Chapter 8

WELFARE OF THE RACEHORSE DURING EXERCISE TRAINING AND RACING

D.L. EVANS
Faculty of Veterinary Science, University of Sydney, NSW 2006, Australia

Abstract. The welfare of horses in training for racing and competition can be compromised by errors of management of many processes. Lameness is usually identified, as the major problem facing horse trainers and high lameness rates in racehorses is a major welfare concern. Recent epidemiological studies have shed light on important environmental risk factors for lameness and catastrophic incidents during training and racing. Another important threat to the welfare of the athletic horse is failure of appropriate preparation of the horse for competition, resulting in earlier fatigue during a race. Fatigue during racing causes sub-optimal performance, increases the likelihood of injury and, in prolonged exercise contributes to exhaustion and even death. Failure to allow appropriate recovery periods after episodes of training and competition also contributes to a state of chronic fatigue. Trainers recognise that affected horses (or 'stale' horses) often have mood disturbances and are reluctant to exercise. Continued excessive training and inadequate recovery (termed, over-training) can result in weight loss and poor performance that is not reversed by short-term recovery periods. In events involving prolonged exercise, the performance and welfare of the horse are compromised by inappropriate fluid balance before and during exercise. Failure to properly prepare and maintain fluid balance of endurance horses results in a severe threat to welfare. Pronounced dehydration and hyperthermia can result in exhaustion and death.

1. Introduction

Racehorses are generally required to compete at maximal speeds for between one and three minutes, and endurance horses compete at slow speeds over many kilometres. Most Thoroughbred and Standardbred races occur on circular tracks, with horses required to travel at 50–60 kilometres per hour. Competition at these speeds results in very high metabolic rates, and high impact forces on the limbs. It is not surprising that injuries are common in racehorses, and lameness is the most common health problem and cause of wastage. In endurance horses, the challenge to health is mostly related to the demands of maintaining body temperature and body fluid status.

In this chapter results of recent studies of risk factors for lameness during racing is reviewed. As well, racing of two year old Thoroughbreds is discussed in the light of recent studies, and the overtraining syndrome discussed. Recent studies on mechanisms of exercise-induced pulmonary haemorrhage and appropriate training of horses for competition, are reviewed. Strategies for appropriate fluid and electrolyte balance in endurance horses are also considered.

N. Waran (ed.), The Welfare of Horses, 181–201.

2. Musculoskeletal Injuries and Lameness

Musculoskeletal injuries are very common in athletic horses, and lameness is probably the greatest cause of concern for the welfare of horses in training for racing and eventing (see Figure 1). There have been several studies of the epidemiology of lameness in racehorses, and this section illustrates the scope of the problem. It is important that studies of this type are conducted because solutions to the problem of high lameness rates are unlikely to be found if the nature of the problem is not clearly described and understood by all persons and organisations with an interest in the welfare of the racehorse.

MInjuries and disease sustained in training are less visible to the public than racing injuries, yet they represent an important source of wastage to the industry (Jeffcott *et al.*, 1982) and raise similar concerns for animal welfare. Whilst racing injuries are officially recorded by veterinarians employed by race-clubs in Australia, official records of injuries in training are not maintained. Trainers are not usually required to report injuries sustained during training and the veterinarians servicing the stables are not compelled to notify the stewards of cases they have treated. In contrast, the regulation of veterinary services by the racing authorities in Japan and Hong Kong makes it possible to maintain central records of injuries sustained in training (Watkins 1985; JRA 1991).

Maintenance of detailed records of injuries sustained during training and after racing is fundamental to the process of investigating the causes of the problems,

Figure 1. Racing imposes certain risks of injury on the horse.

and measuring the success or failure of changes to factors such as training, racing, and track design and reconstruction. It is unfortunate that large sums of money are frequently spent on redesign and construction of racetracks in the absence of either good evidence for the changes, or studies of the effect of the changes. Racetracks for Standardbred racing have undergone radical changes in design in many countries. These changes to racetrack construction are an important contributor to improved horse welfare because increased banking of the turns significantly reduces lameness rates after races on these tracks (Evans & Walsh 1997).

Most Thoroughbred horses in Australia are trained on racetracks and must therefore gallop around corners during training. Research has shown that the strain on the third metacarpal bone increases when turning a corner, and increasing the tightness of the corner increases the strain. The strain on the outside limb was consistently more than on the inside limb when exercising around a turn. This difference is accentuated when speed is increased (Davies 1996).

Standardbreds race at approximately 800 metres per minute, often on small racetracks with a circumference of 800 metres. The strains on the limbs will be increased if the design of the racetrack includes irregularities in the surface, and if the turns are not properly banked, as in a cycling velodrome. Underbanking on the turns of a racetrack refers to a design that results in excessive centrifugal forces on the horse as it travels around the bend. Investigations of racetrack design for Standardbred trotters have confirmed the need for adequate banking. When a racetrack was redesigned to remove underbanking in semicircular curves, improve the transition between curves and remove sloping sections on the straight there was marked reduction in gait asymmetry and the heat in fetlock joints (Fredricson *et al.*, 1975a, b). These results suggest the strain on the limbs had been reduced when the banks were steeper on the corners (Fredricson *et al.*, 1975a, b).

The results of these studies indicate that track design and banking of corners may also be a major factor contributing to injuries in Thoroughbred racehorses. Increasing the radius of corners and the degree of banking and placement of inclines in straight stretches may be useful in reducing low-grade lameness such as shin soreness. In addition, during the early stages of training, it would also be advisable to reduce the speed at which horses travel around corners.

Increasing the load a horse must carry increases the ground reaction forces. This increase in ground reaction forces could increase the load placed on the bone during training. Therefore it is possible that the use of heavier riders could increase the incidence of injuries. The skill of the rider may also affect the forces placed on the third metacarpal bone. Studies in trotting horses have demonstrated that a rider is able to redistribute weight borne by the horse from the front limbs to the hindlimbs (Schamhardt *et al.*, 1991). Training without a rider, for example, on a treadmill, may help reduce lameness rates. However, treadmill training is not specific for the demands of racing, and should not be used exclusively.

Reduced lameness rates could be a factor in the superior earnings from prize money in Thoroughbred stables in USA that use treadmills as part of their routine training. 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 trained conventionally. In all age groups and classes the treadmill-trained horses were equal or superior to the conventionally trained horses.

