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Electrocardiographic and Echocardiographic Measurements and Their Relationships in Thoroughbred Yearlings to Subsequent Performance

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ABSTRACT. This study was initiated to assess various cardiac parameters in Thoroughbred yearlings and to investigate their relationship to one another, to body weight and height and to subsequent performance. Electrocardiography was used to determine heart score, and echocardiography was used to measure left ventricular parameters and the intraventricular septum in M-mode and 2-D mode, in systole and diastole. A total of 630 yearlings were examined. Two horses had significant arrhythmias, 125 received race ratings at 2 years of age and 127 were rated at 3 years of age. Echocardiographic measures for these yearlings were within the ranges previously reported for adult horses. There were differences between echocardiographic measures recorded on the right and left thorax. Heart score and an echocardiographic estimate of heart weight were more closely related to height than to body weight. There was no significant correlation between either heart score or echocardiographic measurements and subsequent performance, at either 2, or 3 years of age.

Key words: Heart score; echocardiography; Thoroughbred yearlings; performance; horses.

INTRODUCTION

The high correlation (0.89) between mean QRS duration recorded from the standard limb leads (heart score) of the equine electrocardiogram and heart weight provides a means of evaluation of the relationship between heart size and racing performance in adult horses.[12] A correlation of 0.44 was observed between heart score and total stake monies won by horses, and this is supported in similar studies.[8,13,14] However, other reports have produced results which do not demonstrate the same strengths of relationship.[2,7] This may be due to the influence of many confounding variables[10] and the indirect nature of the inference of heart size.

Visualisation and measurements of cardiac structure and function in the horse may be achieved using echocardiography[1,11] and the relationships between echocardiographic and autopsy measures of the equine heart have been described and permit the prediction of cardiac weight.[9]

The initial report of echocardiography in the horse described placement of the ultrasound probe on the right thorax at the level of the third intercostal space[11] and this convention has been followed.[9] However, it has been suggested[15] that a clear echocardiogram can be obtained by placing a probe in the fourth intercostal space on either the left or right side. Stroke index as measured by echocardiographic methods may be significantly increased in horses with excellent racing performance.[6]

Performance ability in racehorses will depend on many interactive factors which may include heart weight, body weight and total muscle weight,[5] stride length and frequency,[3,4] temperament, injury, disease and other factors. The isolation of parameters such as heart score,[10] may only be meaningful in the comparison of an individual with an appropriate population. Such evaluations have been attempted in Thoroughbred yearlings prior to sale at auction, using heart score and echocardiographic measurements. The present study was undertaken to quantify the relationship between heart score and echocardiographic features and subsequent racecourse performance.

MATERIALS AND METHODS

Horses

A total of 630 Thoroughbred yearlings, 466 males and 164 females, have been included in the present study, which has extended over a four year period. Echocardiographic studies commenced in 1986 and heart score determinations commenced in 1987. The mean age of the yearlings at the time of examination was 19.3 (SD=1.2) months and their mean body weight measured on weighing scales was 437 (SD=35) kg. They were examined in stables, at rest, during the initial stages of preparation for racing during a programme of ridden and treadmill exercise. Height was measured by tape measure in years 1 and 2 and by measuring stick in years 3 and 4. The height of horses measured in years 3 and 4 was shorter ($\bar{x}=3.0$ cm, $n=252$) than the values recorded in years 1 and 2 ($n=379$). A deduction of 3.0 cm was therefore made from all height measures obtained in years 1 and 2 and the resultant data set ($n=631$) was used in this study.

Heart scores

Heart scores were determined as described previously using a portable, mains electricity rechargeable, battery powered electrocardiograph (CR200 Minigraph, Cardiac Recorders, London, England), using plate electrodes and elasticated straps. Measurements of heart scores was achieved using a $\times 10$ magnification Scale Lupe.

