



Cardiovascular variables in eventing and endurance horses over a season

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KEYWORDS

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Holter;
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Abstract *Introduction:* The objectives of this study were to describe the changes in clinical cardiovascular examination variables over a competition season in groups of competitive eventing and endurance horses and to compare these findings to non-competitive controls of the same breeds.

Animals: This study included two eventing horses, 11 endurance horses, and 13 eventing and seven endurance control breed-matched horses.

Materials and methods: Cardiovascular examinations were performed before starting the competition season, in the middle and at the peak/end of the competition season. Examinations included auscultation of the heart; M-mode echocardiographic measurements and calculated values; left atrial, pulmonary artery, and aortic diameters; color flow Doppler; exercise electrocardiograms (ECG) measuring peak heart rates and quantifying premature complexes; and 24-h continuous ECGs quantifying premature complexes per hour. *Results:* Auscultation, echocardiograms, arrhythmias during exercise, and 24-h continuous ECGs did not change significantly throughout the season ($p > 0.05$ for all variables). *Conclusion:* Cardiovascular examination variables of eventing and endurance horses throughout a competition season are reported here for the first time. Although the present study did not reveal significant changes, data should be interpreted carefully as only a small number of horses were examined.

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Abbreviations

ECG	electrocardiogram
SVPC	supraventricular premature complex
VPC	ventricular premature complex

Introduction

Endurance and strength training cause many cardiovascular adaptations in animals and humans, some of which can become maladaptations and place athletes at risk for cardiovascular morbidity [1,2]. In endurance horses, cardiovascular changes including echocardiographic size and function, cardiac biomarkers, arrhythmias, auscultation findings during or after competition [3–5], and the relationship of cardiovascular parameters with performance [6] have been reported. Echocardiographic changes with training have been investigated in racehorses [7–9] and some warmbloods [10] but not in eventing or endurance horses. Prevalence of exercising arrhythmias in several disciplines, breeds, and in poorly performing horses have been reported [11–17]. These studies provide evidence that the occurrence of cardiac arrhythmias varies with breed and/or discipline and that certain arrhythmias occur in horses without apparent clinical consequences. There are few studies reporting multiple exercise electrocardiograms (ECGs) in the same group of horses [18].

While continuous ECG recordings or Holter monitors are considered part of a complete cardiovascular examination, little data have been published regarding normal findings or repeatability of 24-h continuous recordings in horses [19–22],^c. The frequency of arrhythmias in human athletes is higher when compared with non-athletic populations [23], and this aspect has not been explored in equine athletes.

The objectives of this study were to describe normal findings in repeated cardiovascular examinations in eventing and endurance horses at different time points of a competition season and to compare these with examinations in matched populations of non-competitive horses. The hypotheses were that competitive horses would have more arrhythmias and larger echocardiographic measurements than control horses and that those arrhythmias would become more

frequent, and echocardiographic measurements would increase as the season progressed.

Materials and methods

A prospective longitudinal cohort study was performed with the approval of the appropriate committees for animal use and experimentation (permission VD2809). Inclusion criteria in the eventing or endurance group at each time point were normal physical and lameness examinations and the goal to compete in one or more International Federation for Equestrian Sports (FEI) sanctioned eventing competitions CCI*-CCI**** (Concours Complet International) or endurance races CEI**-CEI**** (Concours de Raid d'Endurance International) during 2014. Control horses for the eventing and endurance groups were breed-matched pleasure riding horses with normal physical and lameness examinations and ridden less than 5 h per week. All horses were enrolled by convenience sampling.

Three examinations were scheduled during the 2014 competition season. The first time point (preseason) was at least 4 weeks before the first competition of the season. The second time point (midseason) was approximately halfway through the season. The third time point (peak season) was within 4 weeks of the final and/or most demanding competition. Control groups were examined within 3 weeks of competition horses. The duration of an average competition season in the region where the study was performed is 7–9 months, approximately from March to October. The number of days between time points was recorded.

Echocardiograms

Two-dimensional (left atrium, aorta, pulmonary artery), M-mode, and color Doppler echocardiographic images were obtained using portable ultrasound equipment^d with a 22 mm 2–3.5 MHz phased array probe as previously reported [6]. A continuous single-lead ECG was recorded simultaneously. Two investigators performed the echocardiograms, and all measurements were obtained off-line by one investigator. M-mode measurements were obtained from three non-consecutive cardiac cycles and averaged as previously described [7]. Fractional shortening, left ventricular mass, mean wall thickness, and relative wall

^c Reef VB. Frequency of cardiac arrhythmias and their significance in normal horses. 1989 Proceedings: ACVIM.

^d MyLab 30 or MyLab Five, esaote, Florence, Italy.

thickness were calculated, using previously described formulas [7]. The size of the regurgitant jet was graded from 0 to 4 according to the extent into the receiving chamber with 0 being no jet, 1 being a jet extending into one-fourth of the chamber, 2 being a jet extending half way into the chamber, 3 being a jet extending three-fourth of the way into the chamber, and 4 being a jet that extends into the entire length of the chamber.

