Equine Exercise Physiology 3: 475–481, 1991

T-waves in the Equine Electrocardiogram: Effects of Training and Implications for Race Performance

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ABSTRACT. The incidence of T-wave abnormalities and their association with retrospective race performance and training status were examined in 53 horses, and the association between T-wave abnormalities and current race performance was examined in 27 horses. There was no association between either the number of abnormal T-waves or mean T-wave amplitude in 4 chest leads with race performance measured by Timeform rating. In a longitudinal study of 9 horses and 5 controls, exercise training resulted in the number of abnormal T-waves increasing significantly ($p<0.05$) from 0.7 ± 0.71 before training to 2.6 ± 1.88 after training. The results of this study indicate that the T-wave patterns described in the literature as abnormal are found in a large proportion of trained Thoroughbred racehorses. They are a normal response to training in many horses, and they are not necessarily associated with poor performance

Key words Horses; electrocardiogram; T-waves; exercise; training.

INTRODUCTION

In 1963, Steel[7] investigated resting electrocardiograms in a large sample of Thoroughbred horses. The study concluded that there were abnormal patterns of ventricular repolarisation in some racehorses, and that these abnormalities indicated myocarditis. An association between the T-wave vector in certain limb and chest leads and poor performance of horses in race was proposed. This hypothesis has been supported by other recent studies.[6,8] Stewart et al.[8] found that racehorses presented for clinical examination for poor performance syndrome had a high incidence of T-wave abnormalities. The frequency of these abnormalities was significantly higher than found in a control group consisting of racehorses clinically examined for musculoskeletal problems or for heart score determination. It was also reported that the T-wave abnormalities often resolved during periods of detraining. The aetiology of poor race performance was hypothesised by Stewart et al. as impaired cardiac function, possibly related to training stress. Chest lead T-waves with high amplitude were also thought to indicate more severe cardiac disease.

There have been no longitudinal studies of the T-wave changes in a population of racing Thoroughbred horses. The aim of this study was to examine the patterns of ventricular repolarisation in Thoroughbred racehorses during a period of training and racing, and to investigate the relationship between equine athletic performance and T-waves in the resting electrocardiogram (ECG).

The results of this study indicate that the T-wave patterns described in the literature as abnormal are found in a high proportion of trained Thoroughbred racehorses. They are a normal response to training in many horses, and they are not associated with poor performance.

MATERIALS AND METHODS

Resting ECGs were recorded on horses while they stood quietly in their stables. The floor of the stables consisted of a rubber/fibre material. A Cambridge Instruments electrocardiograph (London, UK) was used to record the six bipolar and unipolar limb leads (Leads I, II, III, avR, aVL and aVF). Four chest leads were also recorded. These were the unipolar lead (CV) and three bipolar leads (CR, CL and CF). The chest electrode was placed approximately 5 cm caudal to the left olecranon, and limb electrodes were placed in the standard locations over the caudal aspect of the distal radius and cranial aspect of the distal tibia. In order to reduce the influence of variable duration of diastole on the pattern of ventricular repolarisation, ECGs were recorded with heart rates less than 45 bpm. Records were made at 25 mm s^{-1} and 1 mV cm^{-1}, not less than 3 hours after exercise.

The criteria used for diagnosis of T-wave abnormality followed that used in previous studies.[6,7,8] T-waves were classified as abnormal if they were positive or diphasic in Lead I, negative in aVR, and positive in the four chest leads. The presence of three or more abnormal T-waves were used as evidence of abnormality. T-wave amplitude in each chest lead was calculated by summing the positive and negative components in three consecutive T-waves, and expressing the mean result in millivolts (mV). The T-wave amplitude for any horse was then taken as the mean of the amplitudes from the four chest leads.

The investigation was conducted by undertaking two cross-sectional studies and one longitudinal study in horses under the care of one trainer.

Cross-sectional studies

Cross-sectional studies were undertaken in March and August of the 1987 English flat racing season. These studies were used to determine the incidence of T-wave abnormalities in a population of Thoroughbred racehorses, and to investigate the relationship between these abnormalities and athletic performance.

In the first study ECGs were recorded in 53 racehorses being trained for racing. There were 8 four year old colts, 25 three year colts and 20 three year old fillies. The horses were not necessarily all at the same stage of training at the time of electrocardiography. Twenty-nine horses (20 colts and 9 fillies) were trotting and slow cantering 6 days per week, and 24 horses had progressed to galloping twice weekly as well as the slower work.

