THE EFFECT OF STEPWISE EXERCISE ON SOME CARDIORESPIRATORY FUNCTIONS IN SPORT HORSES

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Abstract

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Heart frequency (f_H) and total minute oxygen uptake (V_{O_2}) were radiotelemetrically studied in 12 horses, ranging in age from 4—12 years, at stepwise exercise. From the obtained results the value of the so-called pulse oxygen (T_{O_2}) representing the amount of O_2 transported by one heart systolic volume was determined. The dependence of the oxygen uptake upon exercise was linear. A positive correlation is given by very close coefficients of correlation ($r = 0.99$ and 0.97). The value of pulse oxygen was, however, in a parabolic dependence not only on the speed but also on the heart rate and oxygen uptake. The steepest increase of the T_{O_2}) was found to be up to f_H 170 and up to the speed of 500 m/min. If the oxygen consumption is higher than 55 l/min, corresponding thus to work effort (WE) of 70 % max., the T_{O_2} was found to decrease.

Horse, exercise, walk, trot, cauter, gallop, pulse oxygen

Exercise of a horse places heavy demands on the cardiovascular system as far as blood volume and pressure are concerned. The former are associated with energy demands and large respiratory gas exchange. The pressure demands follow from the need to sustain the circulatory balance in the whole organism. Exercise places heavy demands also upon the thermoregulatory processes where not inconsiderable role is played also by cardiovascular system, or the distribution of the cardiac output, in order to ensure the thermoregulation requirements of a working organism.

The efficiency of the cardiovascular system and functions at horse exercise has already been discussed in several excellent review (Engelhardt 1977; Holmes 1982; Fregin and Thomas 1983; Physick-Sheard 1985; Rose and Evans 1987). From these studies follows that the oxygen uptake is determined by parameters of circulation, i. e. the value of cardiac output (Q), given as a product of stroke volume (Q_S) and heart frequency (f_H) (that is the central component) and by hemoglobin content and changes in the vessel bed including arteriovenous oxygen difference ($C_{aO_2} - C_{vO_2}$) (that is the peripheral component). This can be expressed by the equation

$$V_{O_2} = Q \cdot (C_{aO_2} - C_{vO_2}) = Q_S \cdot f_H \cdot (C_{aO_2} - C_{vO_2})$$

The presented interpretation assumes that the respiratory system itself is not a limiting factor of maximal aerobic performance of a horse but that this performance is conditioned first of all by cardio respiratory functions, i. e. by the value of cardiac output and the degree of oxygen desaturation of blood (Gillespie 1974; Gillespie and Pascoe 1983). At present, disputes are very lively about the significance and changes of the stroke volume during exercise. A great role has been attributed to the blood transport capacity and to the spleen as a red cell reserve for peripheral circulation at exercise (Persson 1967; Persson et al. 1973a, b; Persson and Bergsten 1975).

The aim of the present study has been to evaluate the dynamics of some cardiorespiratory functions during the stepwise exercise in sport horses as a suitable criterion for an assessment of fitness.

Materials and Methods

Altogether 12 sport horses, ranging in age from 4—12 years, weighing in average 477.5 ± 32.8 kg, were used in the experiment. Horses were ridden by 70—80 kg weighing riders and were subjected to a 3 000 m exercise at the walk, trot and gallop. The speed of these rates represented in every horse 15, 30 and 50 % of horses' individual utmost speed (WE max) measured with identical riders in a pre-trial at the 400 m distance. Further 6 horses selected from this set were subjected on a following day to further exercise (1 500 m distance), the speed corresponding to 70 % of the maximum work effort of every horse (%WE max).