Standardized exercise tests

Standardized exercise tests for the eventing and eventing control groups, adapted from previously reported protocols in eventers [24], were performed on an all-weather-sand 1490 m racetrack and included the following: 10 min of walking, 10 min of trotting, 1490 m of cantering at 450 m/min, 1490 m of galloping at 500 m/min, and 1490 m of galloping at 550 m/min and 10 min of walking. Gallops were separated by 5 min of trotting. The standardized exercise tests for the endurance and endurance control groups, adapted from previously reported protocols in endurance horses [25], were performed on an all-weather-sand 1490 m racetrack and included the following: 10 min of walking, 10 min of trotting, 30–60 min of cantering at 350 m/min, 1490 m of galloping at 450 m/min, and 1490 m of galloping at 533 m/min and at least 10 min of walking. Gallops were separated by 5 min of trotting. Blood samples were obtained by direct jugular venipuncture immediately before and after exercise (30 mL), after each gallop (0.5 mL) and 24 h later (30 mL). Whole blood lactate^e was measured immediately in all samples, and results are reported in a separate manuscript [26]. Samples were placed in tubes with no anticoagulant, tubes with EDTA, and tubes with sodium citrate on wet ice until centrifuged at 1500G for 10 min at 4 °C. Plasma and serum were transferred into 1.5-mL vials and stored at –80 °C. Cardiac troponin I was measured on plasma from the EDTA tubes using a chemiluminescent assay, previously used on horses^f [27]. The lower limit of detection and the reference range for the laboratory were 0.01 ng/L and <0.03 ng/mL, respectively. Only samples from workouts with >2 isolated atrial or ventricular premature complexes during peak exercise or multiple premature complexes (>5), pairs or paroxysms of premature

complexes, during peak exercise or immediately after exercise were analyzed.

The cardiac rate and rhythm was recorded throughout the exercise test with a digital telemetry unit^g. Electrodes^h, secured with adhesive foamⁱ and glue^j were placed in a modified base apex lead following manufacturer's recommendations. A GPS system, synchronized with the telemetry unit, was carried by the rider,^k and the speeds were also timed manually. The ECG data were stored on a Secure Digital card, and each R–R interval was analyzed manually and using electronic calipers to determine R–R intervals^g. The peak heart rate for each test was recorded. Data collected were used to study repeated measurements of autonomic tone markers and quantify fitness levels of the groups at different time points [24].

Supraventricular premature complexes (SVPCs) were defined as complexes for which the R–R interval decreased >10% during exercise or >20% at rest in duration from the previous R–R interval, and for which, there was no change in configuration of the QRS complex. If a complex with this description occurred during prominent waxing and waning of the rate, it was classified as a sinus arrhythmia. Ventricular premature complexes (VPCs) were defined as complexes for which the R–R interval decreased >10% during exercise or >20% at rest in duration from the previous R–R interval, and for which, the configuration of the QRS complex was obviously abnormal, compared with the previous sinus QRS complex [11,12]. Complexes with obviously abnormal QRS configuration, when compared with the previous sinus QRS complex, but with R–R intervals that did not meet the aforementioned criteria for prematurity, were defined as idioventricular. Couplets, triplets, or runs of tachycardia (>3 consecutive premature complexes) were recorded separately. Only exercising recordings for which more than 90% of R–R intervals could be identified were analyzed. Arrhythmias during exercise were considered separately from arrhythmias during warm-up and cool-down periods.

For 24-h continuous ECGs, horses were equipped with a digital ECG monitor^g. Electrodes^h stabilized

^g Televet, Engel Engineering Services GmbH, Heusenstamm, Germany.

^h Philips M2202A, Philips Medical Systems, Boeblingen, Germany.

ⁱ Animal Polster, Snogg AS, Mosby, Norway.

^j Medical Adhesive B, Ulrich Swiss, St. Gallen, Switzerland.

^k Televet Mobile Kit, Engel Engineering Services GmbH, Heusenstamm, Germany.

^e Lactate Pro, Axonlab, Baden-Daettwil, Switzerland.

^f Architect 4000, Abbott Laboratories, Abbott Park, Illinois, USA.

with a border of cardboard, to increase stiffness and decrease motion artifacts, were secured according to the user manual for horses without a saddle. The ECG was stored on a Secure Digital card. Twenty-four continuous hours were recorded when possible, and the number of readable hours was reported. The ECG was analyzed as described previously with the number of abnormal beats reported as beats per hour.

Statistics

The sample size calculation, using means and standard deviation from an analogous previously published manuscript [28], was performed with an online calculator for a comparative study of means^l. Sample size calculations determined that 11 horses per group were needed to detect echocardiographic differences expected according to the previously cited reference. A power of 80% and a significance level of 5% were used for calculations. The Shapiro–Wilk test was used to assess normality. Summary statistics were reported as mean \pm standard deviation for normally distributed data and median (range) for non-normally distributed data. For 16 of 54 horses participating in the study, there were missing data points for at least one time point.

