate exceeded 150/min. during and after work</td>
<td>( \bar{x} ) 3 min. 17.3 sec.</td>
<td>( \bar{x} ) 9 min. 43.7 sec.</td>
<td>Time on track nearly 3 times longer (295.8%)</td>
</tr>
</tbody>
</table>
times longer on water (295.8%). Neither should one forget that during a single training canoeists have to paddle at similar speeds sectors 100 and 500 metres long over a dozen times.

Table V

Comparison of the reaction of the organism during bicycle ergometer tests under a load of 4 watts per 1 kg of body weight and during field ski training

<table>
<thead>
<tr>
<th>Specification</th>
<th>Bicycle Test</th>
<th>Ski Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of test</td>
<td>13 min.</td>
<td>39 min.</td>
</tr>
<tr>
<td>Volume of work performed</td>
<td>105,390 J</td>
<td>10,743 kpm</td>
</tr>
<tr>
<td>Heart rate frequency</td>
<td>191</td>
<td>197</td>
</tr>
<tr>
<td>Maximum value per min.</td>
<td></td>
<td>(3.1%)</td>
</tr>
<tr>
<td>Heart rate frequency during entire test</td>
<td>143.7</td>
<td>143.1</td>
</tr>
<tr>
<td>Time during which heart rate exceeded 150/min.</td>
<td>6 min. 20 sec.</td>
<td>31 min. 30 sec.</td>
</tr>
<tr>
<td></td>
<td>Less than 1/2 of test duration (48.7%)</td>
<td>Nearly 5 times longer (80.8% of the entire training)</td>
</tr>
</tbody>
</table>

Another example illustrates the comparison of the reactions of the organism during bicycle ergometer tests under a load of 4 watts per 1 kg of body weight and during field exercises (Table V). The duration of the test was 13 minutes and the duration of the exercises 39 minutes. The maximum pulse rate during the test reached 191/min., and during skiing exercises 197/min. (3.1% more). The frequency of heart contractions calculated for the entire length of the experiment amounted to 143.7 and 143.1 per minute (almost identical). On the other hand, the time period during which the pulse rate during the bicycle ergometer test exceeded 150/min. amounted to 6 mins 20 secs only, that is less than 50% of the entire duration of the test, and during skiing exercises this time was nearly 5 times longer (31 mins 30 secs), while the faster heart rate of over 150/min. remained for over 80% of the duration of the training exercises.

Space does not permit the presentation of further examples, but one may draw the general conclusion that the capacity of the circulatory system determined by laboratory effort tests may have insufficient prognostic value for determining whether a given sportsman is sufficiently fit and prepared, particularly when it comes to withstanding the tremendous loads of modern competitive training which lasts not infrequently for several dozen minutes.

Another example from the field of skiing can be given. Two competitors, both of them runners, who already do not train systematically, have a similar starting capacity, but telemetric tests carried out during a 10-kilometre race showed quite significant differences between them. Table VI shows in percent the acceleration of the speed of running in metres per second and also in percent the increase of the number of metres run per one heart contraction by one runner in comparison with the other. Skier "Z" ran not only faster on the various sectors of the race (upper figures) but also more economically with a slower heart work. The lower figures which are higher than the upper ones show distinctly that the number of metres per one heartbeat is proportionally higher than the number of metres per one second. The increase in the number of metres per one contraction and per one second is unproportional. This is particularly visible on sector 1-3 (130 m flat and 70 m downhill) and on sector 5-1 (390 m downhill). Skier "Z" was capable of a better use of these sectors. His drop of pulse rate, more distinct in him than in the other runner, may be to a certain extent proof of a lowering of the intensity of energy processes. This permits a more rational exploitation of the potential possibilities of the organism, as it introduces elements of rest during the race itself.

Tests conducted under natural training conditions permit a thorough assessment of the capacity of the subjects. They permit a much more accurate comparison of two seemingly similar organisms, when the tests are carried out in more complicated and stress-producing situations. Intensified prolonged activity requires a full mobilization of all functions of the organism. The compensation mechanisms of certain individuals may not be enough in those situations. The tests reveal faults which might be undetectable at rest or under brief observations. One finds, for example, quite frequently arrhythmias of various origin.

This is why at a time when we emphasize ever more strongly the need of steering the process of achieving a good sports result, the possibility of a penetrating evaluation of the capacity of the organism under natural conditions assumes prime importance. It is hardly necessary to stress the value of telemetric tests for practice, the need to develop this research, to improve apparatus and methods. Speaking of the advantages of the method of the evaluation of physical capacity under natural conditions of the motor activity of man, one should not pass over in silence the difficulties connected with the analysis of the collected information. Continuous and prolonged registration of data, even with regard to only a few functions of the organism, requires automated methods of the processing of these
Table VI

Acceleration of speed in m/sec and the number of metres per one heart contraction in skier “Z” in comparison with skier “G” on various sectors of the route expressed in %

<table>
<thead>
<tr>
<th>Distance</th>
<th>1 km</th>
<th>2 km</th>
<th>3 km</th>
<th>4 km</th>
<th>5 km</th>
<th>6 km</th>
<th>7 km</th>
<th>8 km</th>
<th>9 km</th>
<th>10 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m/sec</td>
<td>14.9%</td>
<td>17.3%</td>
<td>18.8%</td>
<td>13.4%</td>
<td>16.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m/HF</td>
<td>20.0%</td>
<td>24.8%</td>
<td>22.1%</td>
<td>14.8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m/sec</td>
<td>17.7%</td>
<td>7.5%</td>
<td>14.5%</td>
<td>8.6%</td>
<td>11.0%</td>
<td>3.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m/HF</td>
<td>19.6%</td>
<td>12.0%</td>
<td>15.5%</td>
<td>11.3%</td>
<td>12.5%</td>
<td>5.7%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>4-5</td>
<td></td>
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</tr>
<tr>
<td>m/sec</td>
<td>14.7%</td>
<td>9.2%</td>
<td>14.5%</td>
<td>4.6%</td>
<td>17.2%</td>
<td>11.3%</td>
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</tr>
<tr>
<td>m/HF</td>
<td>12.5%</td>
<td>12.0%</td>
<td>18.6%</td>
<td>8.0%</td>
<td>18.9%</td>
<td>15.6%</td>
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<td>5-1</td>
<td></td>
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</tr>
<tr>
<td>m/sec</td>
<td>22.6%</td>
<td>14.0%</td>
<td>16.8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m/HF</td>
<td>24.4%</td>
<td>16.7%</td>
<td>21.1%</td>
<td></td>
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</tbody>
</table>

The first, preliminary trials in this field have been already carried out. Teleelectrocardiograms are registered on an apparatus for the tape recording of biological currents. Then the tape recording is converted in an analog digital computer. The conversion of the potential course of the teleelectrocardiograms to a progression of numerical values is done on a special ANOPS computer designed and built at the Chair of Computers of the Warsaw Polytechnical Institute. The information recorded on a paper tape is then introduced into a universal computer UMC-10 which carries out an analysis and statistical processing in accordance with a special programme. For the time being, however, we are still in the phase of preliminary trials.

Conclusions:

1. Reactions of the organism during natural motor activity are frequently much greater than during laboratory tests under maximum load, and effort reactions of the organism remain much longer under natural conditions.

2. Tests carried out during natural motor activity of man permit a more accurate evaluation of the real capacity of the organism.

REFERENCES


______________________________
CHANGES OF CARDIAC PACE MAKER ACTIVITY AT INTENSIVE PHYSICAL EXERCISE
(Mathematical Model)

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Introduction

Increase of heart rate during physical exercise, resulting from reduction of the cardiac cycle duration, is the most important adaptation enabling optimum cardio-vascular functioning under certain conditions. Exercise tachycardia depends upon a number of factors of which the most important are the power of physical exercise (N) and its duration (t).

