Training and Fitness in Athletic Horses

A report for the Rural Industries Research and Development Corporation

by David L. Evans
Department of Animal Science
University of Sydney

February 2000

RIRDC Publication No 00/1
RIRDC Project No. US-77A

ISBN 0 642 58031 6
ISSN 1440-6845

Training and Fitness in Athletic Horses
Publication No 00/1
Project No. US-77A

Researcher Contact Details
Dr David Evans
Senior Lecturer
Department of Animal Science
University of Sydney NSW 2006
Australia

Phone:	02 9351 2474
Fax:	02 9351 3957
Email:	davide@vetsci.usyd.edu.au
Website:	http://www.usyd.edu.au/su/vetfac/faculty/staff/devan.html

RIRDC Contact Details
Rural Industries Research and Development Corporation
Level 1, AMA House
42 Macquarie Street
BARTON ACT 2600
PO Box 4776
KINGSTON ACT 2604

Phone:	02 6272 4539
Fax:	02 6272 5877
Email:	rirdc@rirdc.gov.au
Website:	http://www.rirdc.gov.au

Published in February 2000
Printed on environmentally friendly paper by Canprint

Foreword

RIRDC is committed to seeing the results of research and development brought to the horse industry. The areas of horse training and fitness have been the focus of much research activity over the last twenty five years, both in Australia and overseas. However, there has been limited transfer of new methods and technologies to the various industry sectors. This slow rate of technology transfer probably reflects, at least in part, a lack of relevant information in a form that can be understood by most industry participants.

In this book the main research findings in exercise physiology of training and fitness assessment of horses are reviewed and practical techniques for fitness testing are described. Important principals for training racehorses, event and endurance horses are included. Some of the practical information has been based on Dr Evans' experiences as a consultant in commercial Thoroughbred horse training.

The book has been written in a style that should be accessible for students, horse owners and trainers. Some veterinary surgeons are increasingly interested in this field, and are sometimes expected to assist or advise owners and trainers concerning use of heart rate meters, measurement of blood lactate concentrations after exercise, and other techniques. The material should also contribute to veterinary education and lower wastage rates in the industry.

This report, a new addition to RIRDC's diverse range of over 450 research publications, forms part of our Equine R&D program, which aims to assist in developing the Australian horse industry and enhance its export potential.

Most of our publications are available for viewing, downloading or purchasing online through our website:

- downloads at www.rirdc.gov.au/reports/Index.htm
- purchases at www.rirdc.gov.au/pub/cat/contents.html

Peter Core
Managing Director
Rural Industries Research and Development Corporation

Acknowledgments

In 1993 I commenced research work in the science of exercise and training of racehorses. Until that point, my only experience of racehorses was as a veterinarian. In between carrying out heart scores, heart strain diagnosis, lameness evaluations, blood counts and castrations not once was I intelligent enough to ask trainers about how the horses were trained. Since then I have been lucky enough to work with patient people who have taught me a lot, and provided opportunities to learn. I owe a large debt to Professor Reuben Rose, who has helped me to learn about the process of scientific investigation.

I also learned a great deal from Mr Luca Cumani, Newmarket, England. After confirming that I could actually ride a horse, Luca employed me as a consultant in the areas of training and fitness assessment in a stable with 120 Thoroughbreds. I learned more than I had bargained for in that short period about training, feeding, management, equine physiotherapy, and veterinary science. Thanks also to Mr Les Edwards, who was brave enough to let me train his horses for 9 months. I have spoken to many trainers, both Standardbred and Thoroughbred over many years, on many of the topics in this book. They too have all contributed to my learning, and in a way, to the book as well. They have helped me better understand what is really important, and what is and is not feasible in the real world. Charlie Stewart, veterinarian and horse trainer, and Dr Allan Davie deserve special mention in this context.

My sister once bought a Thoroughbred, and I was silly enough to suggest putting it into work. It never won a race, but Helen did manage to train several winners in a short career training Thoroughbreds. I also learned a great deal from Helen about horse care and training.

Advances in knowledge are mostly predicated on the hard work performed by research students. I have been fortunate to be able to work with many dedicated and committed students over the last 10 years, and they too have contributed to this publication. Specifically, figures used to illustrate heart rates in event horses during field exercise tests, interval training and swimming used in this book have been kindly provided by Mr Marcos Serrano. These figures were constructed using data obtained during Marcos' studies towards a BSc(Vet) at the Faculty of Veterinary Science, University of Sydney in 1999. Marcos also kindly proof read the final draft and provided valuable advice that improved several aspects of the book.

Contents

List of Figures

1. Introduction

1.1. Background

A horse trainer has an extremely difficult task, regardless of whether the job is to prepare a racehorse, event, endurance or other type of performance horse. Firstly, the trainer may be asked to make judgements concerning the racing or performance potential of a young horse, usually with little or no information available except breeding, or bloodlines. The trainer may have to speculate about whether the horse in question is likely to be able to run very fast over 1200 or 3200 metres, or be able to gallop and jump skilfully, or compete over long distances in an endurance ride. Not surprisingly, visual appraisal and assessment of the appropriateness of the horse's breeding may have limited capacity to predict future performance. The trainer must then prepare the horse to perform, and to realise its full potential. The horse must be kept healthy, and ideally not be undertrained or overtrained. It should be presented at competition with no muscle, skeletal, respiratory or other body system disease that could reduce or limit performance. As well, the horse must be keen to compete on the day, and be unlikely to behave in a manner that will limit performance.

Over the last 40 years there has been much research on the exercise physiology of equine athletes, including racehorses, event horses and endurance horses. Many new industry participants have more formal education in equine science, and there is an increased interest in the applications of research results in the horse training industries. However, the results of this research have not been comprehensively assembled in a format that is accessible to most industry participants. It is hoped that this book will address that problem.

1.2 Aims

The presentation of information concerning training of horses and assessment of fitness in a format suitable for use by industry participants will contribute to adoption of new technologies. Adoption of new techniques in training, fitness assessment, and techniques for routine monitoring of horses in training should lead to fitter horses with lower rates of injury and fatigue. Industry wastage rates are very high, and many horses never win a race. Research results do provide some guidelines in use of techniques to increase fitness and reduce ill health in athletic horses. Both of these factors are important in any attempts by horse trainers to improve performance and reduce industry wastage rates. Most information on research and fitness assessment is found in scientific journals, and is inaccessible to most industry participants. Likewise, interpretation of the results of many studies can be difficult.

This book attempts to present the results of many studies in a readable format, and concentrates on aspects of training and fitness assessment. It concentrates on the principles of training and fitness assessment. Many of the principles are common in training programs for all equine athletic competitions. There are many gaps in our knowledge, and more studies of normal horses in their commercial training environments are required. Successful conduct of those studies will necessitate cooperation between trainers and scientists, and this is not always easy within the constraints of a busy training establishment. However, my perception is that horse trainers and owners are seeking more information. It is my hope that this review of many scientific studies, coupled with a few personal comments, will assist all horse trainers who are interested in adopting new methods that are soundly based on evidence, rather than on hearsay, hope or tradition.

2. Overview of Equine Exercise Physiology and Biochemistry

2.1. Introduction

Exercise physiology and biochemistry are both important areas of study related to the science of training and fitness assessment. Exercise physiology refers to studies of how a horse responds to exercise, and how those responses are modified after different interventions. These interventions include training, periods of rest (detraining), and dietary changes. Studies of exercise physiology frequently involve measurements of body temperature, heart rate, blood lactic acid concentration and oxygen uptake in the exercising horse. These measurements help scientists describe the intensity of exercise, and are fundamental in most measurements of fitness. In training centres devoted to preparation and monitoring of elite human athletes these measurements are frequently used to guide training intensity, and to demonstrate whether or not an individual is increasing fitness. Physiological measurements are also used to identify talented individuals, suited to specific athletic events. These appraisals sometimes also involve measurements of body shape and size.

The biochemistry of exercise refers to studies of how the body's cells and cellular components respond during exercise. Some examples of questions in biochemistry of exercise include; how do the cells provide the energy for exercise, and which fuels are used during exercise of different events? How does training, diet or other interventions change cell function and either enhance performance or limit fatigue? What is the cause of fatigue?

In this chapter a brief summary of normal physiological and biochemical responses to exercise and training will be presented. It is not meant to be a comprehensive discussion. However, some understanding of these basic principles is required in order to understand material in following chapters of the book.

2.2. Energy supply during exercise

All exercise depends on supply of molecules of adenosinetriphosphate (ATP). ATP, when split into ADP and Pi (adenosine diphosphate and an inorganic phosphate) releases energy. The energy derived from the splitting of ATP molecules is used to maintain body temperature, and by nerve and muscle cells for many important functions. These include maintenance of the normal distribution of sodium and potassium ions in the body, and several roles in the contraction and relaxation of the cells in the exercising muscles. Without an adequate supply of energy from ATP, elements of muscle filaments cannot be energised, the cells cannot relax quickly, and calcium cannot be "pumped" into its storage sites (the sarcoplasmic reticulum) within the skeletal muscle cells.

The chemical reaction so fundamental to mammalian life and performance of exercise is:

$$ATP + H_2O \rightarrow ADP + Pi + H^+ + energy$$

Most of the energy is released as heat. Some energy is used in the processes involved muscular contraction, such as energising myosin filaments in muscle cells, and pumping calcium back into its storage sites in the cells.

The horse has very small stores of ATP within its muscles. These stores, along with stores of creatine phosphate (CP) are quickly used within seconds of commencement of exercise. The reaction is:

$$CP + ADP + H^{+} \rightarrow \text{creatine} + ADP + \text{energy}$$

In order for a horse to sustain exercise for more than a few seconds, it must be able to replenish ATP at an appropriate rate. There are several metabolic pathways that can contribute to ATP resynthesis. The relative importance of each pathway is determined by the intensity and duration of exercise.

The flow of substrates (fuels) for ATP resynthesis, and the products of anaerobic and aerobic metabolism are summarised in Figure 1. This figure was originally published in an article by Duren and Crandell (1998) and is reproduced with permission from World Equine Health Network).

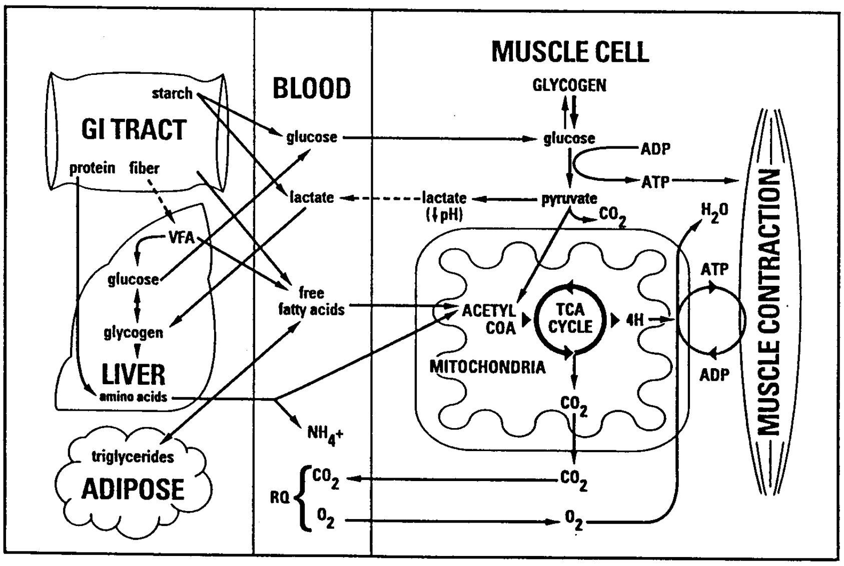

Figure 1. *Summary of muscle cell metabolism.*

2.3. Aerobic metabolism

When the demands for energy are low during slow speed exercise, aerobic metabolism is capable of meeting the requirements for continued ATP resynthesis. Aerobic metabolism is therefore the primary pathway by which ATP is regenerated during endurance exercise.

Aerobic metabolism is the process by which fats and carbohydrates are oxidised, culminating in the production of ATP, carbon dioxide and water (Figure 1). Fat is stored in depots around the body and as triglycerides within muscle cells. Non esterified fatty acids (NEFAs) are transported to the muscle from the blood. Carbohydrates are stored in the muscle and liver in the form of glycogen. Glucose is the product of metabolism of liver glycogen, and the glucose is transported to the muscle cells by the blood stream.

$$\text{Glucose} + 6O_2 + 36\text{ADP} \rightarrow 6CO_2 + 6H_2O + 36\text{ATP}$$

Mobilisation of NEFAs is slow, and their contribution as a substrate for aerobic metabolism increases as the duration of exercise increases.

$$\text{Palmitate} + 23O_2 + 130\text{ADP} \dashrightarrow 16CO_2 + 16H_2O + 130\text{ATP}$$

The capacity of the horse to generate energy aerobically is primarily limited by the availability of oxygen in the working muscles. Potential limitations include the function of the upper airways, lungs and cardiovascular system, and haemoglobin concentration in the blood. The concentration of enzymes in the muscles appears to be in excess of the levels required to fully metabolise the oxygen delivered by the blood. Training enhances the capacity for oxygen delivery to the muscle, therefore increasing the capacity of the animal to generate energy aerobically. Aerobic metabolism occurs in the mitochondria within cells, and mitochondrial density and enzyme concentrations increase in muscle cells after training.

2.4. Anaerobic metabolism

Anaerobic metabolism refers to biochemical reactions for synthesis of ATP that do not require oxygen. During high intensity exercise of short duration (2-3 minutes in horses), the degradation of muscle glycogen to lactate is the main pathway for supply of the ATP. Accompanying the metabolism of glycogen are marked increases in concentrations of lactate, hydrogen ions and inorganic phosphate (Pi) in the cells.

$$\text{Glycogen} + 3\text{ADP} \rightarrow 2\text{lactate}^- + 2H^+ + 3\text{ATP}$$

At the onset of fast exercise, the delivery of oxygen to the muscles does not instantaneously reach the level required to support aerobic metabolism. Approximately 30-45 seconds of exercise is required before maximal rate of oxygen use are achieved. During this period, the deficit in energy production is met by anaerobic metabolism. There is an increase in heart rate and ventilation, an increase in the oxygen carrying capacity of the blood as the splenic erythrocyte reserve is mobilised, and redirection of blood flow to the skeletal muscles. Increases in body temperature may enhance enzyme activity.

Some lactate molecules diffuse from muscle cells to the blood stream and are transported to the liver where they are oxidised to glycogen and stored in the liver. During exercise, mobilisation of liver glycogen stores helps to maintain blood glucose concentrations. As well, lactate molecules can be metabolised aerobically during and after exercise in heart muscle fibres, and in muscle fibres with high aerobic potential, such as slow twitch fibres.

Fast exercise should not be thought of as purely anaerobic exercise. Aerobic metabolism also contributes greatly to the energy supply during high intensity exercise such as galloping or fast pacing. Anaerobic metabolism makes up the deficit in total energy resynthesis during high intensity exercise. In a horse galloping over 1200 m, aerobic metabolism accounts for approximately 70% of the ATP generated (Eaton et al., 1995). Demands for ATP resynthesis during exercise at gallop speeds less than 18 sec/200m can usually be mainly met by aerobic metabolism in fit horses.

During times of extreme energy demands, when ATP resynthesis is inadequate and ADP is accumulating, a high energy phosphate group may be transferred from one molecule of ADP to another. One molecule of ATP is produced with one molecule of adenosine monophosphate (AMP) which is metabolised to inosine monophosphate, and ammonia and uric acid. This is referred to as the myokinase reaction:

$$ADP + ADP \text{----}\rightarrow ATP + AMP$$

2.5. Heart rate during exercise

In resting, calm horses heart rates range from approximately 20-40 beats per minute. During exercise at maximal speeds, maximal heart rates are usually in the range of 210-240 beats per minute. Figure 2 shows the typical relationship between heart rate and velocity during a stepwise exercise tewst. These tests involve performance of exercise over a set distance or time at gradually increasing speeds. Rest periods may or may not be used between the steps of increased speed. Heart rate increases as the horse increases velocity from a trot (T) to slow gallop (SG). In this horse, heart rate does not increase above 225 beats per minute. At this speed of exercise an increase in speed results in a plateau of the heart rate. The highest heart rate measured in this plateau is referred to as maximum heart rate (HRmax). V200 is the velocity of exercise at which the heart rate is 200 beats per minute.

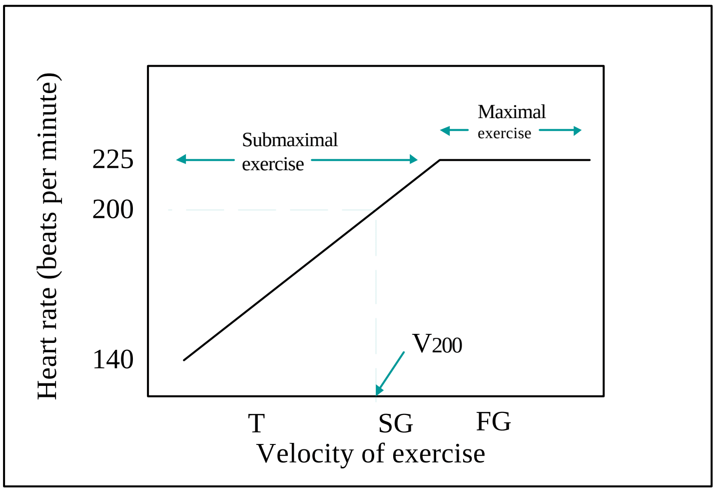

Figure 2. *Heart rate during an exercise test with gradually increasing speed of exercise. The test is finished when the horse is fatigued, or when maximal heart rate is demonstrated.*

Measurement of heart rate during exercise is easy. Modern equine heart rate monitors are reliable and accurate. The signal is rarely lost, and the receivers are rugged. It is also possible to buy software to enable down load of the record of heart rates over the duration of the training period or exercise test. If velocity is calculated, it is a simple matter to draw a graph of heart rate versus velocity, as in Figure 2.

Figure 3 shows typical heart rates recorded in an event horse during a field exercise test. The horse performed a fitness test based on performance of four bouts of exercise at increasing speed. The horse exercised at a trot, then slow canter, then faster canter, and finally a slow gallop. Between exercises, the horse walked back to the start of the 600 metre track. The whole procedure took approximately 20 minutes. Note that the first increase in heart rate is not associated with exercise. It illustrates that heart rates during anxiety or excitement can increase to over 150 beats per minute. Note also that in this exercise test the horse did not exercise at sufficient speeds to demonstrate HRmax.

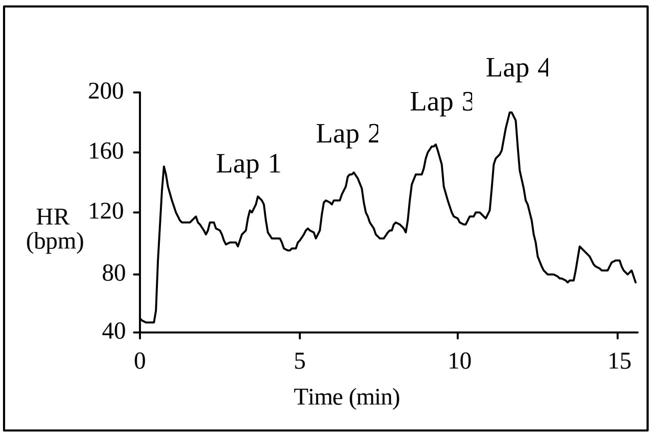

Figure 3. *Heart rates recorded in an event horse during a field exercise test. The horse did not exercise at high speeds, and maximal heart rate was not recorded.*

The results of this field test were used to draw a graph of speed of exercise (using records from times of each bout of exercise to calculate speeds). Graphs such as those in Figure 4 enable calculation of V200.

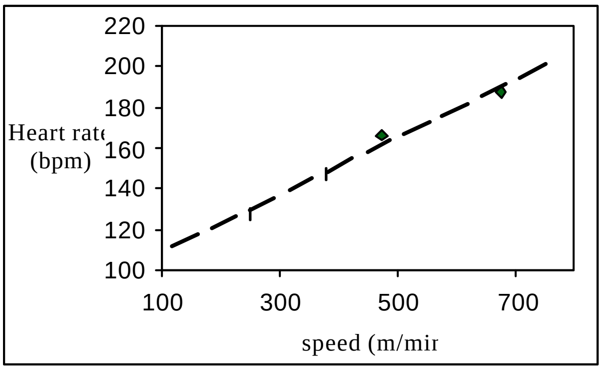

Figure 4. *A relationship between heart rate and velocity, derived from results of the field test shown in Figure 3.*

At the commencement of exercise without prior warm up, heart rate only slowly increases to reach its maximal value over 2-4 minutes (Evans and Rose 1988b). This phenomenon could explain why some riders observe that heart rate during fast exercise only reaches 180-200 beats per minute, even though the horse is exercising at maximal or near maximal speeds. Heart rates and oxygen transport to exercising muscles will be higher at the start of exercise if an appropriate warm up is used. A minimum of 5 minutes of trot and canter exercise is advisable.

