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Respiratory function dynamics in individuals with increased motor activity during standard exercise testing

Функціональна діагностика – одна з найважливіших сфер спортивної медицини, яка відіграє важную роль в спортивному відборі, оптимізації тренувального процесу, ранній діагностиці чи профілактиці спортивної патології. Функціональний стан організму знаходиться під впливом багатьох факторів. Фізичні можливості обмежені рівнем розвитку системи дихання та кровообігу, типом енергозабезпечення, який переважає при фізичному навантаженні, умовами тканинного дихання. Обстеженими були висококваліфіковані баскетболісти віком від 18 до 29 років (n = 42). Результати досліджень показали, що максимальне споживання кисню є інтегральним показником функціонування кардіо-респіраторної системи в такому виді спорту як баскетбол, де переважає змішаний тип енергозабезпечення м'язової діяльності – аеробно-анаеробний, з переважаючим розвитком специфічної фізичної якості – як ігрової витривалості (аеробний метаболізм). Показано, що такий тип рухової активності детермінований діяльністю всіх ланок системи транспорту кисню: системою кровообігу, але більшою мірою системою дихання. В зв'язку з чим, як основні показники-індуктори, які можна використати в оцінці детермінування функції системи зовнішнього дихання є легенева вентиляція, максимальний обсяг видоху, рівень вентиляції. Ці показники найбільше корелюють з показником максимального споживання кисню в умовах ергометричного тестування.

INTRODUCTION

Modern achievements in sport are determined not only by a careful selection of extraordinary individuals suitable for professional sport, optimisation of the training process and attempts of a number of different specialists. In recent years, sports medicine has become increasingly important for the achievement of optimum results [1-7, 9, 10]. Functional diagnostics is one of the key areas of sports physiology, dominating in the athletes' selection and optimisation of training process, early diagnostics and prophylaxis of sports pathology [1, 2, 5, 7, 9, 10]. The functional condition of an athlete's body is constantly changing under the influence of many factors [3, 6-8, 11,12]. These changes may be considerable and pose problems in recruiting athletes to teams in game sports and forming combined teams in individual sports [4, 11]. Physical ability is determined by the quality of external breathing and cardiovascular functions and by peculiarities of metabolism related to the tissue breathing and transport of substrates [3, 12-14]. In making qualitative assessment of these phenomena one must relate the parameters of the individual's functional conditions to the required or desired values. The International Olympic Committee (IOC) has set general norms for the evaluation of physical ability and integrated breathing quality for highly trained athletes, while international federations of various sports have their own norms determined by the biodynamic peculiarities of the relevant sports, which naturally results in considerable differences [6]. Certain norms and indicators have been agreed upon and adopted by official international organisations such as IOC, WHO(Word Health Organisation), AHA (American Heart Association), ACSM (American College of Sport Medicine, ATS (American Thoracic Society), ERS (European Respiratory Society), etc., however, discussions are still held about the adopted norms of functional indicators [1, 2, 5, 6, 13]. Individual authors offer quite different opinions and assessments. Some propose that parameters of the body's functional condition should be compared with reasonable demographic norms of healthy individuals as a reference point. A reasonable argument for this opinion is that the norms presented are based on large-scale epidemiological studies, while the majority of the functional condition parameters are related to the regularity of normal distribution, which facilitates analysis and evaluation of samples similar to normal ones and enables comparisons. Nevertheless one must recognise that there exist many models of human physical activity, with their specificity determined by the relevant kind of sport and inherent features of the individual as well as by time and geographic factors. Even in individuals who do not go in for sports, behavioural and nutrition-related peculiarities determine different metabolic characteristics and, at the same time, activities of functional transport systems. Athletes are influenced not only by general differences in geographic and cultural factors or specificity of the sport concerned but also by different schools of sport, i.e. methods of training [5, 11]. However, many important things including parameter nomograms of the integrated breathing system functions have not been published as yet. There exist no norms for a comprehensive evaluation of the Lithuanian residents' physical capacity and breathing system and metabolic function capacity including persons going in for sports. It is not clear whether one may rely upon the nomograms drawn up by foreign authors

The purpose and tasks of the work is to evaluate the dynamics of indicators of physical and functional cardio respiratory and metabolic capacity in highly trained athletes during standard exercise testing, to determine their critical values and to draw up nomograms.