To determine quantitative reactions between the cardiac cycle, on one hand, and values N and t, on the other, one can obtain a mathematical model clarifying the kinetics of the heart-pace control system, since it will assist in prognosticating optimum frequency of heart pulse under various working conditions, as well as being of theoretical interest.

Method

Without resorting to an analog or other existing computing facilities, we proceeded from the fact that the behaviour of the pace maker in the course of physical exercise, as well as a number of other cardiodynamics characteristics, can be described by use of a linear differential equation of the 3rd order (V. L. Karpman, 1968)

\[
\frac{d^3 C}{dt^3} + R_1 \frac{d^2 C}{dt^2} + R_2 \frac{dC}{dt} + R_3 \cdot C = 0 \quad (1)
\]

The solution of equation (1) boils down to:

\[
C = K_1 \cdot e^{t/T_1} + K_2 \cdot e^{t/T_2} + K_3 \cdot e^{t/T_3} \quad (2)
\]

where C is the heart cycle duration;
T_1, T_2, T_3 are time constants;
t is duration of the physical exercise;
K_1, K_2, K_3 are constants;
e is a base of the Napierian logarithms.

Because the heart pace-control system is substantially non-linear (Warner, Cox, 1962; V. L. Karpman, 1968), a section was separated out of a wide range of physical exercise powers, provided an adequate linearization of changes of values C (N) is made possible within the limit of this section.

It was later found out (V. L. Karpman, 1970) that the C — N relationship can be approximated by the equation

\[
C(N) = 415 \cdot (e^{-2.1 \cdot N} + e^{-0.11 \cdot N}), \quad \text{(3)}
\]

Where C is expressed in terms of milliseconds and N — in thousands of kgm/min.

Experiments were undertaken on highly qualified sportsmen who were subjected to physical exercises on a bicycle ergometer with a load of 1000, 1300, 1500 and 2000 kgm/min. Altogether 75 men aged from 15 to 30 underwent this test, all being quite healthy and in good training.

The subject under test started bicycling (without warming-up) on the ergometer (at a speed of 75 r.p.m.) at constant load prescribed by the experimenter for 5 minutes.

During the first two minutes the electrocardiogram was recorded continuously, and when stabilization of the heart rate occurred recordings were made during the last 15 seconds of each subsequent minute of exercise.

Results

On the basis of the results of each experiment transient curves were plotted in coordinates C — t. Averaged curves of a transient were derived then for
each series of experiments in which the same exercise was practiced (Fig. 1). Each curve was then subjected to graphical analysis in semilogarithmic coordinates (Fig. 2). Herewith, in conformity with the theory it proved that the experimental points are fine to be approximated by the sum of three exponents (see formula 2) of which the first \((K_1 \cdot e^{t/T_1})\) corresponds to the “start reaction” phase, and the second one \((K_2 \cdot e^{t/T_2})\), to the “initial stabilization” phase of the adaptation period. The third exponent \((K_3 \cdot e^{t/T_3})\) shows steady state of the pacemaker operation.

![Fig. 2. Analysis of the curve describing the heart-pace control system activity.](http://bjsm.bmj.com/)

**Ordinate** — cardiac cycle duration (semilogarithmic scale)

**Abscissa** — Time of muscular work performance

In the course of the graphical analysis of the averaged curves of transients of values of factors \(K_1, K_2\) and \(K_3\) (in msec) and time constants \(T_1, T_2\) and \(T_3\) (in min) for four levels of exercise load (see Table I).

The data tabulated below indicate that factors \(K_1, K_2\) and \(K_3\) somehow depend on the exercise power. On the contrary, time constants \(T_1, T_2\) and \(T_3\) are independent of \(N\). The mentioned data are essential to construct a generalized model of variation of \(C\) with \(N\) and \(t\) in progress.

| Table I |
| FACTORS \((K)\) AND TIME CONSTANTS \((T)\) |
|---|---|---|---|---|---|
| Exercise load \((N)\)| \(K_1\) | \(K_2\) | \(K_3\) | \(T_1\) | \(T_2\) | \(T_3\) |
| 1000 | m/sec | min | min | min |  |
| 1.0 | 285 | 120 | 470 | 0.05 | 0.47 | 53 |
| 1.3 | 300 | 140 | 410 | 0.04 | 0.51 | 48 |
| 1.5 | 320 | 140 | 395 | 0.05 | 0.55 | 53 |
| 2.0 | 325 | 185 | 375 | 0.05 | 0.48 | 46 |

The law of Variation of \(K_3\) with change of \(N\) can practically be described by equation (3) since this value is contained the third member of equation (2) which describes the variation of activity of sinoatrial node at steady state. However a correction is required here as \(K_3\) is taken at \(t = 0\) and \(C(N)\) at \(t = 5\) min.

The correction will on average be equal to 34 msec. Thus:

\[
K_3 = 415 \cdot (e^{-2.1t} + e^{-0.11t}N) + 34 \quad (4)
\]

\(K_2 \rightarrow -N\) relations may be expressed, with a certain assumption, by means of the common equation that follows:

\[
K_2 = 60 (N + 1) \quad (5)
\]

where \(N\) is given in thousands of kgm/min.

Quantity \(K_1\), can be determined as a difference between the heart cycle at rest (see \(C_0\) in the Table) and the sum \(K_2 + K_3\). As it follows from the Table, \(C_0\) averages 851 msec. Then, employing equations (4) and (5) we shall obtain:

\[
K_1 = 757 - 60 \cdot N - 415 (e^{-2.1t} + e^{-0.11t}N) \quad (6)
\]

As seen from the Table, the time constants depend upon no particular \(N\). Besides they appeared to be fairly similar in value despite the fact, that different persons were involved in each experiment. Therefore the time constants were averaged as follows: \(T_1 = 0.05\) min, \(T_2 = 0.5\) min, and \(T_3 = 50\) min. Thus \(T_3 = 100 \cdot T_2 = 1000T_1\).

The above calculations give us particular values of the factors and time constants which after being introduced in equation (2) will ensure that formal relations between \(C, t\) and \(N\) are rendered concrete. With this in view, equations (4), (5) and (6) were substituted for the respective components. For the sake of simplification the time constants were changed in equation (2) by inversely proportional values — speed constants \((1/T)\).

Set forth is the final expression of the mathematical model clarifying variation of activity of the heart pace maker under the effect of intensive physical exercise.

\[
C(t,N) = [757-60N-415 (e^{-2.1t} + e^{-0.11t}N)] \cdot e^{.20t} + \\
+60(N+1) \cdot e^{-2t} + [415 (e^{-2.1t} + e^{-0.11t}N) +34] \cdot e^{-0.02t} \quad (7)
\]

**Discussion**

The curves illustrating variations of heart cycle duration in the process of physical exercise (Fig. 1) made
at a constant power are actually pacemaker activity control curves.

The analysis of these curves makes it evident that rhythmical adaptation to physical load is of a rather ordinary aperiodical character. Within the range of powers selected for study, more complex transients were not noted, though the latter had been described by some authors (N. V. Zimkin, S. A. Razumov, 1965; V. V. Matov, I. D. Surkina, 1964, etc.).

As shown in Fig. 2 the entire control curve in semilogarithmic coordinates can be divided reliably into two sections, of which the first one defining the transient of the heart-rate control system corresponds to the period of adaptation, and the second one presents the characteristics of the system in steady state.

![Fig. 3. Changes of adaptation period duration at muscular exercise of different loads.](http://bjsm.bmj.com/)

The duration of the adaptation period within the power ranges selected for the test proved to be bound up with the exercise intensity. Fig. 3 shows that this period gets longer with increase of the exercise load (up to 1500 kgm/min) and then becomes stable making up some 105 sec on the average. Thus the sino-atrial node completely readapts itself to new conditions within a comparatively short period of time.