A study examining all types of lameness in a number of different racing stables found that lameness decreased in stables with higher numbers of horses and increased in stables with higher levels of veterinary and farrier involvement (Ross & Kaneene 1996). It is not clear what effect these factors would have on the incidence of shin soreness. Furthermore these results could reflect differences in rates of injury detection, rather than rates of lameness.

Bone mineral density contributes to bone strength, and it can be measured accurately in the distal limb of growing or training horses. Training results in increased mineral density (Firth *et al.*, 2000). A study comparing pasture raised foals to those raised in boxes with and without additional exercise found that pasture raised foals appeared to have a "stronger" musculoskeletal system (Weeren *et al.*, 2000). However, most of the difference in bone mineral density between the three groups disappeared after six months without exercise. Furthermore, as this study did not follow the horses beyond 11 months it is not possible to draw conclusions regarding the permanent damage and consequences for later performance of housing during early development. Differences in exercise levels in foals also had implications for development of articular cartilage, tendon and muscles, and can influence gait. Enforced withholding of exercise retarded development. The authors reported that absence of exercise in the foals had a long-term effect on collagen characteristics in articular cartilage. They speculate that it is possible that this effect could have implications for injury resistance later in life. The authors recommend pasture raising for foals in the first year of life.

2.1. INJURIES IN TWO YEAR OLD THOROUGHBREDS

The training and racing of two-year-olds is a contentious issue because of welfare concerns about subjecting relatively immature horses to high work demands. Mason and Bourke (1973) followed 74 Thoroughbreds in Australia during their two-year-old racing season and reported that 40% were unsound at the end of the season. The most common cause of unsoundness was sore shins (46% of cases). Shin soreness is a training injury that affects the upper dorsal aspect of the third metacarpal bone. The complaint is most commonly observed in young Thoroughbred and Quarter horses during their first racing preparation. The condition is characterised by pain on palpation of the metacarpus and is often associated with an unwillingness to work at high speed. Continued training may lead to diffuse soft tissue swelling visible on the dorsum of the metacarpus (Stover *et al.*, 1988).

Approximately 9% of cases of lameness were associated with sore shins in the UK (Jeffcott *et al.*, 1982; Rossdale *et al.*, 1985). A survey of veterinarians and trainers estimated that shin soreness affected 80% of two-year-olds in Australia (Buckingham & Jeffcott 1990) and 70% in the United States (Norwood 1978). The higher frequency of shin soreness in Australia compared to the UK may be due to the greater emphasis on two-year-old racing in Australia. It also may be associated with the training of horses on tracks involving turns in Australia, unlike many of the straight training tracks in the UK, because strains increase on the cannon bone when horses are exercised around a turn (Davies 1996).

Knee problems (17%), splints (13.5%), sprained fetlock joint (9.5%) and sesamoid problems (5.4%) were also common in the study by Mason and Bourke (1973). The fetlock joint of the front leg is susceptible to injury because it has a relatively small surface area, it has the greatest range of motion of any of the limb joints, and flat racing horses transmit all of their weight through this one joint during one phase of the stride (Pool & Meagher 1990).

In a study of the racing careers of 353 horses sold as yearlings in Australia (Bourke 1995), it was reported that horses that raced as two-year-olds had a greater number of starts over a lifetime and raced in more seasons than those racing first at three years of age. This suggests that there is no detrimental effect of starting racing at two-years of age. However, some horses that first raced in later years may have been given time to mature. Others could possibly have entered training as two-year-olds but had their racing debut delayed because of injury or a lack of ability (Physick-Sheard 1986), and both these factors could subsequently limit the horses' careers. Racing could also be delayed if horses had poor conformation. In the United States, a higher proportion of two-year-olds sustain an injury compared to older horses (Robinson & Gordon 1988), and in Germany, a larger proportion of two-year-olds have training failures compared to older age groups (Lindner & Dingerkus 1993). A similar situation exists in the UK, where two-year-olds lose a greater proportion of available training days due to lameness compared to three-year-olds (Rossdale *et al.*, 1985).

One of the major aims of an epidemiological study by Bailey (1998) was to document the time lost in training due to various categories of injuries and disease. This information could then be used to determine the relative importance of lameness and respiratory conditions, and to determine to what extent injuries and disease in training are responsible for the high proportion of elite horses that do not race as two-year-olds in Australia.

From 525 yearlings catalogued at a major yearling sale in 1995, 169 horses placed with 24 participating trainers were enrolled in a long-term study designed to identify causes of wastage to the Thoroughbred industry (Bailey 1998). Horses were followed from the time of sale until the end of the cohort's three-year-old racing season. Records were maintained on the training, injury and disease status of the horses in the cohort.

Of the 169 horses included in the study, 160 (95%) had entered training in the stable by the end of the two-year-old season, whereas only 76 (45%) had raced as two-year-olds. Eighty-five per cent of the horses suffered at least one incident of injury or disease whilst in training as a two-year-old. The most common injury in two-year-olds was shin soreness, which affected 42% of the 160 horses, followed by fetlock problems (25%) and coughs and nasal discharges (16%). Thirteen per cent suffered from cuts or traumatic injuries, 9% from foot problems, 7% from knee problems, 6% from tying up, 5% from ligament sprain, 3% from fever of unknown origin, 2% from upper respiratory obstruction (*e.g.* roarers) and 1% from tendon strain. Of the horses that suffered from shin soreness as two-year-olds, 40% developed shin soreness a second or third time as a two- or three-year old. The corresponding figure for recurrences of fetlock problems was 48%, and for coughs and nasal discharges 27%.

Bailey (1998) reported that lameness, excluding cuts and traumatic injuries, was the most important veterinary cause of lost training days during the study period (56.2% of total days modified), followed by respiratory conditions (15.8%). These results support those from studies on Thoroughbreds in the UK (Jeffcott *et al.*, 1982, Rossdale *et al.*, 1985) and Germany (Lindner & Dingerkus 1993). This finding was not surprising given that lameness encompasses a wide range of problems and the musculoskeletal system is subjected to frequent stresses from training and racing (Pool & Meagher 1990).

