F. Fitness Tests and Assessment

STANDARDISATION OF PHYSICAL FITNESS TESTS

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On behalf of the International Committee for the Standardisation of Physical Fitness Tests, I as the Executive Secretary would like to present this paper on physical fitness tests.

Introduction

Physical fitness is one of the most important problems in the present time, because we cannot forecast whether physical fitness of mankind will develop or not. There are many factors which may cause deterioration in physical fitness. For instance, traffic development, automatization, air pollution, excessive food intake and lack of physical exercise are increasing now. Therefore, we might lose our fitness, unless we recognize the importance of physical fitness and make efforts to develop it. However, we do not know how our fitness level is and how it tends in the future, because we have no standardised measure to assess it. This is the reason why the International Committee for the Standardisation of Physical Fitness Tests (I.C.S.P.F.T.) was founded.

In 1964, the important scientific meeting, the International Congress of Sports Sciences, was held in Tokyo under the collaboration of F.I.M.S., F.I.E.P., I.C.S.P.E., I.C.H.P.E.R. and other related bodies. At that meeting, I.C.S.P.F.T. as well as the Doping Committee were established.

Since that time, I.C.S.P.F.T. has met together every year to discuss and promote test standardisation. At first, the members talked over about what area should be covered by physical fitness and decided to have the following four areas: (1) medical examination (2) physiological measurements (3) physique and body composition and (4) performance tests. Then, all members were divided into four groups and worked out to establish the definitive tests. Just prior to the present congress of F.I.M.S., I.C.S.P.F.T. held the 7th annual meeting and arranged the final manuscript for the standardised tests, explained in detail below.

Medical examination consists of medical history, family history, physical examination and laboratory data. It has two forms, i.e. short form consisted of basic items and long form, which includes more precise information, either of which can be utilized according to the preference of a physician. Medical examination is really a prerequisite to determine whether a subject can participate in the following tests. Therefore, a physician shall arrange a certificate for a subject to permit him to be tested with maximal or submaximal loads.

Physiological measurements aim mainly at assessing aerobic capacity using treadmill, bicycle ergometer and stepping ergometer. Standard procedure is set with successively increased loading in consideration of metabolic rate of the subject. Maximum oxygen intake thus measured will be expressed in ml per minute per kg of body weight for the convenience of comparative study among different subjects. Precautions are taken on several criteria in preventing some accidents.

Physique and body composition consists of many measurements, of which the following items are basic: weight, standing height, sitting height, bi-acromial diameter, bi-iliac diameter, bi-epicondylar diameter of the humerus, bi-epicondylar diameter of the femur and skinfolds (triceps, subcapular and suprailiac). Some anthropometric indices are also included to assess body proportion. Body composition is assessed by sophisticated measurements of densitometry, total body water and total body potassium.

Performance tests include the following basic items: 50 metre sprint, standing long jump, distance run, grip strength, pull-ups for males (flexed arm hang for females), 40 metre shuttle run, 30 second sit-ups and flexibility. The last item is left to the selection of a tester whether he prefers standing forward flexion or sitting forward flexion.

We have just finished our work on test standardisation. Therefore, we are arranging to publish a professional textbook, in which the test manual is to be included. A popular book will also be published for the general public.

We now come to a new point of view and are designing a framework for international study of physical fitness. The framework consists of project
Objective and population study. Project concerns test items to be measured. Objective aims at further test standardisation, comparison among subjects of different status, effect of internal and external factors on physical fitness and relationship between many components. Population studies are made for clarifying national, racial, environmental, social, chronological and occupational differences of physical fitness among populations.

At the beginning of the foundation of the Committee, we made up our mind to limit the number of members in order to keep the standard of our research high, irrespective of national policies. This principle is being kept now, but our Committee is becoming larger year by year and it contains 90 scientists covering 6 continents of the world. We welcome many persons to participate in our Committee in so far as they are scientific. The activity of our Committee has been fruitful and, I believe, it is ever contributing to wellbeing of whole populations in the world. At last but not the least, we should like to express our sincere gratitude to the collaboration of F.I.M.S. which has been extended since the establishment of our committee. We hope its collaboration will continue in the future.

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THE RELATIONSHIP OF CARDIORESPIRATORY AND ANTHROPOMETRIC FACTORS, TO AEROBIC WORK CAPACITY, IN YOUNG WOMEN

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Submaximal and maximal exercise tolerance tests were given to 32 female Physical Education students 19-21 years old. Each subject worked on a Müller bicycle ergometer with pacemaker control, following a schedule of stepwise increased work loads of 60, 100, 140, 180, 220 and 260 watts, pedalling at 75 r.p.m. until maximal work capacity was achieved. The subject rode for 6 minutes followed by a 5 minute rest, and oxygen uptake $V_O_2$ litres/min. STPD, fraction of utilised oxygen $F_U_O_2$ % STPD, pulmonary ventilation $V_E$ litres/min. STPD and heart rate $f^H$ beats/min., were determined at each respective work load, using an open circuit method incorporating a Pauling paramagnetic oxygen analyser, Kofranyi Michaelis Respirometers, Douglas Bag, and an 8 channel A.E.I. Polygraph pen recorder. A plateau of maximal $V_O_2$ was observed. The mean maximal $V_O_2$ was 2.39 litres/min. or 38.99 ml/kg/min.; mean maximum $f^H$ 190 beats/min., mean maximal $V_E$ 64.93 litres/min.

Bivariate analysis showed that submaximal $V_O_2$ at 5 work levels was significantly correlated with $f^H$ ($r = 0.733$) and $V_E$ ($r = 0.865$) and that maximal $V_O_2$ was significantly correlated with $V_E$ ($r = 0.751$). However, there was no significant relationship between maximal $V_O_2$ and $f^H$ ($r = 0.026$) this was due to the asymptotic nature of the $f^H/V_O_2$ curve at maximal work levels, indicating serious limitations of the extrapolation methods for predicting maximal $V_O_2$ from submaximal $f^H$. Body weight Kg (mean = 62.13) was also seen to correlate with maximum oxygen uptake ($r = 0.602$).