MATERIAL AND METHODS

Highly trained athletes (basketball-players) – men aged 18-29 participated in the study (n=42). The control group (n=19) consisted of healthy men aged 18-29 practising no sports in whom no diseases which could potentially influence functional condition were diagnosed during medical examination. All tests were carried out under laboratory conditions complying with the ATS regulations. The external breathing functions were investigated by means of VMAX229 diagnostic system. ECG was recorded and evaluated using the system CARDIOSYS MARQUETTE 3.01 with CORINA electrocardiograph. A spirometer integrated in the VMAX229 system operates as a computerised volume and flow analyser with a thermal sensor complying with the ATS standard. For the oxygen concentration analysis a special accelerated VMAX paramagnetic analyser with a parameter check system was used. For the purposes of carbon dioxide analysis, a special super-accurate VMAX infrared spectrum analyser with a parameter check system was used. Both these analysers comply with the ATS standard in respect of continuous analysis of both still and ergo metric conditions. An integrated CORINA and evaluation system for rhythm, conductivity and ischemia. It is equipped with a blood pressure measuring device, therefore, calculation and interpretation of double product rate (DPR) is conducted. The system has a continuous and final interpretation program installed, however, the results must be presented for a physician for review. A cycle ergo meter ERGO 9000 was used as a peripheral device controlled by the system, with the error for load up to 500 W not exceeding 1% and with the free rotation resistance maintained in the interval of 0-5 W. During the investigation under consideration, computer-controlled rate of 60-70 rpm was set.

All athletes were examined by the cycle ergometer test method using a incremental multistage protocol (50W each 2 min.). The tests were continued until peak oxygen uptake (VO_{2MAX}) or up to decrease in the efficiency of the heart or lungs activity. The VO_{2MAX} was considered achieved if VO_2 was not increasing more than 1 min. under stable loading or without increase in mechanical efficiency. The decrease in the efficiency of the heart/lung activity was established if no increase was recorded in the heart rate (HR), double product (DP) indicator or ventilation volume for more than one minute. No limitation of load according to the AHA recommendations was applied. The anaerobic threshold was determined by the V-slope method using the ratio of VCO_2 and VO_2. As required by AHA, electrocardiogram was made prior to ergometric test. The data were analysed using the MARQUETTE-CARDIOSYS 3.01d diagnostic algorithm and were reviewed by a physician. To assess the external breathing function, indicators reflecting functional lung volumes, air velocity in the bronchial tubes during expiration, breathing rate and power of breathing-related muscles were recorded and analysed. The indicators were evaluated according to the ATS regulation and Morris-Polgar manual. The breathing reserve was assessed according to the classical ATS regulation and Johnson - Weisman loop analysis method.

Samples were formed for each 30 s interval for the evaluation of the lung ventilation indicators (VE - ventilation volume, PEF - peak expiratory flow and RR -respiratory rate), heart activity (HR) and aerobic uptake (VO_2). A sample was marked with an index reflecting the moment of time counted from the start of the test. Thus the numerical value provided is an average of the last 30 s, with the recording of moments of establishing of each breathing cycle indicator. A standard statistical analysis using a STATGRAF 5.0D program package was made.

The following analytical methods were employed:

1. Evaluation and checking of samples:

According to standard excess and asymmetry indicators, a sample was considered to be similar to normal if the indicators did not exceed 2. The Shapiro-Wilks indicator was calculated (reverse accuracy of means); if the value was not lower than 0.95 (i.e. corresponding to a 5% mean accuracy), it was assumed that the sample could be represented by the mean.