Echocardiography

Ultrasonographic examinations were carried out using a mobile machine (Diasonics DRF200, Sonatron S.A., France) and a 2.25 MHz probe on the left thorax at the level of the third or fourth intercostal space as determined by the quality of the image, in years 1 and 2 of this study. Similar examinations were carried out from the right thorax in years 3 and 4 of this study using a portable machine (Microimager 1000, Ausonics, Melbourne, Australia), and a 2.5 mHz probe. Both machines were equipped with computer software and caliper devices that permitted measurement of screen images at the time of examination in years 1 and 2. In years 3 and 4, these images were recorded on videotape cassettes, and measurements were carried out at a later time. Left ventricular posterior wall thickness (LVPWT), left ventricular internal dimension (LVID) and intraventricular septal thickness (IVST) were measured in diastole (d) and systole (s) in M-mode. An indication of heart weight as evidenced by mean wall thickness at systole and diastole (MWT) was obtained from the formula:

$$\mathrm{MWT} = \frac{\mathrm{LVPWT(d)+LVPWT(s)+IVST(d)+IVST(s)}}{4}$$

as previously described.[9] Left ventricular area (LVA), in diastole (d) and systole (s) was measured in 2-D mode using the measurement tracers on the ultrasound machines. An estimate of left ventricular mass (LVM) was obtained by multiplying the left ventricular area in diastole by the LVPWT(d) value obtained in this case, in 2-D mode (Rantanen, personal communication).

Performance ability

Performance ability was assessed through the use of Timeform ratings (Timeform,

Table 1 *Bodyweight, height, heart score and echocardiographic features of Thoroughbred yearlings (mean and SD)*

LVPWT = Left ventricular posterior wall thickness, LVID = Left ventricular internal dimension, IVST = Intraventricular septal thickness, MWT = Mean wall thickness, LVA = Left ventricular area, LVM = Left ventricular mass (estimated), (d) = diastole, (s) = systole

Parameter		All yearlings	Male	Female	Significance of difference male vs. female
Weight (kg)	$\bar{x}$	437	443	418	<0.001
	SD	(35)	(34)	(30)	
	n	479	356	123	
Height (cm)	$\bar{x}$	157.7	158.2	156.0	<0.001
	SD	(3.6)	(3.7)	(2.7)	
	n	481	364	117	
Heart score	$\bar{x}$	112.7	113.4	110.6	NS
	SD	(11.1)	(11.2)	(10.4)	
	n	522	390	132	
M-mode					
LVPWT(d) (cm)	$\bar{x}$	2.4	2.4	2.4	NS
	SD	(0.4)	(0.4)	(0.4)	
	n	600	442	158	
LVPWT(s) (cm)	$\bar{x}$	3.8	3.8	3.7	<0.002
	SD	(0.6)	(0.5)	(0.5)	
	n	600	442	158	
LVID(d) (cm)	$\bar{x}$	10.5	10.5	10.4	NS
	SD	(0.9)	(0.9)	(0.9)	
	n	599	442	157	
LVID(s) (cm)	$\bar{x}$	6.3	6.4	6.3	NS
	SD	(0.9)	(0.9)	(1.0)	
	n	598	441	157	
IVST(d) (cm)	$\bar{x}$	2.9	3.0	2.7	<0.001
	SD	(0.4)	(0.3)	(0.4)	
	n	598	441	157	
IVST(s) (cm)	$\bar{x}$	2.0	4.2	3.9	<0.001
	SD	(0.5)	(0.5)	(0.5)	
	n	598	441	157	
MWT (cm)	$\bar{x}$	3.3	3.4	3.2	<0.001
	SD	(0.3)	(0.32)	(0.31)	
	n	599	441	157	
2-D mode					
LVA(d) (cm^2)	$\bar{x}$	67.7	68.6	65.2	<0.001
	SD	(10.4)	(5.9)	(4.9)	
	n	579	435	143	
LVA(s) (cm^2)	$\bar{x}$	25.5	25.7	24.7	NS
	SD	(5.7)	(5.9)	(4.9)	
	n	579	435	143	
LVM (estimated)	$\bar{x}$	158.4	160.2	152.6	<0.025
	SD	(33.0)	(33.0)	(32.6)	
	n	579	435	144	

Table 2. *Echocardiographic measurements ($\bar{x}$ and SD) obtained on the right and left thorax in Thoroughbred yearlings*

LVPWT = Left ventricular posterior wall thickness, LVID = Left ventricular internal dimension, IVST = Intraventricular septal thickness, LVA = Left ventricular area, (d) = diastole, (s) = systole