In a second study, electrocardiography was performed in 27 horses (17 colts and 10 fillies) which had been racing during the previous 4 months and were considered by the trainer to be fit for racing at the time of the examination. The horses had been racing over distances from 6 to 12 furlongs (approximately 1 200–2 400 metres), depending on the individual animal's ability.

Timeform rating (Timeform, Halifax, UK) was used as the measure of performance ability. This rating expresses a horse's racing ability in pounds of weight. Higher ratings imply a record of superior performance in races. Very good performances are reflected in ratings of 120–140, whereas those horses which perform poorly have Timeform ratings of less than 90.

Longitudinal study

A longitudinal study was carried out to investigate the effects of training and racing on patterns of ventricular repolarisation. Nine horses were used. Seven colts and two fillies were electrocardiographed before and after a period of strenuous training and racing. Initial ECGs were recorded while the horses were at an early stage of training (trotting and slow cantering). Subsequent ECGs were recorded 5 months later, after all horses had undertaken further training and had raced approximately 3 to 4 times each.

A control group of 5 horses was used. Two horses were stable hacks which undertook some walking and trotting exercise 6 days each week. The remainder were racehorses which had not trained and raced after the initial examination because of musculoskeletal problems.

The effect of training on both the number

Table 1. *T-wave patterns in 53 Thoroughbred racehorses classified by current training routine*

	Training routine	
	Trot/ canter	Canter/ gallop
Number of horses	29	24
Number of horses abnormal	13	20
Incidence of abnormality	45%	85%**
Number of abnormal T-waves	2.5±2.39	3.9±1.56**
Mean T-wave amplitude in 4 chest leads (mV)	0.7±0.65	1.1±0.55*

* $p<0.05$, ** $p<0.01$. mV = millivolts.

of abnormal T-waves and the mean T-wave amplitude in the 4 chest leads was investigated. Heart rate was calculated on each chest lead from the R-wave to R-wave interval at the point at which T-wave amplitude was measured. Resting heart rate was calculated as the mean of the heart rates in the four chest leads.

Statistics

Mean values were compared by an appropriate Student *t*-test, and frequencies by a chi-squared test. The association between variables was measured by least squares linear regression analysis and calculation of the coefficient of determination. Means are expressed ± SD.

RESULTS

Cross-sectional studies

Thirty-three out of 53 horses, or 62%, were classified as abnormal, having three or more ECG leads with abnormal T-waves. There was no significant difference between males and females in frequency of T-wave abnormality.

The presence of T-wave abnormalities in this group was related to the stage of training. These results are summarized in Table 1. Horses which were at a more advanced stage of training involving fast cantering and galloping had a higher incidence of abnormality. The mean T-wave amplitude was also significantly greater in these horses compared with horses trotting and slow cantering.

Only 22 out of 53 of these horses had a racing history sufficient to establish a Timeform rating. A scatter plot of the relationship between number of abnormal T-waves and Timeform rating at the conclusion of the previous season's racing for these 22 horses demonstrates that there was no association between ECG abnormality and retrospective race performance (Fig. 1). The mean Timeform rating in 7 horses with normal ECGs was 90±11.3, and the mean rating in 15 abnormal horses was 97±17.3. The difference was not significantly different. There was also no association between Timeform rating and the mean T-wave amplitude in the 4 chest leads (Fig. 2). There was no relationship between the number of abnormal T-waves and the number of races that horses had run (Fig. 3).

In the study 27 horses that were racing fit, 20 (74%) were classified as abnormal, with 3 or more abnormal T-waves. The mean Timeform rating in the 20 abnormal horses was 105±13.6, which was not significantly different from the mean rating of 99±6.9 in 7 horses with normal ECGs. There was no correlation between Timeform rating and either the number of abnormal T-waves (Fig. 4) or the mean T-wave amplitude in the four chest

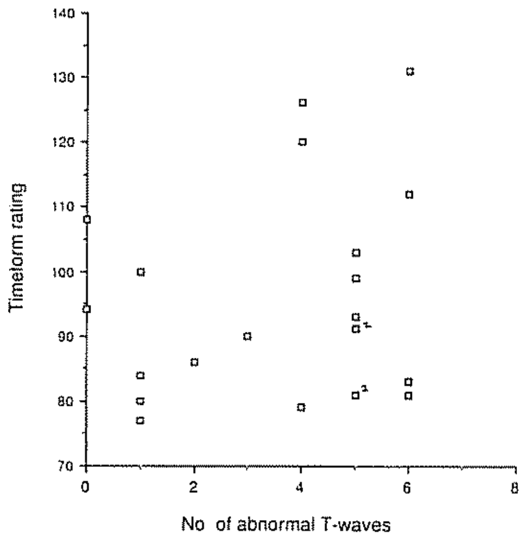

Fig 1 Number of abnormal T-waves and Timeform ratings at the conclusion of racing in the previous year

