abdominal contraction were thought to contribute to expiratory effort.[7]

Our study is of limited value because we were not able to measure diaphragmatic contraction (via electromyography), abdominal inertance or exactly record the relationship of individual foot placement to respiratory events for each gait. These data would be necessary to support our suggestions regarding the abdominal piston.

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Draught Load and Speed Compared by Submaximal Tests on a Treadmill

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ABSTRACT. Six Standardbred trotters exercised on a horizontal treadmill with consecutively increasing draught load (D-test) or speed (S-test). D-test was performed at a walk of 2 m s^{-1}. Oxygen uptake ($\dot{V}O_2$), heart rate (HR) and minute ventilation ($\dot{V}E$) increased linearly in both tests and reached a mean of 73 ± 9 ml kg^{-1} min^{-1}, 172 ± 12 bpm and 917 ± 93 l min^{-1} at the heaviest draught load (107.1 kp). The values for HR and $\dot{V}O_2$ were close to those measured at a speed of 8 m s^{-1} in the S-test. The relationships between $\dot{V}O_2$ and HR, $\dot{V}E$ and blood lactate concentration did not differ between the two tests. Stride frequency increased in both tests, whereas stride length increased in S-test and decreased in D-test. In conclusion, similar cardiopulmonary and lactate responses were obtained in the two tests. D-test may therefore be an alternative to S-test for horses which have difficulty trotting fast enough for exercise tolerance testing.

Key words: Horses; draught load; training; oxygen uptake; heart rate.

INTRODUCTION

Pulmonary ventilation and oxygen uptake have previously been measured in several studies in horses performing exercise at different speeds on a treadmill.[2,3,8,11,13] Little is known however, about respiratory gas exchange during draught work. This is worthy of study, as draught-loaded exercise is used as a method of training Standardbred horses for racing.

When Standardbred trotters are trained conventionally, the work intensity is increased by increasing speed. During draught-loaded exercise the work intensity may be enhanced by increasing draught resistance, by which high work intensities can be reached at low velocities. This may affect the cardiorespiratory system, blood lactate response and locomotion pattern differently. The purpose of this study was to compare incremental draught load versus speed in exercise tolerance testing using oxygen uptake, heart rate and blood lactate responses as parameters.

MATERIALS AND METHODS

Six clinically healthy, lightly trained Standardbred trotters were used. They were 1 mare, 4 geldings and 1 stallion ranging in age between 4 and 13 years (mean = 7 ± 4).

Incremental draught work was performed on a horizontal treadmill (Sikob) at a walk of 2 m s^{-1}. Weights were suspended from a rope which was horizontally connected to the harness and passed over a pulley mounted on a support behind the treadmill. The draught resistance, beginning at 4.1 kilopond (kp), was increased by 20.6 kp every 2 min up to a final level of 107.1 kp. One kilopond = 1 kg m s^{-2} = 9.81 N.[6] The horses wore a mask for determination of oxygen uptake ($\dot{V}O_2$) during the test. The draught resistance was measured before the test by a force transducer (strain-gauge, Type KRG-4) fastened between the harness and the rope and coupled to a transducer indicator (Type BKI-1). From this the output signal was scaled, low-pass filtered and recorded by a stripchart recorder (modified Moseley Model 680 M).

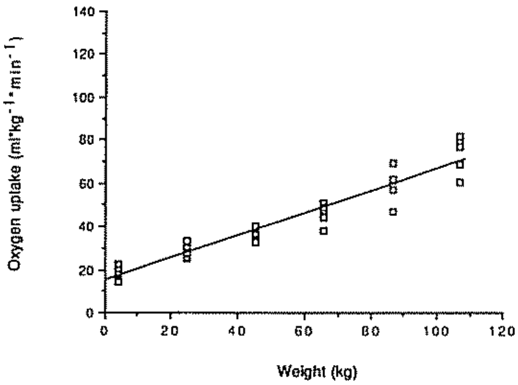

Fig. 1a. Oxygen uptake in 6 horses performing treadmill exercise with increasing draught resistance (D-test). $r=0.96$, $Y=15.12+0.51X$.