Multiple regression analysis showed that the Vitalograph measurements of forced vital capacity FVC litres BTSPS (mean = 3.97) and forced expiratory volume 0.75 second FEV 0.75 litres BTSPS (mean = 3.30) lacked significant correlation with maximal $V_O_2$ ($r = 0.210$ and $r = 0.171$ respectively).

Haemoglobin concentration Hb grams % (mean = 13.8 grams%) as measured by a photometric technique, did not significantly correlate with maximal $V_O_2$ ($r = 0.139$). Lean leg volume LLV litres (mean = 8.54 litres) calculated from an anthropometric truncated cone method, showed significant relationship with maximal $V_O_2$ ($r = 0.825$).

Comparative contributions of each cardiorespiratory and anthropometric parameter, to the total prediction of maximal $V_O_2$ was calculated as beta weights. Two statistics, $V_E$ and LLV accounted for 74.5% of the variance in maximal $V_O_2$ litres/min. STPD.

The maximal $V_O_2$ test was an objective measure of the individual's physiological capacity to perform hard physical work.
A TEST OF CARDIAC FUNCTION DURING STRENUOUS EXERCISE

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Director of Physical Education, Liverpool Polytechnic, England

Most objective tests of cardiac function during exercise examine the work capacity of the heart at submaximal steady state, or the recovery of the heart after work of various intensity. There does not appear to be an established test of general application which can assess the reaction of the heart to exercise at maximal levels.

The most readily measured aspect of cardiac function is heart rate, which varies linearly with exercise intensity over part of its range, but non-linearly at the upper and lower extremities of range. If the lowest heart rate, normally achieved during deep sleep out of rapid eye movement phase, is taken as being indicative of the basal level of cardiac function, then the amount by which an individual can proportionately increase that level to cope with increasing severity of physical work is a measure of that individual's tolerance of stress. This measure may be most easily expressed in the form:

Cardiac Assessment Factor (CAF) = \( \frac{H.R. \text{ max} \times 10}{H.R. \text{ min}} \)

where H.R. max is the highest achieved heart rate, and H.R. min the lowest.

Because of the non-linearity of the overall heart rate reaction, the CAF cannot be validly considered as better than ordinal scale of measurement, though between normal limits it is amenable to treatment as interval scale data. The CAF makes no assumptions concerning the relationship between heart rate and stroke volume, but does depend upon the fact that increasing heart rate is related to increasing work stress.

Measurement of H.R. min provides only a minor problem of organisation. Coaches of individual sportsmen or of teams merely need access to the sportsmen during sleeping hours. The technique used in this study has been to take a total pulse count for one minute three times, and then to use the lowest of these three counts as H.R. min. Heart rate telemetry is the most reliable method of detecting the pulse, but with large groups it is more feasible to use palpation of the radial artery.

Measurement of H.R. max poses two major problems. The first of these is the method of precipitating H.R. max, which in itself can be subdivided into timing of effort, and type of work. As reported previously to the Physiological Society, the type of work in gross muscular activity has no significant effect on H.R. max — this being specific to the individual rather than to the activity. (Fig. 1)

A sample of N = 42 subjects, composed of volunteer sportsmen of first class standard, were tested on a cycle ergometer. Tests were either of constantly increasing work load, or of intermittent high intensity activity. The increasing work load was highly significantly more effective (p < 0.0006) as a method of precipitating maximum heart rates (H.R. max), \( (x = 193.5, SD = 9.9) \). (Table I) Recovery curves were plotted for all subjects establishing the relationship between H.R. max and recovery heart rates at intervals of 5 seconds from the cessation of exercise, H.R. pe5, 10, 15, etc. (Heart-rate, post exercise).

Alternative methods of measuring and precipitating H.R. max were proposed in cases where direct measurement of heart rate during exercise was not possible. Different types of work task were examined and found not to differ significantly as methods of
achieving H.R. max, but to differ significantly (p < 0.016 & 0.031) in respect of submaximal heart rates and of heart rate recovery at times in excess of 60 seconds from cessation of exercise.

Table I

A Comparison between Constant and Intermittent Work Load in Precipitating Maximum Heart Rates (N = 42)

<table>
<thead>
<tr>
<th>Constant H.R. max</th>
<th>Intermittent H.R. max</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x = 198 )</td>
<td>( x = 189 )</td>
<td>3.42 Sig. at 0.0006</td>
</tr>
</tbody>
</table>

The second major problem is of detecting the pulse at H.R. max. With reliable heart rate telemetry recorders the task is fairly simple. In the absence of such equipment, manual palpation is necessary, which is extremely difficult even during exercise of a stationary nature. The heart rate curves of 136 international standard sportsmen were established during and after extremely strenuous work on a cycle ergometer. Multiple regression coefficients were established between H.R. max and post-exercise rates (H.R. pe) at five second intervals. It was found possible to train operators to obtain H.R. pe5 with a standard error of 2.1 beats per minute, using ten pulse intervals as the method of measuring heart rate. This then allowed a prediction of H.R. max, with a standard error of 2.8 beats per minute. (Table II)

Normal values of CAF were established with a small group of 133 first class, international and club sportsmen. (Table III) A hypothetical scale ranging from 10, representing an individual who could not increase his heart rate, to 100, representing an increase from 25 to 250 beats per minute, can be envisaged. During international training, the author attained a CAF of 65.1 with an H.R. min of 33 and an H.R. max of 215.