Parameter		Right	Left	Significance of difference
M-mode				
LVPWT(d)	$\bar{x}$	2.3	2.7	<0.001
(cm)	SD	0.3	0.4	
	n	418	182	
LVPWT(s)	$\bar{x}$	3.8	3.9	<0.005
(cm)	SD	0.5	0.6	
	n	418	182	
LVID(d)	$\bar{x}$	10.8	10.0	<0.001
(cm)	SD	0.8	0.8	
	n	417	182	
LVID(s)	$\bar{x}$	6.5	5.9	<0.001
(cm)	SD	0.9	0.7	
	n	417	181	
IVST(d)	$\bar{x}$	2.9	2.8	<0.001
(cm)	SD	0.4	0.4	
	n	418	180	
IVST(s)	$\bar{x}$	4.2	4.1	<0.05
(cm)	SD	0.5	0.6	
	n	418	180	
2-D mode				
LVA(d)	$\bar{x}$	70.3	61.0	<0.001
(cm^2)	SD	9.6	9.1	
	n	418	161	
LVA(s)	$\bar{x}$	25.8	24.6	0.05
(cm^2)	SD	5.4	6.1	
	n	418	161	

Halifax, England) as published in the Timeform Annual, for horses trained in England, through the use of Turform ratings (Turform, Kildare, Ireland) for horses trained in Ireland, and through the use of Official Free Handicap figures published in France.

Statistical methods

Standard statistical methods were used throughout this study, *z* tests and *t* tests were used to compare means and assess the relationships between the different variables.

RESULTS

The values obtained for body weight, height, heart score and echocardiographic measurement for these horses when they were yearlings appears in Table 1.

The values obtained from echocardiographic measures obtained on the right and left thorax are summarised in Table 2. The relationships between heart score and mean wall thickness (MWT), and height and weight are summarised in Table 3. Regression analyses of heart score data and echocardiographic measures other than MWT demonstrated R^2 values of 2.5% ($p<0.001$, $n=500$) for heart score: IVST(d), 5.3% ($p<0.001$, $n=500$) for heart score: IVST(s), and 0.8% ($p<0.05$, $n=500$) for heart score: LV mass. There were no other significant correlations between heart score and echocardiographic measurements.

Performance ability

A total of 399 of the 630 yearlings (63.3% i.e. those examined in the first 3 of the present 4 years of study) could have raced at either 2 and/or 3 years of age, to date. The numbers of yearlings that have been assessed in Timeform, Turform or the French Free Handicap at the end of each year of the study appears below in Table 4. Of the 399 yearlings that might have received a numeric rating at the end of their 2 year old racing career only 125 (31.3%) have done so. 127 of the 206 (61.7%) yearlings that might have received a numeric rating at the end of their 3 year racing career, have done so to date. Heart score and echocardiographic measurements were available from 124 of the 125 horses with numeric ratings at 2 years of age, 108 of these were males, 16 were females. The mean rating for male horses was 87 (SD = 15) and for the females, 91 (SD = 14). The difference between ratings for males and females was not significant at this age, and this was also the case at 3 years of age when the

Table 3. *Relationships between indicators of heart weight (heart score and mean wall thickness (MWT) at systole and diastole) and body weight and height in Thoroughbred yearlings*

	MWT (cm)			Height (cm)			Weight (kg)		
	r^2 (%)	p value	n	r^2 (%)	p value	n	r^2 (%)	p value	n
Heart score	3.1	<0.001	500	3.0	<0.001	380	0%	NS	376
MWT	–	–	–	10.9	<0.001	475	1.3	<0.013	474

p values are based on z tests.

mean rating for males was 95 (SD=20, n=98), and for females 91 (SD=19, n=30).

Regression analysis demonstrated an R^2 value of 49% (p<0.001, n=52) between numeric ratings obtained at 2, and those obtained at 3 years of age. Regression analyses on all other parameters measured in the course of the present study failed to demonstrate a significant relationship between any of these measures, and the subsequent numeric ratings achieved by these horses. Further regression analyses of the value obtained by dividing the measured parameters by body weight also failed to demonstrate any significant relationship between any of the measures and subsequent performance ability.