All samples were checked according to the Kolmogorov-Smirnov criterion and standard grouping into classes was used; the degree of freedom was established according to the normal distribution standard (k=m-p-1); it was considered that appropriate a was 0.9, critical p was 0.1.

A hypothesis that each sample is similar to a normal sample was checked (H0 rejection; alternative marked as NE – non-equivalent); the mean and dispersion confidence was evaluated (the degree of freedom was taken as n-1) specifying $\alpha<0.05$ (a level standard for medical investigations).

2. Evaluation of numerical characteristics of samples:

Sample means, medians, modas, average square deviations, excess and asymmetry indicators were calculated. Reliable intervals were calculated for samples similar to normal (95% level, $p<0.05$ considered sufficient).

A hypothesis of difference in means was checked by verifying samples reflecting the same phenomenon at different moments of time (HR0, HR30, HR60, …, HR1170 and HR_{MAX}, VO_20, VO_230, VO_260, …, VO_21170, VE0, VE30, VE60, …, VE1170 and RR0, RR30, RR60, …, RR1170 and PEF0, PEF30, PEF60, …, PEF1170), with the samples considered independent; the t criterion was used for the evaluation of the reliable mean interval and dispersion, provided that the similarity of dispersion was proved based on Fisher's distribution (if F<Fα).

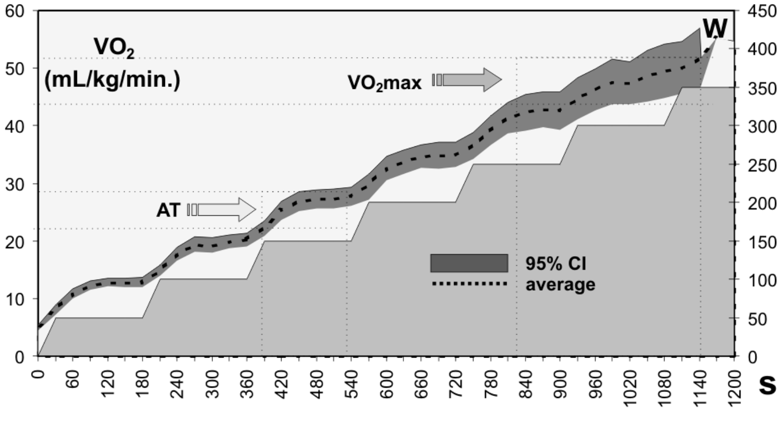
3. Linear graphs were drawn: the moment of time (every 30 s) was recorded on x axis; HR, VO_2, VE, RR and PEF sample means and reliable intervals (set for each 30 s period) were recorded on Yl axis if the consistence of a sample allows comparing it with other dependent ones and the difference in means was established based on the t criterion and the similarity of dispersion was proved based on Fisher's distribution (if F<Fα); the level of physical load was recorded on y 2 axis.

4. A regress linear analysis according to a standard model ($Y=a + b \cdot X$) was made following a standard confidence level (α=0.05) between time, load intensity, VO_2, VE, HR, RR and PEF.