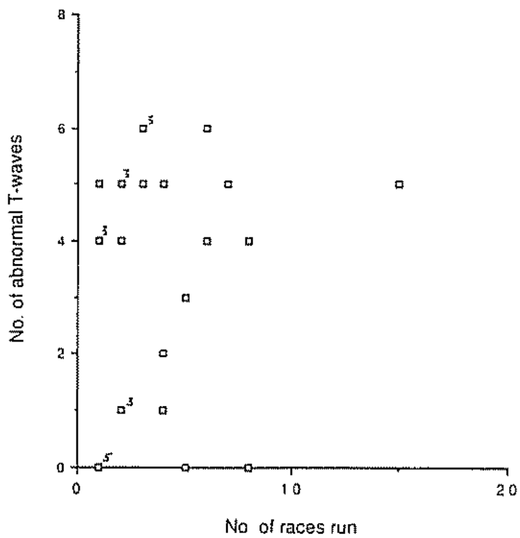

Fig 3 Number of abnormal T-waves versus the number of races in which each horse had competed.

leads (Fig. 5). There was no significant correlation between resting heart rate and either the number of T-wave abnormalities (Fig. 6) or Timeform rating.

Twenty-one of the horses had a Timeform rating at the commencement of the racing season. The mean increase in Timeform rating in 5 horses with less than 3 abnormal T-waves was 12.6 ± 6.27. In 16 horses with 3 or more abnormal T-waves at the commencement of the racing season, the mean increase in Timeform rating was 13.5 ± 12.85.

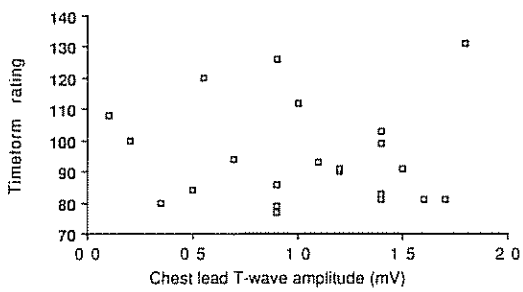

Fig. 2. Mean T-wave amplitude in four chest leads and Timeform ratings at the conclusion of racing in the previous year.

Longitudinal study

The results of the longitudinal study are presented in Table 2. There was no significant difference between the training and control group in resting heart rate, number of abnor-

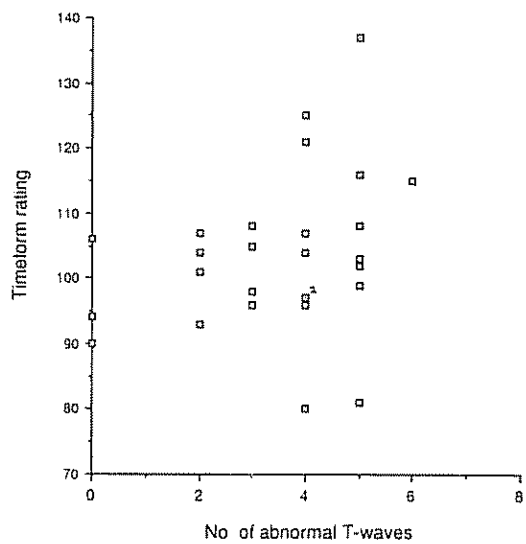

Fig 4 Number of abnormal T-waves and Timeform rating in 27 race-fit horses.

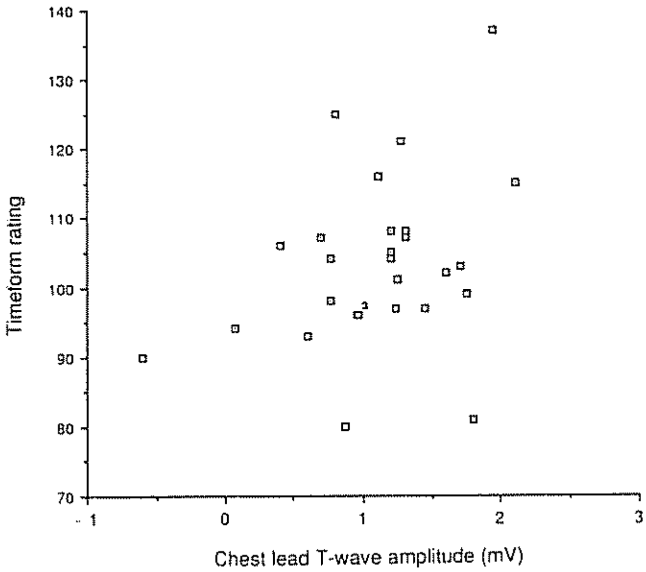

Fig 5. Mean T-wave amplitude in 4 chest leads and Timeform rating in 27 race-fit horses.

mal T-waves or amplitude of T-waves in the initial ECG.