Using a radiotelemetrical method (Hanák and Zakopal 1979; 1980; Hanák 1980) heart frequency (f_H), breathing frequency (f_b) and tital volume (V_T) were monitored at rest and at four types of exercise. Multiplying the f_b and V_T values the minute pulmonary ventilation (V_E) was calculated and then tabularly corrected to the BTPS conditions. The percentage of 0_2 uptake was determined on a Scholander instrument from the analysis of atmospherical and expired air samples collected from the respiration mask by a special five-port collector and then tabularly corrected to the STPD conditions. From the V_E value and from the percentage of oxygen uptake the value of total oxygen uptake per minute (VO_2) was determined. This value divided by that of heart frequency (f_H) expressed the value of the so called pulse oxygen (TO_2) representing the amount of 0_2 transported by one stroke volume (Q_s).

The results were statistically and graphically processed on a model 9810 A Hewlett-Packard computer. The method of a simple analysis of variance and Duncan's test were used to analyze the statistical significance of set differences. The closeness of the relationship was expressed by coefficient of correlation (r), the dependence between the studied values by regression equations.

Results

From Fig. 1 follows that heart rate is linearly dependent upon the exercise speed. A positive correlation is given by a very close coefficient of correlation ($r = = 0,997$) and by regression equation of the straight line presented in Table 1.

The dependence of oxygen uptake (VO_2) on the heart frequency (f_H) was found to be also linear as can be seen from Fig. 2. It is expressed by regression equation of the straight line at a very close positive relationship (Table 1). The value of pulse oxygen (TO_2) was, however, found to be in parabolic dependence both on
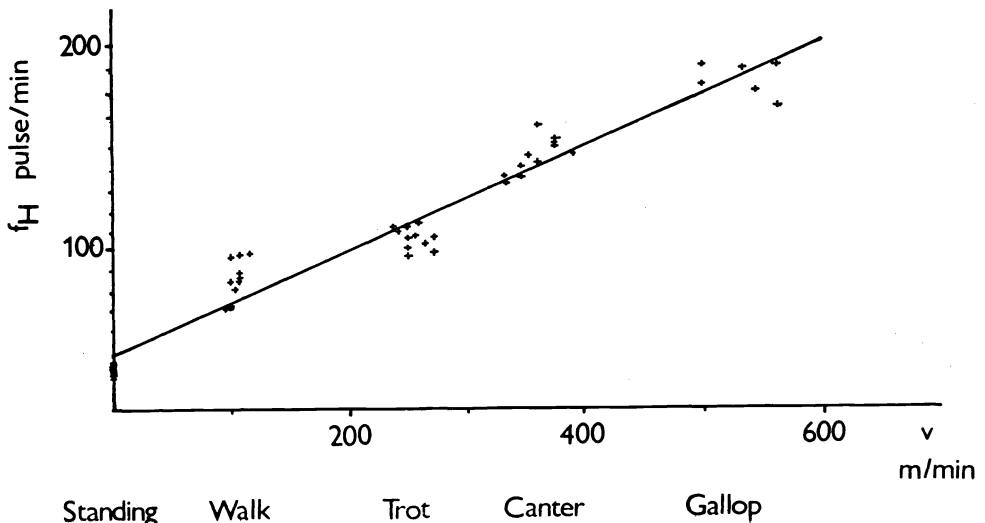

Fig. 1,

heart frequency (Fig. 3) and exercise speed (Fig. 4) and thus also on exerted work effort (WE). The relationship is expressed by regression equations and coefficients of correlation in Table 1, the latter ones being somewhat broader. From Figs. 3 and 4 is evident that the steepest increase of the $T0_2$ value is observed up to f_H 170 and speep of 500 m/min. At higher heart frequency and speeds the increase of $T0_2$ values is already very low. Due to the parabolic dependency it can be assumed that the $T0_2$ at high heart frequency can even drop.

The above-mentioned assumption can also be confirmed by a parabolic dependence of $T0_2$ on the $V0_2$ value in Fig. 5 that is given by a regression equation and by even closer positive correlation (Table 1). An apparent tendency to a decrease of $T0_2$ at $V0_2$ higer than 55 l/min, corresponding to work effort higher than 70 % of the maximum, is evident from the figure.