Most studies have reported that there is no change in resting heart rate or in maximal heart rates after training. Training does result in a decrease in heart rates during submaximal exercise. The drawn relationship between heart rate and velocity moves to the right. In this example, V200 increases from a slow gallop to a faster gallop. The horse is also able to exercise at higher speeds before reaching maximal heart rate.

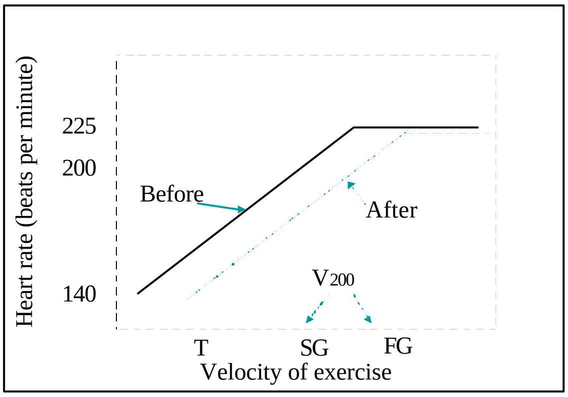

Figure 5. *Typical changes in heart rate in a horse due to training. T refers to exercise at a trot, SG a slow gallop, and FG a fast gallop.*

2.6. Maximum oxygen uptake

Oxygen uptake of a horse is a measurement of the rate at which oxygen used. When an animal or human exercises at progressively increasing intensity, a speed of exercise is reached, where for a short period, power (work per minute) can be measurably increased without further increase in the rate of oxygen uptake by the animal. Exercise responses in humans and horses are qualitatively similar in horses and humans except for three aspects:

1) splenic contraction in the horse approximately doubles haematocrit at maximal oxygen uptake compared to truly resting values, while in man there are virtually no changes in haematocrit;

2) oxygen transport flow rates are about twice as great per kg in the horse as in man, and

3) pulmonary function is compromised in the horse. This compromise is reflected in considerable hypoxaemia (low blood oxygen concentration) and haemoglobin desaturation, changes that are only seen in elite human athletes (Wagner, 1995).

In both species, maximum oxygen uptake is usually limited by oxygen supply to the mitochondria rather than by intrinsic mitochondrial oxidative capacity (Wagner, 1995. The general consensus is that the rate of oxygen flow through the lungs and heart sets the upper limit of an animal's maximum oxygen uptake (Bassett and Howley, 1997). This implies that the capacity of the heart to pump blood to the muscles is the major limiting factor in determining an animal's maximum oxygen uptake.

The maximal cardiac output will depend on the horse's maximal heart rate and the maximal stroke volume (volume of blood ejected from the left and right sides of the heart in each contraction). Maximal heart rates are usually in the range of 210-240 beats per minute. Stroke volume in the exercising horse ranges from approximately 0.9 – 1.3 litres, and is increased after training (Evans et al., 1988). The maximal rates of blood flow from the heart (cardiac output, or heart rate x stroke volume) can therefore range from approximately 200-350 litres per minute, depending on inherited heart capacity, maximal heart rate and state of training.

Maximal oxygen uptake is technically difficult to measure. In Australia, the measurement is only currently available at the Equine Performance Laboratory, University Veterinary Centre Camden.

Oxygen uptake is measured by applying a mask to the horse's nose or face, and measuring respiratory gas flow and the concentrations of oxygen and carbon dioxide in the exhaled respiratory gas. In a resting horse oxygen uptake is approximately 2-3 ml/kg/minute, or 1-1.5 litres per minute for a 500 kg horse.

Figure 6 shows the relationship between velocity of exercise and rate of oxygen uptake, expressed in ml oxygen per minute, per kg of body weight (ml/min/kg. During submaximal exercise oxygen uptake increases as exercise speed increases from trot (T) to slow gallop (SG) to fast gallop (FG).

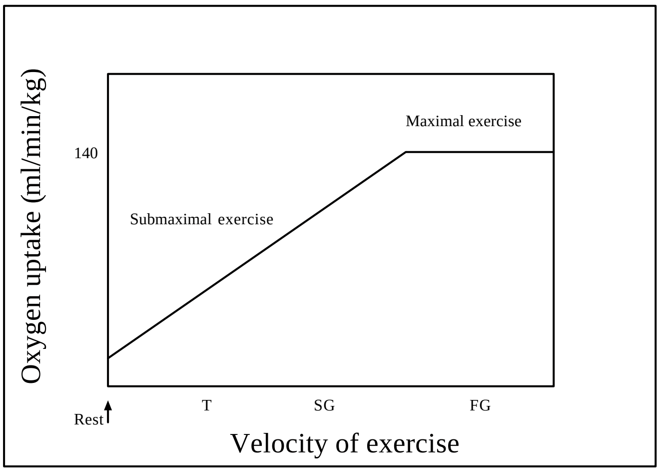

Figure 6. Relationship between velocity of exercise and rate of oxygen uptake

In the example shown in Figure 6, oxygen uptake does not increase above 140 ml/min/kg. At this speed of exercise an increase in speed results in a plateau of the oxygen uptake. The highest rates of oxygen uptake measured in this plateau (maximal exercise) are referred to maximum oxygen uptake. This is usually written as $VO_{2\,max}$. A horse that produced a relationship such as that in Figure 6 has a $\dot{V}O_{2\,max}$ of 140 ml/min/kg.

Maximum oxygen uptake ($VO_{2\,max}$) expresses the maximum rate use of oxygen during exercise, and it defines the aerobic capacity of the horse. The $VO_{2\,max}$ is the maximum amount of oxygen that the horse has the capacity to transport through the lungs, pump by the heart and use in muscles for the production of energy. It sets the upper limits for a high work potential, especially in events lasting longer than approximately 50-60 seconds.

The work intensity of any exercising horse can be described as a velocity, but this does not indicate the metabolic demands (oxygen uptake or heart rate) in an individual horse. Two horses exercising at the same velocities can have very different heart rates and oxygen uptakes. Likewise, they can be exercising at different relative intensities. Relative intensities describe the intensity of exercise compared to either maximal heart rate or maximal oxygen uptake. For example, a horse exercising at a heart rate of 176 beats per minute is said to be exercising at 80% of maximal heart rate if it has a maximal heart rate of 220 beats per minute (176 x 100%/220). Likewise, relative exercise intensity can be described as relative to maximum oxygen uptake. For example, a horse exercising with an oxygen uptake of 135 mlO_2/min/kg is exercising at 84% of $VO_{2\,max}$ if the $VO_{2\,max}$ is 160 ml/min/kg (135 x 100%/160).

In Thoroughbred horses exercising on a treadmill oxygen consumption is predicted reasonably well by the heart rate during exercise. The equation, applicable for heart rates up to 220 beats per minute, is:

Oxygen uptake (ml/min/kg) = 0.833 (heart rate, beats per minute) – 54.7 (Eaton et al., 1995)

Relative heart rate during treadmill exercise (expressed as percentage of maximal) is also a good predictor of relative oxygen uptake.
Percent of maximal oxygen uptake ($VO_{2\,max}$) = 1.384(% of maximal heart rate) - 41 (Eaton et al., 1995)

Therefore, if it was decided that strenuous treadmill training should occur at 80% $VO_{2\,max}$ the horse should exercise at a velocity that results in 87% of maximal heart rate ((80+41)x100% /1.384)).

Typical maximal rates of oxygen uptake in untrained horses are 80-140 ml of oxygen per minute, per kg of body weight. These rates compare with values of approximately 30-50 ml/min/kg in untrained humans. The higher rates of maximal oxygen consumption in horses is mainly due to the much greater arterial oxygen content in horses during maximal exercise, secondary to splenic contraction and addition to the blood oxygen transporting capacity.

Maximal oxygen uptake increases by approximately 10-20% after training in horses. Figure 7 shows the typical changes seen in oxygen uptake during a stepwise, incremental speed exercise test. There has been no change in the oxygen uptake during submaximal exercise. This means that in most cases a horse trotting or slow galloping will use oxygen at the same rate before and after training. The efficiency of locomotion has not changed. In real life it is likely that the efficiency the gait does increase, as horses learn to gallop at high speed with an economical gait. However, these changes are probably small, and would be difficult to measure in a laboratory.

However, the maximal rate of oxygen uptake has increased from 130 ml/min/kg before training, to 150 ml/min/kg after training. As well, the horse is able to exercise at higher speeds before the plateau at $VO_{2\,max}$ is reached.

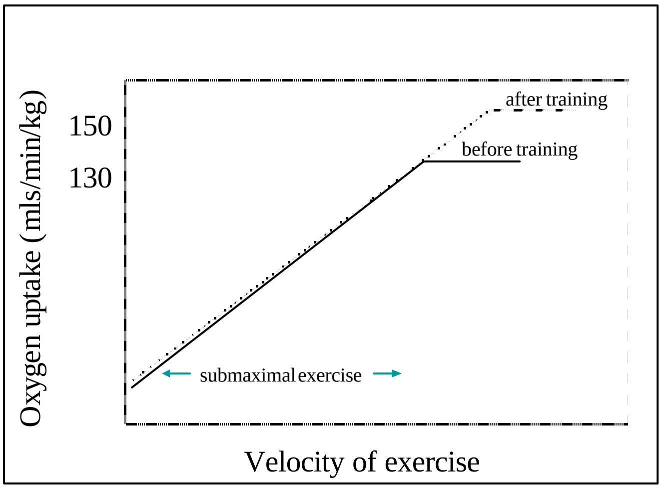

Figure 7. *Typical changes in oxygen uptake during a stepwise, incremental speed exercise test. Oxygen uptake during submaximal exercise is not changed with training. Maximal rate of oxygen uptake has increased from 130 ml/min/kg before training to 150 ml/min/kg after training.*

Elite middle distance and staying Thoroughbreds have recorded values for $\dot{V}O_{2\,max}$ in the range 160-175 ml/min/kg. Good class Standardbred pacers have values in the range 150-160 ml/min/kg. Most of the increases in $\dot{V}O_{2\,max}$ occur in the first 6 weeks of training. However, in a study of prolonged training, there was a gradual further increase in $\dot{V}O_{2\,max}$ over a 7 month training period (Tyler et al., 1996).

A high $\dot{V}O_{2\,max}$ does not guarantee excellent performance, but, in general, Standardbred horses with a higher $\dot{V}O_{2\,max}$ have superior performance (Gavreau et al., 1995). Unfortunately there have been no studies of the associations between $\dot{V}O_{2\,max}$ and racing performance in Thoroughbreds, event or endurance horses. Performance of horses with a high $\dot{V}O_{2\,max}$ but low anaerobic capacity will probably be limited by poor sprinting ability.

Figure 8 illustrates the relationship between velocity and oxygen uptake in two horses with equal $\dot{V}O_{2\,max}$ (at C), but different rates of oxygen uptake during submaximal exercise (A). This reflects a superior economy of locomotion, or economy of gait, in the horse with the lower rates of oxygen use during the trot and slow canter. There is little energy wasted in movements that are not directed at moving the animal forward. A high stepping gait tends to be inefficient. In this case both horses have the same velocity at which the rate of oxygen uptake reaches a plateau.

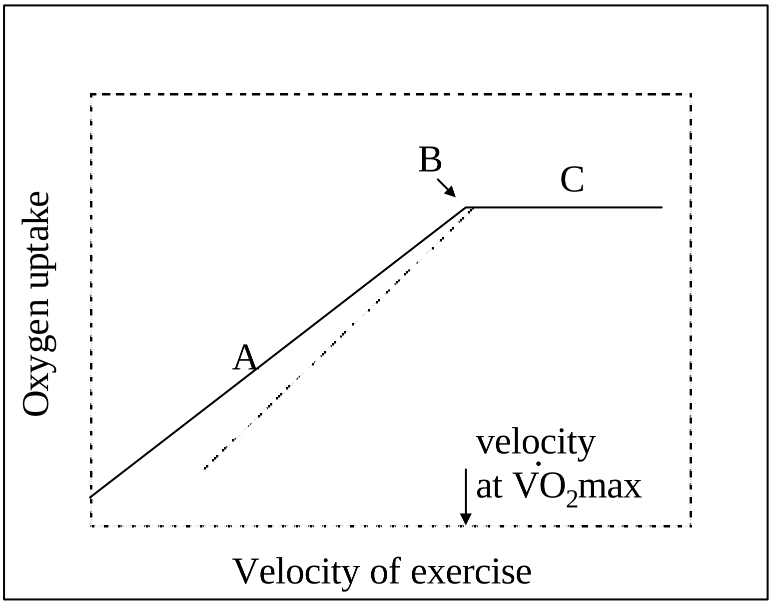

Figure 8. *The relationship between velocity and oxygen uptake in two horses with equal* $\dot{V}O_{2\,max}$ *(C) but different economies of locomotion (efficiency of gait) during submaximal exercise (A). Both horses reach* $\dot{V}O_{2\,max}$ *at the same velocity (B).*

In elite athletes exercising over long distances, the economy of exercise is also an important factor limiting performance. Economy of exercise, or efficiency of locomotion, is expressed as ml O_2 consumed per kg body weight, per metre travelled (ml O_2/kg/m). Gait efficiency is an important determinant of economy of exercise. The contribution of this factor to performance in any form of equine competition is unknown. The relevance of economy of locomotion is probably greater in endurance events, where wasted, inefficient movements during slow exercise generate more heat and contribute to greater hyperthermia and dehydration.

Inefficient movements could include a high stepping gait and head movements. An endurance horse with superior economy of gait could be expected to win more competitions, other factors being equal. An example of poor efficiency of locomotion in racing is a horse that is "pulling". Energy is wasted, and so heart rates and blood lactate concentrations are likely to be higher earlier in the race than normal, and fatigue occurs earlier in the race.

In Thoroughbred horses exercising on a treadmill the most efficient gaits were trotting and low gallop at 3-6 m/s, regardless of treadmill incline (Eaton et al., 1995).

Each litre of oxygen used generates 20.1 kJ of energy, and 75-80% is released as heat (Carlson and Jones, 1996). The metabolic energy released during exercise depends on oxygen uptake, body weight and time (Carlson and Jones, 1996).
Metabolic Energy = weight (kg) x time (minutes) x oxygen uptake (ml/kg/min) x 20.1 kJ/L O_2

For example, a 450 kg event or endurance horse trotting for 30 minutes at 50 ml O_2/kg/min generates 13,567 kJ of energy. The amount of energy released as heat in this bout of exercise could be decreased by;

1. reducing the oxygen uptake (by reducing load carried or the oxygen cost of exercise)
2. reducing the body mass of the horse.

Note that energy and power are not the same thing. Power equals work (energy) divided by time; for example, power = litres of oxygen consumed/minute (Fox and Matthews, 1981). In the above example the horse is using approximately 22.5 litres of oxygen per minute, or approximately 475 kJ/minute. On an historical note, horse power (HP) is an old unit for power. One litre of oxygen per minute equals approximately 0.474 HP.

Other things being equal, performance of horses in events of long duration will be maximised if the horse has a low body mass, an efficient gait (low oxygen cost of exercise) and carries a light weight. It should be remembered that body weight should not be lowered before such events by reducing the water content. Dehydration will limit performance in prolonged events because it reduces the volume of water that can store heat and transport it to the skin and respiratory tract.

2.7. Lactic acid accumulation during exercise

At very high speeds all horses must use more of the anaerobic energy supply pathways to support the energetic requirement of the exercise, and accelerated anaerobic metabolism of glycogen (glucose stored in the muscle cells) occurs. At exercise speeds greater than those that cause metabolic rates of approximately 65-85 % of maximum oxygen uptake, blood lactate concentrations rapidly increase (Evans et al., 1995, Eaton et al., 1995).

During exercise at high speeds, lactic acid concentration increases in the exercising muscle cells, and then diffuses into the blood. This response is attributable to a limitation to the use of oxygen by the exercising muscle cells. During exercise at higher speeds the cells can only maintain the required rate of ATP supply to the muscle cells by anaerobic use of glucose. Anaerobic glycolysis results in accumulation of lactic acid in the muscle cells.

Blood lactate concentration in horses at rest is approximately 0.5 mmol/L. Small increases in this concentration occur as speed of exercise increases, and then at higher speeds, the blood lactate concentration increases exponentially. The characteristics of this typical relationship have been used to monitor responses to training and investigate factors limiting race performance. Figure 9 shows the typical relationship found in exercise tests that involve measuring blood lactate in a series of 5-8 steps of exercise, at gradually increasing speed. Speed is usually increased every 1-2 minutes. These plots are used to calculate VLa4, the velocity at which the blood lactate concentration is 4 mmol/L. Results from these types of exercise tests can also be expressed as a lactate concentration at a set speed, such as 10 m/s. In this case the index of performance is expressed as La-10. Blood lactate concentrations after exercise can increase to 20-30 mmol/L or greater.

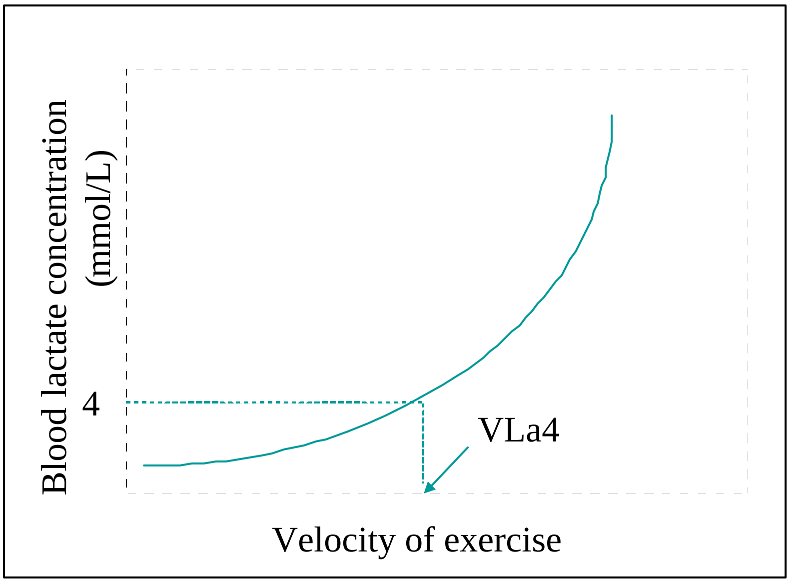

Figure 9. *Typical relationship between blood lactate concentration and velocity in exercise tests involving a series of 5-8 steps of exercise, at gradually increasing speed*

The shape of the lactate versus velocity curve depends on the protocol used for the exercise test. In non-continuous tests a linear relationship is found, rather than a curved relationship (Kronfeld et al., 1995). A clear point of inflexion can be demonstrated, and an appropriate index of fitness is the intersection of the two straight lines. Use of exercise tests that identify the inflexion point is common in human exercise tests. A linear relationship between blood lactate concentration and speed has also been demonstrated in pooled results from field exercise tests in Thoroughbred horses (Davie and Evans, in press).

The speed at which lactic acid accumulates depends on many within-animal factors as well. These include the rate of cardiac delivery of oxygen to exercising muscle, the ability of the muscle cells to use oxygen, and the rate at which lactate is metabolised in muscle cells during exercise. These factors are limited by an individual horse's inherited physiological characteristics, but they can also be improved by training.

It is important to appreciate that lactate production in muscle cells and accumulation in blood is a normal response to energy production at moderate to high speeds or intensities of exercise. The actual speed at which lactate begins to accumulate within the muscle cells and blood will depend on gait, breed, horse, diet and state of training (fitness). In resting horses, elevated blood lactate concentrations indicate failure of blood flow to the body organs and tissues, and is often associated with colic. In normal, healthy Thoroughbred horses blood lactate concentrations increase when the speed of exercise is increased to approximately 11-12 m/s (700-800 m/min) (Evans and Davie, in press). In pacing Standardbreds lactate does not accumulate in blood until speeds exceed approximately 650-700 m/min (Wilson et al., 1983).