This study of horses in training by Bailey (1998) has provided objective information on the relative impact of injury and disease in Australian Thoroughbreds. Although there is considerable emphasis on two-year-old racing in Australia, less than 50% of elite horses raced during this year. The principal reason for this low figure was the high number of cases of low-grade injuries and disease that occurred during the training of two-year-olds. These minor incidents often altered training or resulted in the horse being rested at pasture, but did not prevent the horse from racing in subsequent seasons. In contrast, major injury was relatively uncommon in young horses in training. Therefore, whilst major injury is relatively uncommon in young horses in training, low-grade injury and disease have the potential to disrupt training schedules, cause significant economic loss and are an important welfare concern.

These findings emphasise the need for further studies of the risk factors for lameness. Epidemiological studies that investigate the multifactorial nature of lameness have contributed important knowledge already, but more studies are needed. It is likely that results of studies in one training environment will not be directly applicable in another because training facilities and practices differ widely. Studies of trotters, pacers, endurance, event and Quarter horses are also needed.

2.2. SHIN SORENESS

Shin soreness is a major cause of lameness in young Thoroughbred horses. The inflammation of the dorsal aspect of the metacarpus is a major animal welfare concern, and a cause of industry wastage. In the following section this disease will be discussed in more detail. The normal responses of bone to the forces that occur during exercise are outlined, and the current knowledge of risk factors for the disease is discussed.

When horses enter training the thickness of the third metacarpal cortical bone increases (Davies *et al.*, 1999). This thickening helps the bone to resist bending forces in the dorsal palmar direction (Nunamaker 1996). Bone remodelling involves changing the internal architecture of the bone cortex without altering the shape of the bone. The remodelling process allows the bone to adapt to mechanical loading and is thought to prevent the accumulation of micro fractures. During the remodelling process a small packet of bone tissue is reabsorbed and new bone is deposited in its place. At the completion of re-modelling the bone requires approximately three months to mineralise sufficiently (Pool 1991; Nunamaker 1996; Brunker *et al.*, 1999).

Following reabsorption there is a period of 1–2 weeks before new bone formation commences. During this period the bone density at that site is reduced and the bone is weakened. Continued loading during this period may result in micro damage accumulation and the beginning of overuse injuries, such as shin soreness (Riggs & Evans 1990; Nunamaker 1996). It has been demonstrated in Quarterhorses that bone density decreases significantly during the first 2 months of training and does not begin to increase until after nearly 3 months of training (Nielsen *et al.*, 1997). The duration of training in many establishments is therefore unlikely to be sufficient for optimal adaptation of bone prior to racing.

The application of load, below that required to cause complete fracture, produces micro damage. If this load is applied repeatedly the level of micro damage will increase and the remodelling process will be accelerated. At a microscopic level the first signs of accelerated remodelling are vascular congestion, thrombosis and resorption of bone. In humans accelerated remodelling does not, initially, produce any symptoms. However as remodelling progresses mild pain will occur during exercise. If loading does not stop then the pain will persist even after the completion of exercise (Brunker *et al.*, 1999).

If the bone loading continues then the size of the resorptive cavities increases, resulting in the appearance of micro fractures that extend into the cortex. These cracks cause a marked reduction in bone strength. At some point there may be insufficient bone to withstand the load. If this happens then a complete fracture occurs (Riggs & Evans 1990; Nunamaker 1996).

The incidence of shin soreness is highest in two-year-old racehorses (Moyer *et al.*, 1991, Bailey 1998). However, there has been no investigation to determine if the age at which training commences influences the incidence of shin soreness. Bailey (1998) found that overall injury rates were no different between males and females. There has been no work conducted to determine if conformation plays a role in the development of shin soreness.

Bone strength at the commencement of training may be an important factor affecting the likelihood of developing shin soreness. The strength of the bone will influence its ability to withstand repeated loading. The total strength of the bone is determined by its stiffness or elasticity, mineral density and shape. Bone density can be estimated by examination of x-rays. However this technique is not precise. Precision can be improved with photon absorptiometry. Combination of photon absorptiometry and ultrasound velocity can be used to estimate the bone elasticity (Jeffcott *et al.*, 1988). It is possible to determine the shape of the bone by manually measuring the cortical thickness from x-ray, although the technique is highly subjective (Brunker *et al.*, 1999).

Bone geometry, or cross sectional area is an important factor in determining the

Table 1. Distances exercised per week in five stables for horses that did and did not develop skin soreness (adapted from Boston & Nunamaker 2000).

		Stable					
		1	2	3	4	5	Average
Total distance (meters/week)	Shin sore	15568	6880	8160	16048	11712	11904
	Not shin sore	12144	8624	9424	14512	14928	10704
Jogged (meters/week)	Shin sore	5296	1232	1904	5856	8288	3744
	Not shin sore	4512	1712	2272	5344	9968	3568
Galloped (meters/week)	Shin sore	10064	5296	6112	9952	3376	7952
	Not shin sore	7424	6384	7024	8928	4768	6880
Breezed (meters/week)	Shin sore	208	352	144	240	48	208
	Not shin sore	208	528	128	240	192	256

load a bone can withstand before failing. In Quarter horses greater cortical mass in the dorsal and medial metacarpal at the commencement of a training program has been associated with a lower injury rate (Nielsen *et al.*, 1997).

An inability to attain a previous maximum exercise speed in a subsequent run, within the same exercise period, is associated with an increase in bone strain (Davies 1996). Therefore the ability of a muscle to withstand the demands of exercise and resist fatigue could be an important factor in the development of shin soreness. These results emphasis the importance of training techniques that maximise the adaptations of exercising muscle that facilitate coping with the demands of competition.

Training methods are an important risk factor for shin soreness in Thoroughbreds. A study in the USA found that varying the speed and distances galloped during "fast work" could reduce the incidence of shin soreness. In this study training speeds were divided into breezing (approximately 900–960 m/min), galloping (approximately 660 m/min) and jogging (approximately 300 m/min). The average distance breezed and galloped in each stable is shown in Table 1. The results showed that the risk of developing shin soreness increased as the weekly distance galloped increased. However the risk decreased as the weekly distance breezed increased. Furthermore the weekly distance jogged did not affect the risk of horses becoming shin sore. The authors concluded that in order to reduce the incidence of shin soreness, trainers should allocate more training time to regular short-distance breezing and less to long distance galloping. However the distance breezed and/or raced should not exceed 5000 m in a 2 month period because it could increase the risk of a fatal injury (Boston & Nunamaker 2000).