RESULTS

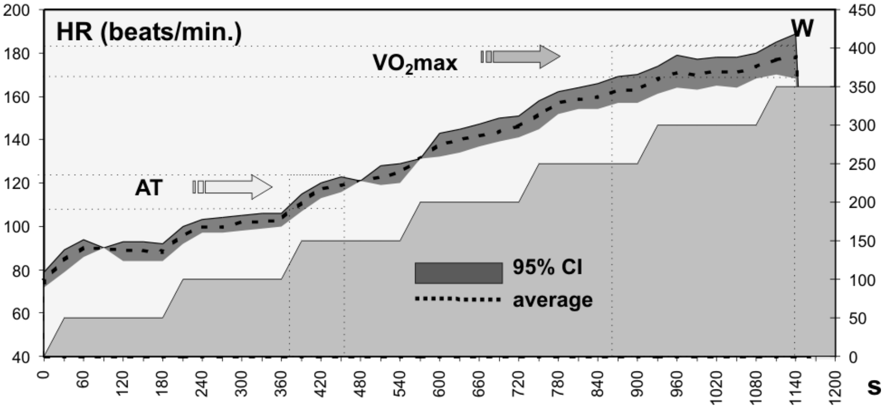
The dynamics of oxygen uptake is depicted in Figure 1. The region presented in the graph represents the reliable interval of the mean, while the line inside it has been drawn through the points of means recorded every 30 s. The volume of samples decreased along with increase in load, since increasing intensity meant smaller number of individuals able to continue the test. The data were evaluated until the 1140th s of the test (19 min. of the test) until a 350W load was achieved. After this point the evaluation of data was stopped because on the 1110th s of the test (350 W) there remained only 17 tested individuals who were able to continue the test, on the 1140th s – 13 (load intensity 400W), on the 1170th s – 9, and the sample distribution characteristics changed. It has been established that the mean anaerobic threshold reached by the tested individuals was 25 mL/min./kg (reliable interval 22.3-27.6; $p < 0.05$) or 50-54% VO_{2MAX}. This occurred at the load of 150-200 W (moda 150W) or on the 420-600 s of the test. These data are marked in the graph presented in Figure 1. It has been established that Wasserman's indicator under VO_{2MAX} varies between 12.8-14.2 L/min./kg/W (according to Wassermann's manual, it must be 10.8±0.6 L/min./kg/W for healthy non-athletes), while in the control group this indicator was 12.6 L/min./kg/W. The difference in the mean (compared with the athletes) was verified. Based on the distribution analysis, a hypothesis that samples $VO_2$30-$VO_2$1140 fall within the sphere of normal distribution ($p<0.05$) on a standard confidence level was not denied. An analysis according to Fisher's criterion confirms that the sample scattering difference cannot be proved on a standard level. Since there were no distribution and scattering differences in samples $VO_2$30-$VO_2$1140, the means were compared and reliable intervals were established.

Fig. 1. Laid athletes' oxygen uptake dynamic values during exercise test



Based on the results of the distribution analysis, a hypothesis that samples HR30-HR1140 belong to normal distribution ($p<0.05$) was not denied on a standard confidence level. An analysis according to Fisher's criterion has shown that the sample scattering difference cannot be proved on a standard level, except for intervals 60-90, 450-480 and 540-570 s from the start of the test. During these intervals the heart rate varies greatly. The first interval may be determined by the fact that under light loads (and with low oxygen demand) the regulation of the oxygen transport system is not determined by metabolic factors, whereas psychogenous factors operate constantly (unusual environment, waiting for the result of the test etc.). The second interval of wider scattering is found in the approximate area of passing the anaerobic threshold; after the third interval, a smaller increment of oxygen uptake upon increase in load is observed. In spite of inequivalence of these three intervals in the nomogram, the mean and the confidence interval up to the 1140th second of the test (19 minutes of the test) may be assessed by marking the parameters of the numerical characteristics on the graphical axes. A reduction in the volume of samples is seen in the course of investigation, since, along with the increase in load, the number of those able to continue the test decreased, however, due to technical problems the heart rate of one individual tested was excluded from the sample in the interval from the 210th to 630th second. The dynamics of the heart rate is presented in Figure 2. The results of the test show that the heart rate reached under VO_{2MAX} conditions is within the range of 300-350 W load on the 13th –18th minute and is 170-182 contractions/min. At the time of establishing the anaerobic threshold the heart rate was 110-125 contr./min. within 150-200 W on the 6th – 8th minute.