Horses with a high maximum oxygen consumption can be expected to exercise at higher speeds before there is evidence of accumulation of lactate in either muscle cells or the blood. A measurement of the lactate response to a standardised exercise test can therefore provide valuable information concerning the extent of anaerobic supply of ATP during the exercise.

A typical difference in blood lactate response during exercise in untrained and trained horses is illustrated in Figure 10. The trained horse has lower blood lactates during submaximal exercise, and higher VLa4.

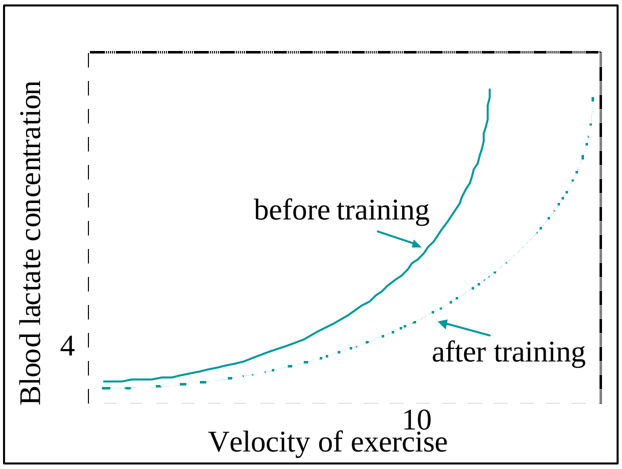

Figure 10. *Blood lactate response during an incremental speed exercise test in an untrained and trained horse.*

After collection of the blood the assay for lactate concentration can be completed on whole blood, or on plasma collected after centrifuging the blood. It is important that the assay is conducted on blood or plasma. Results from blood and plasma assays cannot be compared because the concentrations of lactate in plasma are up to 50% higher than in the red blood cells (Rainger et al., 1995). Assays on whole blood are probably preferable because lactate molecules in the cells are included in the assay, and it is a simpler technique because no centrifugation is required. Assays of plasma lactate concentration can also be conducted in modern biochemical analysers.

2.8. Adaptations in muscle and tendons during training

Prolonged training in enhances the metabolic capacity of skeletal muscle (Hodgson et al., 1986). Training results in increased concentrations of hexokinase and citrate synthase in skeletal muscle, indicating increased muscular capacity for aerobic metabolism (Cutmore et al., 1985). Long term training also increases the resting muscle glycogen concentration (Tyler et al., 1998). More recent studies have demonstrated that training has the potential to minimise fluid loss (Marlin et al., 1999), improves exercise tolerance and changes the threshold for sweating.

Collection of a small sample of muscle tissue (biopsy) for investigation of cell structures and function has also been investigated as a tool for measuring the changes in muscle during training. Rivero (1996) found that training resulted in muscular adaptations to training. Fibre area (size) and the number of capillaries in contact with type-1 (slow twitch) and type-2A (fast twitch, high oxidative) muscle fibres were dependent on state of training, particularly in biopsy samples collected from a deep sampling site in the middle gluteal muscle. It was concluded that these methods could become a useful aid for evaluation of the individual horse's response to training.

Lovell and Rose (1991) found high intensity training resulted in an 11% increase in the lactate dehydrogenase concentration in skeletal muscle of Thoroughbreds after a high intensity treadmill training program. This adaptation to training suggests that there was an improvement in the capacity of the anaerobic energy pathway. Such a response has not been associated with conventional training programs, and the intensive treadmill training technique used in this study may have been responsibly for this unique result. The methods used in this study are described in a following section (3.4. Strenuous training).

Tendons connect muscles to bones, and contain collagen fibrils that provide the tendon with its strength. Pattersonkane et al. (1997) investigated the idea that collagen fibrils would hypertrophy (grow larger) in response to a specific defined training program. Fibril diameters were measured in central and peripheral regions of the superficial digital flexor tendon (SDFT) samples from five 18-month-old horses which underwent a subsequent 18 month training program, and 6 age- and sex-matched controls that were not trained. Central region fibrils from the trained horses had a mass-average diameter (MAD) of 105.3 nm, which was significantly lower ($P < 0.01$) than that of 131.7 nm for the same region in the control horses. This reduction in fibril diameter was interpreted as evidence of microtrauma. It implies the region was weakened by the training regimen. The authors concluded that repeated episodes of microtrauma to the tendons may accumulate and eventually result in degenerative lesions and clinical tendonitis (inflammation). These results also suggest that further studies of the impact of shoeing, track surfaces, speeds and distances of training and other possible risk factors for collagen fibril shrinkage and tendonitis in racehorses are warranted.

The effect of 18 months treadmill training (galloping) on the diameters of collagen fibrils in the deep digital flexor tendon (DDFT) and suspensory ligament (SL) of 21 month old (on average) Thoroughbred fillies has been investigated (Pattersonkane et al. 1998). Six horses underwent a specific 18-month treadmill training program involving galloping exercise, and six horses served as controls, undertaking low-volume walking exercise over the same period. The collagen fibril mass-average diameters did not change significantly with exercise training for either the DDFT or the SL. It was concluded that loading of the DDFT as a result of this exercise regimen was not sufficient to stimulate collagen fibril hypertrophy. This confirms that the DDFT is subjected to low loads during exercise, compared with the superficial digital flexor tendon.

2.9 Adaptations in bone during training

Sore shins is a major problem in young Thoroughbred racehorses in training particularly in two year old horses (Bailey, 1998). Bailey (1998) reported that shin soreness had the highest injury rate in a study of 169 Thoroughbreds studied over a two year period. As well, shin soreness was the cause of 27% of all lost training days. The next most common cause of lost training days was fetlock problems (9%). Shin soreness also was responsible for 23% of the weeks spent rested at pasture. Shin soreness causes most of the wastage in two year old Thoroughbreds in training.

Shin soreness may be due to failure to provide an adequate, progressive training stimulus for bone. Until recently there have been few studies of how bone in young horses responds during training. Price et al. (1995) investigated whether or not exercise induces an adaptive response in the developing skeleton that may be monitored by measuring biochemical markers of bone metabolism in the blood. The results indicated that the treadmill exercise regimen resulted in a general increase in bone turnover in 2-year-old thoroughbreds (Price et al., 1995).

A study of the breaking strength of the right third metacarpal (cannon) bones in 24 Thoroughbreds, 24 to 48 months old and in race training found that horses with more training months had greater bone diameter, cortical area and area moment of inertia (Sherman et al., 1995). However, these adaptations did not affect metacarpal bone breaking strength.

Recently there has been interest in using growth hormone to treat and prevent a range of musculoskeletal diseases in equine athletes. Day et al., (1998) investigated the effect of equine somatotropin injections over 112 days in two year old Quarter horses in a regimen typical for racehorses in training. X rays were used to study bone density of the third metacarpal (cannon) bone during training. The treatment resulted in increases plasma concentrations of insulin-like growth factor (IGF-1). However this treatment had no significant effect on the responses to training, which were an initial decrease and then increase in density of the cortical bone.

The effects of age and exercise on shape and volumes of the navicular bone were studied by Gabriel et al. (1999). All the external measurements of the navicular bone decreased significantly with increasing age. However, in sporting horses, the navicular cortical bone volume increased with age and the cancellous bone volume decreased. Exercise appeared to have decreased bone resorption and increased bone formation. The findings confirmed that exercise might be good practice to prevent age-related bone loss in horses.

A high intensity treadmill exercise protocol resulted in rapid changes in the carpal (knee) bones (Firth et al. 1999). Using 2 levels of controlled and defined exercise, it was observed that the increase in trabecular thickening and density was localised to those regions underlying common sites of cartilage degradation and bone fractures.

2.10. Limits to performance in equine competitions

There is a wide range of metabolic and physical demands in equine competitions. A Quarter horse must run 400 yards in less than 20 seconds, and an endurance horse may be required to exercise over 50 - 160 kilometres. These events represent extremes, similar to the wide demands of a human 100 metre race and 42 kilometre marathon. Success in any event will primarily depend on whether or not the individual is physiologically suited to the demands of the event. A successful Quarter horse needs large muscles that consist mostly of Type IIb fibres. These fibres fatigue easily but generate high speed and power. The energy for the event will be derived mostly from glycogen (stored glucose) in the muscle cells, and depend less on the animals capacity to deliver oxygen to the cells. Success in sprint events will also depend on the horse's muscle cells ability to buffer the lactic acid that accumulates in the cells.

At the other end of the spectrum, a successful endurance horse will have muscles with few type IIb fibres, and more Type I and IIa fibres. These muscle fibres predominate in Arab and Arab cross horses. They resist fatigue, and have a superior capacity for using oxygen. It is also important that endurance horses have an efficient gait, and so generate less heat during exercise. Superior performance in endurance rides therefore depends on a highly system for delivering and using oxygen in the muscle cells. An important aspects of a superior rate of oxygen uptake during exercise is a large cardiac stroke volume, the volume of blood pumped from the heart with each beat. A well-developed network of blood vessels in the muscle cells also assists supply of oxygen to the muscle cells. The muscle cells need to be well endowed with mitochondria and the associated enzymes that convert fat and glucose into ATP. A successful endurance horse should also have a large volume of plasma in the blood. This component of blood helps store heat, and move it to the skin where it can be sweated and radiated to the environment. A large plasma volume tends to dilute the red blood cells, and therefore a high red blood cell count and haemoglobin concentration are not features of superior capacity for performance in endurance rides. A low red blood cell count and haemoglobin concentration may be found in excellent performers.

Thoroughbred and Standardbred horse racing, and event competitions, represent intermediate metabolic and physical demands. Successful racehorses must be able to accelerate quickly, maintain an efficient gait, cruise at high speeds, and sprint quickly over 200-600 metres.

Event horses do not depend as much on acceleration and sprinting ability, but must be able to run at moderate to high speeds without fatigue, and to jump and run fast at the same time! Superior performance on day 2 of a three day event depends on a high level of fitness, developed over many months, and skilful jumping at high speed. In the showjumping in a three day event, skill, strength, fitness and adequacy of recovery from the previous day's exertions will all be important factors determining success.

The potential of a horse to perform at a high level in any event with demands ranging from those in a 1000 metre race to the demands of Day 2 of a 3 Day event depends on many factors. However the main determinant of success are likely to be maximal oxygen consumption, or $VO_{2\,max}$ and blood lactate responses to exercise. The important roles of these factors have been demonstrated in Thoroughbred and Standard racing, but unfortunately there is no evidence yet to support this contention for event horses. However, the metabolic demands of eventing and jumping have been described, and these findings strongly suggest that superior performance will depend on a high maximal rate of oxygen consumption and low rate of lactic acid accumulation in muscle cells during the event.

2.11 The bases of fatigue during exercise

Fatigue is a decrease in the ability to do work. It is manifest as a horse slowing in a race, or unable to jump as high, or unable to maintain pace with a treadmill. Detection of fatigued muscle is difficult. A recent study suggests that electromyography may be useful. Cheung et al. (1998).

It is now known that fatigue and decreased speed during high intensity exercise is associated with a decline in the concentration of ATP in the muscle cells, and an accumulation of ADP and Pi (Harris et al., 1987). Muscle ATP loss with exercise has implications for both fatigue and muscle damage (Harris et al. 1997). To study this process at the single muscle fibre level, five trained thoroughbred horses performed a treadmill study at high exercise intensities. Muscle biopsies of the m. gluteus medius were taken at rest, post-exercise and during 24 hour recovery. ATP loss after consecutive 90 second gallops on an inclined treadmill followed by a final gallop to fatigue exercise was 32.2%. Following exercise ATP levels were close to zero in some muscle fibres. At the same time, blood lactate was 20.0 mmol/L or more, and plasma ammonia 300-800 micromol/L, following the final gallop. Interestingly, the exercise caused similar post-exercise decreases in the ATP contents of types I (slow twitch) and IIa and IIb (fast twitch) muscle fibres. The results pointed to marked differences between individual fibres in their biochemical response with exercise, independent of fibre type.

Increased lactic acid concentration in muscle cells may have an affect on muscle contraction by inhibiting the release of the Ca^{2+} ions from the sarcoplasmic reticulum. Acidosis of the cells also has an inhibitory affect on an important enzyme in the glycolytic pathway. These responses both limit the ability to produce energy, and so result in fatigue. The horse slows down because the physical demands of competition are not met by the output of the muscle cells. Fatigue limits performance, but it should also be regarded as an important mechanism for preservation of the health of the horse. If there were no limits to muscle cell activity during high intensity exercise, the pH of the cell would continue to decline and irreversible damage would occur. As with many other physiological systems, fatigue is a process designed to preserve the health of the animal.

Fatigue during prolonged exercise has a very different basis. During an endurance ride, prolonged exercise does not cause accumulation of lactic acid. There may be small increases attributable to a sprint at the finish of an endurance ride. Fatigue is attributable to the combination of the effects of exhaustion of the energy supply (glycogen), hyperthermia and dehydration. Unfortunately this combination does not always result in slowing of the speed of exercise, or refusal to exercise. Horse can willingly continue to exercise at slow speeds in the face of severe dehydration and hyperthermia, and can die during recovery from “exhausted horse syndrome”. Careful administration of the rules of endurance riding is in the interests of the welfare of the horses.

Blood lactate concentrations gradually decline to normal over a 1-3 hour period after fast exercise. The rate of decrease is greater in some horses that walk or trot for 30 minutes (Marlin et al., 1987).

Given that accumulation of lactate in muscle cells during exercise contributes to fatigue, it is reasonable to consider whether or not there are strategies for limiting the rate of lactate build up and fall in pH. The most useful strategy is to train horses appropriately. This means training to increase the maximum rate of oxygen consumption. This has the effect of increasing the speed at which the lactate accumulation commences. The horse is able to run faster without lactic acid build up. It is also appropriate to train at speeds that promote the development of improved buffering capacity in the muscle cells. Buffers are chemicals that limit the fall in pH of a fluid when acid is added. Proteins and amino acids, especially carnosine, are important buffers in muscle cells, and training at appropriate speeds can increase buffering capacity of the muscle cells. It should be noted that there is no evidence that amino acid administration as food supplement significantly increases the muscle cell buffering capacity.

3. Exercise Training of Horses

3.1. Introduction

Training involves the use of regular periods of exercise to promote changes in the structure and function of the animal in order to enable it to compete more effectively. Adaptations occur in the cardiovascular system, muscle cells, and in the structural elements such as tendons and bone. An efficient training response depends on the use of appropriate training stimuli. The appropriateness of the training stimulus necessitates consideration of the following questions:

1. At what age should training commence?
2. How fast should the horse exercise?
3. Over what distance should the horse exercise?
4. What type of exercise should be used, considering gait, and use of swimming, treadmill exercise, and jumping?
5. How is the intensity of the training stimulus best measured?
6. Is the training stimulus adequate to produce an adaptive response in the horse?
7. Is the training stimulus inadequate (undertraining), or is it too intense (overtraining)?
8. Over how many weeks should the horse be prepared prior to competition?
9. How many weeks should be used for training at slow speeds during the first phase of training?
10. How often should the horse perform at speeds at or near racing or competition speeds?
11. How often can the horse be exercised at strenuous submaximal speeds (approximately 70-90% of maximal speeds)?
12. How can a trainer judge or measure whether or not the training is resulting in a change in fitness?
13. What are the signs of overtraining in horses?
14. Is the horse mentally prepared for competition?
15. Is the horse likely to behave in a way that will maximise, or at least not limit, performance?

There are, of course, many other questions that need to be addressed during training of horses. These relate to education and behaviour of the horse, and its transport, diet and stable management. Strategies for “keeping the horse happy” should not be underestimated, and much of the art of training involves maintaining the horse’s keen attitude over many weeks of training and racing.

Most trainers manage to conduct their businesses without consciously considering the above questions each day. However, many have learned answers to the questions, either by observation of other trainers, or by trial and error. It is important to realise, however, that although science has helped us to better understand the answers to many of these questions, there will never be a recipe for ideal training. The large differences between Thoroughbred training techniques in England, United States and Australia illustrate that there are many paths to training success.

As well, training for each horse should be individualised, according to each horse's own temperament, and capacity for exercise. It must also take into account the event that the horse is being prepared for. However, regardless of whether a horse is being prepared for a 1200 meter two year old Thoroughbred race or 160 kilometre endurance ride, there are several principles of training that, if not followed, lead to undertrained or overtrained horses. Both of these states limit performance, and waste an owners time and money.

A common problem in horse training is a period of 'over-reaching". This term refers to a condition found in horses that have had a sudden increase in training speeds or distances, or have been entered in competition before they are fully prepared. The sudden increase in intensity of exercise causes a sudden increase in stress on bone, tendons and other structures, and there may be injuries as a result. After the exercise or race, horses are often slow to recover, and have a poor appetite. If horses are continually trained at high speeds, a more serious condition can occur, called overtraining. This state can be likened to chronic fatigue. Overtrained horses race poorly, lose weight, and cannot be kept in training. They must be given a prolonged spell to recover.

Lameness due to inflammation or damage to musculoskeletal structures (muscle, tendons, ligaments, cartilage) is a daily concern of trainers, probably more so than the fitness of the animal. Many trainers use training techniques that are designed to reduce lameness, rather than increase fitness. Many trainers are fearful of more strenuous training programs because of perceptions that they will result in more lameness. Unfortunately it is likely that easy training, and training that does not provide for gradual adaptation of the fitness and strength will increase injury rates rather than decrease them.

Wilson and Robinson (1996) have reviewed risk factors for equine racing injuries, with a focus on overseas racing. They observed that despite the long history of horse racing, only recently have studies enumerated and elucidated the risk factors for racing injuries. They also state that many industry observers believe that the overall number of injuries has increased rather than decreased in spite of medical and surgical advances in diagnosis and treatment during the past decade. As well, the authors expressed the view that if the horse racing industry in the United States was able to design an economically feasible method for minimizing race-related injuries, the high injury rate that occurs on U.S. racetracks could be considerably reduced.

Training practices, the frequency of speed work, racetrack surface and condition, age, and the presence of preexisting lesions have emerged as important factors in injury occurrence (Wilson and Robinson, 1996). In addition, new links between nutrition and injuries have also been identified. The authors also note that there have been declines in injury rates in Japan and Great Britain following implementation of recommendations to improve racing safety.

The following sections outline the general principles of training. Where appropriate, scientific studies that have provided evidence for or against certain training strategies will be included. Unfortunately there have been insufficient studies to help us answer all the questions relevant to training. Equine training studies are very expensive and time consuming, and it is difficult to conduct experiments that compare the effects of different approaches to training on performance or injury rates. Large scale studies of normal populations of horses in commercial training will help answer these questions in the future.

3.2. Types of training used for horses

Training of horses should follow several important principles. Firstly, all horses will need to complete a period of base training. In the past, this type of training has been referred to as aerobic training, endurance training, and long, slow distance training. In this section these terms will be avoided. All forms of exercise involve some aerobic and anaerobic component. The term "long, slow distance" implies that horses only do very long distances at slow speeds.

Endurance training involves use of base training techniques for many months in order to prepare a horse for an endurance race. Three day event horses should also undertake extensive base training, but they also need other training methods.

During initial training of a racehorse and event horse it is important that the stimulus does not remain the same from week to week. Every 10-14 days, the speed of the exercise and or the distance should be increased. This increase promotes gradual adaptation of the muscles, tendons, and bones, enabling structural changes that help the animal cope with increased demands of higher speed work.

In the author's opinion, many problems in racehorse preparation can be attributable to failure to gradually increase the training stimulus. One day the horse is trotting and slow cantering, and on the next day it is exercising at a strong half pace (about 600 metres per minute). Thoroughbred horses also frequently go from trot and canter work on pre-training farms to exercising at three quarter pace or faster (working gallops) on racetracks with very little exercise at intermediate speeds. Sudden increases in velocity place the support structures (bone, tendon and muscle in particular) under great stress, and under such conditions there is often failure of the structure to resist the strain imposed. The result is seen in sore shins and sprained fetlocks, especially in two year old Thoroughbreds.

Basic training
will be used to describe training at speeds of 200-approximately 500 and 600 metres per minute in Standardbred and Thoroughbreds.

Strenuous training
will be used to describe training at speeds higher than 600 metres per minute that results in accumulation of lactate in the blood, but at slower than racing speeds.

Sprint training
refers to exercise at or near racing speeds.

Interval training
refers to use of multiple exercise bouts, separated by rest periods for partial recovery.

Skills development
refers to use of training techniques that increase the ability of the horse to complete a task.

Cross training
refers to use of exercise that is not specific to the event performed, such as swimming.

Recovery days
are days designated for recovery after races or hard training. They enable restoration of energy stores (glycogen) and repair of minor injuries.