Further research needs to be conducted to determine training-related risk factors for shin soreness in other countries, where training techniques are likely to be different.

Training surfaces have long been considered a contributing factor to shin soreness (Buckingham & Jeffcott 1990). Hard tracks are a problem because the ground reaction forces are increased, thereby increasing the strain on the bone. Alternatively training on soft surfaces, whilst providing cushioning, may hasten muscle fatigue (Brunker et al., 1999), which would also increase the strain on the bone (Davies 1996).

Training on wood fibre surfaces may decrease the occurrence of shin soreness (Moyer *et al.*, 1991; Moyer & Fisher 1992). Thirty four percent of horses trained exclusively on dirt developed shin soreness compared to 13.5% of horses trained on woodchip. In addition the horses trained on woodchip accumulated 86 miles of fast work before the onset of shin soreness, whilst horses trained on dirt accumulated only 32 miles. It should be noted that the horses were trained not only on different surfaces but also at different training centres. It is therefore possible that the different injury rates were due to factors other than the differences in the surfaces, such as track geometry.

Dietary deficiencies, especially in calcium, may influence bone density and remodelling. Young Quarter horses entering training and fed high levels of calcium (34.9 grams/day) and phosphorous (26.4 grams/day) had a higher bone density in the third metacarpal bone than those feed 28.3 grams/day of calcium and 21.9 g/day of phosphorous (Nielsen *et al.*, 1998). It is not known if increasing the level of calcium and phosphorous will reduce the risk of shin soreness in Thoroughbred or Quarter horses.

2.3. RISK FACTORS FOR CATASTROPHIC INJURY IN RACEHORSES

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 a 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 (laid up) 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.

The association between distances of high-speed exercise and injury has also been investigated in Thoroughbreds in Kentucky (Cohen *et al.*, 2000). This study found no association between high-speed exercise and onset of either catastrophic or non-catastrophic injury. In fact, cumulative high-speed exercise was inversely associated with risk of injury. This means that the more exercise a horse accumulated, the less likely it was to become injured. For example, a horse with 10 more cumulative furlongs of high-speed exercise during the 1 month period before a race than another horse was nearly 2 times less likely to be injured. These results also suggest that in order to adapt a horse for safe racing, it is important to give high-speed exercise during training. Lack of high-speed exercise in training may cause decreased skeletal density, and consequent increased risk of injury. These results conflict with those reported for Californian Thoroughbreds (Estberg *et al.*, 1998). Cohen *et al.* (2000) suggested that there might be regional differences in the role of high-speed exercise as a risk factor for injury. In addition, the association of increased risk of injury with accumulated high speed exercise in the Californian study might reflect pre-existing health problems or injury that limited the ability to perform high speed exercise. Trainers might try to limit high-speed exercise in horses that have existing injuries, or have had previous lameness.

These findings by (Cohen *et al.*, 2000) illustrate the importance of specificity of training. Horses are more likely to cope with the demands of racing if the training includes appropriate use of the workouts at the speeds used in races. Of course these high-speed workouts should be introduced gradually, and used at appropriate frequencies.

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 a 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 either no lay ups or greater than or equal to 2 lay-ups. Horses with humeral fractures were typically 3-year-old males that had had one 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 might be reduced if horses are cautiously reintroduced into race training after a lay-up.

Risk factors for catastrophic musculoskeletal (MS) injury in Thoroughbred racehorses racing on dirt and grass racetracks in Florida has also been reported (Hernandez *et al.*, 2001). The incidence of MS injury overall was 1.2/1000 race starts. Higher risk of injury was associated with more than 33 days since the last race, and turf-racing surface. Geldings also had higher risk. The association with the number of days since last race may reflect a previous injury or health problem. Higher risk on grass tracks in this study could have been due to turf races, with larger fields and higher prize money being more competitive than races on dirt. The higher risk for geldings may be associated with their racing more frequently or having more races per career than fillies and mares.

Eighteen fractures were reported in a group of 209 thoroughbred racehorses studied over a 12 month period in the UK (Pickersgill & Reid 2002a). The racing fracture incidence rate was over 16 times greater than the incidence rate on training days. No relationship was identified between either age or gender and the occurrence of fractures. Fractures are a significant cause of wastage in the Thoroughbred flat racing population. The authors also concluded that the results were suggestive of a protective effect of training horses on equitrack surfaces. The increased use of such a surface might reduce the incidence of both racing and training injuries. Further investigations of the relationships between training track usage and injury rates during training and racing are urgently needed. Such studies have the potential to change the strategies for design and use of training and racing tracks. Studies of extrinsic risk factors for injury and adoption of sensible findings by industry participants should promote racehorse welfare.

2.4. TENDON INJURY IN NATIONAL HUNT THOROUGHBRED RACEHORSES IN THE UNITED KINGDOM

The prevalence of tendinitis in one National Hunt racehorse stable in the United Kingdom was very high. Twenty five of 96 horses in the study developed tendinitis of the superficial digital flexor tendon over a 12 month period (Pickersgill *et al.*, 2002b, in press). Only 55 (57%) showed no evidence of tendinitis. Other cases included 12 horses that had chronic tendinitis, and 4 that had acute exacerbations of chronic injuries. The likelihood of a horse developing tendinitis increased with age in males and females. However, females were more likely to develop tendinitis at all ages.

2.5. EXERCISE-INDUCED PULMONARY HAEMORRHAGE

Exercise-induced pulmonary haemorrhage (EIPH) occurs in horses that compete at high speeds, including Thoroughbreds, Standardbreds and Quarter Horses. It is a major welfare issue, because horses can bleed to death during a race, or fall during a race and present a danger to other horses and their riders or drivers. The sight of a racehorse bleeding profusely from the nostrils during or after a race frequently arouses great concern about the welfare of the horse and racehorses in general. EIPH is also a likely cause of inflammation in the lower airways (McKane & Slocombe 1999) and so may contribute to poor performance and coughing in racehorses.

It is generally accepted that the cause of EIPH is rupture of the thin membrane that separates the pulmonary blood from the pulmonary alveoli and airways. Rupture is attributed to the high blood pressure that occurs normally in the pulmonary capillaries during intense exercise. Stress failure of the pulmonary capillaries occurs at pulmonary capillary pressures of 75 to 100 mmHg. These high pressures are to be expected in the pulmonary blood vessels in strenuously exercising horses (West & Mathieucostello 1994). Lung trauma in galloping horses resulting in shock waves in the thorax has also been suggested as a cause of EIPH (Schroter *et al.,* 1998).

