Respiratory Adaptations to Exercise in the Horse

R. J. Rose and *D. L. Evans*

Department of Veterinary Clinical Studies, University of Sydney

Introduction

The respiratory system of the horse has received little attention in the recent studies of exercise physiology. The majority of the research that has been carried out has focussed on the cardiovascular and musculoskeletal systems. The major reasons for this have been the difficulty in studying the respiratory system during exercise and the assumption that the respiratory system plays only a passive role during exercise and is therefore not rate limiting. More recently, studies by *Bayly* et *al.* (1983) and *Thornton* et *al.* (1983) have shown that the respiratory system may be of greater importance in limiting performance than was previously thought. Both these studies have shown that an arterial hypoxaemia and hypercarbia develops in the horse during maximal or near maximal exercise. In horses with chronic obstructive pulmonary disease (COPD), *Littlejohn* et *al.* (1983) have shown that during moderate exercise intensities, these horses had higher heart rates and greater arterial-mixed venous oxygen differences than normal horses. The ability of the respiratory system to transfer oxygen efficiently to the arterial blood and to remove carbon dioxide from the mixed venous blood is of vital importance to the exercising horse. Although horses exercising at maximal intensities are more reliant on their anaerobic capacity, it is still important for the oxygen transfer systems to be working at their greatest capabilities. This article will review some of the current information on the responses of the respiratory system of the horse to exercise and present some results of recent work undertaken in our laboratory.

Respiration and Locomotion

Attenburrow (1982) has demonstrated that there is a consistent relationship between respiration and limb movement in the horse exercising at the canter and gallop. The respiratory and limb cycles were found to be synchronised so that inspiration occurred during forelimb protraction. *Attenburrow* (1983) suggested from analysis of his data that the protraction of the forelimbs and retraction of the hindlimbs could assist or „force“ inspiration during 75 per cent of the inspiratory period at the canter and 90 per cent at the gallop. In contrast, the chief factor in the assistance of expiration was considered by *Attenburrow* (1983) to be weight bearing by the forelimbs. In contrast, *Karlsen* and *Brejtse* (1965) reported a 1 : 2 or 1 : 3 relationship between respiration and stride frequency in trotters at maximal work effort, resulting in a much greater tidal volume.

Ventilation and Oxygen Consumption

Hornicke et *al.* (1983) reported a series of results from their studies on respiratory measurements performed by radiotelemetry. Measurements included oxygen consumption ($\dot{V}O_2$), tidal volume (V_T) and minute respiratory volume ($\dot{V}_E$). All horses were ridden and the maximal speeds were 8.7–9.5 metres/sec. At this top speed the $\dot{V}O_2$ of four horses was 60 ± 5 L/min. with a mean heart rate of 186 beats per minute. This compared with $\dot{V}O_2$ values of 2.5 L/min. at rest. There was a close relationship between $\dot{V}O_2$ and velocity and also between $\dot{V}O_2$ and $\dot{V}_E$. Weaker correlations were found for $\dot{V}O_2$ with V_T and heart rate. These figures only represent the situation for submaximal exercise although the maximum $\dot{V}O_2$ reported by *Hornicke* et *al.* (1983) was similar to that reported by *Karlsen* and *Nadaljak* (1964) in Russian trotters. However, in the latter study the horses were probably considerably lighter in body weight than the former study, so that $\dot{V}O_2$ in ml/min./kg may have been higher than in the study of *Hornicke* et *al.* (1983). The major problem in the study of $\dot{V}O_2$ is the measurement of maximal oxygen uptake ($\dot{V}O_{2max}$), which is only reached at high exercise intensities. The first report of $\dot{V}O_{2max}$ was that of *Karlsen* and *Nadaljak* (1964) who found values of 63–64 L/min. in trotters. Because $\dot{V}O_{2max}$ is only reached at high work intensities, its measurement has been quite difficult. More recently *Taylor* (1985) reported $\dot{V}O_{2max}$ values in ponies, which occurred at lower treadmill speeds than those required for larger horses. *Persson* (1983) has suggested that because of the dangers involved in exercising horses at the intensities required to produce $\dot{V}O_{2max}$, a more simple index of a horse's aerobic capacity may be more practical. The value that *Persson* (1983) has found to be of the most value is the speed at a heart rate of 200 beats/min. (V_{200}), which is highly correlated with $\dot{V}O_{2-200}$ (*Persson,* 1983).