It is difficult to establish the validity of CAF, since there is no other similar measure of the same parameter. Correlations were established between it and other measures of fitness. (Table IV) Of these, only \( V_{O2} \) correlated significantly, but still only accounting for a small part of the variance. The validity of the measure may be examined in another way, that is by noting

Table II

Multiple Regression... VT 2

<table>
<thead>
<tr>
<th>Variable No.</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Correlation X vs Y</th>
<th>Regression Coefficient</th>
<th>Std. Error of Reg. Coef.</th>
<th>Computed T Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>191.25000</td>
<td>9.68829</td>
<td>0.95844</td>
<td>0.80035</td>
<td>0.08958</td>
<td>8.93437</td>
</tr>
<tr>
<td>15</td>
<td>187.92647</td>
<td>9.83164</td>
<td>0.93582</td>
<td>0.12189</td>
<td>0.12990</td>
<td>9.3832</td>
</tr>
<tr>
<td>16</td>
<td>185.10294</td>
<td>10.15749</td>
<td>0.90347</td>
<td>0.08805</td>
<td>0.12527</td>
<td>7.0254</td>
</tr>
<tr>
<td>17</td>
<td>181.75000</td>
<td>10.20149</td>
<td>0.88451</td>
<td>-0.01584</td>
<td>0.12479</td>
<td>-1.2697</td>
</tr>
<tr>
<td>18</td>
<td>178.09559</td>
<td>11.03589</td>
<td>0.83410</td>
<td>0.14755</td>
<td>0.09906</td>
<td>1.48932</td>
</tr>
<tr>
<td>19</td>
<td>176.39706</td>
<td>11.34919</td>
<td>0.80858</td>
<td>-0.14393</td>
<td>0.11936</td>
<td>-1.20587</td>
</tr>
<tr>
<td>20</td>
<td>173.52941</td>
<td>12.52904</td>
<td>0.75273</td>
<td>-0.04826</td>
<td>0.10437</td>
<td>-0.33701</td>
</tr>
<tr>
<td>21</td>
<td>171.37500</td>
<td>12.93398</td>
<td>0.73276</td>
<td>0.12189</td>
<td>0.14753</td>
<td>0.93832</td>
</tr>
<tr>
<td>22</td>
<td>168.85294</td>
<td>13.12872</td>
<td>0.68992</td>
<td>0.03215</td>
<td>0.15301</td>
<td>0.21009</td>
</tr>
<tr>
<td>23</td>
<td>166.18382</td>
<td>13.61165</td>
<td>0.64651</td>
<td>-0.19357</td>
<td>0.14405</td>
<td>-1.34379</td>
</tr>
<tr>
<td>24</td>
<td>163.58824</td>
<td>14.31781</td>
<td>0.60619</td>
<td>0.30998</td>
<td>0.15916</td>
<td>1.94696</td>
</tr>
<tr>
<td>25</td>
<td>160.84559</td>
<td>15.42767</td>
<td>0.55430</td>
<td>-0.14727</td>
<td>0.10574</td>
<td>-1.39278</td>
</tr>
</tbody>
</table>

Dependent 26 | 193.48529 | 9.91220       |

Intercept 4.08696

Multiple Correlation 0.96316

Std. Error of Estimate 2.79273

Analysis of Variance for the Regression

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of freedom</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attributable to Regression</td>
<td>12</td>
<td>12304.6546</td>
<td>1025.38788</td>
<td>131.47149</td>
</tr>
<tr>
<td>Deviation from Regression</td>
<td>123</td>
<td>959.31603</td>
<td>7.79932</td>
<td>10.0046</td>
</tr>
<tr>
<td>Total</td>
<td>135</td>
<td>13263.97059</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
changes taking place over a period of time. Groups of sportsmen were exposed to short duration high intensity training, and to long duration training as physical education students. Very highly significant improvements in CAF were noted.

Table III

Normal Values for CAF for 133 club, first class, and international male sportsmen, aged 18-38.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>CAF Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-29</td>
<td>Poor</td>
</tr>
<tr>
<td>30-34</td>
<td>Fair</td>
</tr>
<tr>
<td>35-40</td>
<td>Average</td>
</tr>
<tr>
<td>41-49</td>
<td>Good</td>
</tr>
<tr>
<td>50-59</td>
<td>Very Good</td>
</tr>
<tr>
<td>60+</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

A test-retest reliability coefficient of 0.96 was established for CAF over an interval of one week, using heart rate telemetry.

Table IV

Correlation Coefficients Between CAF and Other Indices of Fitness

<table>
<thead>
<tr>
<th>Index</th>
<th>r.</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forced Expiratory Flow</td>
<td>0.301</td>
<td>10%</td>
</tr>
<tr>
<td>Pulse Pressure</td>
<td>-0.01</td>
<td>N.S.</td>
</tr>
<tr>
<td>Predicted Oxygen Uptake</td>
<td>0.603</td>
<td>5%</td>
</tr>
<tr>
<td>Aggression</td>
<td>0.07</td>
<td>N.S.</td>
</tr>
<tr>
<td>Grip Force</td>
<td>0.01</td>
<td>N.S.</td>
</tr>
</tbody>
</table>

The CAF is suggested as an easily administered test of cardiac stress tolerance, for use in laboratory and field tests of subjects who frequently undertake extremely strenuous exercise during training, competition and work.
CORRELATIONS BETWEEN SOME LABORATORY FUNCTIONAL PARAMETERS AND SPORTS PERFORMANCE

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Introduction

During the years 1965-1967 we examined repeatedly 10 cyclists aged 17-18 years, under laboratory as well as natural conditions (13, 15). We observed longitudinally relations between individual values of spiroergometrical tests (14) and even between the quality and quantity of the training load, on the one hand and the parameters of physical fitness measured in the laboratory (15) on the other hand. See Fig. 1.

Fig. 1: Average values of the training load and some functional parameters obtained in 10 cyclists during the two years.

In Fig. 1 there can be seen an increase of some limiting functional values till April 1966, then a slow decrease in August, due to the quality and quantity of the training in the first year. After the modification of the training, in the second year, there can be observed the best functional values at the height of the competitive season — in August 1967.

When considering the correlations of various physical fitness features, it is important to take into account also their relation to the sports performance proper, as it was shown in numerous contributions confined to the problem (e.g. 2, 3, 5, 17, 18). In our previous studies, we have already proved the validity of the spiroergometrical test in the assessment of cyclists sports efficiency, by the test of agreement (12), and attempted the selection of those spiroergometrical parameters, by means of the rank correlation, which are of the greatest validity (11).