<div align="center">Table 1</div>

Dependence between the speed (v), heart rate (f_H) oxygen uptake ($V0_2$) and the value of pulse oxygen ($T0_2$) expressed by regression equations and coefficients of correlation

| Dependence	r	P
$f_H \;\; = 46.942\,9 + 0.257\,8 \cdot v$	0.97	0.01
$V_{0_2} = 0.79 + 0.10 \cdot v$	0.99	0.01
$V_{0_2} = -16.139\,4 + 0.378\,3 \cdot f_H$	0.97	0.01
$T_{0_2} = 47.853 + 0.889\,5 \cdot v - 0.000\,75\,m \cdot v^2$	0.86	0.01
$T_{0_2} = 88.250 + 3.60 \cdot f_H - 0.01 \cdot f_H^2$	0.82	0.01
$T_{0_2} = 30.950 + 10.16 \cdot V_{0_2} - 0.10 \cdot V_{0_2}$	0.95	0.01

Discussion

The uptake of oxygen ($V0_2$) and the efficiency of its transport from lungs to the mitochondrial system of working tissues is summarily expressed by the oxygen pulse value ($T0_2$). It represents the amount of oxygen delivered into the circulation and transported by one systolic volume. Thus, it is an indicator of the efectiveness of cardiovascular system work at oxygen transport and, indirectly, also the indicator of stroke volume changes (Q_s) at exercise (W a s s e r m a n and W h i p p 1975). It also informs how the organism compensates for the increased hemodynamic requirements of exercise by the increase of either heart rate or stroke volume:

A whole series of factors that increase the oxygen transport capacity of the cardiovascular system can contribute to the $T0_2$ elevation during exercise. The decisive factors in the increase of $T0_2$ are, however, oxygen uptake ($V0_2$) and stroke volume (Q_s). Also the quality of red blood cell turnover (Er, Hb, HK), limiting the hemoglobin binding capacity for oxygen and thus other parameters of blood gas transport, contribute in a high degree to the elevation of $T0_2$. It can thus be concluded that changes in $T0_2$ during exercise correspond closely with the changes of oxygen uptake, stroke volume, mobilization of splenic red cell reserve and also with the fluid shift between intravasal and extravasal spaces.