Statistical modeling was performed with the software SAS 9.4^m. The continuous variables of the echocardiograms were modeled as mixed linear models with SAS PROC MIXED. The hierarchical structure of the data (repeated measurements on the same horse) was accounted for by adding the individual horse as the subject in the repeated statement. Time and group (control or athlete), as well as their interaction were included as explanatory variables. The level of significance was set to 0.05. Normal distribution of residuals and equality of variance were assessed by normal probability plots and scatterplots of standardized residuals compared with predicted values.

The number of arrhythmias during peak exercise, warm-up/cool-down together, and 24-h continuous monitors were analyzed in separate negative binomial models with SAS PROC GENMOD. Model fit was evaluated by visual assessment of residuals, and scatterplots of standardized residuals were compared with predicted values.

Results

A total of 54 horses were examined, including 20 controls. Table 1 shows demographics, number of days between examinations, and competition levels. There was no significant difference between age or weight of endurance horses (12 ± 2 years, 406 ± 43 kg) compared with controls (14 ± 3 years, 440 ± 40 kg) or between eventing horses (10 ± 3.4 years, 550 ± 40 kg) and controls (8.9 ± 3 years, 576 ± 63 kg) [24]. Sixteen horses were withdrawn throughout later time points of the study for reasons including rider-related (four eventing, two eventing control, three endurance) and musculoskeletal disease (one eventing, four eventing control, and two endurance). Fitness variables including speed at a lactate of 4 mmol/L (VL4) for eventers showed eventers to be more fit than controls [24]. While endurance controls did perform three increasing canter speeds, very few achieved the desired speeds, and therefore, fitness variables were unable to be compared, and their HR_{peak} was lower than expected.

Four eventing group horses had grade 1 or 2/6 systolic murmurs, with a point of maximal intensity over the aortic ($n = 2$), tricuspid ($n = 1$), or mitral valve ($n = 1$) areas. Auscultation findings did not change in individual horses over the season. One horse of the endurance group had a 2/6 early diastolic murmur, with the point of maximal intensity over the aortic valve found at all examinations. Three endurance horses had 1 or 2/6 systolic murmurs over the aortic to pulmonic valve areas auscultated at one time point that were not associated with echocardiographic changes and consistent with physiologic ejection murmurs.

Results of echocardiographic measurements at individual time points are reported in Tables 2 and 3. There was no significant difference in echocardiographic measurements between the eventing and endurance group and their respective controls any time point over the season or a change throughout the season. Statistically significant differences in IVSs and FS that did not follow prospective hypotheses were observed in endurance control horses overtime. Seventeen eventing, eight eventing controls, four endurance, and two endurance controls had mild or clinically insignificant regurgitations jets with no or mild valvular lesions. Regurgitations jet size and valvular defects did not change in individual horses over the season.

Seven of 130 (5.3%) exercising ECGs were excluded because of poor quality. Results of exercising ECGs are summarized in Table 4. There

^l <http://sampsizemethod.sourceforge.net/iface/s2.html#means>.

^m SAS/STAT®9.4 User's Guide, Cary, NC, USA.

Table 1 Demographics of horses at different time points of a training season.

Discipline	Breed	Age (years)	Preseason, n (g/m/s)	Pre to mid (days)	Midseason n (g/m/s)	Mid to peak (days)	Peak season n (g/m/s)	Prelim	1*	2*	3*	4*
Eventing	Warmblood	10 ± 3.4	22 (17/5/0)	127 (+/-34.4)	17 (13/4/0)	106 (+/-27)	17 (13/4/0)	1	13	8	2	0
Eventing control	Warmblood	8.9 ± 3.1	13 (5/7/1)	143 (+/-36.2)	8 (4/4/0)	79 (+/-33.1)	8 (4/4/0)	-	-	-	-	-
Endurance	Arabian	11.8 ± 2.2	11 (6/4/1)	116 (+/-41.7)	9 (5/4/0) ^a	48 (+/-15.6)	7 (3/4/0)	-	3	3	5	1
Endurance control	Arabian	14.3 ± 3.6	7 (4/3/0)	109 (+/-43.2)	7 (4/3/0)	51.5 (+/-28.5)	7 (4/3/0)	-	-	-	-	-

Preliminary and stars refer to the highest level FEI competition competed in 2014. *n*, total number of horses.

g, gelding, m, mare; s, stallion.

^a One endurance horse was examined at the midseason and peak season but not at the preseason.

was no significant difference in the peak heart rate during exercise or the number of premature complexes in the peak exercise and warm-up and recovery periods between the eventing group and controls at any time point and no effect of time. In the endurance horses, the number of arrhythmias during warm-up and cool-down periods was smaller at midseason and peak season compared with preseason (Table 5). There was no significant difference between endurance horses and control horses. Arrhythmias during exercise were not different between endurance horses and controls and did not change over time. Plasma concentration of

cardiac troponin I was within the normal range (≤ 0.03 ng/mL) in all the 33 horses measured. Figs. 1–3 show examples of arrhythmias displayed by the study horses.