The values of the measured parameters obtained from 12 of the yearlings with the highest numeric ratings at 3 years of age were compared with the measured parameter values obtained from 12 of the yearlings with the lowest numeric ratings, using Studens t-test (Table 5).

DISCUSSION

The recognition of two horses with clinically unsuspected, significant arrhythmias that had not been present either at the time of purchase for horses bought at auction, or had not been detected in the case of home bred individuals may indicate one of the benefits of clinical examination of horses entering a training programme. Electrocardiographic examination of yearling horses may be other-

Table 4. *Numbers of yearlings with performance ratings at 2 and 3 years of age*

		Timeform or other ratings			
		2 years		3 years	
Year of present study	Total no. of yearlings examined	Total no. of horses that raced	No. of horses with numeric ratings	Total no. of horses that raced	No. of horses with numeric ratings
Year 1	95	34	26 (27%)	64	62 (65%)
Year 2	111	42	39 (35%)	66	65 (59%)
Year 3	193	60	60 (31%)	–	–
Year 4	231	–	–	–	–
Total	630	136	125	130	127

Table 5. *Comparison of measured parameters obtained from 24 yearlings with highest and lowest subsequent numeric ratings at 3 years of age*

LVPWT = Left ventricular posterior wall thickness, LVID = Left ventricular internal dimension, IVST = Intraventricular septal thickness, MWT = Mean wall thickness, LVA = Left ventricular area, LVM = Left ventricular mass (estimated), (d) = diastole, (s) = systole

Parameter	Group: Highest rating ($\bar{x}$)	Group: Lowest rating ($\bar{x}$)	Significance of difference: *p*	Significance of difference: *n*
Numeric rating (2 y)	106	72	0.005	8
Numeric rating (3 y)	128	68	0.001	24
Weight (kg)	423	410	NS	21
Height (cm)	159	157	NS	21
Heart score	122	122	NS	21
M-mode				
LVPWT(d) (cm)	2.8	2.5	NS	20
LVPWT(s) (cm)	4.0	3.7	NS	20
LVID(d) (cm)	10.0	10.0	NS	20
LVID(s) (cm)	6.0	6.2	NS	20
IVST(d) (cm)	2.9	2.8	NS	20
IVST(s) (cm)	4.2	4.0	NS	20
MWT (cm)	3.5	3.3	NS	20
2-D mode				
LVA(d) (cm^2)	65.2	59.4	NS	18
LVA(s) (cm^2)	27.9	24.7	NS	18
LVM (estimated)	135.6	138.1	NS	18

wise of no demonstrable benefit. Despite finding that two of the most successful racehorses included in this study had heart score values in excess of 130 as yearlings, no correlation between heart score and subsequent performance ability could be demonstrated, in contrast to a previous report.[14]

Echocardiographic measurements obtained from these yearlings were of a comparable order of magnitude to those previously reported in older horses.[1] There has not been an opportunity to assess these yearlings again in later life, as either 2 or 3 year old racehorses and thus the degree of cardiac hypertrophy as a result of ageing and training that may have occurred from their entry into training until the end of each year of their racing career remains unknown.

It has been suggested that clear echocardiographic measurements can be obtained by placing the ultrasound transducer on either the right or left side of the thorax. The need for consistency of technique is illustrated by the significant differences observed in the present study, between measures obtained on either side of the thorax (Table 2).

Heart score has been used as an indicator of heart weight despite criticism of the technique used in the original heart score study,[1] and of the statistical treatment and interpretation,[10] and although heart weight can be predicted from echocardiographic wall thickness regressions, the heart removed at autopsy may be unsatisfactory for comparison with the *in vivo* situation.[9] Both heart score and MWT are related to one another and each is more closely related to height rather than weight (Table 3), although these are weak relationships. Heart score could not be related to any other of the echocardiographic parameters examined, and none of the echoparameters could be related to performance.

The difficulty of prospective studies of groups of horses that may succeed in racing in later life is illustrated by the fact that only some 30% of the yearlings examined received numeric race ratings at 2 years of age (i.e. within 12 months of the measurement of the parameters examined). Although in excess of 60% of these yearlings raced with sufficient success to achieve a numeric race rating by the end of their 3 year old careers, the measurement data related to their status some 24 months previously. Injury, temperament and disease, and the effects of the many physiological factors, other than cardiac parameters may all have had a greater or lesser influence in the interim. It is therefore not surprising to find that there was no significant correlation between any of the parameters measured and the subsequent performance of the horses that have raced to date, as a group. The practice of examining yearlings prior to sale, using either an electrocardiogram to determine heart score or to achieve similar determinations based on echocardiography, appears to be extremely questionable as a basis for predicting subsequent performance.