It is the purpose of this paper to outline the practicability and relevance of correlation calculus for sports-medical conclusions. In April 1966, before the beginning of the competitive season, we had to decide about the sports specialization of eight members of the above-mentioned group (age 18.0; ± 0.141). Therefore, we carried out two-dimensional (16 and others) and three-dimensional correlations (1, 4, 6, 7, 8, 10) between the selected parameters of laboratory examination and three kinds of cyclist performances limited by various factors:

a. 1 km ride, as a speed-power performance with prevailing muscle endurance (9).

b. 3 km ride, as a strength-endurance performance with prevailing circulation endurance (9).

c. 40 km ride, as an endurance performance with prevailing energetic endurance (9).

Assessing the relations of individual functional parameters to various sports performances, we tried to attack the following problems:

1. Finding the kind of cycling performance correlating with the highest number of laboratory functional features.

2. Investigating the practicability of the spiroergometrical test when deciding about the specialization of young cyclists having different prerequisites for different cycling performances.

3. Estimating those parameters of physical fitness, from numerous spiroergometrical values, which are of the greatest validity in the assessment or prediction of sports efficiency of cyclists and in the modification of the training process.
Method

The laboratory examinations have already been described in our previous work (13). The methods of statistical data processing are based on the fact that the study is confined, in the main, to the investigation and measurement of associations between quantitative measuring data, i.e. sports performance in the first place, and some functional parameters.

On the basis of logical analysis, we arrived at the conclusion that these associations are mostly of linear character. For this reason, we made use of linear correlation and regression analysis. Values of sports performance, given in the form of times reached at a certain distance were chosen as dependent variables (y), values of functional parameters were taken as independent variables (x, z). In the cases where the dependence of the variable \( y \) upon one single independent variable \( x \) was observed, we made use of the following formula (4) to calculate the correlation coefficient:

\[
 r_{yx} = \frac{\text{cov} \, yx}{\sqrt{\text{var} \, y \cdot \text{var} \, x}} = \frac{\sum (x_i - \overline{x}) \cdot (y_i - \overline{y})}{\sqrt{n \cdot s_x \cdot s_y}}
\]

The significance of the coefficient of correlation \( r_{yx} \) was proved by the t-test following to R. A. Fisher's formula (10).

\[
t = \frac{r \sqrt{n - 2}}{\sqrt{1 - r^2}}
\]

The number of degrees of freedom \( f = n - 2 \).

The estimation of the theoretical values of the dependent variable \( y' \) was carried out according to the equation of regression line:

\[
y' = a + b \cdot x
\]

Observing the dependence of the variable \( y \) upon two independent variables \( x, z \), i.e. the dependence of the sports performance on two functional parameters, we used the method of three-dimensional linear correlation and regression analysis. The coefficient of the three-dimensional correlation \( r_{yxz} \) was calculated according to the formula (6):

\[
r_{yxz} = \sqrt{\frac{r^2_{xy} - 2 \cdot r_{xy} \cdot r_{yz} \cdot r_{xz} + r^2_{yz}}{1 - r^2_{xz}}}
\]

The significance of the \( r_{yxz} \) coefficient was tested by means of the modified t-test, the number of degrees of freedom being \( f = n - 3 \) (10).

Theoretical values \( y' \) in the three-dimensional regression were estimated according to the regression plane equation (4, 6, 8)

\[
y' = a + b \cdot x + c \cdot z
\]
Results and discussion

1. Basic examination values

Table I

Some average values of laboratory examinations and times achieved in various cycling performances.

<table>
<thead>
<tr>
<th></th>
<th>n = 8</th>
<th>x</th>
<th>s</th>
<th>sX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body height (cm)</td>
<td></td>
<td>180.62</td>
<td>7.563</td>
<td>2.674</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td></td>
<td>71.60</td>
<td>8.303</td>
<td>2.935</td>
</tr>
<tr>
<td>Kaup — Index</td>
<td></td>
<td>2.19</td>
<td>0.130</td>
<td>0.046</td>
</tr>
<tr>
<td>Heart rate at 1000 kpm/min (5th min)</td>
<td></td>
<td>140.63</td>
<td>9.334</td>
<td>3.300</td>
</tr>
<tr>
<td>Heart rate at 1500 kpm/min (5th min)</td>
<td></td>
<td>169.25</td>
<td>9.721</td>
<td>3.437</td>
</tr>
<tr>
<td>Max. heart rate</td>
<td></td>
<td>196.25</td>
<td>5.825</td>
<td>2.059</td>
</tr>
<tr>
<td>HR 10th min recovery</td>
<td></td>
<td>109.38</td>
<td>12.939</td>
<td>4.575</td>
</tr>
<tr>
<td>Theoret. Pulse freq. at 900 kpm/min</td>
<td></td>
<td>134.90</td>
<td>10.118</td>
<td>3.577</td>
</tr>
<tr>
<td>Max. O₂ — pulse (ml STPD)</td>
<td></td>
<td>19.87</td>
<td>1.888</td>
<td>0.667</td>
</tr>
<tr>
<td>Max. O₂ — pulse/kg B. weight</td>
<td></td>
<td>0.28</td>
<td>0.022</td>
<td>0.008</td>
</tr>
<tr>
<td>W₁/₀ (kpm/min)</td>
<td></td>
<td>1533.28</td>
<td>179.868</td>
<td>63.593</td>
</tr>
<tr>
<td>W₁₀/₀/kg B. weight</td>
<td></td>
<td>21.49</td>
<td>1.821</td>
<td>0.644</td>
</tr>
<tr>
<td>Wmax (kpm/min)</td>
<td></td>
<td>2024.11</td>
<td>328.106</td>
<td>116.003</td>
</tr>
<tr>
<td>Total work amount (kpm)</td>
<td></td>
<td>27451.2</td>
<td>9521.12</td>
<td>3366.23</td>
</tr>
<tr>
<td>Total work amount/kg B. weight</td>
<td></td>
<td>375.80</td>
<td>100.68</td>
<td>35.60</td>
</tr>
<tr>
<td>V₀₂ max (ml/min STPD)</td>
<td></td>
<td>3765.75</td>
<td>397.522</td>
<td>140.545</td>
</tr>
<tr>
<td>V₀₂ max/kg B. weight</td>
<td></td>
<td>52.79</td>
<td>3.759</td>
<td>1.329</td>
</tr>
<tr>
<td>VE₀₂ at 1500 kpm/min (I BTPS)</td>
<td></td>
<td>2.02</td>
<td>0.126</td>
<td>0.045</td>
</tr>
<tr>
<td>VE₀₂ at V₀₂ max (I BTPS)</td>
<td></td>
<td>2.26</td>
<td>0.136</td>
<td>0.048</td>
</tr>
<tr>
<td>Relat. O₂-Debt 10 min (ml STPD)</td>
<td></td>
<td>4646.00</td>
<td>1403.521</td>
<td>496.220</td>
</tr>
<tr>
<td>Relat. O₂-Debt/kg B. weight</td>
<td></td>
<td>65.23</td>
<td>19.238</td>
<td>6.802</td>
</tr>
<tr>
<td>Respirat. quot. 2nd min recovery</td>
<td></td>
<td>1.16</td>
<td>0.114</td>
<td>0.040</td>
</tr>
<tr>
<td>1 km Ride (time in s)</td>
<td></td>
<td>78.65</td>
<td>2.746</td>
<td>0.971</td>
</tr>
<tr>
<td>3 km Ride with mouthpiece (s)</td>
<td></td>
<td>281.99</td>
<td>9.565</td>
<td>3.382</td>
</tr>
<tr>
<td>3 km Ride without mouthpiece (s)</td>
<td></td>
<td>245.42</td>
<td>6.497</td>
<td>2.297</td>
</tr>
<tr>
<td>40 km Ride (s)</td>
<td></td>
<td>3566.25</td>
<td>126.591</td>
<td>44.757</td>
</tr>
</tbody>
</table>