Arrhythmias during the continuous recordings are reported in Table 6. There was no significant difference in the number of SVPCs/hour or VPCs/hour between eventing or endurance group horses and their respective controls and no change over the season. Two eventing horses had >1 SVPC/hour at preseason and one eventing horse had >1 SVPC/hour at midseason. One eventing control and one endurance horse had >1 VPC/hour at preseason.

Table 2 Echocardiograms in eventing horses and respective controls.

Discipline [n]	Preseason		Midseason		Peak season		p-value
	Eventing [22]	Control [13]	Eventing [16]	Control [8]	Eventing [17]	Control [8]	
IVSd (cm)	3.4 ± 0.4	3.2 ± 0.4	3.3 ± 0.3	3.2 ± 0.3	3.3 ± 0.4	3.1 ± 0.4	0.45
LVIDd (cm)	11.7 ± 0.7	11.6 ± 1.0	11.9 ± 0.7	11.8 ± 1.1	11.5 ± 0.5	11.6 ± 1.0	0.76
LVPWd (cm)	2.6 ± 0.2	2.6 ± 0.3	2.5 ± 0.2	2.5 ± 0.5	2.6 ± 0.2	2.5 ± 0.5	0.93
IVSs (cm)	4.8 ± 0.5	4.9 ± 0.5	4.9 ± 0.4	4.9 ± 0.5	4.8 ± 0.4	4.7 ± 0.6	0.81
LVIDs (cm)	7.0 ± 0.6	6.9 ± 0.8	6.7 ± 0.9	7.0 ± 0.9	6.8 ± 0.6	6.7 ± 0.9	0.97
LVPWs (cm)	4.2 ± 0.4	4.1 ± 0.4	4.4 ± 0.4	4.3 ± 0.6	4.2 ± 0.2	4.2 ± 0.4	0.18
LA (cm)	12.2 ± 0.5	12.1 ± 1.0	12.1 ± 0.6	12.0 ± 1.1	12.0 ± 0.5	11.6 ± 1.1	0.78
PA (cm)	6.7 ± 0.4	6.6 ± 0.5	6.5 ± 0.5	6.6 ± 0.6	6.3 ± 0.4	6.6 ± 0.6	0.43
Ao (cm)	7.7 ± 0.6	7.7 ± 0.7	7.9 ± 0.6	8.0 ± 0.6	7.8 ± 0.5	7.7 ± 0.6	0.45
FS (%)	40 ± 4.6	42 ± 5.9	44 ± 7.0	41 ± 3.9	41 ± 5.2	42 ± 5.0	0.61
MWT (cm)	3.0 ± 0.2	2.9 ± 0.3	2.9 ± 0.3	2.9 ± 0.4	2.9 ± 0.2	2.8 ± 0.3	0.60
RWT	0.51 ± 0.05	0.50 ± 0.05	0.49 ± 0.06	0.49 ± 0.04	0.51 ± 0.05	0.49 ± 0.06	0.36
LVM (g)	4068 ± 500	3862 ± 807	3990 ± 568	4009 ± 1113	3812 ± 420	3727 ± 852	0.88

Results are reported as mean ± standard deviations at individual time points. *n*, number of horses.

p-value represents significance for change over the course of the season and is derived from the model described in the Materials and methods section.

Ao, aorta; IVSd, interventricular septum during diastole; IVSs, interventricular septum during systole; FS, fractional shortening; MWT, mean wall thickness; LA, left atrium; LVIDd, left ventricular internal diameter during diastole; LVIDs, left ventricular internal diameter during systole; LVM, left ventricular mass; LVPWd, left ventricular posterior thickness wall during diastole; LVPWs, left ventricular posterior wall thickness during systole; PA, pulmonary artery; RWT, relative wall thickness.

Table 3 Echocardiograms in endurance horses and respective controls.