While this is a useful practical measurement, further studies of the respiratory response to high speed exercise are important to aid in the understanding of the dynamics of the respiratory system. Our research has involved use of a high speed treadmill to investigate the effects of maximal exercise.

Methods

The respiratory response to increasing exercise intensities was evaluated using a multi-stage exercise test on a treadmill (Equitred, Ipswich, Australia) set at a slope of 10 per cent. The exercise test commenced with a two minute warm up at a speed of 3 metres/sec. followed by seven additional stages, each of one minute duration up to a maximum speed of 12 metres/sec. Some horses were unable to tolerate speeds greater than 10 metres/sec. and in such cases the exercise test was terminated at this stage. The horses used were Standardbred geldings aged form 4–7 years and weighing between 390 and 530 kg. The horses had all been accustomed to the presence of a face mask for the collection of respiratory gases and had all worked up to maximal exercise intensity on the treadmill prior to the experiments

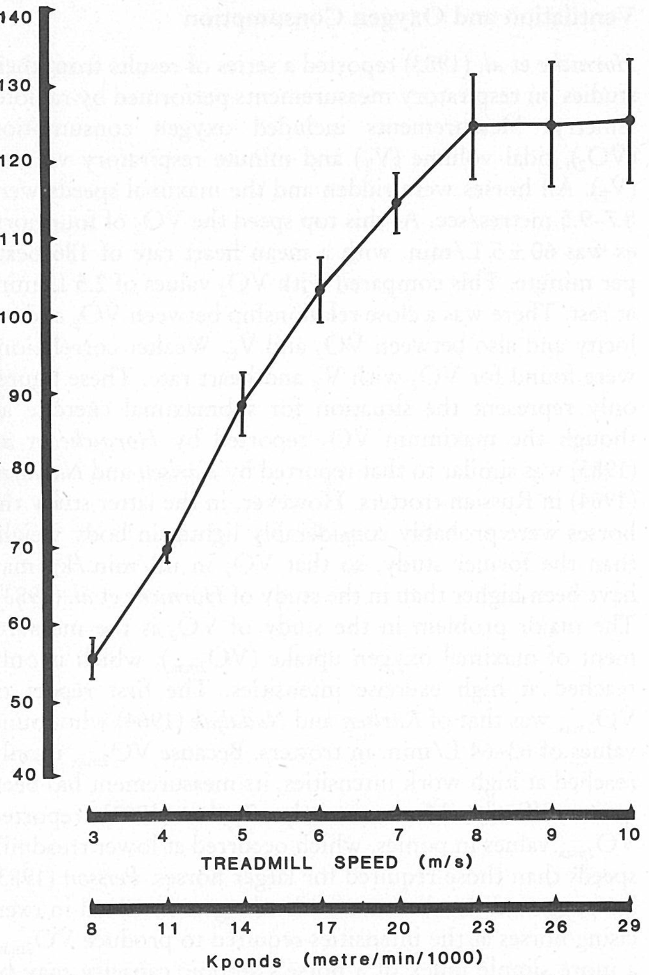

Fig. 1: Oxygen consumption ($\dot{V}O_2$) in horses during graded treadmill exercise. Results are shown as mean ± sem.