2. Cross correlation between the 3 km-ride, with mouthpiece and spirometer on the back, and the same ride without any apparatus appeared as insignificant (r = 0.6796; p > 0.05). The valve and the weight of the gasometer influenced the performance negatively to a different degree in different individuals. Therefore, it was not considered suitable to put into correlation with laboratory examination values those sports results achieved under abnormal conditions.

3. Cross correlation of various kinds of sports performances
Cross correlation of time values achieved in the individual cycling performances (n = 8).

<table>
<thead>
<tr>
<th>CORRELATION</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 km Ride</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3 km with mouthpiece</td>
<td>0.5738</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3 km without mouthpiece</td>
<td>0.8103</td>
<td>0.6796</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>40 km Ride</td>
<td>0.2751</td>
<td>0.3236</td>
<td>0.5427</td>
<td>-</td>
</tr>
</tbody>
</table>

Significance level: 0.05 = 0.7067; 0.01 = 0.8343

There can be seen only one example of significant correlation, namely, between the times of 1 km-ride and 3 km-ride without a mouthpiece. The correlation between typical endurance performance, speed power performance and endurance power is low and non-significant.

4. Correlations between laboratory examination values and sports performances

At first sight, there is striking prevalence of high and statistically significant correlation coefficients expressing the relationship between absolute functional values obtained by spiroergometrical examinations (HR_{1500}, maximal oxygen pulse, W_{170}, W_{max}, total work amount, V_{O_2 max}) and the endurance performance (40 km-ride). This is speaking well for high validity of these values in the assessment of endurance efficiency. The above-mentioned values correlate insignificantly with the times achieved at the 1 km-ride and 3 km-ride, with the exception of W_{max} value, which is strongly influenced by the factors of motivation and muscle strength (19), i.e. factors limiting the 3 km-ride performance, too. The correlation coefficients of all relative values expressed per 1 kg of body weight were found low and insignificant, with the exception of the total work amount and the 40 km-ride, where the r-value is reaching its critical value for p = 0.05. As for the relationship of relative V_{O_2 max} values and the endurance performance, it has already been investigated by Wilmore (20). We have discussed the problem in our previous work (13). The results reported are supporting our assumption that the sports cycling performance is limited more by the absolute physical fitness values than by the relative ones.

Insignificant relations were also disclosed between all sports performances and the values of TPF_{900} and VE_{02}/1500 km/min, which is proving low validity of these parameters. Somewhat surprising is the slight dependence of the times of 1 km- and 3 km-rides on the relative O_2 debt. Here, we expected higher correlation, because both performances are dependent considerably upon the anaerobic capacity of the human organism. Our result can be explained by the fact that the values of

![Correlation coefficients expressing the relationship between some functional parameters and the times achieved at the 1 km-ride (perpendicularly hatched columns), 3 km-ride (horizontally hatched columns) and 40 km-ride (black columns), in 8 cyclists. Perpendicular broken lines are denoting critical values for p = 0.05, solid lines are denoting critical values for p = 0.01, n = 8.](http://bjsm.bmj.com/first-published-as-10.1136/bjsm.7.1-2.137-on-1-november-1973-downloaded-from-http://bjsm.bmj.com/)
relative $O_2$ debt were measured in the laboratory, after a long-lasting exhaustive work.

5. Examples of the presentation of regression lines and correlation fields

To provide certain conception, we are introducing in the Fig. 3-6 the regression lines and correlation fields of some functional parameters and the times of the 1 km-ride, 3 km-ride and 40 km-ride, the time-scale range being $\bar{y} \pm 2s$.

The apparent difference in the course of the regression lines and in the distribution of the individual values along these lines are showing apparently closer correlation between the maximal oxygen pulse and the time of the 40 km-ride.

The difference in the course of the regression lines in Fig. 4 is not so apparent as in the previous case because the dependence of both shorter cycling performances (1 km-ride and 3 km-ride) upon the $W_{170}$ value is closer. Similarly in Fig. 5 there can be seen only slight difference in the correlations between individual performances and the total work amount.

Minor differences can be explained by the fact that for reaching favourable $W_{170}$ values and values of total work amount there is not only important the capacity of the $O_2$-transport but also the factors of motivation and muscle strength (19) belonging to the limiting factors of all the three types of sports performance. On the opposite, in Fig. 6 there is shown apparent difference in the dependence of the individual performances upon maximal aerobic capacity.