Discipline [n]	Preseason		Midseason		Peak season		p-value
	Endurance [11]	Control [7]	Endurance [8]	Control [7]	Endurance [7]	Control [7]	
IVSd (cm)	2.8 ± 0.3	3.1 ± 0.3	2.9 ± 0.1	2.7 ± 0.3	2.8 ± 0.3	2.7 ± 0.4	0.33
LVIDd (cm)	11.4 ± 0.8	11 ± 0.6	11.3 ± 0.9	11 ± 0.9	11 ± 0.9	10.8 ± 0.9	0.68
LVPWd (cm)	2.6 ± 0.5	2.6 ± 0.1	2.4 ± 0.2	2.4 ± 0.3	2.4 ± 0.4	2.2 ± 0.1	0.31
IVSs (cm)	4.7 ± 0.4	4.5 ± 0.5	4.7 ± 0.4	4.4 ± 0.2	4.5 ± 0.4	4.1 ± 0.3	0.049*
LVIDs (cm)	6.6 ± 0.4	6.5 ± 0.6	6.6 ± 0.7	6.6 ± 0.9	6.5 ± 0.5	6.6 ± 0.6	0.99
LVPWs (cm)	4.0 ± 0.3	4.1 ± 0.5	3.9 ± 0.4	3.9 ± 0.5	4.2 ± 0.4	3.7 ± 0.2	0.66
LA (cm)	11.6 ± 0.8	11.5 ± 0.7	11.6 ± 0.7	11.4 ± 0.9	11.4 ± 0.8	11.1 ± 0.6	0.81
PA (cm)	5.9 ± 0.4	6.2 ± 0.5	6.2 ± 0.5	6.2 ± 0.4	5.8 ± 0.7	6.1 ± 0.6	0.65
Ao (cm)	7.0 ± 0.3	7.1 ± 0.5	7.2 ± 0.4	7.2 ± 0.5	7.2 ± 0.6	7.2 ± 0.6	0.81
FS (%)	42 ± 2.6	45 ± 7.2	47 ± 2.1	49 ± 5.3	48 ± 3.6	50 ± 4.9	0.02*
MWT (cm)	2.7 ± 0.3	2.8 ± 0.2	2.6 ± 0.1	2.6 ± 0.2	2.6 ± 0.2	2.4 ± 0.2	0.07
RWT	0.48 ± 0.06	0.51 ± 0.06	0.47 ± 0.03	0.47 ± 0.06	0.48 ± 0.04	0.46 ± 0.06	0.48
LVM (g)	3443 ± 646	3420 ± 350	3217 ± 591	2995 ± 340	3132 ± 675	2686 ± 411	0.09

Results are reported as mean ± standard deviations at individual time points. n, number of horses.

p-value represents significance for change over the course of the season and is derived from the model described in the Materials and methods section.

Ao, aorta; IVSd, interventricular septum during diastole; IVSs, interventricular septum during systole; FS, fractional shortening; MWT, mean wall thickness; LA, left atrium; LVIDd, left ventricular internal diameter during diastole; LVIDs, left ventricular internal diameter during systole; LVM, left ventricular mass; LVPWd, left ventricular posterior thickness wall during diastole; LVPWs, left ventricular posterior wall thickness during systole; PA, pulmonary artery; RWT, relative wall thickness.

* Significance is due to difference in preseason and peak season in control horses.

Discussion

This study describes cardiological findings in eventing and endurance horses at three time points throughout one competitive season. Previous studies in equine athletes have shown that age has an effect on the prevalence of arrhythmias [17], and it has been suggested that adaptations to training over time could be the underlying mechanism. The data presented in the present study gives information about arrhythmias at different time points during a competitive season, as an initial step to evaluating the potential effect of training on arrhythmias in eventing and endurance horses.

The presence of more premature complexes during warm-up and cool-down periods compared with intense exercise is consistent with previous reports [11,12,16,29]. Although a definition for 'clinically significant' arrhythmias in horses has been proposed [15], this definition has been challenged, and specific definition for the number of ectopic beats that constitute an abnormal exercising electrocardiogram is currently lacking [30]. The number of premature complexes detected in the eventing horses in the present study is similar to that reported in dressage horses [11] during and after exercise, lower compared with Standardbreds

after race [29] or show jumpers during a jumping course [12], and higher compared with Thoroughbreds during warm-up, training, and recovery [16]. The lower number of arrhythmias observed during warm-up and cool-down periods during exercise tests performed at midseason and peak season in endurance horses goes against one of the study hypotheses. As discussed previously, the number of arrhythmias was similar to previous studies and within the ranges described in horses without cardiovascular disease and unlikely to be clinically relevant. Arrhythmias during warm-up and cool-down periods have been proposed to be affected by autonomic tone and perhaps by psychological factors, and this decrease could reflect habituation of horses to the environment or the exercise test routine [18,29]. The higher heart rate during peak season of the eventing controls compared with eventing horses suggests that the eventing horses were more fit. It is possible that arrhythmias would have been more frequent if horses had been exercised at maximal heart rates.

The overall results of the cardiovascular examinations and performance of horses up to rider expectations did not suggest the presence of cardiovascular disease. This suggests that all, or most, the exercising arrhythmias detected in this study are likely to be of no clinical relevance. Our

Table 4 Arrhythmias during the standardized exercise tests.