The dependence of $T0_2$ upon exercise intensity, heart rate and oxygen uptake is parabolic. The steepest increase in the $T0_2$ value was found at heart rate up to about 170 beats/min, speed of 500 m/min and $V0_2$ 50 l/min. At higher intensity of exercise with working effort WE = 70 % max, represented by $f_H = 170-200$ beats/min, v $= 500-600$ m/min and $V0_2 = 55$ l/min, the increase of $T0_2$ was
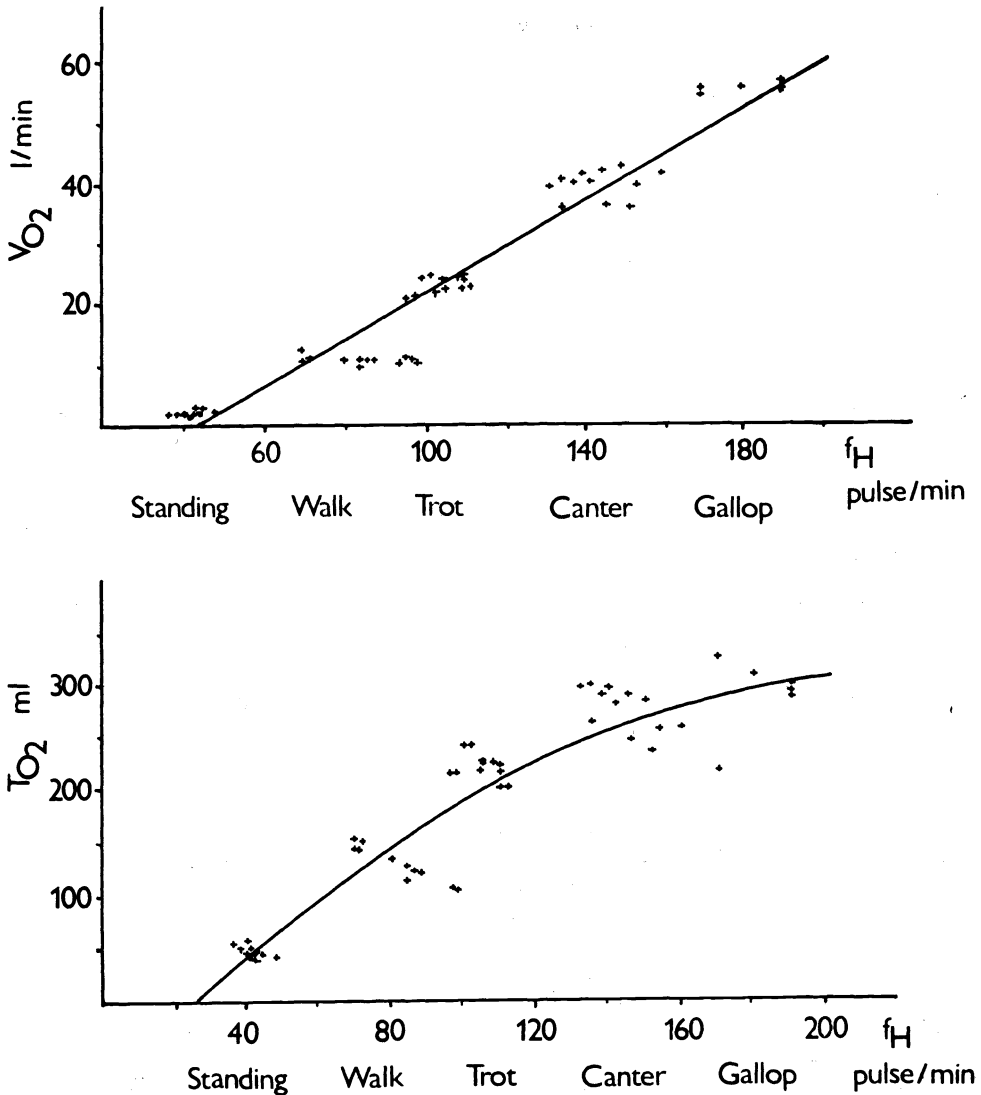
F. 2. (top) and Fig. 3. (bottom).

found to be very slight. It can thus be concluded that at exercise intensity over 70 % WE max the higher oxygen transport to tissues is provided not by the elevation of TO_2 but by that of f_H. A question thus aries what caused this relative stabilization of TO_2 at WE 70 % max?

On one hand, this T_{O_2} stability at WE 70 % max could be associated with the arrival to the maximum rate of oxygen consumption (V_{O_2} max) when the oxygen uptake does not increase any more. From our preceding study on ventilatory equivalent changes and O_2 utilization from inspired air (Hanák 1987) follows that the restriction of oxygen uptake occurs at intensities higher than 70 %

WE max as well. The limit of T_{0_2} stabilization and of the restriction of oxygen uptake is thus approximately indetical. From that the answer to the above placed question could be obtained that at exercise with work effort of 70 % WE max the T_{0_2} max is achieved, being conditioned by the oxygen uptake near V_{0_2} max. Heart rate $170-200$ beats/min, $v = 500-600$ m/min and V_{0_2} at about 55 l/min correspond to this limit in sport horses.

On the other hand, the relative stabilization of $T0_2$ ($T0_2$ max) at the limit of 70 % WE max could also be caused by the so called regulatory heart dilatation and a maximum stroke volume (Q_s max). It would not only confirm the above presented fact that higher oxygen transfer to tissues is, starting from the mentioned level, ensured by the increase in heart frequency only but also that the total hemodynamic requierements upon the elevation of cardiac output (Q) are at higher exercise intensity ensured only by the increase of heart frequency at Q_s max or even lower (Engelhardt 1977). To this effect, $T0_2$ would also inform indirectly about the economy of heart work as was reported by Wasserman and Whipp (1975).