The course of the regression lines and the correlation fields are illustrating the sequence of the dependence of the performance: the time of the 1 km-ride appears to be least dependent upon maximal aerobic capacity, then follows the time of the 3 km-ride, and the endurance performance in the form of the 40 km-ride is found as most dependent. This can be caused by different character of the individual performances and by the different factors limiting these performances.
Fig. 4: The regression lines of the correlations between the \( W_{170} \)-value and the times of the 1 km-ride, 3 km-ride and 40 km-ride.

\[
\begin{align*}
1 \text{ km} & \quad \circ \quad y = -0.0007565 \times +90.75 \\
& \quad \tau = -0.495 \\
& \quad \rho > 0.05
\end{align*}
\]

\[
\begin{align*}
3 \text{ km} & \quad \Delta \quad y = -0.018273 \times +273.44 \\
& \quad \tau = -0.506 \\
& \quad \rho > 0.05
\end{align*}
\]

\[
\begin{align*}
40 \text{ km} & \quad \square \quad y = -0.550832 \times +4410.83 \\
& \quad \tau = -0.783 \\
& \quad \rho < 0.05
\end{align*}
\]

Fig. 5: The regression lines of the correlations between the total work amount and the times achieved at the 1 km-ride, 3 km-ride and 40 km-ride.

\[
\begin{align*}
1 \text{ km} & \quad \circ \quad y = -0.0001215 \times +81.99 \\
& \quad \tau = -0.421 \\
& \quad \rho > 0.05
\end{align*}
\]

\[
\begin{align*}
3 \text{ km} & \quad \Delta \quad y = -0.0004286 \times +257.19 \\
& \quad \tau = -0.628 \\
& \quad \rho > 0.05
\end{align*}
\]

\[
\begin{align*}
40 \text{ km} & \quad \square \quad y = -0.0005589 \times +3828.65 \\
& \quad \tau = -0.719 \\
& \quad \rho < 0.05
\end{align*}
\]
Fig. 6: Regression lines of the correlations between maximal oxygen intake and the times of the 1 km-ride, 3 km-ride and 40 km-ride.

6. Application of the three-dimensional correlation to the assessment of the relationship between the laboratory and sport results

Table III

Examples of the three-dimensional correlations between two independent functional values (x, z) and the times achieved in the 1 km-ride, 3 km-ride and 40 km-ride (y).

<table>
<thead>
<tr>
<th>THREEDIMENSIONAL CORRELATION</th>
<th>1 km ride (y)</th>
<th>3 km ride (y)</th>
<th>40 km ride (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(x)</td>
<td>r y,xz</td>
<td>p</td>
<td>r y,xz</td>
</tr>
<tr>
<td>HR (1500 kpm/min) max O2 -Pulse</td>
<td>0.4888 N 23.90 0.4970 N 24.70 0.8078 * 65.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR (1500 kpm/min) Wmax</td>
<td>0.6474 N 41.91 0.9062 ** 82.11 0.8454 * 71.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR (1500 kpm/min) VO2 max</td>
<td>0.4894 N 23.95 0.5788 33.50 0.8973 ** 80.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR (1500 kpm/min) relat. O2 -debt</td>
<td>0.4856 N 23.58 0.4776 22.81 0.8760 ** 76.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPF900 max O2 -Pulse</td>
<td>0.5406 N 29.22 0.6726 N 45.24 0.7926 * 63.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPF900 max V02 max</td>
<td>0.6877 N 47.30 0.8470 * 71.74 0.8712 * 75.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPF900 relat. O2 -debt</td>
<td>0.3027 N 9.16 0.2927 N 8.56 0.7004 N 49.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>max.O2 -Pulse</td>
<td>0.6863 N 47.10 0.8444 * 71.30 0.8660 * 74.99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>max.O2 -Pulse</td>
<td>0.3834 N 14.70 0.6002 N 36.03 0.8884 ** 78.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td>max.O2 -Pulse</td>
<td>0.3547 N 12.58 0.4838 N 23.41 0.8376 * 70.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W1 1.0</td>
<td>0.5192 N 26.95 0.5771 N 33.30 0.8956 ** 80.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W1 2.0</td>
<td>0.6698 N 44.86 0.5977 N 35.73 0.8273 * 68.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W1 1.0</td>
<td>0.4959 N 24.60 0.5069 N 25.69 0.8764 ** 76.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wmax</td>
<td>0.7390 N 54.62 0.8028 * 64.45 0.9102 ** 82.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wmax</td>
<td>0.6779 N 45.95 0.8437 * 71.18 0.8998 ** 80.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wmax</td>
<td>0.7209 N 51.96 0.8041 * 64.66 0.8963 * 73.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wmax</td>
<td>0.6357 N 40.41 0.8043 * 64.69 0.9323 ** 86.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wmax</td>
<td>0.6357 N 40.41 0.8089 * 65.43 0.9296 ** 86.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO2 max max</td>
<td>0.5980 N 35.76 0.6433 N 41.39 0.9146 ** 83.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO2 max relat. O2 -debt</td>
<td>0.2848 N 8.11 0.6104 N 37.26 0.8969 ** 80.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO2 max relat. O2 -debt</td>
<td>0.3087 N 9.53 0.6477 N 41.95 0.8946 ** 80.04</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

N = no significance of r y,xz; * = p ≤ 0.05; ** = p ≤ 0.01. Coefficient of determination is given in %.
While the correlation of the couples of functional parameters with the 1 km-ride is low and insignificant, the correlations between the 3 km-ride times are close with those couples of independent variables including the $W_{\text{max}}$ values. This is explicable by the relationship between the $W_{\text{max}}$-value and the time of the 3 km-ride as it is mentioned above.

High correlation coefficients and determination coefficients suggest a high degree of dependence of the 40 km-ride performance upon the couples of variables obtained in spiroergometrical examination. The three-dimensional correlation is proving the greatest validity of spiroergometry for the assessment of endurance ability and is enabling us to select those functional parameter couples being in the closest connection with particular sports performance.