If a horse is not racing or competing, a horse trainer should be able to identify one or more of the above training types on every training day in a horse's preparation.

Other training types, such as fartlek and resistance training, are rarely used in horse training. Fartlek training has been defined as "an unstructured technique…the horse is allowed to run as far and at whatever submaximal speed it wishes (within reason)". Indefinite relief periods are followed by more such exercise (Bayly, 1985).

Resistance training refers to use of exercises where muscle groups work against resistance, as in weight lifting. An example in horses is walking with large weights carried. A recent study in two ponies found that 8 weeks of progressive resistance exercise training increased the strength and size of forelimb muscles (Heck et al., 1996). The ponies carried lead over the wither while walking on a treadmill three days per week. Ponies performed a series of progressive sets of weight carrying to fatigue. After training, ponies were able to carry more weight until the point of fatigue, and there was a 19% increase in forelimb cross sectional diameter.

3.3. Basic training

Basic training involves exercise at low intensities. Such exercise at speeds of about 3-8 m/s (200-500 metres/minute) usually results in heart rates of less than about 180 beats/min, and little or no accumulation of lactate in the blood. The only equine event that may not need a period of base training is dressage. In this case, the exercises undertaken during the dressage training should suffice for fitness development. This approach also has the important advantage of using the nerves and muscle groups that will be used in competition. As a result, dressage training results in specific adaptations in the muscles used in competition.

Basic training of all other horses may involve 5 minutes to several hours of exercise each at the trot and/or canter, depending on fitness, environmental conditions, time available, and the aims of the training.

Low intensity base training is usually employed in the first weeks or months of all training programs. Such training is designed to improve the aerobic capacity and limb strength, and to educate the horse. The duration of this "pre-training" varies markedly between breeds, countries and trainers. Some Thoroughbreds in Australia undergo only 4-5 weeks of slow training before moving on to faster exercise. In England, two months of basic training would often be used, and frequently involve use of repeated slow canters up hills.

Use of many months of distance training before commencement of faster exercise in Thoroughbred and Standardbred horses has been advocated (Ivers, 1983). The principal argument for longer periods of low intensity training is the development of stronger limbs and consequent reduced frequency of limb injury. Anecdotal evidence suggests that the incidence of injuries is lower in horses that have undertaken more slow training. Shin soreness, or bucked shins, is a common problem in the training of young horses, especially Thoroughbreds (Nunamaker et al., 1990). There is a lower incidence of the disease in horses which do not undergo rapid race preparations (Buckingham and Jeffcott, 1990).

There is some evidence that prolonged periods of endurance training stimulate continued adaptation of skeletal muscle. The activities of two enzymes, used as markers of oxidative capacity of muscle, continued to increase throughout a nine month training program in endurance horses (Hodgson and Rose, 1987). The implications of prolonged periods of endurance training for improvements in maximal aerobic capacity have not been reported.

The main limitations to endurance training in horses are time available and hot humid environments. The first priority is allowing sufficient time for the horse to sleep and eat. Care must be taken when increasing distance or speeds of exercise in endurance horses, especially on hot humid days. Deaths and extreme fatigue (exhausted horse syndrome) of horses at endurance rides illustrate that they willingly exercise for periods which result in extreme dehydration and electrolyte imbalance.

Fit Standardbred racehorses often trot or slow canter for 30-40 minutes on "slow" days. Fit Thoroughbred horses might trot or canter for 5-10 minutes over 3,000-5,000 m, and endurance horses often exercise for several hours.

Heart rate meters have been used to ensure that the training intensity is not excessive. Heart rates greater than 180 beats per minute may result in accumulation of lactate in horses early in their base training.

Treadmills can be used to help with the base training of horses. Exercise at 200-450 metres per minute can be used on a treadmill inclined at 10%. Many studies of the adaptations of horses to training have used treadmills exclusively. A summary of different treadmill training protocols follows. Interestingly, in one study, treadmill trained horses earned more from prize money than non-treadmill trained horses (Kobluk et al., 1996).

In the author's experience, appropriate treadmill training coupled with track work over a period of 6 weeks provides an excellent base training. The following table illustrates how 300 kilometres of trot and canter exercise was completed, at speeds up to 600 - 650 metres per minute (18-20 seconds per 200 metres). In the last week of the program horses also completed their strong half pace canters with 200-300 metres of exercise at 750-800 metres per minute (approximately "evens", or 15 seconds per 200 metres). This serves to introduce the horse to the next phase of strenuous training.

The following training scheme was used successfully as base training in approximately 15 Thoroughbreds aged three years or older. None of these horses suffered limb injury in the program, and two horses went on to win metropolitan races in Sydney and Brisbane at their first starts. All horses completed 3 sessions of exercise per day on 6 days per week. Session 1 involved trotting beside a jog cart on a 600 metre track, with no rider. Session 2 was ridden exercise on a racetrack (Canterbury, Sydney), and session 3 involved treadmill exercise, with the treadmill always at 10% slope. Horses had access to food and water between sessions 2 and 3. All distances are metres. Slow, medium and fast canters (SC, MC, FC) in session 2 refer to speeds of approximately 400, 500 and 600–650 metres per minute (maximum 18 seconds per furlong).

Table 1. *A basic training program for Thoroughbreds using a combination of treadmill and track training.*

Week	SESSION 1 (jogged)	SESSION 2 (ridden)	SESSION 3 (treadmill)	km/day
1	trot 1200	trot 1000, SC 1000	trot 2000	5
2	trot 2000	trot 1000, SC 2000	trot 1000, SC 1000	6
3	trot 2000	trot 1000, SC 1000, MC 1000	trot 1000, SC 2000	8
4	trot 2000	trot 1000, SC 1500, MC 1500	trot 1000, SC 2000	9
5	trot 2000	trot 1000, MC 1500, FC 1500	trot 1000, SC 3000	10
6	trot 2000	trot 1000, MC 1500, FC 2000	trot 1000, SC 3000	10-11

Training in weeks 7-10 and 11-14 are described in following sections,

3.4. Strenuous training

Preparation of racehorses and event horses for racing or competition necessitates gradual increases in the speed of exercise. Horses racing over 400-4000 metres and the cross country phase of the second day of a three day event all result in accumulation of lactic acid in muscle cells, and in the blood. This implies that some anaerobic metabolism is involved in the ATP resynthesis during the competition or race. It is likely that anaerobic metabolism in a Quarter horse race supplies most of the ATP. In events of 1000-4000 meters distance, anaerobic metabolism probably only supplies 20-30% of the energy (Eaton et al., 1995). Endurance rides do not stimulate anaerobic glycolysis, and training of endurance horses should involve continuation of the base training described above.

Lactate dehydrogenase (LDH) concentration in skeletal muscle has been used as a marker of anaerobic enzyme activity. Interval training at high speeds on a treadmill resulted in increased concentration of LDH in skeletal muscle, but conventional training does not have the same effect (Lovell and Rose, 1993). In this study Thoroughbred horses were trained for 12 weeks. In the final 3 weeks, horses exercised at a velocity that resulted in 100% of maximal heart rate on 3 days per week, over 600 metres. Speeds of exercise were 9-12 m/s on a treadmill inclined at 10%. Three bouts of exercise were given, separated by recovery periods that were three times the duration of the 600 metres of exercise. On three other days, horses exercised over 3000-4000 metres at 6-7 m/s (a canter). Total distances exercised in the three weeks of training were 18, 20 and 16 kilometres.

Training at a moderate intensity (80% of $VO_{2\,max}$) for 6 weeks did not result in increases in skeletal muscle (gluteus medius) LDH concentration. However, such training did significantly increase the muscle buffering capacity by 8% and increase the ratio of fast twitch, highly oxidative fibres to fast twitch fibres (FTH/FT) (Sinha et al.1991). These adaptations to training did not occur in a group of horses trained concurrently at a lower intensity (40% $VO_{2\,max}$). As well, there was no difference in increases in maximal oxygen uptake between the two groups (Knight et al., 1991).

In summary, strenuous training is designed to stimulate anaerobic glycolysis, but also to manage the training so that fatigue does not occur. Controlled exposure of the horse to exercise that results in moderate increases in blood lactate concentration should:

1. Stimulate contractions in fast twitch muscle cells, and promote their growth by synthesis of more contractile proteins.

2. Increase concentrations of the enzymes that regulate glycolysis, such as lactate dehydrogenase.

3. Promote increased buffering capacity in the fast twitch cells. Higher buffering capacity enables the fast twitch cells to limit the fall in pH during fast exercise, and so resist fatigue.

4. Promote the potential for the muscle cells to use lactate as a fuel during exercise.

It is possible that changes in training strategies, such as interval training at intensities near maximal, could result in beneficial adaptations in muscle. Such training necessitates careful monitoring of the intensity of exercise. Exercise at sub-optimal intensities will limit the rate of adaptation, and frequent training at intensities above optimal will risk onset of fatigue and overtraining syndrome.

The exercise intensity during initial weeks of training is probably not an important determinant of the rate of change in $VO_{2\,max}$. There was no difference in the changes in $V.O_2max$ with training in two groups of horses trained at 40% and 80% of $VO_{2\,max}$ (Knight et al., 1991). Intensity of training may therefore be an important factor in determining the degree of local adaptations in skeletal muscle, but not for increases in maximal oxygen consumption.

Heart rate meters have been suggested as a tool for monitoring the intensity of strenuous submaximal exercise. For example, exercise speed resulting in a heart rate of 200 beats/minute has been suggested as suitable for race training (Gysin et al., 1987). However, there have been no controlled studies that have confirmed this view. As well, the blood lactate concentrations at intensities that result in a heart rate of 200 beats/minute vary greatly. In unfit horses, exercise at heart rates of 200 beats/minute is likely to result in high blood lactate concentrations, and in fit horses such exercise may result in relatively low blood lactate concentrations. The metabolic response to exercise at a heart rate of 200 beats per minute can therefore be highly variable.

There are also practical difficulties in the use of heart rate meters during exercise in galloping horses. It is difficult for jockeys on Thoroughbred racehorses to monitor heart rate and adjust speed accordingly. The maximal heart rate of some horses is also 210-215 beats/min, only 5% greater than 200. As well, muscular adaptations, such as increases in LDH concentrations, may not be optimal unless exercise is at speeds that result in maximal heart rate (Lovell et al., 1991).

Measurement of blood lactate after exercise is the best method of monitoring the intensity of exercise during the strenuous training phase. The appropriate intensity of exercise for strenuous training is that which results in a blood lactate concentration of approximately 4-8 mmol/L at 3-5 minutes after exercise.

At the completion of the six weeks of basic training described in Table 1, Thoroughbred horses commenced a 4 week period of strenuous training designed to stimulate contractions and anaerobic metabolism in fast twitch fibres. Table 2 describes this training. The intensity of training was confirmed with blood lactate assays in samples collected after treadmill and racetrack exercise. Therefore actual speeds used for each horse were adjusted in order to train each horse at a similar relative intensity. Horses completed strenuous treadmill exercise 6 days per week in weeks 9 and 10. After completion of this program, horses were given 3-4 weeks of conventional training before their first race.

Table 2. *A four week strenuous training program for Thoroughbreds using a combination of track and treadmill exercise after six weeks of basic training. Distances are in metres.*

Week of training	SESSION 1 (ridden on racetrack)	SESSION 2 (treadmill)	km/day
7	2 days of T 1000, and SG 600 4 days T and then FC 3000	6 days of T 1000 and then SC 1000, REST, then FC 800	5
8	3 days of T, and SG 600 3 days T and then FC 3000	as above	6
9	4 days of T, and SG 1000 2 days T and then FC 3000	6 days of T 1000 and then SC 1000, REST, then FC 1200	8
10	4 days of T, and SG 1000 (on 2 of these days the horse is allowed to RG for 200-300 m) 2 days T and then FC 1000	6 days of T 1000 and then SC 1000, REST, then FC 1200	9

T trot at 250 m/min for 1000 m (unless otherwise indicated)
SC slow canter at approximately 400 m/min
MC medium canter at approximately 500 m/min
FC fast canter at approximately 600-650 m/min
SG slow gallop at approximately 800 m/min
FG fast gallop at approximately 900 m/min (working gallop)
RG gallop at racing speed

REST is walking for 5 minutes on the treadmill between the first and second bouts of exercise

If set speeds are used for all horses, some horses could be exercising with blood lactates of 2-3 mmol/L, and be undertraining. Others could be exercising with blood lactates of 15-20 mmol/l, and be overtraining. For example, that Standardbred horses that pace over 1600 metres in 130 seconds (halves in 7.5 seconds) have plasma lactates in the range 2-15 mmol/L (unpublished data). The metabolic demands imposed by the exercise are very different in the horses exercising at intensities that result in plasma lactate concentrations of 2 and 15 mmol/L.

How often should horses exercise in order to obtain a training effect? There have been very few studies of this question. However, Gottliebvedi et al. (1995 found that interval training at VLa4 on only three days per week is sufficient to cause adaptational changes in exercise tolerance related parameters. The results also indicated that some adaptations due to training are rapidly lost over a four week period when horses cease training.

Intensity and duration of exercise training may also influence the rate and degree of adaptation to treadmill exercise training. The effect of intensity and duration of training on blood lactate concentrations during and after exercise on a treadmill inclined at 10% was investigated by Evans et al. (1995). Thoroughbred horses were trained at two exercise intensities. One group trained at an intensity that resulted in post-exercise blood lactate concentrations of 4-8 mmol/L. A second group trained at half the speeds of the first group, but twice the distance. Both groups increased fitness, but there was no difference in the changes in fitness between the two groups.

However, Thoroughbred horses trained in a fast group (at 80% of $VO_{2\,max}$) had an increase in the ratio of fast twitch, high oxidative fibres, whereas a group trained at only 40% $VO_{2\,max}$ had no muscle adaptations. Muscle buffering capacity also increased in the fast group (Sinha et al., 1991). These results suggest that training at approximately 80-90% of maximum oxygen uptake stimulates greater adaptation of muscle compared to that found when horses are trained at slow speeds. However, exercise speeds at these high intensities may risk musculoskeletal injury if applied on a racetrack without a period of initial slow speed training.

Sprint training

Sprint training at or near racing speeds over 400-1600 m or more represents the final phase of training. There are considerable differences the frequency of sprint training between the UK, USA and Australia are in. In the UK, a three day cycle is used by some trainers. Monday and Thursday are trot and canter days, Tuesday and Friday are slow gallop days, and Wednesday and Saturday are fast gallop and racing gallop days. In Australia, two or three fast gallops are generally used each week. A three day cycle is not always possible on Australian racetracks, with restricted access to grass surfaces for the fast work on some days.

The sprint training should not be combined with long duration and distances of basic training. If a high volume of base training is combined with sprint training there is a much greater risk of overtraining, resulting in poor food intake, loss of weight, injuries and disinterest in training and racing. In this final phase of race training, it is only necessary for horses to trot and canter approximately 2000-3000 metres on slow days.

It is not necessary to monitor heart rate or blood lactate after fast exercise or sprint training in order to specify exact training speeds. All horses will have maximal heart rates (210-230 beats per minute), and have high blood lactate concentrations (15-25 mmol/L) after such exercise. The horse should be allowed to learn how to gallop, pace or trot at high speeds, and then the distance gradually increased. High-speed sprints are only possible over 800 metres. After 800 metres the blood lactate concentrations are near those found after racing, implying that exercise at top speeds is probably unnecessary over distances greater than 800 metres.

When a horse is race fit, the training schedule between races can be base training, strenuous training or sprint training. Base training is used as low intensity training exercise. Strenuous training should be over 1200 to 2000 metres for Thoroughbreds, depending on the distance that the horse is racing. Standardbred trainers tend to use either two one mile heats, with the second heat as the strenuous training. Alternatively, many Standardbred and Thoroughbred trainers combine the strenuous exercise with a final sprint or gallop over 400- 600 metres.

Most Standardbred trainers in Australia use one fast workout per week between weekly races. However, some Standardbred trainers do not give fast work to some horses between weekly races.

3.6. Interval training

Interval training refers to use of multiple exercise bouts, separated by rest periods. The recovery period between sessions enables completion of extra exercise, and so the duration of the stimulus is increased. There have been studies comparing the responses to interval training with “conventional training”, but no differences have been reported. However, small differences in performance are difficult to demonstrate in treadmill studies with small numbers of horses. Thoroughbred trainers use interval training routinely, as do many Standardbred trainers in Australia. The only argument against use of intervals is that horse “get too fired up”. and become difficult to control. This is certainly a potential problem because a “fired up” horse will over-race, or “pull”, and waste energy. However, a Standardbred trainer reported that the “gate” speed (acceleration) of a horse was improved by training with multiple 100-200 metre sprints.

Several studies have compared responses to interval training. When conventional and interval training of Standardbreds were compared, no significant difference was found in post-exercise heart rates. However the total slow and fast work distances undertaken were the same in both training schedules (Gabel et al., 1983). Interval training over 10 weeks did not produce greater adaptation in Quarter horses trotting on a treadmill (Rodiek et al., 1987).

In a study that compared responses to interval trained and conventionally trained Thoroughbreds in North America no difference was found in heart rate recoveries, run times over 1000 metres on an 800 metre track (Harkins and Kammerling, 1990). Limitations of this study included small numbers of horses studied, few measurements of fitness, and use of an 800 metre track for tests of running speeds.

It has been shown that Standardbred racehorses interval trained on a treadmill have improved metacarpal bone quality (McCarthy et al., 1988). The training schedule consisted of 5 weeks of slow exercise of 6-12 kilometres/day at 5 m/s. This was followed by a 9 week period of interval training, during the last 3 weeks of which the horses performed 3-4 intervals per day over 600-1000 metres at speeds that resulted in maximum heart rate. Bone quality improved throughout the training period.

Interval training may increase the risk of injury (Bayly, 1985). It is therefore very important that the speed of the exercise is closely monitored and is at appropriate speeds, and recovery periods between bouts of exercise are adequate. However, Harkins and Kammerling (1990) interval trained Thoroughbred horses for over 7 months without injury.

Figure 11 shows the heart rates during an interval training session used with an elite event horse. Six periods of exercise at a speed generating heart rates of approximately 200 beats per minute were separated by approximately 2 minutes of walking for recovery periods. The horse was exercising at approximately 90% of HRmax (assuming that the maximum heart rate in this horse was 222 beats per minute).

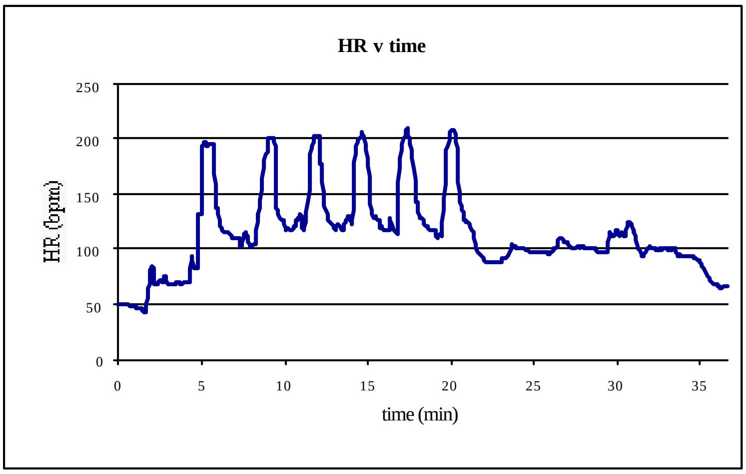

Figure 11. *Heart rates during an interval training session used for an elite event horse.*

Heart rates during recovery in Figure 11 were 110-120 beats per minute. Advocates of interval training have suggested that repeated heats should not occur if the heart rate does not rapidly fall below 120 beats per minute. Elevated heart rates either during exercise or in the recovery period could indicate pain, lameness, fatigue, hyperthermia or dehydration, and are a warning sign. Figure 11 also shows that it is difficult to obtain an estimate of heart rate during exercise from a single heart rate measurement during recovery due to the rapid decrease in heart rate after exercise.

3.7. Skills development

Skills development training is designed to increase the ability of a horse to complete a specific task. Important skills include galloping alongside other horses, entering starting stalls and standing sensibly, jumping out of the stalls, and rapid acceleration at the start of the race. Horses also should learn to gallop beside and accelerate around other horses. Horses also need to learn how to gallop on good as well as soft conditions. Pacers need to learn to pace with hopples, and event horses to jump fences at 600-700 metres/min. Dressage training is mostly about development of skills and temperament for specific exercises.