The problem has not been solved of how and how much the stroke volume increases in horses at stepwise exercise, the literature data on Q_s changes during exercise being very diverse (Rose and Evans 1987; Evans and Rose 1987). Taking into account the finding of Thomas and Fregin (1981) we can see that the increase in Q_s represents 41 % of the rest value (i. e. 1.5 fold). If we compare this result with the 6-times increased value of $T0_2$ confronted with the rest value obtained by us then it is obvious that oxygen uptake, or other factors ensuring the oxygen transport from lungs to working tissues, participate in a higher degree than the rise in Q_s in the increase of $T0_2$ at stepwise exercise of horses. It is predominantly the splenic red cell reserve mobilization that is induced by exercise at heart frequency higher than 100 beats/min. (Persson 1967, 1969). Hemoconcentration with the elevated Er, Hb and HK values is further deepened by the plasma volume tissues (Wittke et al. 1974; Carlson 1983, 1987). Thus the conditions for a higher oxygen uptake and for a T_{0_2} rise up to the 70 % WE max are formed. Together with the significant Q_s increase they represent high economy of heart
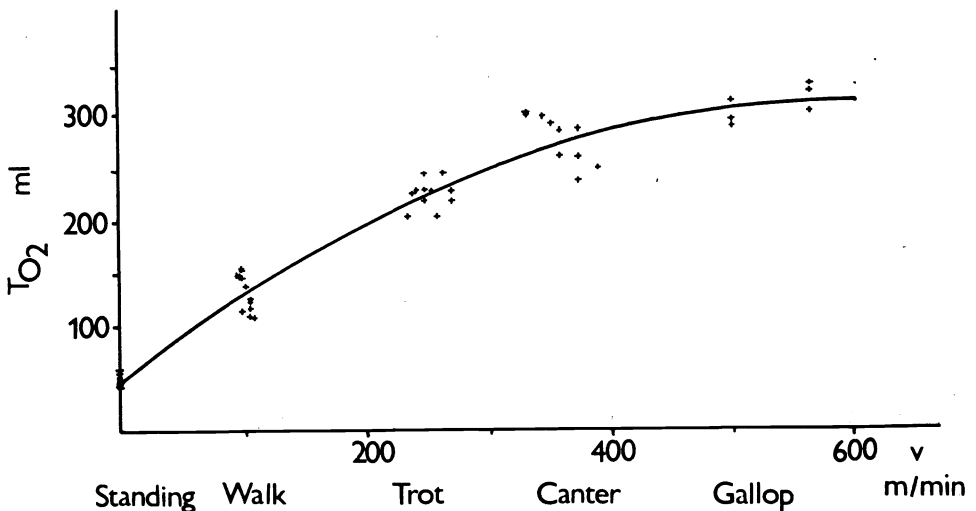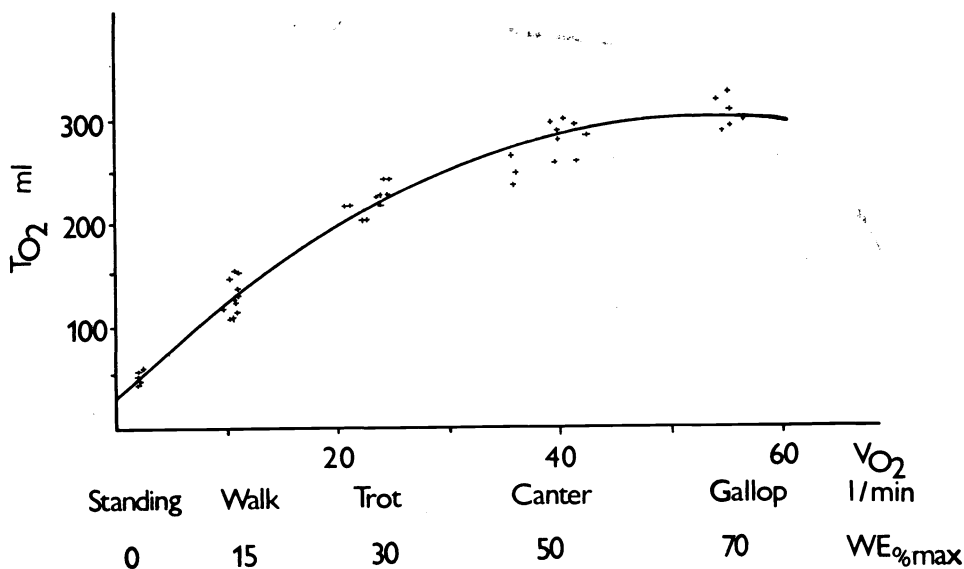