At heart rates near maximal (in the range from 192–207 beats/min), mean pulmonary arterial pressures (mPAP) ranged from 80–102 mmHg during treadmill exercise (Meyer *et al.*, 1998). A positive relationship occurred between the number of red blood cells in the bronchoalveolar lavage (BAL) fluid and mPAP. In addition, the amount of haemorrhage increased as the mPAP exceeded 80 to 90 mmHg. These results suggest that all strenuously exercised horses may exhibit EIPH. The amount of haemorrhage appears to be associated with the magnitude of the high pulmonary arterial pressure (Meyer *et al.*, 1998). Given that up to 90% of racehorses exhibit EIPH following sprint exercise, the condition could be regarded as a normal response to fast exercise, rather than as a disease.

3. Welfare of Event Horses Competing in Hot, Humid Climates

The Atlanta Olympics in 1996 posed a serious threat to the welfare of the horses competing in the 3-day event. Anticipated conditions were 31–36 °C with relative humidity approaching 100%. Research in the years before the event provided a scientific basis for modifications to the event. Jeffcott & Kohn (1999) have reviewed this research effort, and its contributions to the welfare of competing horses. The importance of proper acclimatisation, avoidance of dehydration and use of appropriate aggressive cooling strategies are emphasised. In Atlanta the duration of all phases of the event were reduced so that the thermal load was decreased. These modifications coupled with appropriate housing, monitoring, and use of misting fans, ensured that no horses experienced heat related problems during the competition.

Methods of cooling of heat stressed horses have sometimes been a contentious issue. Some horse owners believe that application of cold water to a horse's body may cause sore muscles. There is no basis for this belief. Aggressive cooling of the whole body with cold water at 9 °C promotes the welfare of heat stressed horses (Williamson *et al.*, 1995). Rectal temperatures decreased more quickly than in horses treated with tepid water at 31 °C, and no signs of muscle disease were noted in the aggressively cooled horses.

Given that many of the horses coming to Atlanta were to be flown in from areas with a temperate climate, several groups undertook studies investigating the effects of acclimation to heat and humidity. Geor *et al.* (1996) found that as little as five days exposure to heat and humidity for 4 hours/day resulted in a lower core temperature and reduced fluid losses in response to a standardised exercise test as compared with those not exposed. These findings were supported by the studies conducted at the Animal Health Trust (Marlin *et al.*, 1996), where it was shown that horses underwent considerable physiological adaptation in terms of heat tolerance in response to daily exposure for 21 days to conditions of high ambient temperature and humidity. Horses transported for competition in hot environments should therefore be given an appropriate period of acclimatisation.

4. Endurance Horses

Failure to adequately lose body heat can be a serious threat to the health and welfare of endurance horses competing in hot, humid conditions. Fluid losses can be 12–15 litres per hour when it is very hot. Horses can lose 40 kg body weight during an endurance ride. Most of the loss is as sweat, which is rich in sodium, potassium and chloride ions.

Unless the losses of water and electrolytes are replaced, horses will become dehydrated and develop electrolyte imbalances. These responses decrease performance, and depress the horse's thirst. Dehydrated horses are also less able to efficiently regulate their body temperature and are more likely to develop severe, life threatening hyperthermia (Geor & McCutcheon 1998). Electrolyte losses contribute to development of 'thumps' (synchronous diaphragmatic flutter), muscle cramping, and 'tying-up' (exertional myopathy). Severe dehydration and electrolyte losses cause exhausted horse syndrome.

There are sensible strategies that help to avoid these threats to the welfare of endurance horses competing in hot humid conditions. Horses in regular training should receive salt (sodium chloride) in the feed. Depending on environmental conditions and sweat losses during training, 50–125 grams per day has been recommended, with free access to water. Salt blocks cannot be relied on to provide every horse with the correct intake of sodium chloride (Jansson & Dahlborn 1999). Access to good quality hay should provide sufficient potassium.

Before and during a ride an electrolyte paste administered with a large syringe can be used to stimulate drinking (Sosa Leon *et al.*, 1998). In a treadmill study, Arabian horses were given either water or an electrolyte paste before and during 60 km (38 miles) of treadmill exercise (D'sterdieck *et al.*, 1999). The exercise was divided into four bouts of 15 km. Ninety minutes before exercise, the supplemented horses were given 75 grams of a 2:1 'salt-Lite' salt/water mixture, with further 38–50 gram doses given at rest breaks between exercise bouts. Horses given the electrolyte supplement consumed twice as much water, lost less weight during exercise and maintained higher blood sodium and chloride concentrations. Horses should be offered water at every opportunity during endurance rides, including immediately after exercise. However, horses cannot be relied on to rehydrate fully by drinking in the 24 hour period after an endurance ride (Schott *et al.*, 1997).

5. Suboptimal Training as a Threat to Horse Welfare

The welfare of athletic horses is promoted by strategies that maximise fitness and reduce the likelihood of fatigue and injury. Excessive training of horses and racing inadequately trained horses are both major threats to horse welfare. There have been many studies of the physiology of exercise and training in horses. These studies have provided important information that can help promote fitness for competition. The following section summarises some research findings that have provided practical information that can be used to refine horse training in order to maximise fitness.

Training of Thoroughbred and Standardbred horses depends on using strategies that promote stamina, acceleration, and speed. Stamina is promoted by use of an initial phase of training at slow to moderate speeds that builds endurance and promotes increases in maximal oxygen uptake. During this initial phase of training occasional use of higher speed work over very short distances (200–300 m) promotes adaptations in bone. These adaptations will help prevent shin soreness later in the preparation.

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 experience an 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 training at slow speeds similar to those used in competition.

5.1. MONITORING EXERCISE INTENSITY DURING TRAINING

There have been several studies that illustrate that superior adaptations to training can be attained if careful monitoring of exercise intensity is used. Studies of the physiological responses to training have used two methods of monitoring the exercise intensity that can be applied by trainers. These methods describe the intensity by measurement of heart rate during the exercise, or by measuring blood lactate concentration during or immediately after the exercise. Exercise speed resulting in a heart rate of 200 beats/minute has been suggested as suitable for race training (Gysin *et al.*, 1987). However, heart rates in horses during Standardbred and Thoroughbred races are maximal, between 210 and 240 beats per minute, and excessive training at a heart rate of 200 beats per minute might not adequately prepare a racehorse for the physiological and metabolic demands of racing.