There was a significant effect of training and racing on the number of abnormal T-waves. The mean number of abnormal T-waves increased from 0.7 ± 0.71 to 2.6 ± 1.88. T-wave amplitude decreased significantly in the control group, from 0.1 ± 0.36 mV to -0.5 ± 0.37 mV. T-wave amplitude was significantly higher in the trained horses than in the control group after training. This was due to the combined effect of a decrease in amplitude in the control horses and an increase in the trained horses. There were no significant changes in the mean resting heart rate.

DISCUSSION

A major difficulty of any study of equine athletic performance is the measurement of the quality of that performance. In this study the Timeform rating was used. Timeform ratings are popular with trainers of Thoroughbred horses as a means of assessment of the relative merit of a racehorse's past performances in races. As well as having respect in the industry, the Timeform rating has been used in other studies of the performance of Thoroughbred racehorses in Great Britain.[3] The rating does not differentiate the ability to sprint from stamina, or endurance fitness, but it does provide a means of comparing the quality of athletic performance based on race results. It is the quality of performance in races that determines the financial value of a horse and selects those horses which are suitable for competition in higher grades of competition.

The results of this study seemingly conflict

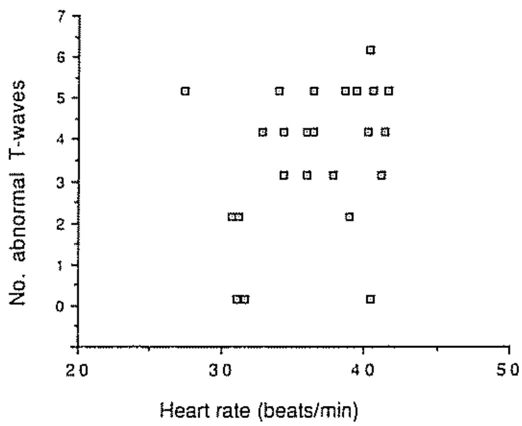

Fig 6. Resting heart rate and number of abnormal T-waves in 27 race-fit horses.

Table 2. *Number of abnormal T-waves, amplitude of chest lead T-waves and resting heart rate before and after training in Thoroughbred horses*

T = number of abnormal T-waves, A = amplitude of T-waves in 4 chest leads (mV), HR = resting heart rate (beats per minute)

	Training group (n=9)			Control group (n=5)		
	T	A	HR	T	A	HR
Before training	0.7 ±0.71	0.5 ±0.24	37 ±5.7	0.4 ±0.89	0.1 ±0.36	38 ±1.3
After training	2.6* ±1.88	0.8 ±0.71	36 ±4.5	0 ±0	−0.5* ±0.37	35 ±1.9

* $p<0.05$.

with those from previous investigations which have associated T-wave abnormalities with poor race performance. Unfortunately the initial work[7] was misleading because no controls were used. There was no quantification of the performance of so-called normal and abnormal horses. Histopathological evidence of myocarditis was found in hearts of horses with abnormal ECGs, but the nature of the ECG abnormalities in these horses was not described in detail.

A retrospective study of ECGs in horses with poor performance found that 80% of horses had abnormal T-waves.[8] This high frequency was significantly greater than found in horses presented at a University clinic for examination for lameness or for heart score determination. The conclusion in that study was that T-wave abnormalities were associated with poor performance. Perhaps this conclusion erroneously assumed that the state of training was the same in both groups of horses, or that training did not result in the observed T-wave patterns described as abnormal. It is possible that the horses examined for poor performance were more highly trained at the time of examination than the group presented for heart score determination or lameness evaluation. This study also did not attempt to quantify the race performance of the two groups of horses.

Some studies have described an association between second degree atrioventricular heart block and poor race performance. Only one horse in the group of 27 race-fit horses had this arrhythmia. This horse coincidentally also had the lowest resting heart rate (27 bpm), and had the most bizarre T-waves, with "abnormal" patterns in six leads and over 2 mV amplitude in the four chest leads. It also had the highest Timeform rating (137), as it had won a Group 1 race.