Time	Eventing						Endurance					
	Discipline [n]	HRpeak [n]	Gallop		Warm-up/cool-down		Discipline [n]	HRpeak [n]	Gallop		Warm-up/cool down	
			SVPC	VPC	SVPC	VPC			SVPC	VPC	SVPC	VPC
Preseason	Eventing	190 ± 12	0 (0–9)	0 (0–2)	0 (0–22)	0 (0–3)	Endurance	173 ± 27			0 (0–6)	
	[17]	[17]	[3]	[3]	[5]	[6]	[11]	[11]	[0]	[0]	[4]	[0]
Midseason	Control	196 ± 16	0 (0–1)	0 (0–1)	0 (0–7)	0 (0–3)	Control	170 ± 14		0 (0–1)	0 (0–4)	0 (0–1)
	[13]	[13]	[1]	[1]	[4]	[5]	[7]	[7]	[0]	[1]	[3]	[1]
Peak season	Eventing	189 ± 8	0 (0–1)		0 (0–17)	0 (0–8)	Endurance	163 ± 23	0 (0–1)	0 (0–1)		
	[17]	[17]	[2]	[0]	[4]	[4]	[7]	[7]	[1]	[1]	[0]	[0]
Peak season	Control	193 ± 8		0 (0–3)		0 (0–1)	Control	162 ± 2		0 (0–2)	0 (0–2)	0 (0–1)
	[8]	[8]	[0]	[1]	[0]	[2]	[6]	[2]	[0]	[1]	[1]	[3]
Peak season	Eventing	187 ± 11*	0 (0–3)	0 (0–4)	0 (0–16)	0 (0–4)	Endurance	168 ± 26	0 (0–2)	0 (0–4)		0 (0–1)
	[13]	[13]	[4]	[1]	[4]	[5]	[5]	[5]	[1]	[1]	[0]	[1]
Peak season	Control	201 ± 10			0 (0–14)	0 (0–14)	Control	139 ± 24		0 (0–2)		
	[7]	[7]	[0]	[0]	[2]	[2]	[6]	[6]	[0]	[1]	[0]	[0]

Number of premature complexes is reported as: median (minimum and maximum) of abnormal beats [number of horses]. All variables showed no significant changes throughout the season, except HRpeak at peak season ($p < 0.05$). n , number of horses in each group.

HRpeak = peak heart rate during the exercise test, reported as mean ± standard deviation; SVPC, supraventricular premature complex; VPC, ventricular premature complex.

Table 5 Results of the negative binomial model on the effect of time and endurance and endurance control horses on arrhythmias during the warm-up/cool-down phase of the standardized exercise tests.

Parameter	Estimate	Wald 95% confidence interval	p-value
Intercept	0.60	-0.53 to 1.74	0.29
Preseason	-(reference)		
Midseason	-1.45	-2.90 to -0.0004	0.0499
Peak season	-2.97	-5.20 to -0.74	0.009
Endurance	-0.36	-1.63 to 0.92	0.58
Control	-(reference)		
Dispersion	1.83	0.63 to 5.32	

study design does not allow to formally define the limit between physiological and pathological arrhythmias, but these data contribute to a growing database which may help to define which arrhythmias can be regarded as incidental findings in eventing and endurance horses.

Similarly, the results of these 24-h continuous ECGs contribute to knowledge of repeated

recordings in a group of well-characterized horses of homogenous breeds and occupations. Previous equine literature describes premature beats as 'infrequent'^c and analyzes small populations [20,21]. In humans, it is reported that men below the age of 40 years should have less than one SVPC or VPC per hour [30]. In human athletes, underlying heart disease is less likely when there are less than 2000 VPCs/24 h period, no sustained ventricular tachycardia, and no structural heart disease [2]. It is uncertain if these criteria apply to the horse, but nevertheless all horses met the latter criteria. Three competition horses had >1 SVPC/hour at one time point, while one competition and one control horse had >1 VPC/hour. Of these horses, one eventing horse also had a higher than average number of SVPCs in its exercise ECG compared to its group, but all others had normal clinical cardiovascular examinations throughout the season. The combination of exercising and continuous-resting ECGs can be complementary when interpreting clinical relevance of arrhythmias [31].

There were no differences in echocardiograms over the training season in eventing and endurance horses in the present study. Previous studies have shown echocardiographic changes (hypertrophy) and an increase in valvular regurgitation as