3.8. Cross training

Cross training refers to use of exercise that is not specific to the event performed, such as swimming. Training of horses should be specific to the athletic event involved whenever possible. This principle need not be followed rigidly, as there are circumstances when alternative types of exercise may be appropriate for some horses. Non-specific training methods can be used to provide an interesting alternative exercise, and swimming exercise does develop and maintain aerobic fitness. Jumping exercise is also useful cross training for Thoroughbred racehorses.

It has been shown that showjumping results in mean post-exercise blood lactate concentrations of 9 ± 0.5 mmol/L (Lekeux et al., 1991). These concentrations are similar to those found in Thoroughbred horses exercising at 12-14 m/s. Jumping exercise for racehorses may be a useful adjunct to the usual training routines. It may relieve boredom, and may provide an alternative to high speed exercise as a means of training the anaerobic and muscle buffering capacity.

Swimming is popular with some trainers, and many training centres provide a swimming pool. Horses use a trotting or pacing gait for swimming, and it has been observed that the breathing pattern was characterised by brief inspiration, prolonged expiration, and looked "painful" (Murakami et al., 1976). Certainly many horses appear to have difficulty breathing when swimming.

Studies of heart rate during swimming indicate that free swimming is similar in intensity to trotting and slow cantering (Murakami et al., 1976). A training effect was found, as heart rate during swimming decreased over a four week period of regular swimming exercise. Heart rates ranged from 140-180 beats per minute, and blood lactate concentrations only increased by 2-4 fold above resting values during swimming. Horses were exercised for 5 minutes daily in the first week, and the duration was increased by 5 minutes each week thereafter.

It was concluded that swimming was appropriate for the development of basic physical fitness and for rehabilitation of horses with limb problems. Prolonged swimming for one hour did not cause excessive increases in body temperature. It was suggested that the direction of swimming in circular pools be changed regularly during prolonged swimming to avoid fatigue in the outside legs.

Heart rates during two swimming sessions in a horse being prepared for eventing are illustrated in Figure 12. Heart rates during swimming (from 15-37 minutes in the recording) were approximately 130 beats per minute.

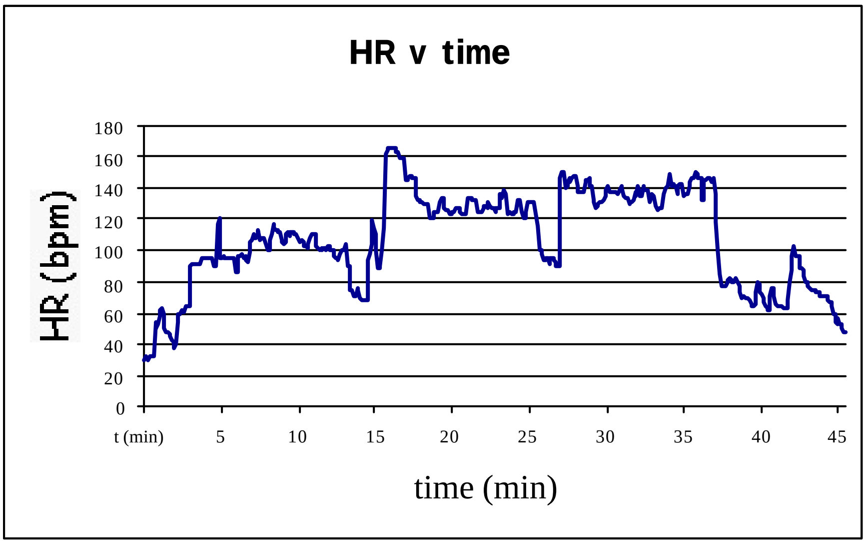

Figure 12. *Heart rates during two swimming sessions in a horse being prepared for eventing*

Tethered swimming may be a useful way of increasing the intensity of swimming exercise. This technique involves securing the horse by a tail rope, and encouraging the horse to greater effort (Thomas et al., 1980). This technique resulted in heart rates of 170-200 bpm, and blood lactate concentrations of 1-10 mmol/L in 5 unfit horses swimming for 5 minutes.

An argument against use of swimming is that it is not event-specific, and so does not train muscles, bone or tendons for demands of any competition. Likewise, the horse is not learning any specific skills for competition.

However, swimming training does provide a training stimulus, and may reduce the frequency of lameness, even though the exercise is not specific to normal equine competitions. A Japanese study investigated whether or not swimming training changes the frequency of locomotor diseases in two year old Thoroughbreds (Misumi et al., 1994). In this study, 24 horses were divided into three groups: Group A, trained by only running; Group B, trained by running plus a gradual increase in swimming, and Group C, trained by running plus constant swimming. Only in Group B was an increase in fitness measured (inferred from the relationship between blood lactate and velocity during standardised exercise tests). The increase in height in Groups B and C was greater than in Group A. Increases in girth and weight were smaller in Group A than in Groups B and C. Groups A and B had 62.5% and 12.5% of horses with locomotor diseases respectively. The authors concluded that a training program that includes swimming training can reduce locomotor diseases in young horses.

3.9. Treadmill training

Treadmills can be used for base training, and for strenuous training. However, treadmill training ignores development of important skills for racing or competition. Treadmills are not appropriate for sprint training.

Treadmills are often used with an incline of 10%. This increases the heart rate, oxygen consumption and blood lactate concentrations (Eaton et al., 1995) because the horse is lifting its mass against gravity as well as moving forward. Treadmill speeds for training usually range from 2-12 m/s (approximately 7-42 kilometres per hour). Gaits at these speeds are walk (2 m/s), trot (3-4 m/s), gallop (greater than 5-6 m/s). At speeds greater than approximately 7-8 m/s (24-28 kilometres per hour) heart rate may be maximal in untrained or partly trained horses. At these speeds it is important to monitor heart rate and blood lactate concentrations after exercise to confirm the training intensity. This procedure should be repeated once per week. Heart rates during and blood lactate concentrations after a standardised treadmill set of exercises will gradually decrease as the horse gains fitness. Treadmill training therefore has the advantage of strict control of training intensity coupled with performance of simple, standardised exercise tests to measure fitness.

Another interesting alternative to high speed exercise for strenuous training is treadmill trotting in combination with weight lifting (Gottlieb et al., 1987). Weights were added to a rope that ran over a pulley, connected horizontally from behind the treadmill to a harness. While trotting at 4.8 m/s and lifting loads of 60-100 kg heart rates increased to a mean of 209 beats/min, and blood lactates after exercise ranged from 5-16 mmol/l. The relationships between oxygen consumption and both heart rate and blood lactate concentrations are similar for draught work and normal submaximal treadmill exercise (Gottlieb-Vedi et al., 1991). This technique may be useful for increasing the intensity of the training stimulus at low treadmill speeds. Addition of loads to the sulky has also been used during training of trotting horses in Sweden.

A large scale study has studied racing performance of Thoroughbreds in North America with a history of treadmill training (Kobluk et al., 1996). Horses that had been trained on the treadmill for at least 50% of their program for at least 60 days prior to the start of racing were defined as treadmill trained. Racing performance in 107 treadmill-trained horses was compared with results in 214 control horses. In all age groups and classes the treadmill trained horses were equal or superior to the conventionally trained horses. The authors argued that treadmill training also facilitates more efficient quantification of performance.

3.10. Recovery days

Recovery days are days designated for recovery after races or hard training. Their importance should not be underestimated. It is during the 1-3 days after fast exercise that the training responses actually occur. Cells are actively repairing damaged structures, and anabolism, or protein building, occurs. The horse also restores its muscle cell glycogen content over a 24 hour period. During the 2 days after a race or intense sprint training horses should be either completely rested, or only lightly exercised. One of Sydney's best Standardbred trainers puts horses in a paddock for two days after racing, and only light exercise will be given on the third day after the race.

During recovery days the appetite, gait and attitude of horses should be closely observed. Minor injuries should be attended to, and ice packs used on any areas that are inflamed (heat and swelling indicate inflammation). The flexible ice packs are excellent for strapping onto shins, fetlocks and flexor tendons for 20 minutes or so. Ensure that there is a layer of cotton between the ice pack and the skin. As well, ice packs should be used immediately after fast exercise on any area of a horse's legs that has been injured in the past. Likewise, previously injured areas should be thoroughly warmed, and, if possible, stretched before training exercise and racing or competition.

It is also appropriate to closely inspect the legs after each race for signs of heat and swelling to ensure that treatment is commenced early in the process, and that the horse is not asked to exercise at high speeds again with an injury. Trainers should also develop the skill of carefully examining the back muscles for signs of soreness after a race. Ice, massage and ultrasound therapy can then be used to treat the painful areas of muscle.

There are no special strategies for recovery from prolonged exercise except provision of water, electrolytes, and a high energy diet. Prolonged hosing with cold water and use of ice will assist the cooling down process. Low energy diets such as hay may contribute to delayed glycogen resynthesis in the 2-3 day period after exercise (Snow et al., 1987). This delay is of little consequence unless the horse is competing on successive days.

The recovery process after intense exercise is influenced by the use of a "warm-down" period of exercise. Both walking and trotting for 20-70 minutes after exercise increase the rate at which blood and muscle lactate concentrations decrease after exercise. Ten minutes of activity had little effect, but by 40 minutes post-exercise, blood lactate concentrations are about 4-10 mmol/l lower with continuous trotting, and 2-5 mmol/l lower if the horses walked during recovery. These results probably reflect increased use of lactate as a substrate for aerobic metabolism, supporting the post-exercise activity (Marlin et al., 1987).

Disturbances to immune function have also been reported in horses during strenuous exercise training (Buschmann et al., 1990). Dysfunction of the lower respiratory tract has also been reported after intense exercise and transport (Raidal et al., 1997a, 1997b). The implications of these observations for performance or the incidence or severity of disease in horses during strenuous training are unknown. However, avoidance of further stress during the 2-3 day recovery period after intense exercise seems sensible.

3.11. Detraining

Detraining refers to the sudden cessation of training. Many horses have their training preparations interrupted by ill-health or injury. In Standardbreds, mean treadmill speed at a heart rate of 200 beats/minute was not significantly different from values obtained after 5 weeks of intense training (Thorntom et al., 1983). The same study found that there was no consistent change in VLa4 (treadmill velocity at which blood lactate is 4 mmol/L) with detraining. It is possible that the weekly exercise tests in this detraining study maintained fitness.

Two weeks detraining reduced $VO_{2\,max}$ to values near those before training (Knight et al., 1987), and the value continued to decrease over a 6 week period. In the same horses, buffering capacity significantly decreased over a 6 week period (Sinha et al., 1991), reversing the adaptation that occurred with prior training.

Three weeks of detraining resulted in a 12% decrease in $VO_{2\,max}$ in ten Thoroughbreds (Art et al., 1993). These results suggest that there is rapid loss of some training adaptations with enforced rest.

3.12. Overtraining

For most horse trainers, there is delicate balance between attaining and maintaining peak fitness, and lameness or overtraining. Overtraining is defined as a loss of performance ability, despite the maintenance of or an increase in training effort. Athletic performance decreases, and horses must cease or reduce training for variable periods of time in order to recover.

The overtraining syndrome has also been described in human athletes subjected to rigorous training programs incorporating inadequate rest periods. Typically, an imbalance between exercise training and recovery periods leads to a situation where further adaptation to training does not occur. The syndrome is characterized by a decrease in performance capacity. In humans, signs of overtraining also include mood disturbances, persistent muscle fatigue and pain, weight loss, inappetence and increased susceptibility to injury and infection (Kuipers 1998, Stone et al., 1991). Similar signs, including poor appetite, body weight loss, behavioural changes and reluctance to exercise typically accompany the reduction in performance observed in overtrained horses (Bruin et al., 1994, Persson et al., 1980). Despite considerable scientific investigation in human athletes, the physiological basis of the overtraining syndrome remains relatively poorly understood. Several mechanisms have been proposed, including decreased adrenal sensitivity to adrenocorticotropin (ACTH) (Lehmann et al., 1997) and failure of the hypothalamus to cope with the total amount of stress (Kuipers 1998).

In a cross-sectional study of overtraining in horses, plasma cortisol concentrations at rest and in response to ACTH administration were lowest in horses with red-cell hypervolaemia and a history of performing below expectation (Persson et al., 1980). The authors suggested that basal and ACTH-stimulated cortisol concentrations could be useful for detecting imminent overtraining prior to the occurrence of red cell hypervolaemia, a syndrome which was associated with a poor prognosis for return to athletic performance. However, plasma cortisol concentration two hours after ACTH administration was significantly higher in a longitudinal study of overtraining in horses (Bruin et al., 1994). In that study the horses may not have been truly overtrained because no decrement in performance capacity (assessed as total run time during a standardised exercise test) was reported. As well, a control group was not included, and it is possible that the result could have been due to prolonged training, rather than overtraining. Signs of overtraining of Standardbred horses were not related to changes in either maximal aerobic capacity (Tyler et al., 1996) or a difference in skeletal muscle adaptations (Tyler et al., 1998).

A longitudinal study of overtraining in Standardbred horses found that the syndrome was not associated with a decrease in adrenal gland sensitivity to stimulation by adrenocorticotropic hormone (Golland et al., in press). Rather, overtraining was associated with a decrease in the cortisol response to intense treadmill exercise, suggesting that the dysfunction in overtrained horses is in the central nervous system. ACTH response tests will not be useful for diagnosis of this condition.

The treadmill velocity at a heart rate of 200 bpm may be increased in overtrained horses (Persson et al., 1980). Regular measurement of heart rate during a standardised submaximal exercise test may assist the management of horses during periods of intense training.

Blood tests are frequently used to monitor horses in training. In a prolonged study of training and overtraining in Standardbred horses there were no significant changes attributable to the overtraining group (Tyler-McGowan et al., 1999, in press). Measurements of red blood cell concentration, haemoglobin concentration, packed cell volume, white blood cell counts, and neutrophil to lymphocyte ratio changed with training, but there were no changes that indicated onset of the stress of overtraining. Regular red and white blood cell counts for monitoring stress of training in horses has no scientific basis.

Overtraining was associated with significant changes in a plasma biochemical marker; AST (aspartate aminotransferase). A gradual increase in plasma AST in blood samples collected before exercise at the same time of the day should be regarded as a warning sign for onset of overtraining (Tyler-McGowan et al., 1999, in press). AST concentrations also increase for several days after exercise, and it is important that both the day and time of the week be standardised for blood collections. For example, there would be little point comparing the results from a sample collected on Monday morning, after a rest day, with results collected on the morning after a day of fast exercise. There was no significant effect of overtraining on plasma GGT or CK activities in the same study.

Regular assessment of a horse's ability to cope with intensive training, transport and racing schedules should not be based on regular measurement of plasma AST concentrations alone. Monitoring of appetite, body weight and the recovery of body weight after racing is advisable.

3.13. Risk factors for injury and rehabilitation strategies

The effect of exercise on the healing of articular cartilage defects in the equine carpus was examined in 12 horses (French et al., 1989). It was concluded that a 13 week period of graduated exercise (walking, trotting and later cantering) after surgical creation of a cartilage defect was not detrimental to the rate of repair.

Training also increases the strength of the suspensory ligaments (Bramlage et al., 1990). The mean absolute load necessary to cause failure of the suspensory ligaments with compression testing was higher in tissue from trained horses. In untrained horses the site of rupture was through the suspensory ligament, whereas in the trained horses, the site of rupture in most cases was through the proximal sesamoid bones. Restoration of strength in the suspensory ligaments should employ a graduated period of exercise training.

Estberg et al. (1998) investigated the relationship between intensive racing and training schedules, and risk of either catastrophic musculoskeletal injury (CMI) or lay-up from racing in Californian Thoroughbreds. Periods of rapid average daily accumulation of high-speed exercise distance were identified for each horse from official race and training histories. Horses that had period of rapid accumulation of high-speed exercise distance (a hazard period) had 4.2 times the risk of CMI within 30 days. Horses were also 4.8 times more likely to have to be spelled after a period of rapid accumulation of high-speed exercise distance. In summary, rapid increases in distance of high-speed exercise in Thoroughbreds increases the likelihood of a catastrophic musculoskeletal injury (CMI) and having to spell the horse.

Of course horses should be cautiously reintroduced to fast exercise after a spell from training. The importance of care in the three week period after a “spell” has been confirmed in a study of Californian Thoroughbreds (Carrier et al., 1998). The study investigated whether a two-month or longer period without official high-speed workouts was associated with humeral or pelvic fracture within hazard periods of 10 and 21 days following lay-up.

The study investigated many aspects of race training of horses that had been euthanased because of a complete humeral or pelvic fracture. Risk factors investigated included age, sex, activity, number of lay-ups, number of days from a race or official timed workout to fracture, number of days from end of last lay-up to fracture, mean duration of lay-ups, and total number of days in race training. Horses with pelvic fractures were more often female, older, and had no lay ups or greater than or equal to 2 lay-ups. Horses with humeral fractures were typically 3-year-old males that had 1 lay-up. Horses with pelvic fractures had more total days in race training, fewer days from last exercise event to fracture, and a greater number of days from end of last lay-up to fracture than horses with humeral fractures. Return from lay-up was strongly associated with risk for humeral fracture during hazard periods of 10 and 21 days. It was concluded that risk of humeral fracture may be reduced if horses are cautiously reintroduced into race training after a lay-up.

3.14. Training the horse's behaviour

Many of the activities involved in horse training are unrelated to development of speed. stamina and strength. Training of the horse's behaviours is just as important. All the hard work and time put into getting a horse physically fit can be undone by inappropriate horse behaviour. Use of counterproductive or inefficient techniques in behaviour modification can limit performance just as easily as inadequate physical fitness. All good trainers know that training the horse's mind, and keeping horses interested in training and competing is as important as training the heart and muscles. It is not within the scope of this book to deal with these behaviour and management issues.

A recent review and Zeeb and Schnitzer (1997) includes discussions of topics such as exercise, social contacts, feeding, climate, grooming and environmental factors in horse management. The chapter on training includes sections on the horse as a gregarious animal, the ability of man to empathise with horses, predator avoiding behaviours, horse learning by reward, and aims and structure of schooling. As well, there are sections on damage and "vices" caused by incorrect horse management.

Strereotypic behaviours are repeated behaviours without a known function, such as wind sucking, wood chewing and weaving. They have been referred to in the past as "vices". These behaviours can be can be reduced by appropriate horse management strategies. Simple changes, such as increasing availability of dietary rougha ge (hay) and increasing social contact between horses can reduce the frequency of equine stereotypic behaviour in a stable (McGreevy et al., 1995).

3.15. Thoroughbred training

The above sections deal with important principals to be followed for training Thoroughbreds. It is not the purpose of this book to provide strict recipes for training horses. Many of the comments in the previous sections of this chapter are relevant to Thoroughbred training. The diversity of training methods used with Thoroughbreds in different countries cautions us all about being too prescriptive about what is right and wrong in Thoroughbred training. Horses in the Japan Cup and Dubai Classic have very different preparations for the same event! The 1993 Melbourne Cup win by an Irish horse, Vintage Crop, after no lead up races in the previous month is also a cautionary tale. There are important principles to follow in horse training, but few rules!

Staaden (1991) is recommended reading. This book provides a fascinating collection of the thoughts on Thorougbred, Quarter horse and Standardbred training by trainers in Australia, UK and USA. The late TJ Smith talks frankly about his training methods and selecting horses. Details of the distances, speeds and times used for training a champion filly over its two and three year old career are included. Harkins and Kammerling (1990) provide details of conventional training of Thoroughbreds in North America for interested readers.

3.16. Standardbred training

Previous sections outline principals to be followed in training Standardbreds. However, one book highly recommended for further reading is "Racehorse training and Driving" (Demmler 1998). The book include some guidelines on preparation of a pacer for racing, and specifics of times, speeds and distances used in training pacers. It also includes excellent information on other aspects of training and managing horses. Others to have described Standardbred training procedures in some detail include Lovell (1994) and Gable (1989).

Shearman and Hopkins (1996) have investigated the training practices used with Standardbred maiden pacers in New Zealand. Interestingly, there was no relationship between rank order of trainer (number of winners) and training load. It was concluded that only large changes in training load are likely to affect the success rate of horses, despite the observation that "training loads generally appeared light relative to those of comparable human athletes". However, trainers who won more races had more horses and more than two preparation phases, suggesting that duration of training may be a factor in training success.