The mathematical model thus obtained gives a quantitative characteristic to the transient of the sino-atrial node under the effect of physical exercise. The transient is made up of two stages of which one is described by the first exponent in equations (2) and (7) at $t_1 = 0.05$ min (approx. 3 sec). The other adaptation stage is defined (Karpman, 1969) as the start reaction phase, while the second stage is denoted as the initial stabilization phase. Both the phases are determined physiologically.

Judging by the individual values of time constant $T_1$, the start reaction phase is momentary since its duration does not exceed 5 – 8 sec, and the duration is not dependent on the physical exercise.

During this phase of the adaptation period a noticeable quickening of the pulse by the 5th second since the start of the exercises is seen, regardless of its intensity, up to 98 – 103 strokes per minute. This shows: (1) invariance of heart-rate under exercise with respect to its original values; (2) reflex feature of the initial chronotropic reaction of the heart. The latter is made obvious if we take into account that energy requirements of the organism are negligible during the initial seconds of physical exercise.

The data obtained in the experiments make it possible to assume the presence of a matrix of heart-rate control under physical exercise, by which the pacemaker increases up to the level at which its correction begins in conformity with the exercise load.

During the second phase an optimum level of the sino-atrial node activity is sought for the given conditions, and as soon as this level is achieved the adaptation period comes to the end giving place to the steady state period.

Under conditions of competition, when prestart heart-acceleration is noted because of emotional reactions, the first phase of the adaptation period may not be revealed. It may well be that the adjustment to the optimum level of activity of the pace maker, could be not only aperiodical, as was observed in the test under discussion, but also oscillatory or stepped.

The reflex tachycardia at the beginning of the adaptation period is due to a number of haemodynamic reactions, but not determined by oxygen requirements alone.

Increase of cardiac output may be regarded as one such reaction in the first instance (Guyton et al., 1962; Ceretelli et al., 1966). At the beginning of the second phase of the adaptation period, stroke volume rises (Durand et al., 1960).

At present dependable criteria have not been worked out for determining the beginning of the steady state period. According to the classical concepts of Hill (1929) the steady state is achieved at the moment when the function under study stops varying any longer as an effect of physical exercise, because dynamic balance is reached. However, such a situation is extremely rare under actual conditions. We consider that a steady state is a situation where the function under study keeps varying monotonously and unidirectionally provided the rate of this variation becomes extremely slow. This may be exemplified by variation of the heart cycle duration.
(Fig. 1), when the control curve assumes a nearly horizontal direction. This portion of the curve is described by the third component in equations (2) and (7) with a large time constant \( T_3 = 50 \) min. The difference between the horizontal line and the actual curve is insignificant, and does not exceed 5 per cent with respect to the maximum deviation of the parameter in the case of physical work. In physiological systems, to which the heart-pace control system belongs, static error can be associated with anaerobic metabolism arising in the case of exercise with full or submaximum intensity. The argument in favour of this proposition is the fact that in the event of moderate-load exercise (for example, at \( N = 500 \) kgm/min), when the pulse rate lies within 120 strokes per minute), the “actual” steady state is observed.

It should be recalled that at such a rate of blood circulation, the amount of oxygen delivered to the working muscles practically corresponds to their metabolic requirements, and anaerobic processes will not arise (Keul, 1969; N. I. Volkov 1969, etc). In this connection we shall determine the origin of the steady state by using the method when the experimental control curve starts to deviate from the straight line plotted in semilogarythmic coordinates \( (K_3 \cdot e^{t/T_3}) \), as shown in Fig. 2.

The clearly revealed Barkcroft phenomenon is also a characteristic of the pace maker action in the steady state. It becomes apparent in increase of the standard deviations \( (\overline{Sx}) \) of the heart cycles under load as compared with values \( \overline{Sx} \) at rest. Thus, at rest for the four combinations of the tested subjects \( \overline{Sx} \) varied from 0.96 to 1.40, but the moment the steady state was attained \( \overline{Sx} \) tended to reduce down to 0.2 - 0.3. It is characteristic that throughout the steady state period \( \overline{Sx} \) varies negligibly. Decrease of interindividual dispersion of the index under study (Barkcroft phenomenon) testifies that in transition from homeostatic control (at rest) to heterostatic control (Jokl, 1964) the properties of the control system change appreciably. Perhaps as far as cardiodynamics are concerned we are dealing with a two-position control system.

Mathematical models of the sino-atrial node under effects of physical exercise were resorted to by some experimenters (V. V. Rozenblat etc. 1969; Suggs, 1968; Cordus, 1968 etc.). In their works the authors approximated pulse frequency recorded in experiments by making use of simple formulae.

The model suggested in this report differs from the early ones in a number of peculiarities. First, our model takes into account not only the duration of exercise, but also its load. Secondly, the model in question, being a general solution of the 3rd order differential equation, takes into account non-linearities essential for biological studies and gives physiological ground to determine the stages of heart adaptation to physical load. Finally the model describes variation of duration of the heart cycle directly characterising the activity of the pace maker, whereas other models merely provide formal registration of heart-rate alterations.

The model offered herewith reproduces dependably our own experimental data within the load range of 1000 to 2000 kgm/min. There is every reason to assume that the model will remain effective even if the range of physical load is extended up to 3000 kgm/min.

Conclusions

1. The mathematical model suggested makes it possible to prognosticate variations of activity of the pace maker under the effect of physical exercise, of maximum and submaximum load (see equation (7)).

2. The initial stage of the adaptation period, is characterised by reflex tachycardia up to the level at which the correct heart-rate for the particular physical loading is achieved.

3. Each member of the model described is determined physiologically. The first member characterises the start reaction phase, the second member specifies the initial stabilizing phase, and the third, the steady state phase.

4. Suggested here are new criteria for determination of the beginning of the steady state period and for subdividing the adaptation period into phases.

5. During the initial stabilizing phase, optimum regulation of the pace maker takes place. Search of optimum heart-rate under laboratory conditions is carried out aperiodically.

REFERENCES


Many top athletes have been tested by the Institute staff for oxygen uptake during walking, running, swimming, skating and cycling at various speeds. A linear correlation was found between oxygen intake and speed. A similar correlation was also found between speed and heart rate. Max $V_O^2$ and corresponding speed were measured in each of the above events.

The Max $V_O^2$ recorded was similar to that measured on veloergometry. Good correlation was recorded between max $V_O^2$, critical speed and performances shown at corresponding distances. Performances at distances covered at above the critical speed agree with maximal oxygen debt values.

The oxygen uptake in high-level athletes was also measured in other events — gymnastics, boxing, basketball, tennis, hockey, football. The oxygen debt was measured in a number of cases. Participants in these events were tested for max $V_O^2$ events.

The correlation between the max $V_O^2$ and oxygen consumption under training conditions was used to calculate the work load.

Regular information on the oxygen consumption and max $V_O^2$ and oxygen debt observed in athletes enables coaches of national teams to control the training process with a better progress.
EVALUATION OF CARDIORESPIRATORY FITNESS
IN MALE EGYPTIAN ATHLETES

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ABSTRACT

The cardiorespiratory endurance capacity of 42 young male Egyptian athletes was assessed by the use of ergospirometry, E.C.G., volumetric heart measurement and vital capacity estimation. The \( O_2 \) consumption, minimum and maximum; minimum and maximum \( O_2 \) pulse and heart volume/maximum \( O_2 \) pulse ratio were measured. The pulse rate, blood pressure and respiratory quotient at rest, exercise, and on recovery, are reported. The maximum oxygen uptake is considered as a measure of the maximum aerobic capacity and cardio-respiratory performance. The mean predicted vital capacity was 94%. A high resting mean pulse rate (80/minute) was found in our athletes. Recovery pulse did not return to pre-exercise level on the 6th. minute of recovery. All had a normal blood pressure (mean 128/72 mmHg) which rose to 188/46 on exercise and dropped to 136/70 on 6th. minute of recovery.