**Regression:**

\[ y = 40 \text{ km-ride (time in sec)}; X = W_{\text{max}}; Z = O_2 \text{ debt} \]

\[ y = 4274.38 - 0.26136 \cdot X - 0.038551 \cdot Z \]

\[ r_{y;x,z} = 0.9523 \]

\[ p < 0.01 \]

Graphic presentation of the three-dimensional correlation illustrates the degree of dependence and the dispersion of empirical values from the theoretical ones.

In Fig. 7, the regression plane is projected vertically on to the horizontal plane ($x, z$); its slope is expressed by the system of graded contour lines dimensioned by the appropriate values of $y'$. The position of the individual measured points with respect to the regression plane is presented as a projection of the shade of the triangle formed by the measured point and its vertical and horizontal projections on to the regression plane, this triangle lying in a plane perpendicular to the contour lines. The measured point situated above the regression plane is denoted by a filled-in circle; the point situated under the regression plane is denoted by a hatched circle; vertical projection of the point on to the regression plane, this projection being given by the values of independent variables ($x, z$), is denoted by a blank circle. Horizontal projection of the measured point on to the regression plane (the top without any mark) lies on the contour line of the regression plane, the height of the contour line being consistent with the value ($y$) of the measured point. The shade of this triangle, expressed by hatching, is projected on to the regression plane. The direction of the light beams was chosen such as to satisfy the following condition: the projection of the shade of the line connecting the measured point with its vertical projection should be parallel with Z-axis and its size should be equal to the difference ($y - y'$). If the measured point lies under the regression plane, the direction of the light beams is considered to be opposite and the shade projected on to the reverse side of the regression plane is presented as a triangle hatched with broken lines.

Detailed explication and more examples of the graphic presentation of the three-dimensional linear regression analysis will be published in some of our further papers.

**Conclusions**

1. The times of sports performances achieved in the testing ride with a measuring apparatus on the back acting negatively on the competitor's efficiency and are not suitable for correlation with laboratory functional results.

2. Absolute values of some laboratory parameters ($HR_{1500}$, maximal oxygen pulse, $W_{170}$, $W_{\text{max}}$, total work amount and maximal oxygen intake) correlated highly and significantly with the times of the 40
km-ride, i.e. with the endurance performance. The relation between the former parameters and the 1 km-ride and 3 km-ride was found non-close and non-significant.

3. Low and mostly insignificant correlations were stated between the relative values of functional parameters, the TPF_900 value, VEGO_2 value, on the one hand, and all the sports performances, on the other hand. The relations between the values of relative O_2 -debt and the sports performances were not very close, too.

4. The above-mentioned parameters estimated in the laboratory are of greatest validity in the assessment of a cyclist's ability to compete in the endurance performance. Their validity is somewhat lower in the assessment of the ability to compete in short-lasting performances limited by other factors.

5. Laboratory spiroergometrical results can be taken into consideration as additional values in deciding about the specialization of individual cyclists. A certain degree of good endurance ability forms an important pre-requisite for all kinds of cycling events in general. However, it can be expected, on the basis of different results that an individual with outstanding values of maximal O_2 -intake and maximal oxygen pulse has a talent for the road race, a competitor with favourable values of W_170 and W_max can become a successful chase racer, and a cyclist with a good anaerobic capacity will make a good sprinter.

The spiroergometrical results alone cannot be sufficient, however to decide about the specialization of a cyclist, because they are covering only a part of a number of limiting factors. For this reason, it is necessary to evaluate each individual completely, in cooperation with his trainer, with respect to other decisive factors (natural talent, character features, motor-skill, reaction ability, technique etc.).

6. It may be concluded that assessing the condition acquired by training, especially in road racers, the following absolute spiroergometrical values are of the utmost validity: maximal oxygen intake, maximal oxygen pulse, total work amount, W_170, W_max. and, possibly O_2 -debt. These parameters can be exploited as comparative criteria at the modification of training process which was already reported (15).

7. The correlation calculus appears to be very useful auxiliary method of functional diagnostics, indicating those parameters, or parameter couples of functional examination, which correlate most closely with the corresponding sports performance. It is of a great help at the determination of most valid parameters simplifying thus the examination procedure, contributing to the precision of functional diagnostics and saving time and money.

REFERENCES


RADIO TELEMETRIC STUDIES OF PULSE RATE AND SPIRO-ERGOMETRIC STUDIES IN THE ASSESSMENT OF ENDURANCE PERFORMANCE CAPACITY AND TRAINING LOADS

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ABSTRACT

Es wird die Möglichkeit überprüft, aus dem Verhalten der Herzfrequenz bei sportlichen Übungen auf die spiroergometrisch setzte Ausdauerleistungsfähigkeit zu schließen.

Ein standardisierter 2000-m-Lauf (2000 m in 10 Minuten) kann als Ausdauerstest herangezogen werden, während geturnte Pflichtübungen nicht dazu geeignet sind.

Die Belastungen beim Tennis-, Hand- und Fußballspiel bieten im Gegensatz zu den kurzdauernden Turnübungen ausreichende Reize zur Verbesserung der Leistungsfähigkeit des cardiopulmonalen Systems.


Unsere Ausführungen beschäftigen sich im ersten Teil mit dem Verhalten der Herzfrequenz während standardisierter sportlicher Belastungen und der Möglichkeit, diese zur Beurteilung der Ausdauerleistungsfähigkeit heranzuziehen. Im zweiten Teil wird die Höhe und Dauer der Herzfrequenzsteigerung als Maß des Reizes zur Verbesserung der Ausdauerleistungsfähigkeit diskutiert. In jedem Fall wurde die kardiopulmonale Leistungsfähigkeit der Probanden durch die spiroergometrische Prüfung untersucht und objektiviert.

Diese bestand aus sechsmalig um 50 Watt ansteigender Fahrradergometerbelastung (Lode, Lanooy) unter den Bedingungen der Außenluft (Knipping Spirograph, Typ 210 D Sport). Die dazugehörige röntgenologische Herzvolumenbestimmung wurde nach der Methode von Musshoff und Reindell (7) aus 2 m Entfernung beim auf dem Bauche liegenden Probanden vorgenommen (genau Versuchsanordnung 1).