The program for a typical top trainer included 5-6 weeks of jogging 6 days per week at speeds of 15-25 km/hour for approximately 40 minutes. A second, 5 week phase of training consisted of hopple workouts twice per week, a hopple or jog one day per week, and 3 jog sessions (between fast days). Hopple speeds in this phase averaged 32 km/hour, but the range of velocities was high. In the final phase (4 weeks duration), horses jogged three times per week, and hoppled 3 times were week.). Hopple speeds in this final phase averaged 40 km/hour. After a race, horses racing every 14 days did not perform hopple workouts until the 4th or 5th day after a race, and then were hoppled again twice before the next race. The final hopple was given two days before a race (Shearman and Hopkins (1996).

3.17. Event horse training

Training the three-day event horse to perform at an elite level is an extremely demanding task. Success in competition necessitates superior stamina, strength (for jumping), skills (dressage, jumping), and a capacity to recover quickly after day 2 of the competition. The trainer must also be able to manage the horse's temperament – calm and relaxed for dressage, keen and fit for cross country and jumping.

Design of suitable training programs depends on an understanding of the metabolic demands of the event. Munoz et al. (1999) investigated the cardiovascular and metabolic responses to two cross-country events (CC* preliminary level and CC*** advanced level) in 8 male eventing horses. Plasma lactate response exceeded the "anaerobic threshold"of 4 mmol/L, reaching a maximum level of 13.3 mmol/l. Heart rates ranged from 140 to more than 200 bpm, peaking at 230 bpm. The authors concluded that muscle energy resynthesis during a cross country event is provided by oxidative metabolism and glycolysis. Both stamina and power exercises are required for event horses during their training.

In another study, blood samples were collected for lactate concentration determination at the arrival of the cross-country phase from 40 horses of various class levels competing in 6 different three-day events in a study by Amory et al. (1993). In 8 horses, heart rate (HR) was also recorded every 5 seconds during the cross-country. Heart rate ranged from 170 to 190 beats/min during the first part of the cross-country, and reached or exceeded values of 190 to 200 beats/min at the end of the course. The authors concluded that the anaerobic threshold is reached during cross-country. Recruitment of anaerobic metabolism at the end of the course was also demonstrated by the high values of blood lactate. These aerobic-anaerobic metabolic requirements should be taken into account when designing the training program of an event horse.

The importance of specific training to match the various demands of the three-day event has been emphasised in an excellent description of training protocols used by a successful event horse competitor. Any person interested in training an event horse should consult the article (Rolton, 1999). Important points made include:

- Start with a healthy horse
- Establish a base level of fitness (using long walks, basic dressage, long trots, using hills if possible)
- Event-specific training and skill development, with interval training

Intensive gallops using Thoroughbred training facilities are described in the article. Two intensive workouts with gallops were performed each week. A heart rate monitor was used to record heart rate during exercise and recoveries between intervals during the interval training.
An example of speed and interval sets described by Rolton (1999) on an all-weather 1400 metre track follows:

5 minutes walk
15 minutes trot
2 minutes canter, 1 minute at 400-500 m/min, 1 minute at 600-700 m/min
3 minute walk (back to the start of the gallop)
2 minute canter, 1 minute at 500-600 m/min, 1 minute at 600-700 m/min
20 minutes trot
6 minutes canter at 500-600 m/min accelerations
6 minutes canter at 500 m/min
6 minutes canter at 500-600 m/min accelerations
5 minutes trot
10 minutes walk

Readers are referred to the original article for further explanatory details, and more excellent advice and information. There are also many other excellent books by experienced event horse trainers. Dyson (1994) and Clayton (1994) are also recommended reading for more details on aspects of training for dressage, jumping and the three day event.

3.18. Quarter horse training

Rammerstorfer et al., (1998) investigated baseline physiological responses to typical reining training in five mature Quarter Horses. In an initial standardised exercise test which simulated reining horse exercises, heart rate and plasma lactate concentration indicated that galloping circles, spinning and stopping were “anaerobic” exercises (203 beats/min and 8.86 mmol/L, respectively). In a subsequent experiment the effects of reining training were investigated in ten mature Quarter Horses. Heart rate and plasma lactate concentrations were lower after 28 days of reining training.

3.19. Endurance horse training

Endurance training involves prolonged use of techniques described for basic training. As well, some strenuous training sessions are also advisable to develop fitness for fast exercise. Ridgeway (1994) emphasises the importance of selecting the appropriate horse, and the processes involved in mental and physical conditioning of endurance horses. Endurance horse trainers should regularly use a heart rate meter to monitor training intensity and recovery of heart rates after training exercise. Fartlek and interval training have been recommended for endurance horses as a way of providing speed training (Ridgeway, 1994).

4. Fitness Tests for Horses

4.1. Introduction

Fitness can be described as the physical capacity to perform in an event or race. A horse's fitness will therefore depend on its inherited physiological attributes, and on the degree to which the structure and function of the animal has been changed during training. Essentially, the issue is: how well will the horse perform in the event, and can something be measured to describe the horse's likelihood of success? The basis of all fitness tests is the same. They involve measurement of one or more aspects of a horse's physiological response to exercise during or after a standardised exercise test. Common measurements include heart rate and blood lactate concentration. The main aims of this section are to describe the principles of and rationale for the use of fitness tests, to outline methods of conducting such tests, and to describe the limitations of such tests.

Tests of fitness are used to try to answer the following questions concerning a horse's capacity for exercise:

1. Will the horse run a good race in its next start?
2. How does the horses fitness compare with that of other horses ?
3. How does the horses fitness compare with its fitness at previous times or during previous preparations?
4. Has the horse's fitness changed with recent training or detraining?

Another question relates to attempts to predict performance in horses not previously raced or used in competition.. A question that all owners eventually ask is: does the horse have the inherent physiological attributes and talent to enable it to compete successfully?

Of all areas in equine exercise physiology, the prediction of performance is one of the most difficult. However, the sizeable nature of the risk associated with purchasing a young racehorse is likely to continue to stimulate research in this area. A recent study of a cohort of young racehorses illustrates the magnitude of the risk (More, 1999). The study developed a profile of the racing careers of Thoroughbred horses in south-eastern Queensland, and examined factors that affect racing during the first years of racing.

Two measures of performance were examined: race earnings during the first year of racing and cumulative proportion of horses still racing up to 2 years after their first start. 1,804 horses were enrolled in the study including 916, 701, 152 and 35 horses that first raced at 2, 3, 4 and 5 years of age, respectively. During their first year of racing, half the horses earned no more than A$450 from race earnings, and 710 (39.4%) horses earned no money at all. In comparison to poorly performing horses, well-performing horses were more likely to be male, to have started as 2-year-olds and to have had more starts during this year. Of the horses that first started as 2 and 3-year-olds, only 71 and 46% continued racing for at least 1 and 2 years after their first start, respectively. This study confirmed a high wastage among racing Thoroughbreds. As expected, premature retirement from racing was linked to poor performance. During the first year of racing, the race earnings of 1,567 (86.9%) horses were insufficient to cover training costs. The 2-year-old racing cohort outperformed the older racing cohorts in each of the performance measures under investigation.

Of course Thoroughbred and Standardbred trainers are able to observe performance during training gallops and trials to help answer these questions. However, many horse trainers and owners have also sought answers to these questions with measurements obtained during specific fitness tests. In the past, haematological and serum biochemical assessments in the week before a race have been popular as means of attempting to assess fitness. The use of these measurements will not be discussed in detail. There have been many recent excellent reviews and articles on the subject. These reviews conclude that haematological parameters such as red and white blood cell counts are not useful in assessment of fitness or predicting performance (Beech, 1988), or for diagnosing poor performance (Stewart et al., 1983). Routine assessments of haematology and plasma biochemistry has a role in diagnosing disease, but has no use for describing fitness (Revington, 1983).

4.2. Fitness and its relevance to performance in equine events

Performance by a horse on any particular day will be limited by fitness, but also by many other factors. These include previous diet, feeding strategies on the day of racing or competition, disease or injury, shoeing and horse's mental attitude and behaviour before and during the race. In this section the focus will be on aspects of "physiological" fitness, both inherited and acquired by training.

The two main issues in physiological fitness are:
- The ability to sprint over 200-600 metres, and to accelerate over 50-100 metres
- Stamina, or the ability to maintain a speed over a long period (or fatigue resistance)

Fitness for sprint and acceleration

Scientists now better understand the physiological bases of superiority in each of these aspects of performance. The rate of acceleration and the ability to sprint over 200-600 metres is dependent primarily on anaerobic capacity. It is not dependent on superior rates of use of oxygen transport by the respiratory and cardiovascular systems, or its use by muscle cells. Rather, a high anaerobic capacity confers superiority for acceleration and speed. This refers to the capacity for ATP resynthesis by metabolism of glycogen. The principal limiting factors are the numbers of Type II muscle fibres that can contract and relax very quickly, and can generate high forces because of their larger size.

Equine scientists have measured anaerobic capacity with specialised treadmill tests. These studies have enabled a better understanding of the proportions of aerobic and anaerobic energy supply in events of different duration. An extremely important finding is that even in events lasting 60 seconds, it seems likely that aerobic ATP supply predominates. Therefore a 1000 Thoroughbred race is not a true sprint, like a human race over 200-400 metres. Metabolically, a 1000 metre horse race depends much more on oxygen consumption than a human 800 metre race. This difference is attributable to the horse's capacity for greatly increasing its oxygen carrying capacity in the blood at the commencement of exercise by splenic contraction. The spleen acts as a store of red blood cells that can be used during exercise, almost like a "self-transfusion" As a result, the red blood cell and haemoglobin concentration increases during exercise by 50% or more in the horse. This confers an advantage because the horse is more able to use oxygen at the commencement of fast exercise.

Another important finding relates to manipulation of the horses energetic response at the beginning of a race by "warm up". The rate of oxygen use in the first 30 seconds is much greater if an appropriate warm up has been given, and there is less reliance on anaerobic metabolism, and less lactate accumulation at the commencement of fast exercise.

A comparatively high maximum oxygen consumption and high rates of increase in oxygen consumption at the start of intense exercise are two factors that explain the physiological superiority of horses compared to other mammals. Maximum oxygen uptake is increased by training, and the rate of aerobic energy delivery at the commencement of exercise can be manipulated.

For example, warm up significantly increases aerobic energy delivery in racehorses during high intensity exercise (Tyler et al. 1996). In this study, the rate of increase in oxygen consumption was measured at the commencement of exercise in two groups. One group completed a five minute walk before the exercise. In the alternative, horses exercised at 50% of maximum oxygen uptake (a slow canter) for 5 minutes for a warm up, then walked for two minutes before starting the high intensity exercise. Horses with a warm-up had faster kinetics of gas exchange and a greater proportion of their total energy requirement was supplied by aerobic metabolism. The aerobic contribution to total energy requirement with and without warm-up was, respectively, $79.3 \pm 1.0\%$ and $72.4 \pm 1.7\%$ ($P < 0.01$). There was also a higher maximal accumulated oxygen deficit ($P < 0.01$) in horses that had not been given a warm-up. The authors concluded that during high intensity exercise to fatigue lasting 1 to 2 minutes, more than 70% of energy supply is from aerobic energy sources, and that this contribution is even greater when the horses have received a warm-up.

It is likely that a lower oxygen deficit at the commencement of exercise will limit the rate of onset of fatigue. Standardbred horses are generally properly warmed up before racing. Many Thoroughbred racehorses are not. Trainers should ensure that horses get at least 5-10 minutes of trotting and cantering before fast training exercise. Before a race jockeys should be cantering or trotting the horse whenever possible.

Fitness for stamina

The factors that limit the horse's ability to maintain a high speed for a period longer than 60 seconds depend on the duration of the event. In events lasting from 60 seconds to the approximately 10 minutes, stamina and the ability to limit fatigue (referred to as "staying ability") will depend greatly on superior oxygen transport and use, and on limited increases in lactic acid, ADP and Pi concentrations in the muscle cells. Superior horses will be able to maintain aerobic ATP resynthesis at high speeds, and do not rely on anaerobic resynthesis of ATP until speed is very high, and near maximal. They are also likely to have superior buffering capacity in muscle cells, limiting the fall in pH during exercise.

In a race over 1200 metres it has been estimated that 60-70% of the energy supply is aerobic (Eaton et al., 1995). In a 3200 metre race, it is likely that 80-90% of energy supply is aerobic, and so the success or otherwise of an individual horse depends more on stamina, and less on the ability to accelerate or sprint. However, in a slowly run race, the ability to sprint will play a greater role in determining the winner. It is also likely that horses that have the highest oxygen uptake and lowest rates of lactic acid accumulation during most Thoroughbred and Standard races will be more capable of a sprint over the final 600 metres. This is because they have less disturbance to the pH, and less accumulation of ADP and Pi during the event.

4.3. Traditional approaches to fitness measurement

Horse owners and trainers have long been interested in fitness measurement. Over the years various measurements such as resting PCV and haemoglobin levels have been used frequently as an index of performance. However, no resting measurement has been shown to provide a valid index of performance. Small changes in these variables can be found in the first few weeks of training, but thereafter no further adaptations tend to occur. Also resting blood data is limited by the existence of a large reservoir of red blood cells in the spleen, which complicates attempts to extrapolate from RBC concentration to the total oxygen carrying capacity during exercise. With prolonged endurance training there can also be a normal decrease in red cell concentrations due to expansion of the plasma volume.

The ultimate expression of aerobic capacity is maximum oxygen uptake, or $VO_{2\,max}$. Measurement of $VO_{2\,max}$ currently necessitates use of a treadmill and expensive equipment for gas analysis. Alternatives are the analysis of HR and blood lactate in response to specific work loads.

4.4. Treadmill fitness tests

Treadmill testing of equine fitness has been used at the University of Sydney for 6-7 years, with over 200 horses tested in that time. The tests are usually used to help diagnose the cause of poor performance.

A typical treadmill test protocol used at the University Veterinary Centre Camden involves a period of 3 days of acclimation to the treadmill, during which time the horses learns to walk, trot and canter at speeds up to 10-13 m/s. A catheter placed in the jugular vein facilitates collection of blood during exercise for measurement of blood lactate concentrations, and a heart rate meter is applied. A loose fitting mask is used to enable measurement of maximum oxygen uptake. The horse is trotted for 3 minutes (at 4 m/s) on a treadmill inclined at 10%, and then exercises for 1minute at 6 m/s, 8 m/s, 10 m/s, 11 m/s and so on until the horse is no longer able to keep pace with the treadmill. This indicates the onset of fatigue. All horses undertake the same protocol. This enables valid comparisons of results in different horses, and comparisons of results from repeated tests in the same horse.

4.5. Heart rate and fitness tests

Increases in fitness are reflected in decreases in heart rate during submaximal exercise. For example, heart rate during trotting at 250 metres per minute could decrease. As well, the velocity at which the horse is exercising at a particular heart rate will increase. For example, V200, the velocity at which heart rate is 200 beats per minute, will increase with training.

Measurement of heart rate 30 minutes after exercise is an important index of fitness in the endurance horse during competition. Increases in heart rate reflect the metabolic disturbances that occur during endurance exercise (Rose et al., 1977). These results provided a simple, practical and accurate method for evaluation of the "stressed" endurance horse. The assessment of the heart rate recovery following exercise is now widely used by riders in the training of endurance horses as well as by veterinarians in the assessment of a horse's "fitness" to continue in an endurance ride.

4.6. Blood lactate measurements in fitness tests

Expression of the relationship between speed and lactate concentration has usually been expressed in two ways. Firstly, VLa4, the work velocity resulting in a blood lactate concentration of 4 mmol/l has been used. This measurement necessitates exercise tests with 4-6 steps of increasing speed. Alternatively, the blood lactate concentration at the completion of, or soon after, exercise for a set duration and speed has been used. For example, La-10 is the blood lactate concentration after exercise at 10 m/s. This measurement has been used in Swedish trotters, with blood collected after 4000 m at 10 m/s. That measurement was negatively correlated with maximal trotting velocity over 1000 m ($r=-0.66$, $p< 0.001$). This means that the fastest trotters had the lowest blood lactate concentrations after the standard exercise test.

Timeform rating in English Thoroughbreds was also highest in horses with the lowest La-10 measured two minutes after treadmill exercise on a 10% incline ($r=-0.68$, $p<0.01$). This result infers that approximately 45-50% of the variability in Timeform was attributable to the variability in the blood lactate response to the submaximal treadmill exercise test (Evans et al., 1993).

In contrast to the above studies, one recent investigation found that running speed of Thoroughbred horses running on a 800m race track was positively correlated with VLa4 measured in treadmill exercise tests (Harkins et al, 1993). However, this result should not be used to infer that superior Thoroughbred racehorses have the highest blood lactate concentrations after an exercise test, as peak running speeds on the track were only about 80% of Thoroughbred racing speeds.

In general, superior trotters and Thoroughbreds have the lowest blood lactate concentrations after standardised submaximal exercise tests. The generation of reliable results from such tests on treadmills depends on appropriate acclimation of the horse to the treadmill routine. Excitement, fear and anxiety can all elevate the blood lactate concentration, as glycogenolysis is stimulated by catecholamines. The production of reliable LA10 values in pacers or trotters depends on the ability of the driver to exercise the all horses over the same distance at the same speed. Minor variations in speed or rates of acceleration could invalidate the test results.

4.7. Field exercise tests

There has been little application of blood lactate measurements or heart rates for fitness tests in commercial training establishments. Part of the reason for the slow adoption of these techniques has been the difficulty of design and implementation of exercise tests in the field. Treadmills are useful because they help with conduct of standardised exercise tests. However, few trainers use treadmills or have access to them. Understandably, trainers also have reservations about adopting new techniques that could disrupt busy training schedules, and for which there is limited evidence for benefits of their use. As well, trainers can earn a living training unfit or poor quality horses. However, many owners continue to be frustrated by lack of information about the performance capacity of horses. Several recent studies have outlined new methods of performing exercise tests on racetracks.

There are several important principles to follow if steps are taken to implement use of field tests of fitness. Firstly, the test protocol must be simple. Multiple steps of increasing speeds of exercise are frequently use in treadmill testing, but these forms of exercise testing in the field are unlikely to be popular with trainers. Exercise tests also need to be easy to implement, and not disrupt normal training schedules.

There are several features of the exercise that must be maintained. These include:
1. Same warm up routine prior to testing
2. Same rates and distances of acceleration during the exercise
3. Same test distance
4. Constant speed during the exercise
5. Distance of the deceleration should be constant
6. Blood should be collected at a constant time after exercise
7. Consistent speeds of post exercise activity should be used

The lactate response to specific speeds has been used in laboratory treadmill testing for assessing performance and fitness. Fitness has usually been described with speed at a lactate concentration of 4 mmol/L (VLa4). As the horse increases fitness, VLa4 increases. Field tests with multiple speeds and blood collections have been conducted in Standardbred horses to assess performance (Wilson et al., 1983). However, multiple exercise speeds and blood collections may not always be convenient.

The exercise test used by Wilson et al. (1983) consisted of four steps of exercise over 1000 metres, as described below. The horse should walk for 3-5 minutes between each of the four steps.

Blood was collected into fluoride oxalate tubes three minutes after each step. Heart rates were also recorded during the exercise test to measure V200.

	Speed (m/min)
Step 1	450-550
Step 2	600-700
Step 3	700-800
Step 4	>800

A plot of speed versus lactate is then drawn on graph paper. By drawing a line horizontal to the 4 mmol/l concentration, the VLa4 can be directly calculated.

Wilson et al., (1983) observed that superior horses seemed to have lower blood lactate responses after this exercise test. However, in a study of Swedish Standardbreds, ten horses performed a submaximal test on the track. The test consisted of five incremental heats at approximate speeds of 9.1, 9.5, 10.0, 10.5, and 11.1 m/s over 1000 metres. A blood sample was drawn from the jugular vein for plasma lactate analysis immediately after each heat. Plasma lactate response to exercise differed between horses, but no correlation was seen with a racing performance index (Roneus et al., 1999).

However, studies of larger numbers of horses that have a large range of racing abilities are more reliable. Courouce et al. (1997) examined the relationship between VLa4, age and racing performance of Standardbred trotters. A total of 159 horses were divided into 5 age-groups from 2 to 6 and over, and performed standardised exercise tests of 3 steps performed at increasing speeds. The velocity of the horses was measured with a tachometer on the sulky. Mean VLa4 values increased significantly ($P<0.05$) with age between 2 and 4 years. Horses were defined as good performers (GP) when finishing between the first and the fifth place in a race or poor performers (PP) when finishing lower than fifth. VLa4 was significantly higher for GP than for PP ($P<0.05$).