The resting mean oxygen consumption was high; 525 ml./min STPD. This rose to 3020 ml./min. and to 3387.2 ml./min. on 250 and 300 watts work load respectively. On recovery the oxygen uptake dropped faster than the pulse rate.

A statistically significant correlation was only found between maximum oxygen uptake and volumetric measurement of the heart. The values of maximum oxygen pulse, maximum heart rate and maximum oxygen uptake were found to be lower than in male international athletic standards. The RQ changes on exercise and recovery were discussed.

Introduction

Physical fitness apparently consists in the ability of the human body to maintain during strenuous exertion the various internal equilibria as closely as possible to the resting state and to restore promptly after exercise any equilibria which have been disturbed (Darling, 1947). The capacity to perform a prolonged muscular exercise depends mainly on an intact cardiopulmonary function and adequate human motor performance. Testing and measuring cardio respiratory function during exercise has an important place in sport and clinical medicine. There is a common agreement among work physiologists that the evaluation of maximal oxygen uptake is essential in the evaluation of cardio respiratory capacity to perform aerobic work (Taylor et al 1956). This has become widely accepted as a criterion for assessment of physical fitness, i.e. cardiorespiratory fitness.

For cardiorespiratory endurance research most laboratories use spiroyergometry (Knipping, 1929). The exercise step test is considered non ergometric but more suitable for field work although the mechanical work done in stepping is difficult to define accurately.

It is the aim of this work to assess the cardiorespiratory endurance capacity of Egyptian athletes of U.A.R. basket-ball national teams. The value of ergometers is discussed by Bobbert (1960).

Material and method:

42 male basketball players from U.A.R. national teams were included in this study. All were examined clinically, an E.C.G. was done at rest and the volumetric measurement of the heart was assessed radiologically (Merker, Zayat, Youssef, 1970). The athletes were prevented from training on the day of ergospirography.

The apparatus used was the bicycle ergometer of Zimmerman. The athlete sits on the bicycle ergometer with the nose clipped, a sphygnomanometer cuff applied on his arm and two E.C.G. leads strapped on 5th. right and left intercostal spaces in the midclavicular lines. Through a mouth-piece connected by elephant tubing the athlete breathes in and out through a Spirolyte (type 11 V E B Tunkalor, G.D.R.) which, by electro-physical analysis, determines the oxygen uptake and CO\(_2\) output.
The test starts by allowing the athletes to breathe quietly at rest for five minutes. The pulse, blood pressure and E.C.G. are recorded at the end of first, third and fifth minutes while continuous recordings for O₂ and CO₂ were made on the spirolyte tracings. Pedalling then starts against an initial load of 100 watts. The pedalling was kept on the rate of 75 turns/minute by instructing the athletes to follow the gauge fixed on the bicycle. At the end of every two minutes of exercise the pulse, blood pressure and E.C.G. were recorded and the load is increased by 50 watts till the athlete is exhausted, reaches 300 watts, or there is any indication to stop exercise. Most of our athletes completed 200 watts test and only 11 males reached 300 watt work load. Continuous recording of O₂ and CO₂ is taken by the spirolyte during exercise as well as on recovery. During the period of recovery the athlete continued to breathe through the spirolyte without pedalling and all the parameters were recorded every minute for at least five minutes.

Results

Table I shows the mean value and the range of the parameters assessed.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Range</th>
<th>standard Deviation</th>
<th>number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>19.9</td>
<td>14.2 - 30.0</td>
<td>± 3</td>
<td>42</td>
</tr>
<tr>
<td>Vital capacity (ml)</td>
<td>4790</td>
<td>3500 - 6600</td>
<td>± 260</td>
<td>42</td>
</tr>
<tr>
<td>*P.V.C. (ml)</td>
<td>4910</td>
<td>3150 - 5700</td>
<td>± 420</td>
<td>42</td>
</tr>
<tr>
<td>V.C./P.V.C.</td>
<td>94%</td>
<td>70% - 170%</td>
<td>± 25%</td>
<td>42</td>
</tr>
<tr>
<td>Min. O₂ uptake (ml)</td>
<td>525</td>
<td>345 - 660</td>
<td>± 79.0</td>
<td>40</td>
</tr>
<tr>
<td>Max. O₂ uptake at 250 W. (ml)</td>
<td>3020</td>
<td>1320 - 3740</td>
<td>± 110</td>
<td>30</td>
</tr>
<tr>
<td>Max. O₂ uptake at 300 W. (ml)</td>
<td>3387.2</td>
<td>3120 - 3720</td>
<td>± 180</td>
<td>11</td>
</tr>
<tr>
<td>Min. O₂ pulse</td>
<td>6.3</td>
<td>4.0 - 9.1</td>
<td>± 1.3</td>
<td>40</td>
</tr>
<tr>
<td>Max. O₂ pulse at 300 W.</td>
<td>18.4</td>
<td>14.2 - 21.7</td>
<td>± 2.1</td>
<td>11</td>
</tr>
<tr>
<td>Max. O₂ uptake/wt.</td>
<td>39.4</td>
<td>27.2 - 50.9</td>
<td>± 12.1</td>
<td>40</td>
</tr>
<tr>
<td>Max. Heart rate at 250 W.</td>
<td>1671</td>
<td>148 - 180</td>
<td>± 8.2</td>
<td>33</td>
</tr>
<tr>
<td>Max. Heart rate at 300 W.</td>
<td>167.5</td>
<td>160 - 187</td>
<td>± 8.1</td>
<td>11</td>
</tr>
</tbody>
</table>

*Predicted Vital Capacity

Discussion

Physical fitness research has at present become an important field of investigation to evaluate human performance and to guard against hypokinetic diseases. Prolonged effort which reaches exhaustion encountered in cycling, long distance running, skiing and swimming depends on a continuous steady oxygen supply. Only at the beginning and during the final spurt are anaerobic processes involved. Some athletic performances such as boxing or gymnastics need bouts of great exertion followed by periods of low activity. This involves both aerobic and anaerobic processes. In cardio respiratory endurance research using ergometry several parameters could be measured i.e. oxygen uptake, heart rate, blood pressure, oxygen pulse, blood lactate concentration, cardiac output, stroke volume pulmonary ventilation, ventilatory equivalent and heart volume. From all these parameters, it has appeared that oxygen uptake has a great validity in measurement of cardio respiratory performance. (Saltin, 1964). To maintain a normal equilibrium under varying exercise conditions an adequate cardio-pulmonary function will always be an important prerequisite.

Pulmonary ventilation which is at rest 5-6 litres/min. may exceed in a short spell of exercise 150 l/min. An increase in cardiac output and in the capillary net work in the lung occurs. The total lung volume may decrease slightly due to increased central blood volume on exercise. During heavy load the heart rate increases until exhaustion is reached at which the recorded heart rate is considered as the maximal attainable heart rate.
The mean maximal pulse rate in males of our group was 167.3. The total mean rise in pulse rate was 90 beats/min. Physically fit individuals have lower pulse rates at rest and on exercise but the relative acceleration on exercise is greater in the athlete (Karpovich, 1966). The increase in heart rate is related to the increase in oxygen uptake; i.e. higher oxygen consumption is achieved with maximum heart rate. This agrees with Andersen, (1968), and in unfit subjects unaccustomed to severe exercise the heart rate approaches the ceiling level in an asymptotic manner, probably reflecting the inability of the heart to produce a larger output. The maximum heart rate reported on exercise at age of 20 is about 200 which is reduced to 155 at the age of 70 (Andersen, 1968).