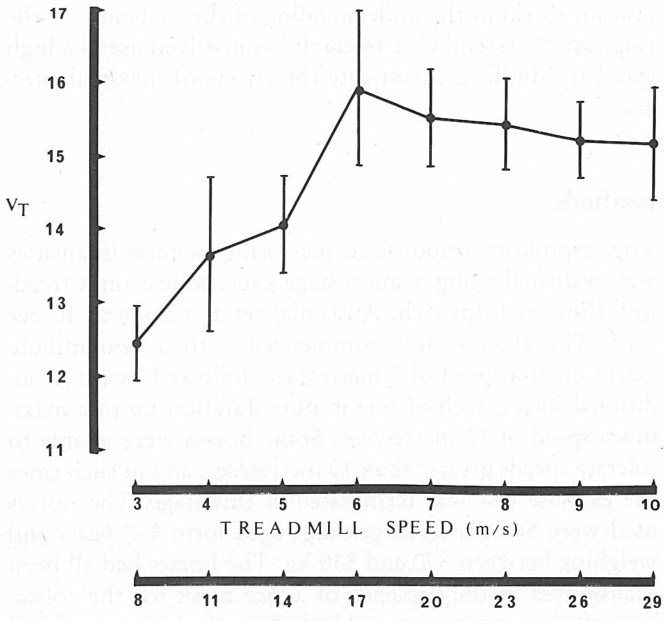

Fig. 2: Tidal volume (V_T) in horses during graded treadmill exercise.

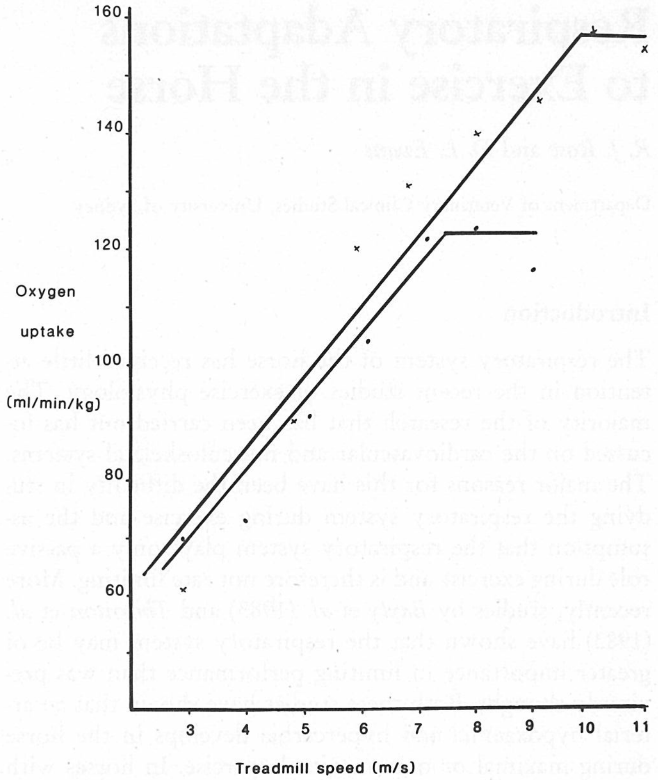

Fig. 3: Maximal oxygen uptake ($\dot{V}O_{2max}$) in 2 horses measured during graded treadmill exercise.