5.2. TRAINING TO MAXIMIZE THE ADAPTIVE RESPONSES

Intensity and duration of exercise training influence the rate and degree of adaptation to treadmill exercise training. Training strategies, such as interval training at intensities near maximal, can 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.

Training methods influence the adaptation of muscle to training. Interval training at high speeds on a treadmill resulted in increased concentration of lactate dehydrogenase (LDH) in skeletal muscle, but conventional training does not have the same effect (Lovell & Rose 1991). Lactate dehydrogenase concentration in skeletal muscle has been used as a marker of anaerobic enzyme activity. In that 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 for 600 metres on 3 days per week. 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. This study shows that interval training on a treadmill at speeds calculated with the help of a heart rate meter did promote superior fitness.

Training at a relative intensity of 80% of maximal oxygen uptake (VO_{2max}) for 6 weeks did not result in increases in skeletal muscle (gluteus medius) LDH concentration (Sinha *et al.*, 1991). However, the 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_{2max}). These results show that superior fitness will be attained with training at higher intensities, approaching those that result in maximal oxygen uptake. At these velocities, horses will be exercising at approximately 90% of maximal heart rate. They will also have slightly elevated blood lactate concentrations, in the range 3–8 mmol/l. These results are relevant to horses being trained for Thoroughbred and Standardbred races, and probably to training of event horses.

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. The training of event horses should be monitored to ensure that some of the exercise results in heart rates and post-exercise blood lactate concentrations that are likely to be experienced during competition.

How often should horses exercise in order to obtain a training effect? There have been very few studies of the importance of frequency of training. However, Gottliebvedi *et al.* (1995) found that interval training at VLa_4 on only three days per week is sufficient to cause adaptational changes in exercise tolerance related parameters. VLa_4 is the velocity approximating that, which results in a blood lactate concentration of 4 mmol/l. The results also indicated that some adaptations due to training are rapidly lost over a four week period when horses cease training.

Sprint training at or near racing speeds over 400–1600 m or more represents the final phase of training for racing. 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.

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 need not exceed 800 metres distance. After 800 metres exercise at maximal velocity the blood lactate concentrations are similar to those measured after racing over longer distances, implying that exercise at peak speeds is probably unnecessary over distances greater than 800 metres.

5.3. USE OF SWIMMING EXERCISE

Studies of heart rates in swimming horses 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.

Some horses seem to have great difficulty breathing during swimming, and sometimes horses seem to be weak after leaving the pool. Blood pressures in the pulmonary blood vessels are also high during swimming. It is not known if these blood pressures are sufficiently high to cause frequent exercise-induced pulmonary haemorrhage (EIPH). However, trainers have reported seeing epistaxis (nosebleed) occasionally after swimming of horses.

Swimming training 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 horse 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 could reduce locomotor diseases in young horses.

5.4. IMPORTANCE OF RECOVERY DAYS TO PROMOTE WELFARE OF HORSES IN TRAINING

During the 2 days after a race or intense sprint training, horses should be either completely rested, or only lightly exercised. It is during this period 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.

Dysfunction of the lower respiratory tract has also been reported after intense exercise and transport (Raidal *et al.*, 1997a, b). The implications of these observations for performance or the incidence or severity of disease in horses during strenuous training are unknown. However, avoidance of strenuous exercise during the 2–3 day recovery period after intense exercise is advisable.

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 20–30 minutes or so.

There are no special strategies for recovery from prolonged exercise except provision of water, electrolytes, and a high-energy diet. Prolonged washing of horses with very cold water will assist the cooling down process immediately after racing or competition. 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. There is no decline in muscle glycogen content with a training protocol typical of that used in many British thoroughbred training yards, and glucose supplements are unnecessary (Snow *et al.*, 1991).

5.5. OVERTRAINING

Many horses have periods of short-term fatigue during their training. This fatigue is usually accompanied by reduced appetite. However, the horse usually recovers in 2–4 days. This short-term fatigue after racing or intensive training is more common in horses that have been inadequately prepared for the intense exercise.

Overtraining refers to a syndrome similar to chronic fatigue. It is associated with reduced performance that is not corrected by several weeks of rest. This more severe form of fatigue results in reduced body weight and loss of interest in exercise. The syndrome is caused by repeated use of high intensity training without adequate rest periods. If the training is not stopped there is a serious threat to the animal's welfare. It has been shown that the syndrome is associated with a reduction in the hormonal response to exercise. Golland *et al.* (1999) found that the cortisol response to a standardised treadmill exercise test was decreased in overtrained horses. This finding was not associated with evidence of adrenal exhaustion.

Regular monitoring of body weight is the best way to detect early signs of overtraining. Trainers may also detect signs of mood change in some horses in the early stages of this syndrome. Unfortunately there are no blood tests that can be performed in resting horses that predict the onset of overtraining syndrome.

In conclusion, the welfare of racehorses will be promoted by training that neither undertrains nor overtrains the horse. Properly prepared horses will be fit to compete in their first race, and should recover well after their first race. Excessive use of racing or competition as a training method is likely to result in fatigue and lameness, and high wastage rates. Use of heart rate measurements during exercise can help refine training and promote horse welfare.

6. References

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

Boston, R.C. and Nunamaker, D.M. (2000) Gait an speed as exercise components of risk factors associated with onset of fatigue injury of the third metacarpal bone in 2-year-old Thoroughbred racehorses. *American J. Veterinary Research* **61**, 602–608.

Bourke, J.M. (1995) Wastage in Thoroughbreds. *Proceedings of Annual Seminar of the Equine Branch of New Zealand Veterinary Association*, pp. 107–119.

Brunker, P., Bennell, K. and Matheson, G. (1999) *Stress Fractures.* Blackwell Science Asia, Carlton, Victoria, Australia.

Buckingham, S.H.W. and Jeffcott, L.B. (1990) Shin soreness: a survey of Thoroughbred trainers and racetrack veterinarians. *Australian Equine Veterinarian* **8**, 148–153.