The time needed for the pulse rate to return to normal after the end of exercise depends on the physical fitness of individual, an intact cardiorespiratory system, and the intensity of work done. The pulse of trained athletes recovers faster than untrained ones. In our group a rapid primary fall of pulse rate occurred in the first five minutes of recovery and was followed by a plateau. If would have been followed for a longer time, a subsequent secondary fall could have been reported. The pulse rate does not return to normal as fast as does oxygen uptake after an oxygen debt has been incurred (Karpovich, 1966).

In general recovery processes occur at a quicker rate in trained subjects. Heart rate, blood pressure, blood flow through muscles (Elsner & Carison, 1962), and respiration (Margaria, 1968) recover at a much quicker rate in athletes, than in non athletes. In heavy exercise with lactate formation the kinetics of respiratory and circulatory recovery are altered and delayed (Margaria et al, 1968).

The anticipation of exercise may cause initial rise in blood pressure which continues to rise during exercise. The combined effect of increases in heart rate, constriction of blood vessel in the splanchic and in the skin results in elevation of blood pressure.

We found the mean systolic blood pressure to rise rapidly with the onset of exercise, to be followed by a gradual decline which did not reach the resting level 6 minutes after stopping exercise. The maximum mean rise in systolic arterial blood pressure was 188/46. A drop in systolic blood pressure during exercise suggests fatigue of a heart unadapted to exertion (Gruchet & Moulinier, 1920). The pulse pressure is increased on exercise. This change indicates an increase in stroke volume during exercise. In general the greater intensity of exertion the greater the rise in systolic pressure. On occasion the diastolic pressure approached a zero level. The systolic arterial pressure increases more in athletes than in non athletes reaching in athletes values of well above 200 mmHg during heavy exercise (Bevegarrd et al, 1960). The pulmonary artery pressure increases more in athletes as their lungs contain more blood during exercise than non athletes.

During exercise metabolism is increased and minute ventilatory volume may reach more than 110 litres/minute. A linear relationship is found between the ventilatory volume on exercise and the rate of oxygen consumption. This linear relationship is disrupted if exercise increases in severity and ventilation increases in excess of the increase in oxygen consumption (levelling off O2 consumption). After the end of exercise the drop in ventilatory volume is quicker than in respiratory rate. This drop is especially rapid during the first two minutes. O2 consumption (VO2) is increased 10-12 times during strenuous exercise (Margaria & Cerretelli, 1968). After the end of exercise (VO2) decreases slowly and reaches the pre-exercise value in several minutes depending on the intensity of exercise. Oxygen uptake increases with the increase of intensity of exercise, but the increase is lessened when higher loads are given approaching levelling of O2 consumption. A limit to maximum O2 consumption is the aerobic power, and may be set by limitation of cardiac output more than by the capacity of the respiratory pump (Margaria & Cerretelli, 1968).

The pH of arterial blood is unaffected by exercise in normal individuals as long as arterial PCO2 (arterial CO2 tension) values do not change. Only during very heavy exercise carried out in anaerobic conditions and involving production of lactic acid does the arterial H+ ion concentration increases in some cases, up to 60% or more (Margaria & Cerretelli, 1968). This favours O2 uptake by tissue but hampers the CO2 uptake by blood perfusing active muscles.

In our work the O2 uptake (consumption) was measured at rest and on several work loads. The level of work found at which a further increase in work does not cause further increase in oxygen uptake could be taken as a criterion of true maximum level of O2 uptake. This measures the maximum power of aerobic metabolism which depends on the lung and cardiac functions, the size of the pulmonary capillary bed interfacing with the alveolar surface and the capacity of blood to carry oxygen. In normal healthy individuals the pulmonary function is seldom a limiting factor (Margaria & Cerretelli, 1968); Åstrand, (1956), considers max. O2 uptake as a measure of maximal cardiovascular performance. In sedentary men max. O2 uptake on exercise may reach 40-50 ml/min. kgm. body weight but in athletes of International standard it may mount up to 80 ml/min. kgm. body weight. Athletic training attributes to this difference. Inactive subjects are able to improve their O2 uptake with training for few weeks. In our group the max. O2 uptake/kgm. body weight ranged
between 27.2 - 50.9 ml. which is well below international athletic standard.

Table II

<table>
<thead>
<tr>
<th></th>
<th>non Athlete male</th>
<th>International male standard</th>
<th>U.A.R. m. Athlete</th>
</tr>
</thead>
<tbody>
<tr>
<td>max. $O_2$ uptake L/min.</td>
<td>3.2</td>
<td>4.8</td>
<td>3.387</td>
</tr>
<tr>
<td>Max. Heart rate</td>
<td>189</td>
<td>178</td>
<td>167.3</td>
</tr>
<tr>
<td>Max. $O_2$ pulse</td>
<td>17</td>
<td>27.2</td>
<td>18.4</td>
</tr>
</tbody>
</table>

This table II shows the max. $O_2$ uptake and other related parameters of young males, non athletes and top athletes, reported by Hermansen & Andersen, 1965, compared with our young athletes studied in U.A.R. It shows low values of these parameters in our group compared to the international standard. In old ages training does not seem to produce any increment in maximal $O_2$ uptake (Andersen, 1967). In our athletes below the age of 16 lower mean figures are found (3020 ml.); this suggests that the size of maximum $O_2$ uptake more or less is established when full growth is reached. $O_2$ pulse can be calculated when $O_2$ consumption on exercise and it's corresponding heart rate are known.

During exercise $O_2$ pulse increased rapidly with acceleration of heart from a mean value of 6.3 (S.D. + 2.1) Andersen (1968) gave an average value of 27.2 for maximum oxygen pulse in athletic males. Genetic and racial factors, adaptation and fitness to physical activity during growth may play a role in explaining this difference.

The relationship between individual max. $O_2$ uptake and heart volume shows the presence of a significant statistical correlation between these two parameters ($r = 0.35$) significant at $P = 0.05$. Ceretelli et al (1967) showed a linear relationship between cardiac output and oxygen uptake and exercise. Our results agrees with Andersen & Wilson (1966) who showed that heart volume is related to max. oxygen uptake. Reindell et al (1967) have found a high correlation between the heart volume and max. oxygen pulse.

Acknowledgements

We are indebted to Dr. Refky Faris for his great help in the statistical analysis done in the report.

REFERENCES


RELATIONSHIP BETWEEN HEART VOLUME AND PULSE RATE IN SPORTSMEN AND NONSPORTSMEN

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Introduction

Heart volume, oxygen consumption and pulse rate are often taken as indicators of the working capacity of sportsmen in the form determined relationships such as oxygen pulse, equivalence of heart volume and others. During effort, in conditions of relative steady state it has been found that a close relationship exists between the volume of the heart, the oxygen pulse and the pulse rate, relationship which increases in importance inasmuch as the effort is greater. It has been proved that in these conditions of investigation the importance of the maximal oxygen pulse in healthy young persons correlates with the heart volume in such a way as to result in an almost constant equivalence of heart volume (1, 3, 7, 8, 9, 11, 12). It is known, moreover, that the pulse rate in effort, in conditions of relative steady state, except the maximal, is lower inasmuch as the volume of a healthy heart is greater (4, 5, 7).

Not so often however do we find data concerning pulse rate, oxygen pulse and equivalence of heart volume during effort in conditions of vita maxima (13). This is why we wished in the course of our investigations, to study more closely the relationships of the mentioned parameters in conditions of effort vita maxima, often used to ascertain the aerobic capacity of the sportsmen.