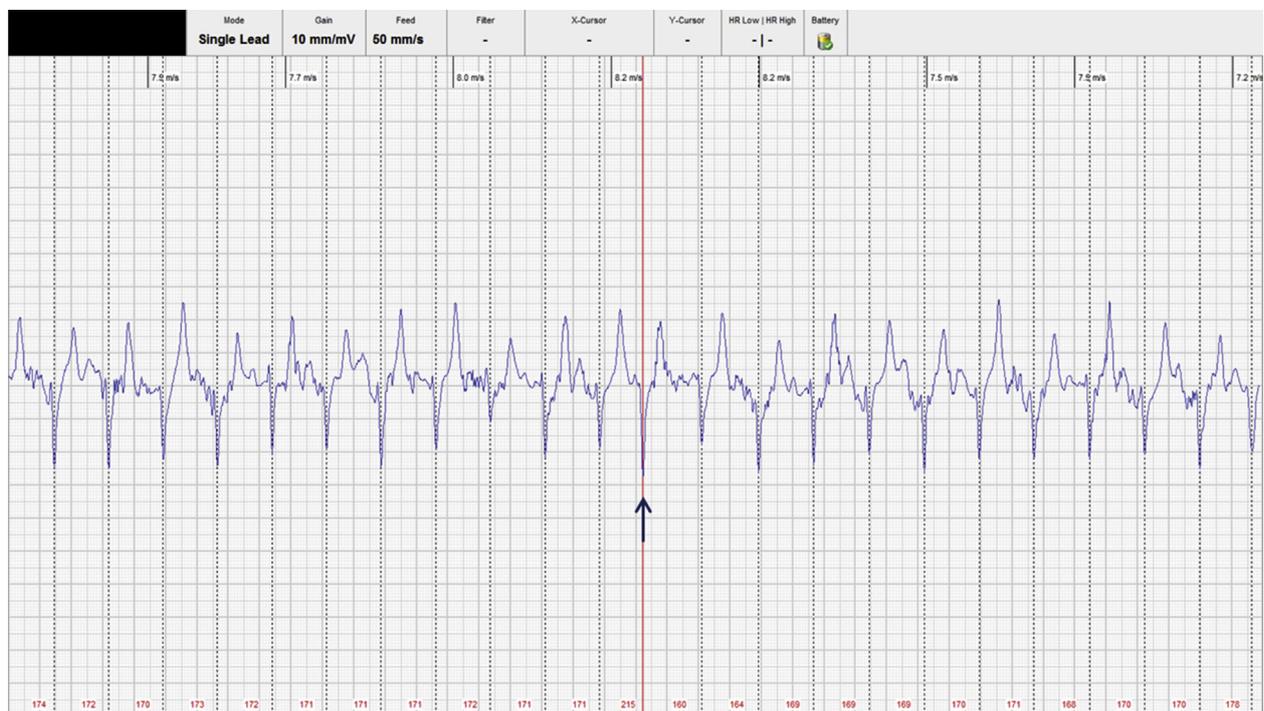


Fig. 1 Exercising ECG of a 15 year old eventing Warmblood gelding. Note heart rate at the bottom of the image and speed at the top. Paper speed 50 mm/s, gain 10 mm/mV, lead II is a modified base-apex configuration. A SVPD during peak exercise is marked with the black arrow.

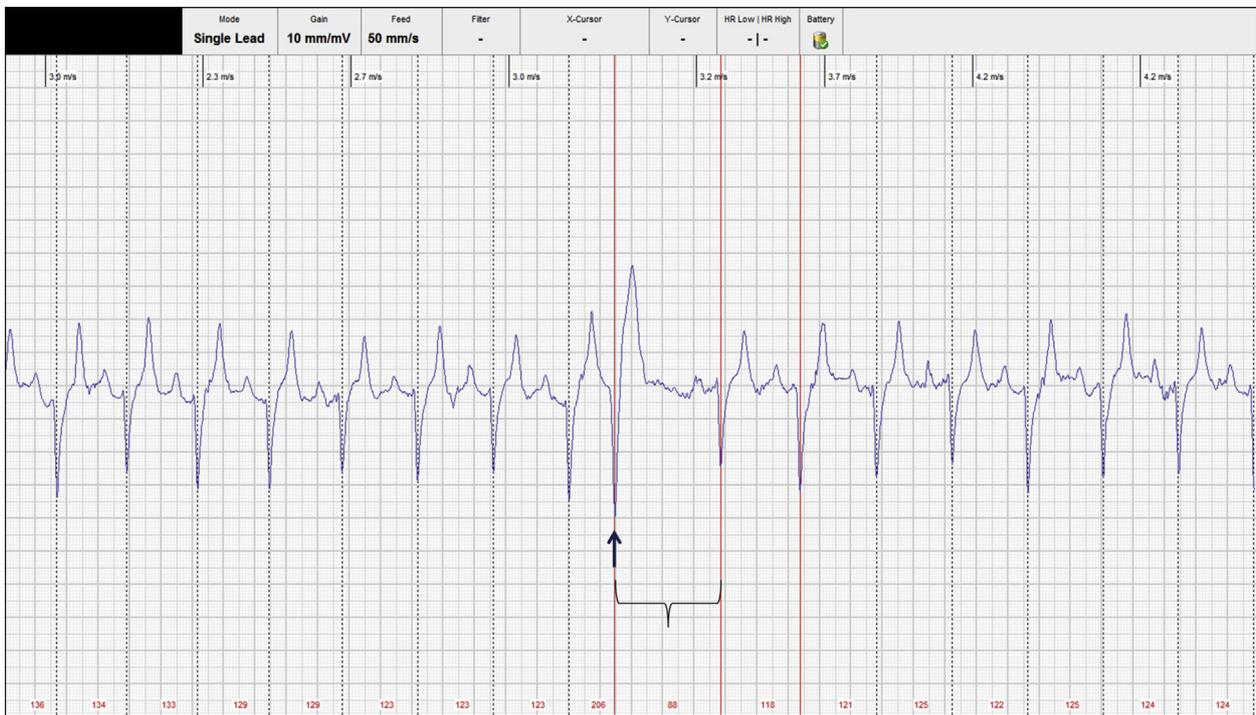


Fig. 2 Exercising ECG of a 9 year old eventing Warmblood gelding. Note heart rate at the bottom of the image and speed at the top. Paper speed 50 mm/s, gain 10 mm/mV, lead II is a modified base-apex configuration. A VPD during peak exercise is marked with the black arrow and the following compensatory pause by the bracket.