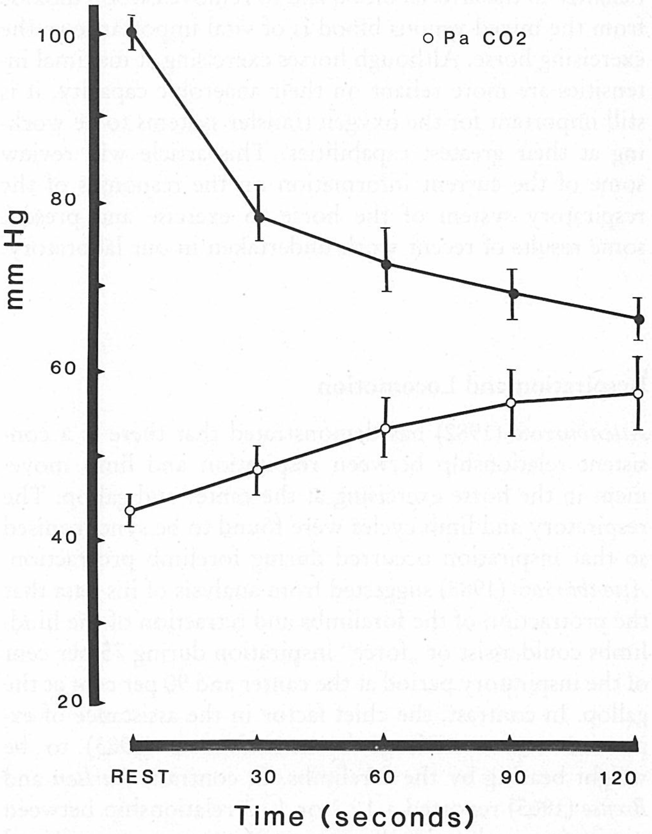

Fig. 4: Arterial blood gases during 2 min. of treadmill exercise at $\dot{V}O_{2max}$.

being undertaken. The mask was constructed of a lightweight material (Polyform, Boehringer Mannheim, West Germany) and had two inspiratory and two expiratory valves, 10 cm in diameter. Gas from the expiratory valves was channeled into a flexible hose, 10 cm in diameter and from there into a perspex mixing chamber, the volume of which was 39 litres. The V_E was measured using a flowmeter (GD 101, Fluid Inventor AB, Sweden). The mixed expired concentrations of O_2 and CO_2 were measured by sampling from the flow meter to appropriate analysers (Servomex OA 570 O_2 analyser; Normocap CO_2–O_2 monitor, Datex, Finland). Respiratory rate was measured by observation and the expired air temperature measured by using a gas thermometer placed in the line of the air flow. All volumes were converted to STPD except V_T which was converted to BTPS. The derived information ($\dot{V}O_2$, $\dot{V}CO_2$ and respiratory exchange ratio, R) was calculated using standard respiratory formulae.

Results

The results of some of the respiratory measurements are presented in Figures 1 and 2. A linear increase in $\dot{V}O_2$ and $\dot{V}_E$ was found to occur with increasing work effort. However, despite all horses working at the same exercise velocity, the actual work rate in kilopond – metres/min. was much more variable due to differences in body weight. The heavier the horse the greater the work being performed. In all horses $\dot{V}O_{2max}$ was reached, although the speed at which this took place ranged from 7.8–10.3 metres/sec. The results of the horses with the lowest and highest $\dot{V}O_{2max}$ value obtained was 113 ml/kg/min. and the highest, 161 ml/kg/min. The $\dot{V}O_2$ values throughout the exercise test bore a very close relationship to the heart rate, right up to $\dot{V}O_{2max}$ which occurred at the maximal heart rate for the individual horse ($r = 0.88$). The V_T values were lower (10–12 L) at the exercise intensities of 3–5 metres/sec. than at the higher work levels where values of 14–16 L were found.

Arterial Blood Gas Values during Exercise

The work of *Bayly* et *al.* (1983) in Thoroughbred racehorses galloping at maximal intensities and that of *Thornton* et *al.* (1983) in Standardbred trotters exercising at high work intensities, has shown that a hypoxaemia and hypercarbia develops at high exercise intensities in the horse. Because of the increase in haemoglobin associated with exercise, the actual content of oxygen in arterial blood showed smaller changes. During galloping exercise, it is common to find PO_2 values around 60 mm Hg and PCO_2 values around 50 mm Hg. We have found that this decrease in PO_2 is related to the intensity of exercise and is first noticeable at 50 per cent $\dot{V}O_{2max}$. In horses exercising for 2 minutes at 100 per cent $\dot{V}O_{2max}$ there is a progressive increase in PCO_2 and a decrease in PO_2 values in arterial blood (Figure 4).

The reasons for these decreases are not clear but a number of possibilities have been put forward (*Bayly* et *al.*, 1983; *Robinson*, 1985). The inability of ventilation to provide metabolic needs at high work intensities is considered by *Robinson* (1985) to be one of the major causes of exercise induced hypoxaemia. Regional differences in the relationship between ventilation and perfusion may develop during exercise, resulting in the mismatching of ventilation and blood flow. This hypothesis is extremely difficult to test due to the complexity of measuring the distribution of ventilation/perfusion ratios. *Bayly* et *al.* (1983) have suggested that at high work intensities the large cardiac output, which results from a high heart rate, gives rise to a very rapid transit time through the pulmonary capillaries, so that there is inadequate time for diffusion to occur. More sophisticated experiments are required to determine which of these hypotheses is correct. However, it is clear that decreases in PO_2 values below those normally expected during exercise may be associated with a reduction in performance (*Bayly* et *al.*, 1984).