Materials and methods

We dealt in the course of our investigations, with 259 of the best Yugoslav sportsmen, members of the country's representative teams in the following: athletics, rowing, canoeing, cycling, water-polo, football, basket ball, net-ball, boxing, wrestling and table tennis from 18 to 35 years of age and also with 79 healthy nonsportsmen aged from 18 to 27 years.

In all these cases a teleroentgenographical determination of the heart volume was carried out according to the Kahlshof, Rohrer method, modified according by Musshoff and Reindell (2, 6, 10) and its conversion into corresponding relative values (absolute heart volume per kg.).

According to the absolute heart volume the subjects investigated have been placed into the following groups: with a heart volume of

a. up to 799 ml.,

b. 800-899 ml.,
c. 1000-1099 ml.,
d. 1100-1199 ml.,
e. 1200-1299 ml.
f. over 1,300 ml.
g. over 1,300 ml.

The respiratory parameters observed have been registered by metabograph according to Fleisch whilst the pulse rate was registered electrocardiographically.

In order to determine the heart volume we took into account the relationship between the absolute volume of the heart and the maximal oxygen pulse obtained in conditions of maximum effort.

The results obtained were worked out statistically. The importance of the difference of the mean values for the physiological parameters observed between sportsmen and nonsportsmen was estimated as well as the correlation between the volume of the heart and the maximal pulse rate on the one, and the volume of the heart and equivalence of the heart volume on the other hand.

Results

In Table one the following has been shown for each particular group: the relative heart volume the maximal pulse rate, the equivalence of the heart volume and the maximal effort sustained.

These results show that the average value of the relative heart volume in the subjects we studied was greater inasmuch as the heart volume was greater.

The average values of the maximal pulse rate obtained in condition of maximal effort show that the values are lower inasmuch as the heart volume is greater, whilst the average values of the equivalence of the heart volume increase progressively with the increase of the heart volume.

The average values of the maximal effort sustained were greater inasmuch as the heart volume was greater.

The results seen in Figure 1 show that in all degrees of effort the average pulse rate is almost as a rule, lower inasmuch as the heart volume is greater.
Table I

<table>
<thead>
<tr>
<th>HV (ml)</th>
<th>( \bar{x} )</th>
<th>n</th>
<th>Rel. HV (ml/kg)</th>
<th>Max. HR</th>
<th>Eq HV</th>
<th>Max. performance (Watt)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \bar{x} \pm s )</td>
<td>( \bar{x} \pm s )</td>
<td>( \bar{x} \pm s )</td>
<td>( \bar{x} \pm s )</td>
<td>( \bar{x} \pm s )</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SPORTMEN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>up to 799</td>
<td>752.7</td>
<td>17</td>
<td>12.0 ± 1.1</td>
<td>189.3 ± 14.9</td>
<td>44.5 ± 3.6</td>
<td>252.5 ± 33.8</td>
<td>63.4 ± 6.6</td>
</tr>
<tr>
<td>800 - 899</td>
<td>855.3</td>
<td>31</td>
<td>12.2 ± 1.1</td>
<td>181.3 ± 9.4</td>
<td>44.6 ± 4.1</td>
<td>273.0 ± 23.2</td>
<td>70.5 ± 6.3</td>
</tr>
<tr>
<td>900 - 999</td>
<td>949.1</td>
<td>52</td>
<td>13.0 ± 1.4</td>
<td>179.0 ± 11.4</td>
<td>46.8 ± 4.8</td>
<td>290.6 ± 33.9</td>
<td>73.8 ± 8.0</td>
</tr>
<tr>
<td>1000 - 1099</td>
<td>1050.1</td>
<td>56</td>
<td>13.5 ± 1.5</td>
<td>175.4 ± 16.0</td>
<td>49.4 ± 5.9</td>
<td>303.4 ± 33.3</td>
<td>79.0 ± 8.2</td>
</tr>
<tr>
<td>1100 - 1199</td>
<td>1139.8</td>
<td>59</td>
<td>14.2 ± 1.3</td>
<td>176.1 ± 15.3</td>
<td>52.0 ± 5.8</td>
<td>312.9 ± 39.1</td>
<td>81.1 ± 7.0</td>
</tr>
<tr>
<td>1200 - 1299</td>
<td>1246.6</td>
<td>28</td>
<td>14.4 ± 1.1</td>
<td>176.6 ± 15.3</td>
<td>55.4 ± 5.9</td>
<td>329.6 ± 38.3</td>
<td>87.1 ± 7.2</td>
</tr>
<tr>
<td>over 1300</td>
<td>1373.0</td>
<td>16</td>
<td>14.8 ± 1.8</td>
<td>170.2 ± 18.2</td>
<td>58.1 ± 7.6</td>
<td>326.0 ± 37.9</td>
<td>94.2 ± 12.3</td>
</tr>
<tr>
<td><strong>NONSPOSTMEN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>up to 799</td>
<td>730.9</td>
<td>37</td>
<td>11.5 ± 1.2</td>
<td>184.6 ± 5.5</td>
<td>54.4 ± 6.9</td>
<td>219.5 ± 25.7</td>
<td>63.9 ± 6.3</td>
</tr>
<tr>
<td>800 - 899</td>
<td>855.0</td>
<td>25</td>
<td>12.1 ± 0.9</td>
<td>183.7 ± 5.5</td>
<td>57.6 ± 6.7</td>
<td>235.2 ± 34.6</td>
<td>70.9 ± 5.9</td>
</tr>
<tr>
<td>900 - 999</td>
<td>956.0</td>
<td>17</td>
<td>12.7 ± 1.1</td>
<td>181.2 ± 11.5</td>
<td>61.9 ± 7.4</td>
<td>240.6 ± 31.7</td>
<td>75.8 ± 8.3</td>
</tr>
</tbody>
</table>

Savić Srdan, Ksenija Adamović and Berislav Dimitrijević: „Relationship between heart volume and pulse rate in sportmen and nonsportmen”. Yugoslav Institut of Physical Culture, Beograd, Kneza Vaseskova Br. 42, SFR YUGOSLAVIA.

Discussion

Investigations carried out up to now have shown that the closest correlation exists, in the case of sportmen, between the heart volume and the maximal oxygen pulse, obtained in effort in conditions of relative steady state. The relationships found between the heart volume and the maximal oxygen pulse in relative steady state are so close that there are practically no important differences in the values of the equivalence of the heart volume pertinent to different volumes of the heart (7) whilst our investigations show that in conditions of maximal effort a positive significant correlation exists (p < 0.005) between the equivalence of the heart volume in connection with the volume of the heart both in sportmen and nonsportmen.

It is interesting to note however that a statistically significant difference (p < 0.001) exists in the equivalence of the heart volume between sportmen and nonsportmen for all the three comparative groups (subjects with a heart volume 799 ml, 800-899 ml and 900-999 ml).

The numerous investigations carried out in sportmen in conditions of relative steady state show that the pulse rate is lower inasmuch as the sportmen's heart volume is greater.

Our investigations clearly show that such a relationship also exists during effort in conditions of maximal effort. The maximal value of the pulse rate obtained in conditions of maximal effort are equal regardless of the heart volume. However when the heart volume is greater the effort in which the values have been obtained is also greater.

In the investigations carried out we have found that in all degrees of temporary effort there exist statistically significant difference in the range of average values of pulse rate between sportmen and nonsportmen with a heart volume of 800-999 ml. In the group of subjects with a heart volume up to 799 ml these differences have not been noticed.