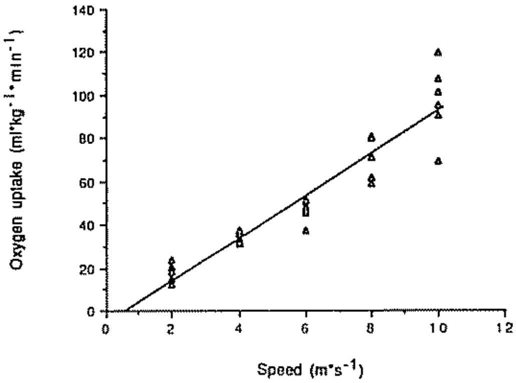

Fig. 1b. Oxygen uptake in 6 horses performing treadmill exercise with increasing speed (S-test). $r=0.95$, $Y=-5.85+9.84X$.

One week after D-test the horses trotted on a horizontal treadmill at speeds from 2 to 10 m s^{-1}, with speed increased by 2 m s^{-1} at 2 min intervals. The horses wore a mask for estimation of $\dot{V}O_2$ during the test.

Heart rate (HR) was recorded during both tests at rest and during the last 15 seconds of each work level by using a bipolar electrocardiogram (Mingograph Type 804).

$\dot{V}O_2$ and minute ventilation (l min^{-1}) were measured by an open-circuit method. The horse wore a mask with inlet and outlet valves and expired air was collected. The air was conducted through two wire-supported tubes (10 cm diameter) to a 200 l mixing chamber, from which the minute ventilation ($\dot{V}E$) was measured by a flowmeter, transduced by a thermoresistance coupling (GD-100, Fluid Inventor). The ventilation was recorded during the last 30 seconds of each work load. The expired air was sampled continuously from the mixing chamber through a catheter, and O_2 and CO_2 concentrations were determined by mass spectrometry (Centronic 200 MGA) during the last 15 seconds of each work load. The respiratory rate (RR) was measured during the last 15 seconds of each work level. All gas volumes are stated in STPD. From a previous study it is known that $\dot{V}O_2$ reaches a relatively steady state within 2 min at various trotting speeds,[2] and this was also found at various draught resistances.

The time taken for 50 paces was recorded at each work load and the mean stride frequency (SF, min^{-1}) was determined and the mean stride length (SL, m) was calculated at each treadmill speed.

Venous samples were taken from a jugular catheter at rest and during the last 15 seconds of each work level. The blood lactate concentration (LA) was determined enzymatically (Boehringer test, Combination no. 124842).

The results were analysed by standard methods[7] for linear ($\dot{V}O_2$, HR, RR, $\dot{V}E$) and exponential (LA) regression by the method of least squares, using analysis of variance in a randomized block design (SF, SL), and the *t*-test for paired observations (respiratory exchange ratio, R). Differences between regression lines were tested for the relation between $\dot{V}O_2$ and circulatory and respiratory parameters and for the relation between HR and LA in D- and S-tests. Means ± SD are reported. Statistical significance was accepted at $p<0.05$.

RESULTS

$\dot{V}O_2$ increased in proportion to increasing draught resistance (Fig. 1 *a*) and speed (Fig.

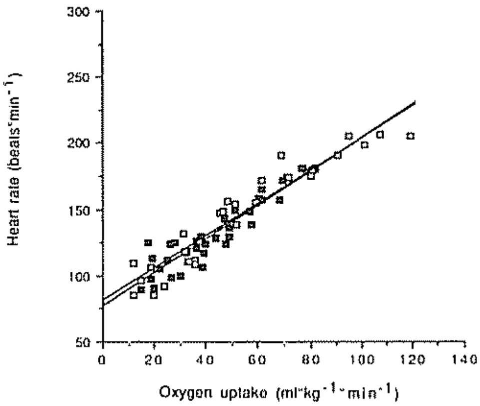

Fig 2a Heart rate in relation to oxygen uptake in 6 horses performing treadmill exercise with increasing draught resistance (D-test) and increasing speed (S-test). ■, D-test: $r=0.93$, $Y=76.4+1.27X$. □, S-test: $r=0.95$, $Y=80.8+1.23X$.