The results in this study also emphasised the need for care when comparing results from different tracks. Veterinarians, trainers or owners interested in using these tests in Standardbred horses should develop their own exercise test routine on a single racetrack. It should also be noted that blood lactate concentration is likely to be increased by excitement during the test, and by "pulling", an inefficient gait due to effort expended against restraint by the driver. Results from exercise tests in which horses pull hard against a jockey or driver should be regarded with suspicion, and the test repeated.

A review of exercise tests for French trotters exercising in the field concluded that track testing provided a more limited range of measurements than treadmill testing, but had the advantage of being performed in the horse's natural environment (Courouce, 1999). Various measurements such as heart rate during exercise and blood lactate concentration after exercise may be measured on the track, enabling calculation of physiological variables such as V200 and VLa4. Although VLa4 is calculated during submaximal intensity exercise, it is related to racing performance and seems to be the most important measurement to assess changes in fitness (Courouce 1999).

Conduct of racetrack exercise tests for measurement of VLa4 or La10 are very difficult in Thoroughbreds, as it is difficult to obtain constant track conditions and constant speeds during exercise. However, Vonwittke et al., (1994) used a standardised. two step exercise test to investigate the blood lactate running speed relationship in 9 thoroughbred racehorses. Each horse completed a two-speed field test at intervals of 6-8 weeks to determine its running velocity (v) eliciting blood lactate concentrations of 4 (v(4)) and 12 mmol/l (v(12)). Changes of v(4) and v(12) in a horse between two consecutive tests were used to assess effects of training history variables calculated for the period between two consecutive tests. The percentage of days with gallop workouts between two consecutive tests showed a significant correlation with changes in v(4) ($r = 0.71$, $P < 0.01$) and v(12) ($r = 0.56$, $P < 0.05$). The number of gallop workouts ($r = 0.60$, $P < 0.05$) and the total time of training ($r = 0.58$, $P < 0.05$) also correlated with the change of v(4). Furthermore the percentage of days without training was negatively correlated to changes of v(4) ($r = -0.75$, $P < 0.01$) and v(12) ($r = -0.56$, $P < 0.05$).

These results imply that increases in fitness, as measured with the blood lactate response to submaximal exercise in a two-step field test are more likely in Thoroughbred horses that have more galloping than trotting, and have higher numbers of gallops in a time period. More days without training was associated with reduced fitness, and more training at higher speeds was associated with greater fitness.

A field exercise test was used with 8 French Thoroughbred horses in France to investigate the use of heart rate measurements during and after track exercise as a suitable measure of changes in fitness (Valette et al., 1996). The test consisted of a warm-up followed by three 3 min-steps one cantering and two galloping, followed by a recovery period. Heart rate was recorded during the entire test, and blood samples were taken during the 2 min rest periods following each step, and after the recovery period for the measurement of lactate concentrations. Fitness was described by the relationships between lactate concentrations, heart rate and velocity. The authors concluded that procedure indicated that the cardiovascular system seemed to be improved during the protocol and that the efficiency score and the cardiac recovery index seemed to be good indicators of potential speed.

An alternative approach is to describe the blood lactate concentration to a single bout of strenuous, submaximal exercise. An appropriate speed of the exercise must be chosen. The aim is to have an exercise test that is demanding for some horses, but achieved easily in others. Typical speeds for such tests are 800 metres in 65-70 seconds in a Standardbred horse (Wilson et al., 1983), and in 55-60 seconds in Thoroughbreds (Davie and Evans, in press). These speeds would need to be confirmed in an individual stable, because they will depend on the quality of horses being trained, and possibly on track size and surface conditions.

A one-step field test has been designed that enables comparisons between Thoroughbred horses (Davie and Evans, in press). This study investigated the feasibility of conducting a standardised, discontinuous, submaximal 800 m exercise test in Thoroughbred horses in the field. Linear and exponential regression analyses were conducted to describe the relationships between blood lactate and velocity of exercise. Predicted lactates for each horse's exercise test velocity were calculated from the line of best fit, and the difference between measured and predicted lactate was used to describe a rating (R) for each horse. It was concluded that there is a linear relationship between blood lactate and velocity in discontinuous submaximal exercise tests over 800 m at speeds between 13 and 16 m/s in Thoroughbred horses. A single step test that takes into account variability of velocity within a test, and which is based on calculation of the difference between the measured and predicted lactate concentration, has potential application in field evaluations of fitness in Thoroughbred horses. Further studies are required to investigate whether comparisons of the blood lactate response to exercise in an individual horse with the predicted response in a reference population is an accurate and reliable correlate of racing performance.

It should be remembered that lactate tests such as those described above are indications of endurance ability, or stamina. Lactate tests measuring VLa4 or La10 do not express the ability of a horse to accelerate at the start or finish of a race, or the ability of a horse to sprint 400-600 m. However, observation and a stop watch are all that are needed to assess these attributes.

Measurement of the blood lactate concentration after maximal exercise has been used to estimate anaerobic capacity, defined as the ability of an individual to resynthesise ATP via anaerobic metabolism. The blood lactate concentration after maximal exercise to fatigue does not change with submaximal exercise training (Evans, et al., 1994), and so is not a useful marker of fitness. As well, the blood lactate concentrations after maximal exercise in trotters (Krzywanek, 1974) and Thoroughbreds (Evans et al., 1993) were not correlated with race performance.

A study of the relationships between racing performance and several physiological measurements was also conducted in 25 Standardbred trotters (Roneus et al., 1999). Blood samples and muscle biopsies were obtained 5-10 minutes after racing. The biopsies were analysed for fibre type composition and enzymatic profile and blood samples for plasma lactate and ammonia concentrations. Fibre type composition varied among horses (range 9-27% for Type 1, 32-54% for Type IIA, and 27-46% for Type IIB). Fibre type composition, muscle enzyme activities, plasma lactate and ammonia responses to racing were not correlated to a racing performance index.

These results suggest that the blood lactate response to maximal exercise has limited usefulness as a measure of fitness in horses. It is unlikely that any physiological measurement after maximal intensity exercise will be more closely correlated with racing ability than information generated by use of a stop watch.

4.8. Maximum oxygen uptake

One study has reported that there was a moderate association of running speed with maximum oxygen uptake in Thoroughbred horses (Harkins et al, 1993). Maximum oxygen uptake is also higher in superior Standardbred horses (Gauvreau et al., 1995).

Gauvreau et al. (1995) compared the metabolic and respiratory measurements in ten Standardbred racehorses during a standardised treadmill test. This is the only study that has investigated the role of maximum oxygen uptake as a limiting factor in racing performance. The horses were divided into two groups: group A (n = 5) had mean racing speeds of 4.4 s faster than group B (n = 5) over a 1-mile distance. Group A had significantly higher ($P < 0.05$) measurements of maximal oxygen consumption ($VO_{2\,max}$), oxygen pulse (volume of oxygen ejected with each cardiac contraction), and tidal volume (volume of respiratory gas exhaled in one breath). Venous lactate concentration was also significantly higher ($P < 0.05$) in group A. Group A was also able to complete a significantly higher ($P < 0.01$) number of workloads before fatigue. It was concluded that the higher aerobic and anaerobic capacity of group A horses may be a major contributor to a faster racing performance.

Many further studies are required to investigate the relationships between maximum oxygen consumption and racing performance. However, these studies necessitate transporting horses from their stables to treadmill laboratories for exercise tests, which is not very convenient for trainers. It is possible that large scale studies of this issue will not be conducted until new technologies enable measurement of oxygen consumption of horses during fast galloping, trotting and pacing exercise on the racetrack (Evans and Marlin, 1999).

4.9. Red cell volume

Total red cell volume expresses the volume of erythrocytes in the circulation of the horse, including the volume in the spleen. It necessitates measurement of plasma volume and the induction of splenic contraction before the haematocrit (PCV) is measured, so that red cells sequestered in the spleen at rest are also measured. Splenic contraction has been induced by adrenaline injections and moderately intensive exercise (Persson, 1967). Total red cell volume relative to body weight was significantly correlated with maximal trotting speed over 1000m in 35 Swedish trotters ($r=0.68$, $P< 0.001$) (Persson and Ullberg, 1974).

These results suggest that the measurement is an important factor in the ability to trot rapidly, but there have been no studies of the relationship in other breeds. However, the PCV after maximal exercise in Thoroughbreds, which ranges from 60-70%, was not correlated with Timeform rating (Evans et al, 1993). As well, the physiological responses to treadmill exercise in red cell hypervolaemic horses are not different from non-hypervolaemic horses (Poso et al., 1993)

4.10. Body fluid status and fitness of endurance horses

Recent research has provided a better understanding of the impact of fluid and electrolyte losses on the fitness for endurance exercise has described effective methods for the treatment of exhausted endurance horses. The results emphasised the importance of body fluid status as an important factor in performance of endurance exercise, and focus attention on strategies for improving fitness by using appropriate pre-race strategies. Oral electrolyte pastes have been used before, during and after endurance rides to prevent and treat dehydration (Schott and Hinchcliff, 1998). Use of oral electrolyte pastes in dehydrated horses is also an effective treatment if water is available (Sosa Leon et al., 1998). It also has been noted that successful endurance horses do not dehydrate as much as less successful competitors (Schott et al., 1997).

4.11. Predicting performance

Some progress has been made in research into use of physiological measurements to predict performance, but there remains a great dearth of knowledge in this area. Answers to several questions are needed. These include:

1. What are the energetic bases of performance in events lasting 1-10 minutes
2. To what extent does performance during racing and other competitions depend on maximum oxygen uptake and other measured of fitness?
3. To what extent does performance during racing and other competitions depend on efficiency of locomotion (oxygen uptake per metre)?
4. Does fitness in unfit two year old horses accurately predict fitness in the same horses after training, or does the response to training vary greatly between horses?
5. Does fitness in 6-12 month old horses predict fitness in the same older, race fit horses?

Answers to these questions will only be obtained from large scale studies of fitness in normal populations of racing horses. Development of suitable fitness testing facilities near race tracks would enable some of these questions to be addressed. As well, new technologies that enable maximum oxygen uptake to be measured in horses during normal racetrack exercise would be a great advance. Small, light-weight masks that enable measurement of respiratory air flow and oxygen uptake have been developed for field studies in human athletes, and this may be the future for equine fitness testing because such techniques obviate the need for expensive treadmill laboratories.

Popular techniques for performance prediction in the past have included measurement of heart score by electrocardiography, and more recently, ultrasonography (cardiac ultrasound).

Heart score is only moderately correlated with race performance at best. Some studies have been unable to demonstrate any correlation between heart score an racing performance, and the gradual decline in the popularity of this techniques for performance prediction is understandable. However, it remains popular with some owners and trainers.

The presence of supposedly abnormal T waves in waves in three or more electrocardiographic leads has been used to diagnose the cause of poor race performance in horses. One study has investigated the relationship between previous racing performance and T waves, and the effect of training on the T wave in Standardbred horses (Evans and Polglaze, 1994). Thirty-two horses were electrocardiographed in two Sydney racing stables. Sixteen horses (50%) had ECGs with three or more leads with abnormal T waves, and these horses had won more races, had a greater ratio of wins per start and a greater number of dollars earned per start than horses with less than three abnormal T waves ($P < 0.05$). Horses with abnormal T waves also had significantly faster racing times ($P < 0.01$).

There were significant ($P < 0.01$) correlations between the number of abnormal T waves and both number of wins ($R = 0.47$) and dollars earned per start ($R = 0.45$). Fastest winning mile rate was also negatively correlated with number of leads with abnormal T waves ($R = -0.52$, $P < 0.01$). There was no relationship between racing performance and heart score.

The effect of training on the T wave was also investigated in nine previously untrained and unraced Standardbred racehorses. There were significant effects of training ($P < 0.01$) on the number of abnormal T waves and mean chest lead wave amplitude. It was concluded that abnormal T waves are a common finding in the race-fit Standardbred horse, and can be found in more than 50% of horses currently performing well in races. In addition, chest lead T waves become more positive after training, confirming findings in Thoroughbred horses (Evans, 1991).

Echocardiography is now popular at horse sales as a tool for performance prediction. The popularity of this approach is based on all or some of the following assumptions:

1. Stroke volume (the volume of blood ejected by a cardiac ventricle) in a 15 month old horse is an accurate predictor of stroke volume during exercise in the same horse as a two year old or older.

2. Stroke volume in a 15 month old horse accurately predicts cardiac output (the product of heart rate and stroke volume) during maximal exercise.

3. Thoroughbred racing performance is highly correlated with stroke volume in an untrained yearling.

Unfortunately none of these premises has been demonstrated. A large scale study did not show any correlations between echocardiographic measurements in Thoroughbred yearlings and racing performance in the same horses as two or three year olds (Leadon, et al (1993). There is no evidence to support the use of echocardiography to predict performance of yearlings with normal hearts.

In the past there has been enthusiasm for use of muscle biopsies to predict future performance. It was thought that classification of horses on the basis of their muscle fibre type percentages in the gluteus medius muscle held promise as a means of talent identification, or predicting the "sprinting" or "staying" potential of horses. Lindholm (1985) also reported that excellent racehorses had higher activities of oxidative enzymes (citrate synthase (CS) and 3-OH- acyl-CoA dehydrogenase (HAD)) and a higher ratio of IIA to IIB muscle fibres.

Unfortunately the fibre type distribution in one biopsy sample is not sufficiently representative of the whole muscle, fibre type varies from muscle to muscle, and depends on depth of the biopsy in the middle gluteal (Kline et al., 1987). Consequently, talent identification by calculation of fibre type distribution has very limited usefulness. The technique is also quite invasive, and has limited aesthetic appeal.

Recent studies in endurance horses suggests that a refined approach to the muscle biopsy technique for performance prediction in endurance horses may be more useful (Rivero et al., 1993, 1998). Biopsies from three different depths of the gluteus medius muscle were obtained from 36 endurance horses. Twenty of the horses were considered excellent performers according to the mean speed of their three fastest records in endurance events. The other 16 horses were considered moderate performers, with a mean racing speed less than 12.5 km/h (in 120- to 180-km endurance rides), less than 14 km/h (in 80-120 km endurance rides), or less than 13.5 km/h (in 40-60 km endurance rides). The activities of citrate synthase (an indicator of the citric acid cycle activity), 3-OH-acyl-CoA-dehydrogenase (a marker for lipid oxidation) and lactate dehydrogenase (an indicator of anaerobic metabolism) enzymes were also studied.

Significant differences in oxidative enzyme activities, but not in the glycolytic lactate dehydrogenase enzyme activities, were recorded between performance categories. Excellent performers had higher activities of citrate synthase ($P<0.001$) and 3-OH-acyl-CaA-dehydrogenase ($P<0.02$) enzymes than the poorest. The three enzyme activities changed significantly with the increase of sampling depth within the muscle Citrate synthase and 3-OH-acyl-CoA-dehydrogenase activities increased by 60% and 75%, respectively, and that of lactate dehydrogenase decreased by 23% from surface to deep sampling depths. When lactate dehydrogenase/citrate synthase and lactate dehydrogenase/3-OH-acyl-CoA-dehydrogenase enzyme activity ratios were regressed on sampling depth in order to describe the general metabolic profile of the muscle, a strong linear relationship was found in both performance groups ($P<0.001$). The authors concluded that the results clearly show that the best performing endurance horses have a greater aerobic capacity and a relatively lower anaerobic capacity in the gluteus medius muscle than those horses that have been moderately endurance raced useful (Rivero et al., 1993, 1998). These results show that the muscle fibre metabolic profile is directly related to the athletic ability of the horse for endurance events.

As well, significant differences in muscle fibre type composition and fibre size were recorded (Rivero et al., 1993). Excellent performers had a higher percentage and a larger size of type I and type IIa fibres and a lower percentage of type IIb fibres including both type IIb oxidative and IIb nonoxidative. The differences in distribution of myofibre types and in fibre sizes were more marked in the deeper parts compared with the superficial regions of muscle.

4.12. Conclusion

Success in equine athletic competition depends on several important factors in healthy horses. These include stamina, sprint speed and acceleration rate. The relative importance of these factors will depend on the metabolic demands of the individual event. Fitness tests can be used to measure factors associated with stamina. These include maximum oxygen uptake and blood lactate response to a standardised submaximal exercise test. Fitness tests that measure maximal rates of oxygen use, lactic acid production during exercise and heart rates have also been widely used by researchers to study training responses and fitness in horses. More large-scale studies are required, using horses in normal training programs, if practical measurements of fitness and predictors of performance are to be described. However, no measurement or combination of measurements will ever be perfectly correlated with the ability to perform. Nevertheless, results of appropriate fitness tests can help guide decisions by horse owners and trainers concerning the training and use of horses in competitions or races.

5. References

Amory H. Art T. Linden A. Desmecht D. Buchet M. Lekeux P. (1993) Physiological response to the cross-country phase in eventing horses. J. Equine Vet. Science, 13, 646-650.

Art T. and Lekeux P. (1993) Training-induced modifications in cardiorespiratory and ventilatory measurements in thoroughbred horses. Equine Vet. J., 25, 532-536.

Bailey, C. J. (1998) Wastage in the Australian Racing Industry. Rural Industries Research and Development Corporation, Canberra, Australia, 1-67.

Bayly W.M. (1985) Training programs. Vet Clin Nth Am Equine Practice, 1(3), 597-610.

Beech, J. (1988) Laboratory testing for poor performance. Proceedings 10th Bain Fallon Memorial Lectures, 86-89.

Bramlage L.R., Bukowiecki C.W., Gabel A.A. (1990) The effect of training on the suspensory apparatus of the horse. Proc Ann Conv Am Assoc Equine Pract, 35, 245.

Bruin G., Kuipers H., Keizer H.A., Vander Vusse G.J. (1994) Adaptation and overtraining in horses subjected to increasing training loads. J Appl Physiol., 76, 1908-1913.

Buckingham S.H.W. and Jeffcott L.B. (1990) Shin soreness: a survey of Thoroughbred trainers and racetrack veterinarians. Aust Equine Vet, 8, 148.

Carlson, G.P. and Jones J.H. (1996) A mathematical model of energy costs for correlation with field studies. In: On to Atlanta '96, An International Update for Eventing Enthisiasts. Ed. Clarke, A.F. and Jeffcott, L.B., The Equine Research Centre, Univerrsity of Guelph, Ontario, Canada, 58-61.

Carrier T.K., Estberg L., Stover S.M., Gardner I.A., Johnson B.J., Read D.H. Ardans A.A. (1998) Association between long periods without high-speed workouts and risk of complete humeral or pelvic fracture in thoroughbred racehorses - 54 cases (1991-1994). J. Am. Vet. Med. Assoc., 212, 1582-1587.

Cheung T.K., Warren L.K., Lawrence L.M., Thompson K.N. (1998) Electromyographic activity of the long digital extensor muscle in the exercising thoroughbred horse. Equine Vet. J. 30, 251-255.

Courouce A., Chatard J.C. , Auvinet B. (1997) Estimation of performance potential of standardbred trotters from blood lactate concentrations measured in field conditions. Equine Vet. J. 29, 365-369.

Courouce, A. (1999) Field exercise testing for assessing fitness in French standardbred trotters. Vet. Journal. 157,112-122.

Cutmore C.M.M., Snow D.H., Newsholme E.A. (1985) Activities of key enzymes of aerobic and anaerobic metabolism in middle gluteal muscle from trained and untrained horses. Equine Vet J., 17, 354-356.

Davie A.J., Evans D.L. Blood lactate responses to submaximal field exercise tests in thoroughbred horses. The Vet. Journal, In press.

Day T.R.J., Potter G.D., Morris E.L., Greene L.W., Simmons J.B. (1998) Physiologic and skeletal response to exogenous equine somatotropin (est) in two-year-old Quarter horses in race training. J. Equine Vet. Science, 18, 321-328.

Demmler, T. (1998) Racehorse Training and Driving. Editor Swann, P., Forty-First Yeneb Pty Ltd, Toolern Vale, Vic, Australia, 1-142.

Duren S., Crandell K. (1998) Feeding the endurance horse. World Equine Vet. Rev. 3, 28-35.

Dyson, S.J. (1994) Training the Event Horse. In: The Athletic Horse Principles and Practice of Equine Sports Medicine. Eds. Hodgson D.R. and Rose, R.J. W.B. Saunders, Phil. USA, 419-428.

Eaton M.D., Evans D.L., Hodgson D.R., Rose RJ. (1995) Maximal accumulated oxygen deficit in thoroughbred horses. J.Applied. Physiol., 78, 1564-1568.