Carrier, T.K., Estberg, L., Stover, S.M., Gardner, I.A., Johnson, B.J., Read, D.H. and 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. American Veterinary Medical Association* **212**, 1582–1587.

Cohen, N.D., Berry, S.M., Peloso, J.G., Mundy, G.D. and Howard, I.C. (2000) Thoroughbred racehorses that sustain injury accumulate accumulate less high speed exercise compared to horses without injury in Kentucky. *Proceedings 46th Annual Convention of the American Association Equine Practitioners* **46**, 51–53.

Davies, H.M.S. (1996) The effects of different exercise conditions on metacarpal bone strains in Thoroughbred racehorses. *Pferdeheilkunde* **12**, 666–670.

Davies, H.M., Gale, S.M. and Baker, I.D.C. (1999) Radiographic measures of bone shape in young Thoroughbreds during training for racing. *Equine Veterinary J. Suppl.* **30**, 262–265.

D'sterdieck, K.F., Schott, H.C., Eberhart, S.W., Woody, K.A. and Coenen, M. (1999) Electrolyte and glycerol supplementation improve water intake by horses performing a simulated 60 km endurance ride. *Equine Veterinary J. Supplement* **30**, 418–424.

Estberg, L., Gardner, I.A., Stover, S.M., and 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. P*reventive Veterinary Medicine* **33**, 159–170

Eaton, M.D., Evans, D.L., Hodgson, D.R., and Rose, R.J. (1995) Maximal accumulated oxygen deficit in thoroughbred horses. *J. Applied Physiology* **78**, 1564–1568.

Evans, D.L. and Walsh, J.S. (1997) Effect of increasing the banking of a racetrack on the occurrence of injury and lameness in Standardbred horses. *Australian Veterinary J.* **75**, 751–752.

Firth, E.C., Rogers, C.W. and Goodship, A.E. (2000) Bone mineral density changes in growing and training Thoroughbreds. *Proceedings of the 46th Annual Convention of the American Association of Equine Practitioners* **46**, 295–299.

Fredricson, I., Dalin, G., Drevemo, S., Hjerten, G. and Alm, L.O. (1975a) A biotechnical approach to the geometric design of racetracks. *Equine Veterinary J.* **7**, 91–96.

Fredricson, I., Dalin, G., Drevemo, S., Hjerten, G. and Alm, L.O. (1975b) Ergonomic aspects of poor racetrack design. *Equine Veterinary J.* **7**, 63–65.

Hernandez, J., Hawkins, D.L. and Scollay, M.C. (2001) Race-start characteristics and risk of catastrophic musculoskeletal injury in Thoroughbred racehorses. *J. American Veterinary Medical Association* **218**, 83–86.

Geor, R.J., MsCutcheon, L.J. and Lindinger, M.I. (1996) Adaptations to daily exercise in hot and humid ambient conditions in trained Thoroughbred horses. *Equine Veterinary J. Suppl.* **22**, 63–68.

Geor, R.J. and McCutcheon, L.J. (1998) Hydration effects on physiological strain of horses during exercise-heat stress. *J. Applied Physiology* **84**, 2042–2051.

Golland, L.C., Evans, D.L., Stone, G.M., Tyler-McGowan, C.M., Hodgson, D.R. and Rose, R.J. (1999) Plasma cortisol and B-endorphin concentrations in trained and overtrained Standardbred racehorses. *Pflugers Archiv – European J. Physiology* **439**, 11–17.

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

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

Jansson, A., and Dahlborn, K. (1999) Effects of feeding frequency and voluntary salt intake on fluid and electrolyte regulation in athletic horses. *J. Applied Physiology* **86**, 1610–1616.

Jeffcott, L.B., Rossdale, P.D., Freestone, J., Frank, C.J. and Towers-Clark, P.F. (1982). An assessment of wastage in Thoroughbred racing from conception to 4 years of age. *Equine Veterinary J.* **14**, 185–198.

Jeffcott, L.B., Buckingham, S.H., McCarthy, R.N., Cleeland, J.C., Scotti, E. and McCartney, R.N. (1988) Non-invasive measurement of bone: a review of clinical and research applications in the horse. *Equine Veterinary J. Suppl.* **6**, 71–79.

Jeffcott, L.B. and Kohn, C.W. (1999) Contributions of exercise physiology research to the success of the 1996 Equestrian Olympic Games: a review. *Equine Exercise Physiology 5, Equine Veterinary J. Suppl.* **30**, 347–355.

J.R.A. (1991) Preventing accidents to racehorses: studies and measures taken by the Japan Racing Association, *Report of the Committee on the Prevention of Accidents to Racehorses*, Japan Racing Association.

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

Lindner, A. and Dingerkus, A. (1993). Incidence of training failure among Thoroughbred horses at Cologne, Germany. *Preventative Veterinary Medicine* **16**, 85–94.

Lovell, D.K. and Rose, R.J. (1991) Changes in skeletal muscle composition in response to interval and high intensity training. *Equine Exercise Physiology* **3**, ICEEP Publications, Davis, Canada, pp. 215–222.

Marlin, D.J., Scott, C.M., Schroter, R.C., Mills, P.C., Harris, R.C., Harris, P.A., Orme, C.E., Roberts, C.A., Marr, C.M., Dyson, S.J. and Barrelet, F. (1996) Physiological responses in nonheat acclimated horses performing treadmill exercise in cool (20 °C/40%RH), hot dry (30 °C/40%RH) and hot humid (30 °C/80%RH). *Equine Veterinary Journal. Supplement* **22**, 70–84.

Mason, T.A. and Bourke, J.M. (1973). Closure of the distal radial epiphysis and its relationship to unsoundness in two year old Thoroughbreds. *Australian Veterinary J.* **49**, 221–228.

McKane and Slocombe (1999) Sequential changes in bronchoalveolar cytology after autologous blood inoculation, Equine Exercise Physiology 5. *Equine Veterinary J. Supplement* **30**, 126–130.

Meyer, T.S., Fedde, M.R., Gaughan, E.M., Langsetmo, I. and Erickson, H.H. (1998) Quantification of exercise-induced pulmonary haemorrhage with bronchoalveolar lavage. *Equine Veterinary J.* **30**, 284–288.

Misumi, K., Sakamoto, H. and Shimizu, R. (1994) The validity of swimming training for 2-year-old thoroughbreds. *J. Veterinary Medical Science* **56**, 217–222.