In comparing the results obtained in investigations in conditions of steady state with the results of our own investigations it is possible to conclude that in conditions of maximal effort, the close correlation between the heart volume and the maximal oxygen pulse (which exists in steady state) disappears, whilst we find an always increasing dependence of the equivalence of heart volume from the absolute volume of the heart. It is possible to conclude also that the pulse rate in sportmen and nonsportmen during increasing effort in conditions of maximal effort is lower inasmuch as the heart volume is greater.

However in equal average heart volume the pulse rate in sportmen is lower than in nonsportmen. This confirms the conception that a trained sportman's heart possesses an increased stroke volume and the capacity to maintain this during the increase of the pulse rate.
FREQUENCY OF PULSE RATE IN RELATION TO HEART VOLUME AND PERFORMANCE IN SPORTMEN AND NONSPORTMEN

Savić Srdjan, Ksenija Adamović and Berislav Dimitrijević: "Relationship between heart volume and pulse rate in sportmen and nonsportmen"
Yugoslav Institut of Physical Culture, Beograd, Kneza Višeslava Br. 42. SFR YUGOSLAVIA
REFERENCES


HAEMODYNAMICS IN ATHLETES DEPENDING ON THE RESULTS OF COMPETITIONS

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It is well known that for the physiological estimation of well-trained condition numerous laboratory investigations of athletes are carried out. However the questions of dependence between the separate physiological parameters and athletic technical results need further study. Our aim was to study by a complex medical examination of athletes the dependence which exists between the level of arterial pressure (AP) and results achieved by athletes.

A complex clinical-physiological examination included 310 well-trained male athletes aged from 19 to 28 years. At the same time we have analysed 1500 records of medical control of Masters in Sport.

The athletes examined were divided into 3 main groups according to their AP. The first group was composed of athletes who had the level of AP from 130/82 up to 150/92; the second group — from 100/60 up to 119/80 and the third group from 84/50 up to 99/66 mm of mercury. 1500 well-trained sportsmen were also divided into the separate groups according to the same principle.

The analysis of this material has shown that the athletes who belonged to the second group differ from the first and the third groups by a higher functional state of some physiological systems. This phenomenon has revealed itself in the following indices.

In respect of the cardiovascular system: Especially demonstrative were some indices of the contractile function of the myocardium which were observed in athletes with various levels of AP, that is, the athletes who composed the second group on having suffered a certain physical charge, showed a more rapid climb in the systolic volume, the volume velocity of blood ejection and the power of systoles coupled with a less clear index of frequency of the pulse.

Studying the functional condition of the cardio-vascular system of athletes we tried to establish the interdependence between some haemodynamic indices, in particular between the pulse frequency and the level of maximal and minimal arterial pressure and athletic technical results.

We compared the pulse frequencies and AP levels in well-trained athletes (the members of country combined teams) — the representatives of the following kinds of sports: 33 skiers, 40 athletes, 14 skaters, 40 rowers, 21 pentathlons, 33 cyclists — in all 181 sportsmen.

All these sportsmen in every kind of sport were divided into 2 groups according to the data and the results of competitions. The first group included the sportsmen-record-holders and champions, the second — persons with lower athletic-technical results (Table I).

The data analysis showed, that athletes with higher competitive results have rather rarefied pulse (p < 0.001 - 0.5) and lower AP (100 mm of mercury column and higher).

Based upon our data, we consider that for the athletes with high athletic results the drop in pulse rate is more characteristic than a decrease in arterial blood pressure.

It was concluded in our investigations that in the case of such standard physical loading as 3 min running on the spot (180 steps in a min.), when muscular work is done in the same tempo in athletes with different athletic achievements in most cases almost the same reaction had been observed in the pulse frequency and AP level.

In the case of utilization of combined functional tests — running for 3 minutes on the spot, after 2 minutes 45 seconds the running is held at a tempo of 180 steps a minute with the consecutive transition to a maximal acceleration (15 sec.) one can see some definite difference in reaction of haemodynamic indices between athletes with high and those with relatively low athletic-technical results.

A comparison of the data of haemodynamic indices of combined functional tests showed that in the reactions received (in the change of pulse frequency and AP) there is no principal difference, but in contrast to the first standard physical loading the later (complex) shows more rapid reaction on the part of physiological parameters of the cardio-vascular system.

We must consider that the rapid transition from running at 180 steps a minute to the high-speed physical charge — to 15 sec. running provokes the athlete’s organism to show its adaptive possibilities more obviously as it takes place in conditions of competition.
Table I

Interdependence of some haemodynamic indices and athletic achievements of well-trained sportsmen.

<table>
<thead>
<tr>
<th>No.</th>
<th>Sport</th>
<th>Athletic achievement</th>
<th>Number of athletes</th>
<th>Pulse frequency /M ±/</th>
<th>Arterial pressure M ± m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cycle</td>
<td>high</td>
<td>13</td>
<td>60.4 ± 1.6</td>
<td>114.6 ± 2.2</td>
</tr>
<tr>
<td></td>
<td>racing</td>
<td>relatively low</td>
<td>20</td>
<td>70.2 ± 2.6</td>
<td>118.5 ± 2.3</td>
</tr>
<tr>
<td>2.</td>
<td>Skiing</td>
<td>high</td>
<td>13</td>
<td>51.7 ± 1.9</td>
<td>104.5 ± 2.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>relatively low</td>
<td>20</td>
<td>64.2 ± 2.9</td>
<td>113.5 ± 2.3</td>
</tr>
<tr>
<td>3.</td>
<td>Modern pentathlon</td>
<td>high</td>
<td>7</td>
<td>54.8 ± 4.7</td>
<td>109.7 ± 2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>relatively low</td>
<td>14</td>
<td>59.1 ± 3.4</td>
<td>111.1 ± 2.3</td>
</tr>
<tr>
<td>4.</td>
<td>Academical rowing</td>
<td>high</td>
<td>20</td>
<td>59.1 ± 2.25</td>
<td>115.8 ± 2.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>relatively low</td>
<td>20</td>
<td>60 ± 1.93</td>
<td>109 ± 2.75</td>
</tr>
<tr>
<td>5.</td>
<td>Skates</td>
<td>high</td>
<td>6</td>
<td>61.7 ± 3.1</td>
<td>107.8 ± 4.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>relatively low</td>
<td>8</td>
<td>59.1 ± 2.4</td>
<td>110 ± 3.0</td>
</tr>
<tr>
<td>6.</td>
<td>Athletics</td>
<td>high</td>
<td>20</td>
<td>63.6 ± 1.81</td>
<td>116.6 ± 2.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>relatively low</td>
<td>20</td>
<td>66.3 ± 2.3</td>
<td>114.6 ± 2.34</td>
</tr>
</tbody>
</table>

Besides that mentioned above it was found out that in the case of the complex test the period of restoration of haemodynamic parameters in most cases was longer. It is known to be one of the main indices in the estimation of the training condition (G. Ja. Mgebrishvili et al. 1956, S.P. Letunov et al., 1958 etc.).

Comparing with the I and III groups the athletes of the II group showed:

External respiration; in comparatively high indices in vital lung capacity and in maximal lung ventilation, in the power of respiratory muscles, the time of suppression of respiration and decrease in the respiratory volume per minute.

Nervous system; — in shortening of the chronaxy of the optocal and neuromuscular apparatus (muscles of the shin and the shoulder), in a longer chronaxy of the vestibular analyzer, not clearly expressed red dermography with a short latent period, high resistibility of the cutis to direct current, in a relatively low temperature of the entis, in a slow hydrophilosis, in a moderate reaction of labyrinthine and somatovegetative reflexes after rotation in the Barany chair.

The analysis of the athletic-technical results has indicated that among the athletes (1500 persons) of the second group 80.4% of them gained high athletic results. The same contingent in the 3rd group was equal to 50% and in the 1st group — 16%.