Eaton, M.D., Evans, D.L, Hodgson, D.R., Rose, R.J. (1995) The effect of treadmill incline and speed on metabolic rate during exercise in Thoroughbred horses. J. Appl. Physiol. 79, 951-957.

Estberg L., Gardner I,A., Stover S.M., Johnson B.J. (1998) A case-crossover study of intensive racing and training schedules and risk of catastrophic musculoskeletal injury and lay-up in California thoroughbred racehorses. Preventive Vet. Med. 33, 159-170.

Evans, D.L., Rose, R.J. (1987) Maximum oxygen uptake in racehorses: changes with training state and prediction from submaximal cardiorespiratory measurements. In, Equine Exercise Physiology 2, eds. Gillespie, J.R. and Robinson, N.E., ICEEP Publications, Davis, Ca, 52-67.

Evans D. L., Rose, R. J. (1988) Cardiovascular and respiratory responses to submaximal exercise training in the Thoroughbred horse. Pflugers Arch., 411, 316-321.

Evans DL, Rose RJ (1988b) Dynamics of cardiorespiratory function in standardbred horses during constant load exercise. J Comp Physiol B 157: 791-799.

Evans, D. L. (1991) T waves in the equine electrocardiogram: effects of training and implications for race performance. Equine Exercise Physiology 3, eds. Persson, S.G.B., Lindholm, A. and Jeffcott, L.B., ICEEP Publications, Stockholm, 475-481.

Evans, D.L., Harris, R.C.,Snow, D.H. (1993) Correlation of racing performance with blood lactate and heart rate in Thoroughbred horses. Equine Vet. J., 25:441-445.

Evans D.L., Polglaze K.E. (1994) Relationships between electrocardiographic findings, racing performance and training in standardbred horses. Aust. Vet. J. 71, 375-378.

Evans, D.L., Rainger, J.E., Hodgson D.R. Eaton M.D., Rose R.J. (1995) The effect of intensity and duration of training on blood lactate concentrations during and after exercise. In: Equine Exercise Physiology 4. Proc. 4th International Conference on equine Exercise Physiology, ed. Robinson, N.E., R and W Publications, Newmarket UK, Equine Vet. J. Suppl. 18. 422-425.

Evans, D.L., Marlin, D.J. (1999) Pulmonary Function Testing. Proceedings of Fifth International Conference of Equine Exercise Physiology, Equine Vet. J. (Suppl.), in press.

Firth E.C., Delahunt J., Wichtel J.W., Birch H.L., Goodship A.E. (1999) Galloping exercise induces regional changes in bone density within the third and radial carpal bones of Thoroughbred horses. Equine Vet. J., 31, 111-115.

Fox, E.L. and Mathews, D.L. (1981) The Physiological basis of Physical Education and Athletics. 3rd edition, Saunders College Publishing, NY, USA, 1-677.

French D.A., Barber S.M., Leach D.H., Doige C.E. (1989) The effect of exercise on the healing of articular cartilage defects in the equine carpus. Vet Surgery 18, 312-321.

Gabel A.A., Milne D.W., Muir W.W., Skarda R.T., Weingold M.F. (1983) Some physiological responses of Standardbred horses to a submaximal exercise test following conventional and interval training. In Snow, DH, Persson, SGB, Rose RJ eds.: Equine Exercise Physiology, Cambridge: Granta Editions, 497-504.

Gabel., A. (1989) Conditioning the Standardbred. In Equine Sports Medicine, Ed. Jones, W.E., Lea and Febiger, Phil., Pa, USA, 302-306.

Gabriel A., Detilleux J., Jolly S., Reginster J.Y., Collin B., Dessy-Doize C. (1999) Morphometric study of the equine navicular bone: age-related changes and influence of exercise. Vet. Res. Comm. 23, 15-40.

Gauvreau, G.M., Staempfli, H., McCutcheon, L.J., Young, S.S., McDonell, W.N. (1995) Comparison of aerobic capacity between racing standardbred horses. J. Appl..Physiol., 78, 1447-1451.

Golland, L.C., Evans, D.L., Stone, G.M., Tyler-McGowan, C.M., Hodgson, D.R., Rose, R.J. Plasma cortisol and B-endorphin concentrations in trained and overtrained Standardbred horses. Pflugers Archiv - European Journal of Physiology. In press.

Gottlieb M., Essen-Gustavsson B., Lindholm A., Persson S.G.B (1987) Cardiorespiratory and muscle metabolic responses to draught work on a treadmill in Standardbred horses. In: Gillespie JR, Robinson NE, eds.: Equine Exercise Physiology 2, Davis: ICEEP Publications, 384-392.

Gottlieb-Vedi M., Essen-Gustavsson B., Persson S.G.B. (1991) Draught load and speed compared by submaximal exercise tests on a treadmill. In Persson SGB, Lindholm A, Jeffcott LB, eds.: Equine Exercise Physiology 3, Davis: ICEEP Publications, 1991, 92-96.

Gottliebvedi M., Persson S., Erickson H., Korbutiak E. (1995) Cardiovascular, respiratory and metabolic effects of interval training at vla4. J. Vet. Med. - Series A. 42, 165-175.

Green, S., Dawson B. (1993) Measurement of anaerobic capacities in humans. Definitions, limitations and unsolved problems. Sport Med, 15, 312-327.

Gysin J., Isler R., Straub R. (1987) Evaluation of performance capacity and definition of training intensity using heart rate and blood lactate measurements. Pferdeheilkunde 3, 193.

Harkins J.D. and Kammerling S.G. (1990) A comparative study of interval and conventional training methods in Thoroughbred racehorses. J. Equine Vet. Science, 10, 45-51.

Harkins J.D., Kamerling S.G. (1991) Assessment of treadmill interval training on fitness. J. Equine Vet. Sci. 11, 237-242.

Harkins, J.D., Beadle, R.E., Kamerling, S.G. (1993) The correlation of running ability and physiological variables in Thoroughbred racehorses. Equine Vet. J. 25, 53-60.

Harris R.C., Marlin D.J., Snow D.H. (1987) Metabolic response to maximal exercise of 800m and 2000m in the thoroughbred horse. J Appl. Physiol, 63, 12-19.

Harris D.B., Harris R.C., Wilson A.M. Goodship A. (1997) ATP loss with exercise in muscle fibres of the gluteus medius of the thoroughbred horse. Res. Vet, Sci. 63, 231-237.

Hodgson, D.R., Rose, R.J., Allen, J.R., Di Mauro, J. (1986) Changes in skeletal muscle composition in response to training. Am. J. Vet. Res. 47, 12-15.

Hodgson D.R. Rose R.J. (1987) Effects of a nine month endurance training program on skeletal muscle composition in the horse. Vet Record, 121, 271-274.

Ivers, T. (1983) The fit racehorse. Esprit Racing Team, Ltd, Cincinnati, USA.

Kline, K.H., Lawrence, L.M., Novakofski, J., Bechtel, P.J. (1987) Changes in muscle fibre type variation within the middle gluteal of young and mature horses as a function of sampling depth. Equine Exercise Physiology 2, eds. Gillespie J. R. and Robinson, N. E., ICEEP Publications, Davis, CA., 271-277.

Knight, P.K., Sinha, A.K., Rose, R.J. (1991) Effects of training intensity on maximum oxygen uptake. Equine Exercise Physiology 3, SGB Persson, A Lindholm and LB Jeffcott (eds), ICEEP Publications, Davis, Ca. 77-82.

Kobluk C.N., Geor, R.J., King, V.L., Robinson, R.A. (1996) A case control study of racing Thoroughbreds conditioned on a high speed treadmill. J. Equine Vet. Science, 16, 511-513.

Kohn C. W., Muir W. W., Sams R.(1978) Plasma volume and extracellular fluid volume in horses at rest and following exercise. Am.J.Vet.Res. 39:871-874.

Kronfeld D.S., Ferrante, P.L., Taylor, L.E., Elizabet-Custalow, S. (1995) Blood hydrogen ions and lactate ion concentrations during strenuous exercise in horse. In: Equine Exercise Physiology 4. Proc. 4th International Conference on equine Exercise Physiology, ed. Robinson, N.E., R and W Publications, Newmarket UK, Equine Vet. J. Suppl. 18.. 266-269.

Krzywanek H. (1974) Lactic acid concentrations and pH values in trotters after racing. J. Sth Afr. Vet. Ass. 45, 355-360.

Kuipers H. (1998) Training and overtraining - an introduction. Med Sci Sport Ex 30, 1137-1139.

Leadon, D., McAllister, H., Mullins, E., Osborne, M. (1991) Electrocardiographic and echocardiographic measurements and their relationships in Thoroughbred yearlings to subsequent performance. In:Equine Exercise Physiology 3. Eds: S.G.B. Persson, A. Lindholm and L.B. Jeffcott. ICEEP Publications, Davis, California. 22-29.

Lehmann M.J., Lormes W., Opitz-Gress A., Steinacker J.M., Netzer N., Foster C., Gastmann U. (1997) Training and overtraining: an overview and experimental results in endurance sports. J Sport Med Phys Fitness 37, 7-17.

Lekeux, P., Art T., Linden D., Desmecht D., Amory H. (1991) heart rate, haematological ans serum biochemical responses to show jumping. . In:Equine Exercise Physiology 3. Eds: S.G.B. Persson, A. Lindholm and L.B. Jeffcott. ICEEP Publications, Davis, California. 385-390.

Lindholm A. (1985) Biochemical investigation of muscle tissue for evaluating effects of training. Proc. 5th Ann.Sci.Mtg., Assoc. Equine Sports Med., 75-79.

Lovell D. (1994) Training Standardbred trotters and pacers. In;The Athletic Horse Principles and Practice of Equine Sports Medicine. Eds. Hodgson D.R. and Rose, R.J., W.B. Saunders, Phil. Pa, USA, 399-408.

Lovell D.K., Rose R.J. (1991) Changes in skeletal muscle composition in response to interval and high intensity training. Equine Exercise Physiology 3, SGB Persson, A Lindholm and LB Jeffcott (eds), 215-222.

Marlin D.J., Harris R.C., Harman J.C., Snow, D.H. (1987) Influence of post-exercise activity on rates of muscle and blood lactate disappearance in the Thoroughbred horse. In: Gillespie JR, Robinson NE, eds.: Equine Exercise Physiology 2, Davis: ICEEP Publications, 321-331.

Marlin, D.J., Scott, C.M., Schroter, R.C., Harris, R.C., Harris, P.A., Roberts, C.A. Mills, P.C. (1999) Physiological responses of horses to a treadmill simulated speed and endurance test in high heat and humidity before and after humid heat acclimation. Equine Vet. J. 31, 31-42.

McCarthy R.N., Jeffcott L.B. (1998) Monitoring the effects of treadmill exercise on bone by non-invasive means during a progressive fitness programme. Equine Vet J Suppl 6, 88.

McGreevy P.D., Cripps P.J., French N.P., Green L.E., Nicol C.J. (1995) management factors associated with stereotypic and redirtected behaviour in the Thoroughbred horse. Equine Vet. J., 27, 86-91.

McKeever K.H., Schurg W.A., Jarrett, S.H., Convertino, V.A. (1987) Exercise-training induced hypervolemia in the horse. Med. Sci. Sport. Ex., 19, 21-27.

Misumi K., Sakamoto H., Shimizu R. (1994) The validity of swimming training for 2-year-old thoroughbreds. J. Vet. Med. Sci. 56, 217-222.

More S.J. (1999) A longitudinal study of racing Thoroughbreds: performance during the first years of racing. Aust. Vet. J., 77, 105-112.

Munoz A. Riber C. Santisteban R. Rubio M.D., Aguera E.I., Castejon F.M. (1999) Cardiovascular and metabolic adaptations in horses competing in cross-country events. J. Vet. Med. Sci. 61, 13-20.

Murakami M., Imahara T., Inui T. et al. (1976) Swimming exercises in horses. Exp Rep Equine Hlth Lab 13:27-48.

Nunamaker D.M., Butterweck D.M., Provost M.T. (1990) Fatigue fractures in Thoroughbred racehorses: relationships with age, peak bone strain and training. J. Orthopaedic Res., 8, 604-611.

Pattersonkane J.C., Firth E.C., Parry D.A.D., Wilson A.M., Goodship A.E. (1998) Effects of training on collagen fibril populations in the suspensory ligament and deep digital flexor tendon of young thoroughbreds. Am. J. Vet. Res. 59, 64-68.

Pattersonkane J.C., Wilson A.M., Firth E.C., Parry D.A.D., Goodship A.E. (1997) Comparison of collagen fibril populations in the superficial digital flexor tendons of exercised and nonexercised thoroughbreds. Equine Vet. J. 29, 121-125.

Persson, S. G. B. (1967) On blood volume and working capacity in horses. Acta Vet.Scand. Suppl. 19, 1-189.

Persson, S. G. B. and Ullberg, L. E. (1974) Blood volume in relation to exercise tolerance in trotters. J.S.Afr.Vet..Assoc. 45, 293-299.

Persson SGB, Larsson M, Lindholm A (1980) Effects of training on adrenocortical function and red-cell volume in trotters. Zbl. Vet. Med. A 27, 261-268

Poso A.R., Essengustavsson B., Persson S.G.B. (1993) Metabolic response to standardised exercise test in standardbred trotters with red cell hypervolaemia. Equine Vet. J. 25, 527-531.

Price J.S., Jackson B., Eastell R., Wilson A.M., Russell R.G.G., Lanyon L.E., Goodship A.E. (1995) The response of the skeleton to physical training - a biochemical study in horses. Bone 17, 221-227.

Raidal S.L., Love D.N., Bailey G.D. (1997a) Effect of a single bout of high intensity exercise on lower respiratory tract contamination in the horse. Aust. Vet. J. 75, 293-295. Citation 1

Raidal S.L., Bailey G.D., Love D.N. (1997b) Effect of transportation on lower respiratory tract contamination and peripheral blood neutrophil function. Aust. Vet. J. 75, 433-438.

Rainger, J.E., Evans, D.L., Hodgson, D.R., Rose, R.J. (1995) Distribution of lactate in plasma and erythrocytes during and after exercise in horses. Brit. Vet. J., 151, 299-310.

Rammerstorfer C., Potter G.D., Cudd T.A., Gibbs P.G., Varner D.D., Householder D.D. (1998) Physiological responses of mature quarter horses to reining training when fed conventional and fat-supplemented diets. J. Equine Vet. Sci. 18, 175-183.

Revington, M. (1983) Haematology of the racing thoroughbred in Australia. I. Reference values and the effect of excitement. II. Haematological values compared to performance. Equine Vet. J. 152,141-144.

Ridgeway, K.J. (1994) Training endurance hortses. In;The Athletic Horse Principles and Practice of Equine Sports Medicine. Eds. Hodgson D.R. and Rose, R.J., W.B. Saunders, Phil. Pa, USA, 409-411.

Rivero J.L.L., Serrano A.L., Henckel P., Aguera E. (1993) Muscle fiber type composition and fiber size in successfully and unsuccessfully endurance-raced horses. J. Appl. Physiol. 75, 1758-1766.

Rivero J.L.L. (1996) Muscle biopsy as a tool for assessing muscular adaptation to training in horses. Am. J. Vet. Res. 57, 1412-1416.

Rivero J.L.L., Serrano A.L., Henckel P. (1998) Biochemical profile of the gluteus medius muscle in horses with different performance records. Archiv Med. Vet. 30, 23-30, 1998.

Rodiek A.V., Lawrence L.M., Russell M.A. (1987) Cardiovascular effects of intermittent or continuous treadmill conditioning in horses. J. Equine Vet. Sci., 7, 14-19.

Rolton G. (1999) Fit for eventing. In: Horse Deals, Published by S. Harris, Mount Gambier, South Australia, 121-124.

Roneus N., Essen-Gustavsson B., Lindholm A., Persson S. (1999) Muscle characteristics and plasma lactate and ammonia response after racing in Standardbred trotters: relation to performance. Equine Vet. J. 31, 170-173.

Rose R.J., Hendrickson, D.K., Knight, P.K. (1990) Clinical exercise testing in the normal thoroughbred racehorse. Aust Vet. J. 67, 345-348.

Rose R.J., Purdue, R.A., Hensley W. (1977) Plasma biochemical alterations in horses during an endurance ride. Equine Vet. J., 9,122-126.

Schott, H.C., McGlade, K.S., Molander, H.A. , Leroux, A.J., Hindes, M.T. (1997) Body weight, fluid, electrolyte and hormonal changes in horses competing in 50 and 100 mile endurance rides. Am. J. Vet. Res., 58, 303-309.

Schott, H.C., Hinchcliff K.W. (1998) Treatments affecting fluid and electrolyte status during exercise. Vet. Clin. Nth Am. Equine Pract. 14, 175-185.

Shearman J., Hopkins W. J. (1996) Training of Standardbred maiden pacers. J. Equine Vet. Sci., 16, 116-119.

Sherman K.M., Miller G.J., Wronski T.J,. Colahan P.T., Brown M., Wilson W. (1995) The effect of training on equine metacarpal bone breaking strength. Equine Vet. J. 27, 135-139.

Sinha` A.K., Ray, S.P., Rose, R.J. (1991) Effect of training intensity and detraining on adaptations in different skeletal muscles. Equine Exercise Physiology 3, eds. Persson, S.G.B., Lindholm, A. and Jeffcott, L.B., ICEEP Publications, Stockholm, 223-230.

Sosa Leon L.A., Hodgson D.R., Carlson G.P., Rose R.J. (1998) Effects of concentrated electrolytes administered via a paste on fluid, electrolyte and acid base balance in horses. Am. J.Vet. Res. 59, 898-902.

Staaden R. (1991) Winning Trainers their Road to the Top. Headway International Publishing, Perth, Australia.

Stone M.H., Keith R.E., Kearney J.T., Fleck S.J., Wilson G.D., Triplett N.T. (1991) Overtraining: a review of the signs, symptoms and possible causes. J Appl Sport Sci Res 5:35-50.

Thomas D.P., Fregin G.F., Gerber N.H., Ailes N.B (1980) Cardio-respiratory adjustments to tethered-swimming in the horse. Pflugers Arch., 385, 65-70.

Thornton J., Essen-Gustavsson B., Lindholm A., McMiken, D., 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 Snow, DH, Persson, SGB, Rose RJ eds.: Equine Exercise Physiology, Cambridge: Granta Editions, 470-486.

Tyler C.M., Hodgson D.R., Rose R.J. (1996) Effect of a warm-up on energy supply during high intensity exercise in horses. Equine Vet. J. 28, 117-120.

Tyler C.M., Golland L.C., Evans D.L., Hodgson D.R., Rose R.J. (1996) Changes in maximum oxygen uptake during prolonged training, overtraining and detraining in horses. J Appl Physiol 81, 2244-2249.

Tyler C.M., Golland L.C., Evans D.L., Hodgson D.R., Rose R.J. (1998) Skeletal muscle adaptations to prolonged training, overtraining and detraining in horses. Pflugers Arch 436, 391-397.

Tyler-McGowan C.M., Golland LC, Evans D.L., Hodgson D.R., Rose R.J. (1999) Haematological and biochemical responses to training and overtraining in standardbred horses. In Proceedings of the 5th International Conference of Equine Exercise Physiology, Supplement to Equine Vet. J., edited by Jeffcott, L.B., In press.

Valette J.P., Heiles P.H., Wolter R. (1996) Multivariate analysis of exercise parameters measured during the training of thoroughbred racehorses. Pferdeheilkunde. 12, 470-473.

Vonwittke P., Lindner, A., Deegen, E., Sommer H. (1994) Effects of training on blood lactate running speed relationship in Thoroughbred racehorses. J. Appl. Physiol. 77, 298-302.

Wagner P.D. (1995) Determinants of V-O2max - man vs horse. J. Equine Vet. Sci. 15, 398-404.

Wickler, S.J., Troy, W. (1993) Blood volume, lactate and cortisol in exercising Arabian equitation horses. Equine Exercise Physiology 3, SGB Persson, A Lindholm and LB Jeffcott (eds), 397-401.

Wilson R. G., Isler, R. B., Thornton J. R. (1983) Heart rate, lactic acid production and speed during a standardised exercise test in Standardbred horses. Equine Exercise Physiology, eds. Snow, D. H., Persson, S.G.B. and Rose, R. J., Granta Editions, Cambridge, 487-496.

Wilson J.H., Robinson R.A. (1996) Risk factors for equine racing injuries. Comp. Cont. Ed. Pract. Vet., 18, 682.

Zeeb K., Schnitzer U. (1997) Housing and training of horses according to their species-specific behaviour. Livestock Prod. Sci. 49, 181-189.