Fig. 4.

Fig. 5.

work at f_H 170—200 beats/min. If the increase in Q_s at intensified exercise compared with the rest value is identical both in man and horses (1.5 fold) then the T_{0_2} increase in the horse represents 0.6—0.8 ml/kg b. w., being two times higher than that in man (0.35 ml/kg b. w.). This presentation shows a doubled capacity of an oxygen uptake transport system in horses compared to man. It has also been confirmed by Engelhardt (1977) or McMiken (1983) that a horse increases the oxygen consumption compared with the rest 35—40 times whereas in man it is only 20 times, i. e. two-fold increase. This capability of a horse is given predominantly by a high efficiency of respiratory functions and by a function of circulatory system, including the mobilization of splenic reserve.

With regard to the described significant effect of $T0_2$ upon $T0_2$ it can be assumed that after reaching the maximum rate of oxygen consumption the $T0_2$ value at exercise intensity higher than 70 % WE max begins to decrease at higher f_H. It follows from Fig. 5 that a pronounced drop of $T0_2$ at $V0_2$ of about 55 l/min and more occurs. It can thus be concluded that either $V0_2$ value of 55 l/min is the limit of the maximum rate of oxygen consumption and $T0_2$ drops after reaching this value, or that other factors than $V0_2$max participate in $T0_2$ decrease. In the latter case the primary role would be played by the reduction in stroke volume, similarly as in man (Wasserman and Whipp 1975). This would occur particularly if the upper anaerobic threshold is exceeded at f_H of about 200 beats/min. (Persson 1983; McMiken 1983; Physick-Sheard 1985) when the diastolic filling time is extremely shortened (Senta et al. 1970; Engelhardt 1977; Hanák 1980, 1987). This latter theory appears to be more probable due to the presented parabolic dependence of $T0_2$ upon $V0_2$ shown in Fig. 5, i. e. that $T0_2$ decreases at $V0_2$ still rising.

In performing individuals $T0_2$, $V0_2$ and Q_s are generally higher and that is the reason why they do not increase heart frequency up to maximum values but closely over the limit of anaerobic threshold of 200—210 beats/min at sub-

maximal and particularly maximal exercise. It seems to be logical because performing horses at relatively identical speeds have higher Q_s and lower f_H (Ehrlein 1970; Engelhardt 1977; Hanák 1980, 1987), reaching thus at higher VO_2 (Evans and Rose 1987) also a higher TO_3 (Hörnicke et al. 1983). The last mentioned author reported in individual cases a close relationship between more rapid and higher TO_3 increase and horse performance.

Our finding obtained particularly at gallop confirms this, as can be seen from Fig. 3 and 4. It can be concluded that more trained individuals have, owing to higher VO_2 max and better heart work economy, also a higher aerobic capacity and maximal aerobic performace which at maximum exercise [represent a lower increase in f_H and lower number of heart beats per exerted work. This has also been confirmed by the results of radiotelemetrical recording of f_H during races reported in our preceding study (Hanák 1987).