Differences in performance ability between racehorses may be of a relatively low order of magnitude for much of the racehorse population, in that most horses will compete in handicap races at some stage in their career. Success or failure in these races may be determined more by the ability of the trainer to obtain a favourable handicap weight than the inherent ability of the horse. This is not the case in the so-called Classic races, or Group races, run in England, France and Ireland. The present study group included 18 horses that had won Classic or Group races. The twelve highest numeric race rated of these horses were compared to the 12 horses that obtained the lowest race ratings at 3 years of age (Table 5). Although the differences in the measures obtained from the most and least successful racehorses were not significant, it is interesting to note that in 9 of the 13 measured parameters higher values were obtained in the more successful horses. Assessment of larger group sizes in the future, when more of the horses studied to date have raced, may or may not alter the significance of these apparent, but non-significant differences. Even if this were to become the case, the differences would be likely to be too slight to permit selection on this basis.

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Hypoxia Does Not Contribute to High Pulmonary Artery Pressure in Exercising Horses

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ABSTRACT. Mean pulmonary artery pressure (P_{PA}) during exercise is higher in horses (≥80 torr) than in humans and other mammals (≤30 torr). The mechanisms are unknown. To see if hypoxic pulmonary vasoconstriction (HPV) was involved, we compared P_{PA}-flow ($\dot{Q}$) curves when inspired O_2 fraction (F_IO_2) was 0.16, 0.21, and 0.30, in 5 normal Thoroughbred horses standing quietly and after 2 and 2.5 min galloping at 10 and 14 m s^{-1} on a level treadmill. We measured P_{PA}, O_2 content of systemic and pulmonary arterial blood, and respired gas composition and flow, and calculated O_2 consumption ($\dot{V}O_2$) and then $\dot{Q}$ with the Fick method. There was no apparent effect of F_IO_2 on slopes and intercepts of $P_{PA}/\dot{Q}$ curves or on $\dot{V}O_2$ at any speed. We think it unlikely that HPV is an important mechanism in the high P_{PA} of exercising horses.

Key words. Acute hypoxia; hypoxic pulmonary vasoconstriction; pulmonary vascular resistance; pulmonary hemodynamics; horses.

INTRODUCTION

During near-maximal exercise, mean pressure in the pulmonary artery (P_{PA}) reaches 80 torr or more in horses[7,13] compared to about 30 torr in humans.[11,12,19] We wondered what mechanisms might be responsible for these high values. Hypoxic pulmonary vasoconstriction (HPV) is one possible active mechanism. Horses are capable of a pulmonary pressor response to hypoxia,[4,25,26] and hypoxia occurs in horses during heavy exercise. That is, not only does systemic arterial and central venous hypoxemia occur,[1,14,21,23] but also there may be alveolar hypoxia in distal regions of the horse's long acinus when O_2 flux is high[24] and hypoventilation occurs.[1,14] To see if HPV contributed significantly to high P_{PA} in exercising horses, we compared $P_{PA}/\dot{Q}$ curves constructed from data taken at rest and while galloping at 10 and 14 m s^{-1} in horses breathing 16, 21 and 30% O_2.

METHODS

We studied five healthy Thoroughbred geldings aged 2 to 6 years and weighing 516±42 kg (mean ± SD).

Animal preparation

At least six months before the beginning of the study, each horse had its left common carotid artery surgically relocated beneath the skin. The horses were trained for 2–3 months to run on a horizontal treadmill (SATO Inc, Uppsala, Sweden) at speeds up to 14 m s^{-1} for 3 min, and were accustomed to a face mask and associated equipment.

Measurements and calculations

P_{PA} was measured with a catheter-tip pressure transducer (Mikro-tip model PC 471A, Millar Instruments Inc., Houston, TX). It was inserted into the right jugular vein through a 7 French introducer. We moni-