Fig. 2. Laid athletes' heart rate dynamic values during exercise test

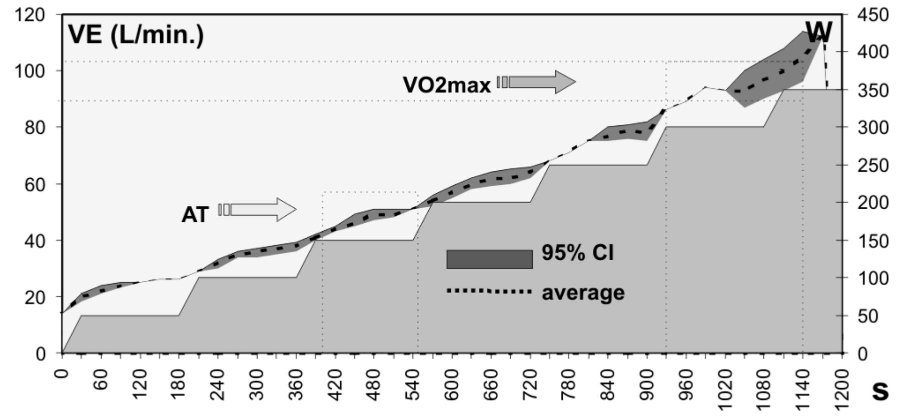


Based on the data of the distribution analysis, a hypothesis that the samples VE30-VE1140 fall within the normal distribution ($p<0.05$) was not denied on the standard confidence level. An analysis according to Fischer's criterion has confirmed that the difference in the scattering of samples cannot be proved on standard level, except for the intervals 0-30, 150-210, 510-540, 720-840 and 900-1020 s from the beginning of the test. During these intervals, the lungs ventilation volume is greatly varied (Fig. 3). The first and the second intervals (0-30 and 150-210 s) correspond to light physical load (intensity 50 and 100 W in the first seconds) and variations in lungs ventilation may be caused by differences in the athletes' psychogenic factor or central nervous regulation. The interval of 510-540 s is in the approximate anaerobic threshold passing area and corresponds to the time of second varying interval of the heart rate. The very high variation interval of 720-840 s takes place during the last sharp (intense) increase in VO_2 (after it no distinct response to the increase in load is seen), thus, its end coincides with the beginning of decreasing efficiency of mechanical-aerobic activity and the first points of the average oxygen uptake plateau. The interval of 900-1020 s coincides with the emergence of the oxygen uptake plateau for the majority of the individuals tested. Despite that these intervals fall out of the nomogram, the data of the mean and the confidence interval may be assessed up to the 1140th s of the test (19 minutes), with the parameters of the numerical characteristics marked on the graphical axes. A reduction in the volume of samples is seen in the course of investigation, since, along with the increase in load, the number of those able to continue the test decreased, however, due to technical problems the heart rate of one individual tested was excluded from the sample in the interval from the 210th to 630th second. The dynamics of the minute lung ventilation is presented in Fig. 3. The results of the test show that the minute lungs ventilation reached under VO_{2MAX} conditions is within the range of 300-350 W load on the 14th –19th minute and is 95-105 l/min. In the graph 2-3, the interrupting region of the confidence interval of the minute lungs ventilation dynamics under standard physical load is marked by a dotted line because the indicator of minute lung ventilation is not statistically verified in these intervals and the line shows just the projected potential dynamics of the indicator.

The verified intervals of developed on the 7th –10th minute. The intervals verified under the PEF anaerobic conditions and the maximal oxygen uptake are shown. The peak expiratory flow respiratory rate under the conditions of the anaerobic threshold and the maximal oxygen uptake are presented (Fig.4). The respiratory rate achieved under VO_{2MAX} is within the interval of load of 250-350 W on the 14th –19th minutes and is 29-37 times/min. The AT interval respiratory rate is within the interval of 100-250 W, it is achieved on the 6th - 9th minute and is 22-25 times/min. In the graph 2-3, the region of the confidence interval interrupted on the 12th and 18th –19th minutes is marked by a dotted line because the RR indicator is not statistically verified in these intervals and the line shows just the projected potential dynamics of the indicator. Based on the data of the distribution analysis, a hypothesis that the samples RR30-RR1140 fall within the normal distribution ($p<0.05$) was not denied on the standard confidence level. An analysis according to Fischer's criterion has confirmed that the difference in the scattering of samples cannot be proved on standard level, except for the intervals 0-60, 120-180, 660-690, and 1050-1140 s from the beginning of the test. The respiratory rate varies greatly during these intervals, corresponds more or less to the analogous minute lung ventilation intervals and probably causes the occurrence of the latter. Despite the "fall out" of the intervals from the nomogram, evaluation of the mean and the confidence interval data up to the 1050th s of the test (18 minutes) is possible, with the numerical characteristics' parameters marked on the graphical axes. A reduction in the volume of samples in the course of the test is observed, since the number of persons able to continue the test decreased as the load was increasing. Similarly to VE there are cases excluded from samples. Later, in the course of the test technical problems were resolved and the recording of RR was normalised.