The results obtained give the reason to believe that there is a certain relation between the normal maximum systolic arterial pressure (100 — 120 mm of the mercury column) and the athletic results gained by an athlete.
ANALYSIS OF THE PARAMETERS OF ELECTROCARDIOGRAMS SURVEYED IN 104 RACING DRIVERS OF THE REGIONS MARCHE-ABRUZZI (Central Italy)

V. FEDERICI, M.D.

Centre of Sports Medicine of Ascoli Piceno, Italy

Introduction

The Italian Sports Automobile Commission (C.S.A.I.) in accord with the Italian Sports Medicine Federation (F.M.S.I.) has established that since 1970 the fitness examinations must be made in the Sports Medical Centres with particular methodologies including the execution of an electrocardiogram (ECG) for a more correct valuation of the racing drivers for speed and reliability trial competitions. The Sports Medical Centre of Ascoli Piceno, the only one in the region of Marche and Abruzzi (Central Italy), has been authorised by the F.M.S.I. to carry out the examinations.

The examinations have been carried-out from December 1969 to June 1970.

Enumeration of cases and methodologies

There have been examined 104 automobile drivers, all regular members of the C.S.A.I., who are dedicated to speed and reliability trial competitions. In the classification of biomechanical orientation of the sports activity proposed by the Institute of Sports Medicine of Rome, sports motoring may be situated in the undergroup of the skill activity when the principal quality is psycho-neuro-sensorial efficiency, although there is muscular work.

In sports motoring the muscular work is constituted by the necessity of operating on the organs of command of the car. The laying-out of the muscular forces, requested in this operation, is relatively modest in modern cars, though it wants precision.

Table I

**DISTRIBUTION OF SAMPLES ACCORDING TO EXAMINED PARAMETERS**

<table>
<thead>
<tr>
<th>Average frequency</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>70</th>
<th>75</th>
<th>80</th>
<th>85</th>
<th>90</th>
<th>95</th>
<th>100</th>
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<tbody>
<tr>
<td>RR</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td>9</td>
<td>17</td>
<td>17</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>PQ</td>
<td>1</td>
<td>1</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>20</td>
</tr>
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<td>QT</td>
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<td>6</td>
<td>7</td>
<td>13</td>
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<td>16</td>
<td>17</td>
</tr>
<tr>
<td>QTc</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>11</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>TV1</td>
<td>4</td>
<td>-3</td>
<td>-2</td>
<td>-1</td>
<td>0</td>
<td>+1</td>
<td>+2</td>
<td>+3</td>
<td>+4</td>
<td>+5</td>
</tr>
<tr>
<td>TV6</td>
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<td>10</td>
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<tr>
<td>Ages</td>
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<td>29</td>
<td>30</td>
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<td>49</td>
<td>50</td>
<td>59</td>
<td>9</td>
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</tbody>
</table>

Variable X = 75
Frequency Y = 104

X = 88
Y = 104
X = 15.6
Y = 104
X = 35.6
Y = 104
X = 37.1
Y = 104
X = 0.4
Y = 104
X = 6.5
Y = 104
X = 35.7
Y = 104
The fitness test has involved a complete objective checking and the performance of an electrocardiogram with its twelve derivations with the ECG kept fixed at the conventional setting of 1 mV = 1 cm.

The subjects examined belonged to ages varying from 20 to 54 years (table no. I) and came from the regions of Marche and Abruzzi.

The professional activities differed, with the accent on professional men, and all have been declared fit on clinical examination.

In every ECG the following parameters were measured:

1. average cardiac frequency for every minute (Fr);
2. average duration of the R-R interval (in hundredth's of a second);
3. duration of atrio ventricular conduction (PQ) interval measured from the start of the P wave to the start of the QRS complex (in hundredth's of a second);
4. duration of the QT interval as electrical expression of ventricular systole (in hundredth's of a second);
5. value of the QTc;
6. height of the T wave in V1 (measured in tenths of mV);
7. height of the T wave in V6 (measured in tenths of mV);

The data surveyed for every parameter have been quoted in table I. In table II are quoted the parameters of ten sports drivers with more than ten years activity.

Table II

PARAMETERS SURVEYED IN A SAMPLE OF TEN RACING DRIVERS WITH MORE THAN TEN YEARS ACTIVITY

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Number of subjects</th>
<th>Averages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average frequency</td>
<td>10</td>
<td>72</td>
</tr>
<tr>
<td>RR</td>
<td>10</td>
<td>84.4</td>
</tr>
<tr>
<td>PQ</td>
<td>10</td>
<td>14.5</td>
</tr>
<tr>
<td>QT</td>
<td>10</td>
<td>35.7</td>
</tr>
<tr>
<td>QTc</td>
<td>10</td>
<td>38.9</td>
</tr>
<tr>
<td>TV1</td>
<td>10</td>
<td>0.3</td>
</tr>
<tr>
<td>TV6</td>
<td>10</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Results

The results of analyses have been summarized in table III, as far as regards the averages.

1. Frequency — the average value of 75 a minute is quite adherent to the average value of an unselected population.

2. The interval of the part R-R in the cardiac cycle turned out equal to 88, a value entering in the average.

3. Atrio-ventricular conduction (PQ) — The average value of 15.6 puts our samples in a position inferior, also in comparison with the median value of an unselected population.

In fact it is possible to find in the medical literature that the PQ interval ranges between 12-20, with 16 as average only 4 tenths off our samples. The PQ reaches the standard top value of 20 hundredths of seconds only in once case and also in one case only it reaches the value of 12 hundredths of seconds, a value considered at a limit lower than the rule.

4. QT interval — In our samples the average value reaches 35.6, equal to the average value of an unselected population.

5. The QT turned out equal to 37.1.

6. Height of the T wave in V1 — In our samples the average value is 0.4. Also this value comes into the average: as a matter of fact this height for a not elected population is equal to 0.84 (N.Y. Heart Association).

7. Height of the T wave in V6+ in our samples it is 6.5. This value is superior in comparison to that one reported in medical literature. In the standard adults it is 2.80 with values varying from 0 to 6.9.

Table III

AVERAGE VALUES OF PARAMETERS SURVEYED

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Number of subjects</th>
<th>Averages</th>
</tr>
</thead>
<tbody>
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<td>Average frequency</td>
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<td>75</td>
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<tr>
<td>RR</td>
<td>104</td>
<td>88</td>
</tr>
<tr>
<td>PQ</td>
<td>104</td>
<td>15.6</td>
</tr>
<tr>
<td>QT</td>
<td>104</td>
<td>35.6</td>
</tr>
<tr>
<td>QTc</td>
<td>104</td>
<td>37.1</td>
</tr>
<tr>
<td>TV1</td>
<td>104</td>
<td>0.4</td>
</tr>
<tr>
<td>TV6</td>
<td>104</td>
<td>6.5</td>
</tr>
<tr>
<td>Ages</td>
<td>104</td>
<td>35.7</td>
</tr>
</tbody>
</table>

Discussion

From the analysis of the data quoted it is clear that there is an absence of variations from the standard ECG parameters, probably due to the fact that this activity does not demand such heavy muscular work as to induce morpho-functional-cardio-circulatory adaptations.

The detailed analysis shows that the value of cardiac
frequency, the R-R, the PQ, the QT, the QTc are placed in the circle of standard values and far from limits higher than standard.

The height of the T wave is oriented towards the negativity in V₁ and towards positiveness in V₆, reaching here a higher limit that the standard. This emphasizes that in the absence of variations in the parameters surveyed we find an index of efficient condition of the cardiac muscle.

The C.S.A.I. did very well to include the ECG in the methodics of the fitness visits because heart integrity is a main factor in the well known triad to be considered in the prevention and in the analysis of the road accidents: man — road — car.