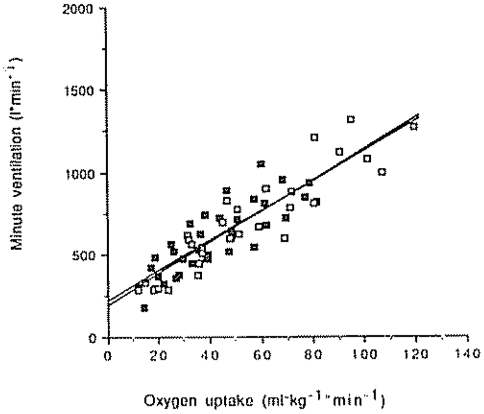

Fig 2b Minute ventilation in relation to oxygen uptake in 6 horses performing treadmill exercise with increasing draught resistance (D-test) and increasing speed (S-test). ■, D-test: $r=0.82$, $Y=210.11+9.08X$. □, S-test: $r=0.92$, $Y=182.46+9.44X$.

1 *b*). $\dot{V}O_2$ averaged 73 ± 9 ml kg^{-1} min^{-1} at the heaviest draught load and 97.2 ± 17.1 ml kg^{-1} min^{-1} at the fastest trotting speed. The $\dot{V}O_2$ at 107.1 kp was equivalent to that measured at a speed of 8 m s^{-1} in S-test (71 ± 9 ml kg^{-1} min^{-1}).

HR increased linearly in both tests (D-test $r=0.98$, S-test $r=0.99$) from means of 104 ± 14 and 96 ± 11 bpm at the lowest work loads to means of 172 ± 12 and 199 ± 7 bpm at the highest work loads in D- and S-tests, respectively. The HR at 107.1 kp (172 ± 12 bpm) was equivalent to that measured at a speed of 8 m s^{-1} in S-test (172 ± 8 bpm).

RR increased linearly in both tests (D-test, $r=0.98$, S-test $r=0.89$) from means of 70 ± 8 and 56 ± 17 breath min^{-1} at the lowest work loads to means of 86 ± 6 and 87 ± 17 breath min^{-1} at the highest work loads in D- and S-tests, respectively.

$\dot{V}E$ increased linearly with increasing draught load ($r=0.99$) and speed ($r=0.99$) from means of 340 ± 105 and 298 ± 18 l min^{-1} at the lowest work loads to means of 917 ± 93 and 1061 ± 257 l min^{-1} at the highest work loads in D- and S-tests, respectively.

R did not differ between the tests. Values of 0.89 ± 0.12 and 0.91 ± 0.06 were measured during the first 2 min, and values of 0.93 ± 0.01 and 0.97 ± 0.04 were measured at the end of exercise in D- and S-tests, respectively.

LA increased exponentially with increasing draught resistance ($r=0.91$) and speed ($r=0.90$) to means of 2.2 ± 0.4 and 3.4 ± 1.0 mmol l^{-1} in D- and S-tests, respectively.

There was no difference between D- and S-tests in the relation between $\dot{V}O_2$ and HR (Fig. 2*a*), $\dot{V}E$ (Fig. 2*b*), RR and LA (Fig. 2*c*). No difference was found in mean lactate concentrations in relation to HR in the two tests.

SL decreased with increasing draught load from a mean of 1.80 ± 0.10 m for the first 2 min to a mean of 1.60 ± 0.08 m with the heaviest draught load ($p<0.01$) and increased with increasing speed from a mean of 1.80 ± 0.11 m for the first 2 min to a mean of 4.68 ± 0.17 m at the fastest trotting speed ($p<0.001$). The SF increased with increasing draught load ($p<0.001$) and speed ($p<0.001$), averaging 66 ± 4 and 60 ± 9 for the first 2 min and 77 ± 4 and 128 ± 5 with the heaviest work intensity in D- and S-tests, respectively.