The dynamics of the maximum expiratory flow rate (Fig. 5) shows that a 3.6-4.4 l/s PEF is achieved under VO_{2MAX} within the load interval 300-350W. The PEF of the AT interval

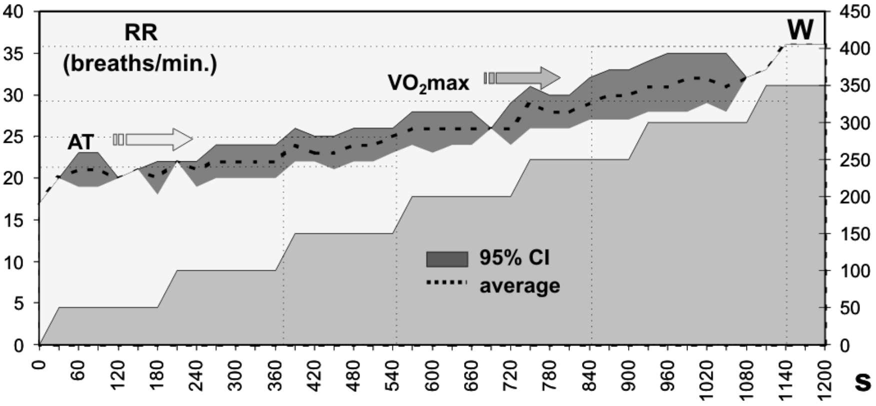
Fig. 3. Laid athletes' minute lung ventilation volume dynamic values during exercise test



is within 150-200W, it is interrupted on the 8th and 10th minute is shown in Figure 5 by a dotted line because in these intervals the indicator cannot be statistically verified, therefore the line shows just the projected potential dynamics of the indicator. Based on the data of the distribution analysis, a hypothesis that the samples PEF30-PEF1140 fall within the normal distribution ($p<0.05$) was not denied on the standard confidence level. An analysis according to Fischer’s criterion has confirmed that the difference in the scattering of samples cannot be proved on standard level, except for the intervals 240-270 s, 420-450 s and 870-900 s from the beginning of the test. This process cannot be explained as yet, however, it is noted that the intervals correspond to the intermediate stabilisation intervals of the indicator (with the indicator of an individual remaining stable for at least one minute). Irrespective of the “fall out” of these intervals from the nomogram, the mean and the confidence interval data may be assessed up to the 1140 s (19 minutes) of the test, with the parameters of the numerical characteristics marked on the graphical axes.

The established PEF under the conditions of maximal oxygen uptake amounting to 4.0 L/s (confidence interval 3.7-4.4) makes up 46% of PEF (confidence interval 42-50). According to Weber, in healthy persons PEF under the maximal oxygen uptake conditions amounts to approx. 40% of the forced expiration PEF (PEF_{EF}). No data on PEF_{EF} for athletes are available. The PEF in the individuals tested under the conditions of anaerobic threshold is 2.1 l/s (for the 1.8-2.3 values the data of the H0 hypothesis denial test corresponded to the standard level), or 22% of PEF. Taking account of the fact that no considerable intensification of lung ventilation was established before exceeding the anaerobic threshold, one may assume that up to 22% of changes in PEF are not determined by the chemical breathing-stimulating factors. The indicator is close to the errors for evaluating forced PEF as provided in the manual. Thus one may assume that approximately 20% of changes in PEF were accidental or determined by psychogenic factors. It has been established that PEF_{VO_2MAX} differs in the athletes group and the control group ($p<0,05$), though no difference in PEF was determined in still condition (in the individuals tested the average PEF under VO_{2MAX} is 4.03, average square deviation 0.99, confidence interval 3.71-4.35; in the control group, the average PEF is 3.54L/s, average square deviation 0.69, confidence interval 2.96-4.11). This shows that under PEF the lungs of athletes activate to a larger extent than those of the individuals who do not go in for sports, though peak possibilities may be equivalent. On the other hand, it is obvious that the compensational adaptation occurs on account of the air flow rate even if equal volumes are ventilated. Such compensation determines greater mechanical efficiency in athletes. A regress analysis has shown that the coefficients of correlation of all indicators are larger than 0.95, with the determination coefficient larger than 95%, and $p<0.01$.