Als standardisierte sportliche Belastung für einen einfachen Ausdauerstest bietet sich das Laufen an, das exakt zu dosieren ist, und bei dem der Wirkungsgrad praktisch nicht verändert werden kann. Unsere Probanden mußten einen 2000-m-Lauf mit gleichbleibendem Tempo in 10 min absolvieren. Damit überschritt die Belastungsduer 6 Minuten, die Zeit, die in den "Vorschlägen zur Standardisierung der ergometrischen Leistungsmessung" (4) bei der Beurteilung der Ausdauerleistungsfähigkeit auf einer Belastungsstufe gefordert wird. Die Laufgeschwindigkeit von 3,3 m/sec liegt deutlich unter der von Minarovjcevic (6) angegebenen Geschwindigkeit von 5 m/sec, bei der es in jedem Fall zu einem Ansteigen der Herzfrequenz auf wenigstens 180/min kommt, und bei der damit die Beziehungen zwischen Laufgeschwindigkeit und Herzfrequenz aufgehoben sind.

Abb. 1: Das Verhalten der Herzfrequenz beim standardisierten 2000-m-Lauf

An dem standardisierten 2000-m-Lauf nahmen 51 Studenten unterschiedlichen Trainingszustandes teil.


Abb. 3: Die Beziehung zwischen der Herzfrequenz beim standardisierten 2000-m-Lauf (HfX.L-2000) und der Laufzeit bei einem 1000-m-Wettlauf


Dazu einige Beispiele: 25 untrainierte Männer, im Mittel 21 Jahre alt, wurden 4 Wochen lang täglich einem Ausdauerlauf von rund einer halben Stunde unterzogen. Die Laufgeschwindigkeit richtete sich nach der Aus-
gangsleistungsfähigkeit, und sie war so bemessen, daß die Belastungsfrequenz 75% der bei der Prüfstanduntersuchung erzielten Frequenzzunahme betrug. Daher war die Trainingsbelastung für alle von annähernd gleicher Intensität. Die Herzfrequenz wurde telemetrisch mit dem dynamisch-elektrokardiographischen System nach Holter Avionics (3) zu Beginn und am Ende der Trainingsperiode überprüft. Zu Beginn lag die Trainingsherzfrequenz im Mittel bei 161/min und nach 4 Wochen bei unveränderter Laufgeschwindigkeit bei 156/min, was schon auf eine verbesserte Leistungsfähigkeit hindeutet. Die Labortests ergaben eine geringe Herzvolumenzunahme (826 : 877 ml, p < 0.001). Der maximale Sauerstoffpuls stieg hochsignifikant von 14.98 auf 17.4 ml und der Watt puls von 1.024 auf 1.194 an. Damit verbesserte sich die Leistungsfähigkeit um 17.3%. Mit 25.7% fand sich die größte Leistungssteigerung bei den Leistungsschwachen im Gegensatz zu 11.8% bei den Leistungstarken. (Abb. 4) Da entsprechend ihrer Leistungsfähigkeit für alle das Training eine mehr oder weniger gleiche Belastung darstellte, zeigte sich, daß der Wirkungsgrad des Trainings (5) – der Quotient aus Leistungszuwachs und Trainingsquantität – von der Ausgangslage abhängig ist: Bei höherer Ausgangsleistungsfähigkeit war die Verbesserung am geringsten.

Bei Turnern unterschiedlicher Leistungsklassen fanden wir wie auch andere (8, 9) keine Verbesserung ihrer kardiopulmonalen Leistungsfähigkeit, obwohl die Herzfrequenz bei der Ausführung ihrer spezifischen Übungen in submaximale und maximale Bereiche ansteigt. Durch die kurzen Übungszeiten ist die Einwirkungszeit des Trainingsreizes zu kurz, um zu einer Steigerung der Ausdauerleistungsfähigkeit zu führen.


**Fußball**

![Graph](image)

Abb. 5: Verteilung der Herzfrequenz während eines Fußballspielen von 2 x 30 min Dauer

**Handball**

![Graph](image)

Abb. 6: Verteilung der Herzfrequenz während dreier Hallenhandballspiele von jeweils 2 x 15 min Dauer (beobachtete Spieler wurden nicht ausgewechselt)
Die 5. Abb. zeigt die Verteilung der Herzfrequenz eines Abwehrspielers und eines Flügelstümers während eines Fußballspiels von 2 x 30 min Dauer. Über 80% der Spielzeit liegt die Herzfrequenz höher als 130/min. Es gibt keinen ausgesprochenen Gipfel der maximalen Herzfrequenz im Gegensatz zu den Handballspielern (Abb. 6). Bei allen drei Spielern, die jeweils in zwei Spielen beobachtet wurden, liegt der Gipfel der maximalen Frequenz in den Bereichen zwischen 180 und 210/min, und zwar mit einem Anteil zwischen 25 und 38%.

Das schnelle Hallenhandballspiel ist fast ausschließlich durch maximale Belastungen gekennzeichnet und läßt daher kaum eine Erholung während des Spiels zu. Daraus ist die Notwendigkeit des Spielerwechsels deutlich zu ersehen. Bei unseren verschiedenen Beobachtungen mit Fuß- und Handballspielern zeigte sich, daß die Dauer der maximalen Belastungen im Training und Wettkampf von drei Faktoren abhängig ist:
1. Der Länge der Spielzeit, 2. der Spielfeldgröße und 3. dem Verhältnis der Spielerzahl zu den Spielbällen.

Zusammenfassend kann gesagt werden, daß die Genüberstellung zwischen sportlicher Belastung (Höhe der Herzfrequenz) und der Prüfstanduntersuchung gute Rückschlüsse auf die Trainingswirkungen eines Ausdauertrainings unterschiedlicher Gestaltung zuläßt. Außerdem konnte gezeigt werden, daß unter standardisierten Bedingungen ein 2000-m-Lauf als einfacher Ausdauertest eingesetzt werden kann.

Schlüsselwörter:
Radiotelemetrie, Spiroergometrie, standardisierter 2000-m-Lauf, Trainingsüberwachung

**LITERATURVERZEICHNIS**