Conclusions

It is apparent that much more research on the respiratory system in exercising horses is necessary. It seems possible that the respiratory system may play a rate limiting role in performance even in the normal animal. Mild respiratory disease could also assume a much more important status when looking for factors responsible for limiting performance, in horses presented for "poor performance" syndrome. Further studies of respiratory responses to exercise in horses with respiratory disease, as well as the study of any respiratory adaptations to training are necessary.

References

Attenburrow, D. P. (1982): Time relationship between the respiratory cycle and limb cycle in the horse. Equine vet. J. 14, 69–72.

Attenburrow, D. P. (1983): Respiration and locomotion. In: Equine Exercise Physiology, Snow, D. H., Persson, S. G. B., and Rose, R. J. (eds.), Granta Editions, Cambridge, 17–22.

Bayly, W. M., Grant, B. D., Breeze, R. G., and *Kramer, J. W.* (1983): The effects of maximal exercise on acid-base balance and arterial blood gas tension in Thoroughbred horses. In: Equine Exercise Physiology, Snow, D. H., Persson, S. G. B., and Rose, R. J. (eds.), Granta Editions, Cambridge, 400–407.

Bayly, W. M., Grant, B. D., and *Modransky, P. D.* (1984): Arterial blood gas tensions during exercise in a horse with laryngeal hemiplegia, before and after reconstructive surgery. Res. Vet. Sci. 36, 256–258.

Hornicke, H., Meixner, R., and *Pollmann, U.* (1983): Respiration in exercising horses. In: Equine Exercise Physiology, Snow, D. H., Persson, S. G. B., and Rose, R. J. (eds.), Granta Editions, Cambridge, 7–16.

Karlsen, G., and *Brejtse, N.* (1965): Synchronisation of rhythm of respiration and movement – a basis for the development of a fast trotter. (In Russian) Konevodstvo i konnyj sport, 33, 22–24.

Karlsen, G., and *Nadaljak, E. A.* (1964): Gas and energy exchange in breathing of trotters during exercise. (In Russian) Konevodstvo i konnyj sport, 34, 27–31.

Littlejohn, A., Bowles. F., and *Aschenborn, G.* (1983): Cardiorespiratory adaptations to exercise in riding horses with chronic lung disease. In: Equine Exercise Physiology, Snow, D. H., Persson, S. G. R., and Rose, R. J. (eds.), Granta Editions, Cambridge, 33–45.

Persson, S. G. B. (1983): Evaluation of exercise tolerance and fitness in the performance horse. In: Equine Exercise Physiology, Snow, D. H. Persson, S. G. B., and Rose, R. J. (eds.), Granta Editions, Cambridge, 441–457.

Robinson, N. E. (1985): Respiratory adaptations to exercise. In Vet Clinics Nth. Am./Equine Prac. (in press).

Taylor, R. C. (1985): What determines the energy cost of locomotion? A closer look at what muscles do. In: Proc. Ass. Equine Sports Med. 5, 15–30.

Thornton, J., Essen-Gustasvsson, B., Lindholm, A., McMiken, D., and *Persson, S.* (1983): Effects of training and detraining on oxygen uptake, cardiac output, blood gas tensions, pH and lactate concentrations during and after exercise in the horse. In: Equine Exercise Physiology, Snow, D. H., Persson, S. G. B., and Rose, R. J. (eds.), Granta Editions, Cambridge, 470–486.

Acknowlegements – Funding for this study was provided by the NSW Racing Clubs Research Fund, The Australian Research Grants Scheme and The Australian Equine Research Foundation.

R. J. Rose,
BVSc, DipVetAn, PhD, MACVSc, MRCVS
Department of Veterinary Clinical Studies
DX 1154 The University of Sydney, N. S. W.
2006, Australia