Fig. 4. Laid athletes’ respiratory rate dynamic values during exercise test



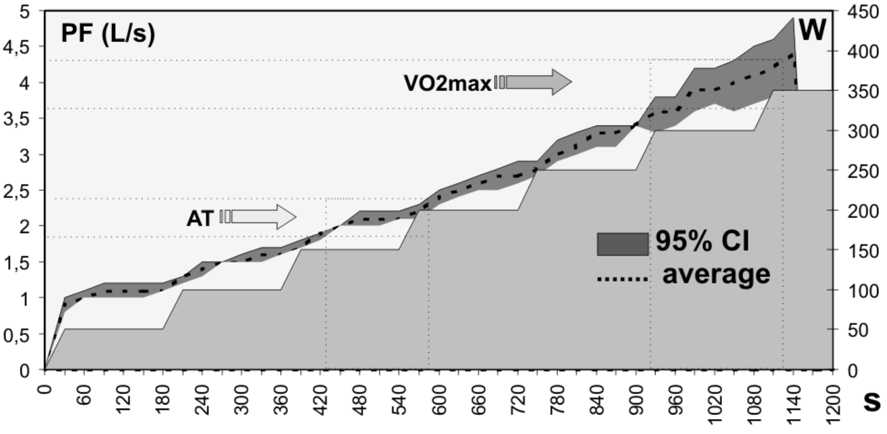
DISCUSSION

The confidence intervals shown in the graph depicting the VO_2 dynamics have been statistically verified and the region shown in the graph may be considered a nomogram of the dynamics of oxygen uptake by individuals with high motor activity during standard exercise testing (50Wx2min.). We see that the increase in VO_2 is a linear progression, which approximately corresponds to the function VO_2= 4.68+ 0.14*P in relation to load (VO_2=P/8) or VO_2= 7,34+0,04*T in relation to time (VO_2 t(s)*19), however, the scattering during the test increases along with load; at the same time, the limits of the confidence interval expand until an interval of 46.2-56.9 mL/min./kg is reached at 350 W and the scattering cannot be verified further (Fig. 1). Thus, at this point the sample should be split, which means that individuals are to be differentiated according to aerobic capacity. The results of the tests allow us to assert that the load of 350 W is a limit load for selection of individuals of very high physical capacity. The athletes whose VO_{2MAX} exceeds 56.9 mL/min./kg may be classified under another set. The athletes whose VO_{2MAX} is lower than 42.2 mL/min./kg are healthy individuals, however, their aerobic capacity and physical ability at the same time is lower than that of the standard sample. One may state that if AT is reached under VO_2>28 mL/min./kg, then both adaptation and physical endurance of the individual must be phenomenal, since such individual is adapted for long aerobic work. If AT is reached at VO_2<22 mL/min./kg, then the individual is categorised under another set (of healthy individuals) and is not very well prepared for long aerobic work.

HR also increases along with load, the linear progression being similar to that of VO_2, which corresponds to the data found in the literature; at 350 W it scatters up to the rate of 168-190 bits/min. We have established that the individuals whose HR>190 bits/min. belong to another set at the load of 350 W (the indicator is normal according to AHA for healthy individuals, with HR_{MAX} corresponding to VO_{2MAX}) but their myocardium activity is less economical than that of athletes. The athletes whose HR_{MAX} at VO_{2MAX} is lower than 168 bits/min. are well adapted for physical load, with the economical heart activity.