Moyer, W., Spencer, P.A. and Kallish, M. (1991) Relative incidence of dorsal metacarpal disease in young Thoroughbred racehorses training on two different surfaces. *Equine Veterinary J.* **23**, 166–168.

Moyer, W. and Fisher, J.R.S. (1992) Bucked Shins: Effects of differing track surfaces and proposed training regimes. *Proceedings of the 37th Annual Convention of the American Association of Equine Practitioners*, 541–547.

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

Murakami, M., Imahara, T., Inui, T., Amada, A., Senta, T., Takagi, S., Kubo, K., Sugimoto, O., Watanabe, H., Ikeda, S. and Kameya, T. (1976) Swimming exercises in horses. *Experimental Reports Equine Health Laboratory* **13**, 27–48.

Nielsen, B.D., Potter, G.D., Morris, E.L., Odom, T.W., Senor, M.A., Reynolds, J.A., Smith, W.B. and Martin, M.T. (1997) Changes in the third metacarpal bone and frequency of bone injuries in young quarter horses during race-training- observations and theoretical considerations. *J. Equine Veterinary Science* **17**, 541–549.

Nielsen, B.D., Potter, G.D., Greene, L.W., Morris, E.L., Murraygerzik, M., Smith, W.B. and Martin, M.T. (1998) Response of young horses in training to varying concentrations of dietary calcium and phosphorus. *J. Equine Veterinary Science* **18**, 397–404.

Norwood, G.L. (1978) The bucked-shin complex in Thoroughbreds. *Proceedings of the 24th Annual Convention American Association Equine Practitioners*, pp. 319–336.

Nunamaker, D. (1996) Stress fractures in Thoroughbred racehorses. *Surgery Forum*, 1–4.

Physick-Sheard, P.W. (1986) Career profile of the Canadian Standardbred I. Influence of age, gait and sex upon chances of racing. *Canadian J. Veterinary Research* **50**, 449–456.

Pickersgill, C.H. and Reid, S.W.J. (2002a) Musculoskeletal injuries and associated epidemiological risk factors among Thoroughbred racehorses in the UK, in press.

Pickersgill, C.H., Marr, C.M. and Reid, S.W.J. (2002b) The epidemiology of superficial digital flexor tendinitis among National Hunt racehorses in the UK, in press.

Pool, R.R. (1991) Pathology of the metacarpus. *Proceedings of the 13th Bain-Fallon Memorial Lectures.* Australian Association Equine Practitioners, Sydney, pp. 105–117.

Pool, R.R. and Meagher, D.M. (1990) Pathologic findings and pathogenesis of racetrack injuries. *Veterinary Clinics North America: Equine Practice* **6**, 1–30.

Raidal, S.L., Love, D.N. and Bailey, G.D. (1997a) Effect of a single bout of high intensity exercise on lower respiratory tract contamination in the horse. *Australian Veterinary J.* **75**, 293–295.

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

Riggs, C.M. and Evans, G.P. (1990) The microstructural basis of the mechanical properties of equine bone. *Equine Veterinary Education* **2**, 197–205.

Robinson, R.A. and Gordon, B. (1988). American Association of Equine Practitioners track breakdown studies – horse results. *Proceedings 7th International Conference of Racing Analysts and Veterinarians*, pp. 385–394.

Ross, W.A. and Kaneene, J.B. (1996) An operation-level prospective study of risk factors associated with the incidence density of lameness in Michigan (USA) equine operations. *Preventative Veterinary Medicine* 28, 209–224.

Rossdale, P.D., Hopes, R., Wingfield Digby, N.J. and Offord, K. (1985) Epidemiological study of wastage among racehorses 1982 and 1983. *Veterinary Record* **116**, 66–69.

Schamhardt, H.C., Merkens, H.W. and van Osch, G.J.V.M. (1991) Ground reaction force analysis of horses ridden at the walk and trot. *Proceedings of the 3rd Equine Exercise Physiology Conference* **3**, 120–127.

Schott, H.C., McGlade, K.S., Molander, H.A., Leroux, A.J. and Hines, M.T. (1997) Body weight, fluid, electrolyte, and hormonal changes in horses competing in 50- and 100-mile endurance rides. *American J. Veterinary Research* **58**, 303–309.

Schroter, R.C., Marlin, D.J. and Denny, E. (1998) Exercise-induced pulmonary haemorrhage (EIPH) in horses results from locomotory impact induced trauma – a novel, unifying concept. *Equine Veterinary J.* **30**, 186–192.

Sinha, A.K., Ray, S.P. and Rose, R.J. (1991) Effect of training intensity and detraining on adaptations in different skeletal muscles. *Equine Exercise Physiology* **3**, ICEEP Publications, Stockholm, 223–230.

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

Snow, D.H., Harris, R.C, Harman, J.C. and Marlin, D.J. (1987) Glycogen repletion following different diets. *Equine Exercise Physiology* **2**, ICEEP Publications, California, pp. 701–710.

Snow, D.H. and Harris, R.C. (1991) Effects of daily exercise on muscle glycogen in the thoroughbred racehorse. *Equine Exercise Physiology* **3**, ICEEP Publications, Stockholm, pp. 299–304.

Stover, S.M., Pool, R.R., Morgan, J.P., Martin, R.B. and Sprayberry, K. (1988) A review of bucked shins and metacarpal stress fractures in the Thoroughbred racehorse. *Proceedings of the 34th Annual Convention of the American Association of Equine Practioners* **34**, 129–136.

van Weeren, P.R., Brama, P.A.J. and Barneveld, A. (2000) *Proceedings of the 46th Annual Convention American Association Equine Practitioners* **46**, 29–35.

Watkins, K.L. (1985) A survey of pre-race veterinary withdrawals and post-race veterinary findings during one racing season in Hong Kong. *Proceedings 6th International Conference of Racing* Analysts and Veterinarians, pp. 343–346.

West, J.B. and Mathieucostello, O. (1994) Stress failure of the pulmonary capillaries as a mechanism for exercise induced pulmonary haemorrhage in the horse. *Equine Veterinary J.* **26**, 441–447.

Williamson, L.H., White, S., Maykuth, P., Andrews, F., Sommerdahl, C. and Green, E. (1995) Comparison between two post exercise cooling methods. *Equine Veterinary J. Supplement* **18**, 337–340.