The relationship between T-wave patterns in the resting ECG and athletic performance has also been the subject of controversy in assessment of human athletes. It has been concluded that changes in T-wave phase or direction are a feature of "athletic heart syndrome", a physiological adaptation of the heart to physical training that is considered abnormal in untrained humans.[1] These T-wave abnormalities have been found in highly trained human athletes, and their presence does not preclude continued participation in sport.[2,5,9]

The mechanisms for the development of T-wave abnormalities remain speculative. It has been reported that T-wave abnormalities in cyclists were progressive in nature, and they seemed to be related to the left ventricular hypertrophy induced by physical training.[4] This report also found that myocardial scintigraphic studies demonstrated normal tracer uptake throughout the myocardium, with no perfusion defect present. It has also been speculated that athletes with a particular inherited pattern of arrangement of myocardial fibres develop hypertrophy that is asymmetrical,[5] and that T-wave abnormalities in asymptomatic, highly trained athletes could have a neurogenic basis.[10] Normalisation of T-waves occurred during exercise and after isoproterenol infusion.[10] These authors suggested that a decreased resting sympathetic tone in trained subjects could unmask, in genetically predisposed athletes, a latent functional asymmetry of the cardiac sympathetic nerves.

The principal conclusion of the current study is that T-wave vectors in the resting ECG of the Thoroughbred racehorse are altered by training. Approximately 80% of trained Thoroughbreds develop a pattern of ventricular repolarisation which has been described in the literature as abnormal and pathological. However, presence of these T-wave patterns in the resting ECG does not indicate that the trained horse is likely to perform badly. The training-induced changes in ventricular repolarisation should be regarded as a normal physiological response to training, rather than as evidence of myocardial disease.

ACKNOWLEDGEMENTS

This study was financially supported and actively encouraged by Mr Luca Cumani, Newmarket, England. Timeform ratings are used with permission from the Directors of Timeform, Halifax, West Yorkshire, UK.

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Equine Exercise Physiology 3: 482–489, 1991

The Effect of Training on Adrenocortical Function in Thoroughbred Racehorses

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ABSTRACT. The effects of training, and of age, on basal and ACTH-stimulated plasma cortisol concentrations were evaluated in 11 two year old and 16 three year old Thoroughbred colts which achieved racing fitness while in flat race training. Cortisol concentrations were measured in samples collected on the morning of rest days, before, and 2 hours after i.v. administration of synthetic ACTH (1 mg). There was no significant difference between the two age groups with respect to baseline and ACTH-stimulated cortisol concentrations; thus they were considered as a single group to evaluate the effect of training. Baseline and ACTH-stimulated cortisol concentrations declined significantly ($p<0.005$) with training but there was no significant change in the ACTH-induced increase in cortisol concentration. It is unlikely that altered sensitivity of the adrenal cortex to endogenous ACTH was responsible for the observed decline in basal plasma cortisol concentrations. This study failed to provide evidence that training induces an increase in "adrenocortical reserve" in Thoroughbred horses.

Key words. Cortisol; adrenocorticotrophic hormone; ACTH; horses.

INTRODUCTION

The endocrine and metabolic responses of horses to maximal and submaximal exercise have been extensively documented.[4,5,8,12,14,18,19,20] The results of these studies indicate that both the intensity and the duration of exercise influence the magnitude and timing of increases in plasma cortisol concentration and that the cortisol response appears to be closely associated with changes in other hormones such as insulin, glucagon, catecholamines and thyroid hormones which are involved in the mobilization of metabolic substrates.[4,5,12,20,24] The effect of training on exercise-associated alterations in endocrine and metabolic functions has been studied in an attempt to evaluate adaptation of these integrated responses to increased work demands.[4,18,19] Limited information is available regarding the effects of training on indices of adrenocortical function measured in the resting horse,[4] despite the popularly held belief that "adrenal exhaustion" may be an important cause of poor performance, especially in the over-trained horse.[9,14,21]

Based on studies in Standardbred trotting horses, which showed higher resting baseline and ACTH-stimulated cortisol concentrations in a group of trained racehorses than in a group of untrained horses, it was suggested that these measures of adrenal function may be useful indicators of state of training.[14] These results also were interpreted as supporting Selye's hypothesis of adrenal adaptation in response to increasing stress demands[17] and the finding that adrenal mass increases in response to increased demand.[3,15,23] A subsequent longitudinal training study involving a small group of Thoroughbred horses failed to demonstrate any significant effect of training (2 months) on resting plasma concentrations of ACTH or cortisol, or in the cortisol response to administration of exogenous ACTH.[4]