Though VE also increases in a linear progression (Fig. 3), there are many non-verifiable intervals, which shows that the external respiratory compensational mechanisms are activated at different rates. The fact that upon reaching 350 W and VO_{2MAX}, the scattering of VE reaches its peak and approximately corresponds to that of VO_2 is well verified. This shows that under extreme physical loads VO_{2MAX} may be determined by VE, while the regulation of external breathing depends on chemical factors of respiratory regulation (caused by the changes in momentary CO_2 retention and pH). Though the RR confidence intervals are well verified and identified (Fig. 4), their progression is not so pronounced. An assumption can be made that RR is not the critical factor of the external respiratory

Fig. 5. Laid athletes' peak flow dynamic values during exercise test



compensation. The characteristics of the PEF dynamics is very similar to that of VO$_2$ and well verified, therefore, one may assume that this indicator is related to the oxygen uptake level, while the air flow rate developed may be a determinant of VO2MAX. It is seen that under extreme physical load the scattering of VO$_2$ and PEF is similar, while the PEF dynamics depends on the degree and quality of activation of the expiration muscles, thus the respiratory compensation may be determined by the condition of the fast cross-striated muscles of the chest.

In conclusions, the results showed, that the different VO$_{2MAX}$ indicators reflecting the dynamic potential of the body are recorded in highly trained athletes during the standard ergometric test. This is most pronounced at the load of 350 W in the 900-1200 s interval of prolonged incremental activity, with the values varying from 46.2 to 56.9 mL/min./kg.

The aerobic capacity is determined by all links in the oxygen transport chain. External breathing indicators (VE, PEF, RR) are characterised by equally good correlation with the oxygen uptake indicators and by high determination coefficients (all $r>0.95$, $R^2>95\%$, $p<0.01$).

The limits of the confidence interval were verified on the level a=0.05 (except for the intervals marked by a dotted line), therefore they can be used as tentative nomograms for standard ergometrics of individuals with increased motor activity in evaluation of the lung ventilation volume, respiratory rate and peak air flow rate.

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RESPIRATORY FUNCTION DYNAMICS IN INDIVIDUALS WITH INCREASED MOTOR ACTIVITY DURING STANDARD EXERCISE TESTING

Functional diagnostics is one of the most important areas of sports medicine, which plays an increasingly role in selection of athletes, optimisation of training, early diagnostics and prophylaxis of sports pathology. Functional condition of the body undergoes constant changes under the influence of a number of factors. The differences may be considerable and pose problems related to the recruitment of athletes to teams in game sports and in individual sports. Physical ability is determined by the quality of external breathing and cardiovascular functions and by peculiarities of metabolism related to the tissue breathing and transport of substrates. In qualitative assessment of these phenomena one must relate the parameters of the individual's functional conditions to the required or desired values, i.e. norms. On the other hand, there exist no norms for a comprehensive evaluation of the Lithuanian persons' physical capacity and breathing system and metabolic function capacity including residents going in for sports. It is not clear whether one may rely upon the nomograms drawn up by foreign authors because they may not be applicable to Lithuanian athletes for a number of possible reasons: differences in training methods, regional cultural environment (differences in energy requirements in daily life), nutritional aspects, even demographic peculiarities taking into account limited assimilation level and small number of inhabitants. It has been established that the maximum oxygen uptake indicators reflecting the body's dynamic potential are different in elite athletes when evaluated during a standard ergo metric test. The aerobic capacity is determined by all links in the oxygen transport chain, since both heart rate (HR) and breathing indicators (VE-ventilation volume, PEF-peak expiratory flow and RR-respiratory rate) are characterised by equally good correlation with the oxygen uptake indicators and high determination coefficients (all $r>0.95$, $R^2>95\%$, $p<0.01$).

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