From the above presented a very importance fact arises that the maximum utilization of oxygen from expired air and the maximum TO_2 and Q_s values are reached at approximately identical heart frequency of 170—200 beats/min, to which the exercise intensity representing 70 % WE max corresponds. At higher exercise intensity and heart rate a further increase of cardiac output for ensuring the hemodynamics and further higher transport of oxygen to working tissues is realized only by an economically less effective increase of heart frequency. TO_2 and Q_s are decreasing. Starting from 170 beats/min or at the limit of about 200 beats/min the maximum rate fo oxygen consumption (VO_2 max) will probably be reached. After arrining at VO_2max at f_H over 200 beats/min the upper anaerobic threshold is exceeded and already fully developed anaerobic energy metabolism is in progress. This finding corresponds to the observation of drastical elevation of lactate over this limit as was referred e. g. by Persson (1983) and others.

We can summarize that the parabolic dependence of the pulse oxygen value upon exercise intensity, heart frequency and oxygen uptake allows to assume that in horses at exercise TO_2 represents an indirect index of VO_2 and stroke volume (Q_s) changes. Changes in TO_2 during horse exercise thus correspond closely with those in VO_2, Q_s with the splenic red cell reserve mobilization and with fluid shift between intravasal and extravasal spaces at exercise. The elevation in TO_2 is primarily conditioned by the increase of VO_2 and by red cell mobilization, secondarily by the Q_s increase. The limit of reaching TO_2 max is identical with that of $Q_s$max at working effort WE = 70 % max and signalizes the arrival at the maximum rate of oxygen consumption (VO_2max). The TO_2 reduction is primarily conditioned by the Q_s decrease and secondarily perhaps by the VO_2 decrease. The drop of Q_s is probably induced by an extreme shortening of diastolic filling time at heart rate over 200 beats/min. At higher exercise intensity the growing hemodynamic and oxygen requirements of a working organism are met by the mechanism of heart rate increase only.

Vliv stupňované pohybové zátěže na některé kardiorespirační funkce sportovních koní

U 12 koní při stupňované pohybové zátěži byla radiotelemetrickou metodou sledována srdeční frekvence (f_H) a celkový minutový příjem kyslíku (VO_2). Z takto získaných hodnot byla stanovena hodnota tzv. tepového kyslíku (TO_2), reprizentující množství O_2 transportované jedním systolickým objemem srdečním.

Závislost příjmu kyslíku na rychlosti pohybu i srdeční frekvenci je lineární. Pozitivní korelační vztah je dán velmi těsnými korelačními koeficienty r (0,99 a 0,97). Velikost tepového kyslíku je však v parabolické závislosti nejen na rychlosti pohybu, ale i na srdeční frekvenci a příjmu kyslíku do organismu. Nejprudší nárůst velikosti TO_2 je do f_H 170 tepů/min a rychlosti 500 m/min. Při spotřebě kyslíku vyšší jak 55 l/min, který odpovídá pracovnímu úsilí WE 70 % max, se TO_2 zmenšuje.

Влияние увеличивающейся двигательной нагрузки на некоторые сердечно-дыхательные функции скаковых лошадей

У 12 лошадей с увеличивающейся двигательной нагрузки с помощью телеметрического метода исследовали частоту пульса (f_H) и общий поминутный расход кислорода (VO_2). По полученным таким способом значениям определяли величину так называемого пульсионного кислорода (TO_2), представляющего количество транспортируемого O_2 одним систолическим объемом сердца.

Зависимость расхода кислорода от скорости движения и частоты пульса является линейной. Позитивное корреляционное отношение дано весьма тесными коэффициентами корреляции r [0,99 и 0,97]. Однако величина пульсионного кислорода находится в параболической зависимости не только от скорости движения, но и от частоты биения сердца и поступления кислорода в организм. Самый стремительный прирост величины TO_2 наступает по f_H 170 пульсаций/мин и при скорости 500 м/мин. При расходе кислорода, превышающем 55 л/мин и соответствующем трудовой нагрузке WE 70 % макс, TO_2 уменьшается.

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