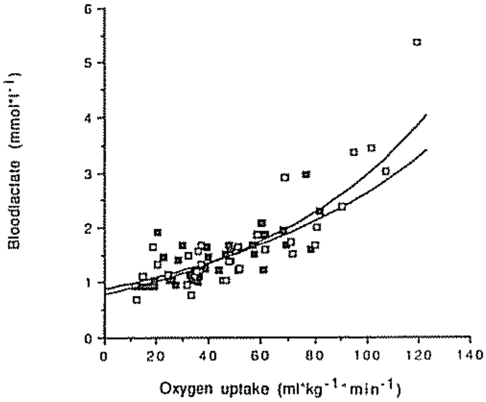

Fig 2c Blood lactate concentration in relation to oxygen uptake in 6 horses performing treadmill exercise with increasing draught resistance (D-test) and increasing speed (S-test). ■, D-test: $r=0.72$, $Y=0.87\times10^{(0.005X)}$ □, S-test: $r=0.85$, $Y=0.78\times10^{(0.006X)}$

DISCUSSION

In analysis of fitness and state of training, physiological parameters are often studied during submaximal treadmill exercise and the work intensity is enhanced by increasing the velocity.[11] This causes HR, $\dot{V}O_2$ and $\dot{V}E$ to increase linearly and in proportion to increasing velocity.[2,3,11,12] The results from the present investigation are in agreement with these observations. The same was found when the work intensity was increased by progressive draught resistance at a low velocity (walk). It was also found that the relation between $\dot{V}O_2$ and HR, $\dot{V}E$, RR and LA did not differ between the two tests. In accordance with a previous study where draught-loaded exercise of increasing resistance was performed at a slow trot (5 m s^{-1}) and compared to unloaded increasing trotting speeds[4] there was no indication that the relation between HR and LA differed between the two types of exercise. It seems, therefore, possible to achieve similar physiological responses, whether the work intensity is increased by increasing draught resistance at a walk or slow trot, or by increasing trotting speeds. This makes it possible to evaluate exercise tolerance with increasing draught load at a walk. Exercise tolerance tests are widely used and usually performed at submaximal levels with increasing speed.[10,11]

Evaluation of factors limiting the energy turnover during exercise allows estimation of state of training and recognition of factors limiting performance in clinical disorders. However, some horses have difficulties in carrying out the test due to inability to exercise at high speed without changing gait, and for these horses the standardized draught-loaded exercise test could be an alternative diagnostic regime.

Both D- and S-tests were performed at submaximal work levels because LA did not exceed 3.4 mmol l^{-1}, HR did not exceed 200 bpm, $\dot{V}O_2$ did not exceed 100 ml O_2 kg^{-1} min^{-1}, and r never exceeded 1.0. Values exceeding these levels are associated with exercise eliciting maximal $\dot{V}O_2$.[1,8,11,12]

The low LA indicate that the predominant pathway for energy supply in the muscles was oxidative metabolism. A previous study, using the same horses as in the present study, has shown that anaerobic metabolism (i.e., glycolysis with lactate accumulation) becomes increasingly more important when draught-loaded exercise is performed at a trot[4] as the total work load becomes much heavier. In that study, the horses performed exercise with consecutively increasing draught resistance at a slow trot (5 m s^{-1}), and the blood lactate averaged 11.1 mmol l^{-1} at a weight load of 86.5 kp during the last 15 seconds of the 2 min period. Changing gait from a walk (2 m s^{-1}) to a slow trot (5 m s^{-1}) seems to increase the energy demand markedly during incremental draught loading.

When the work intensity increases, more muscle fibres are recruited, and more fast contracting fibres are progressively involved, as indicated from glycogen depletion studies.[5,9,14] The low LA could indicate that oxidative muscle fibres were primarily recruited during the exercise, in spite of the fact that the draught load was as heavy as 107 kp. It cannot be excluded, however, that glycolytic fibres were also activated and that the lactate produced by them was oxidized elsewhere. Previous studies have shown that type I and II A fibres are recruited when 80 kp is pulled at a walk,[5] and this has also been found when horses trotted at a speed of 8 m s^{-1}.[14] These two different types of exercise seem to result in similar energy demands and to involve the same types of muscle fibres. However, differences are seen in the locomotion pattern. The performance of a draught-loaded exercise test could therefore be a useful alternative to a high speed test when a horse cannot maintain sufficient speed at the trot.

In conclusion, the relationships between circulatory, respiratory and metabolic parameters did not differ between submaximal draught-loaded exercise at a walk and exercise with increasing trotting speeds. Whether this is true for maximal exercise needs further study.

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