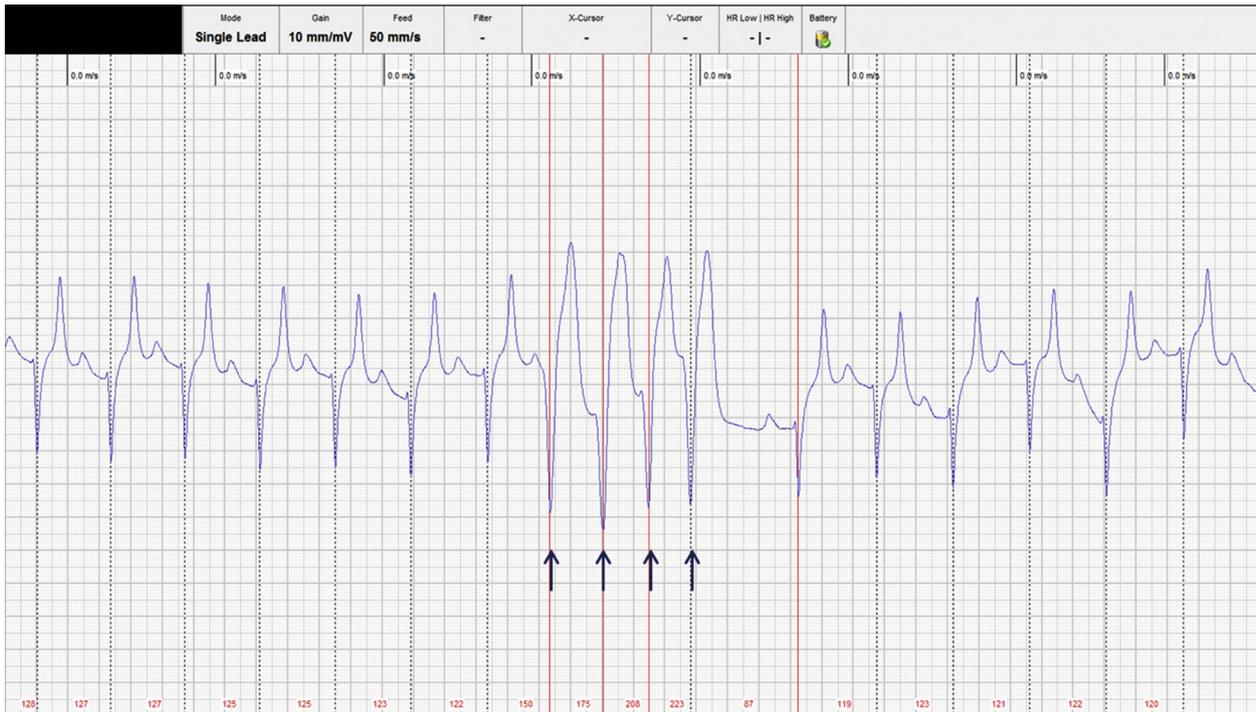


Fig. 3 Post-exercise ECG of a 10 year old eventing Warmblood gelding. Note heart rate at the bottom of the image and speed at the top. Paper speed 50 mm/s, gain 10 mm/mV, lead II is a modified base-apex configuration. Non-sustained ventricular tachycardia during deceleration marked by the black arrows.

Table 6 Twenty-four-hour Holter electrocardiogram results.

Time	Eventing					Endurance				
	Discipline [n]	Readable hours, median (min-max)	SVPC/hour median (min-max)	VPC/hour, median (min-max)	Discipline [n]	Readable hours, median (min-max)	SVPC/hour, median (min-max)	VPC/hour, median (min-max)		
Preseason	Eventing [22]	22 (10-24)	0.2 (0-1.5) [19]	0 (0-0.4) [11]	Endurance [11]	19 (12.8-22.8)	0.1 (0-1.0) [8]	0 (0-1.4) [3]		
	Control [13]	23.1 (18-24)	0.1 (0-0.5) [7]	0 (0-1.2) [5]	Control [7]	19.5 (15.2-22.3)	0 (0-0.3) [4]	0 (0-0) [2]		
Midseason	Eventing [17]	22.8 (14-24)	0.1 (0-1.2) [9]	0 (0-0.04) [2]	Endurance [9]	12.4 (10-20.9)	0.1 (0-0.3) [5]	0 (0-0) [0]		
	Control [8]	22.3 (9-23.8)	0.1 (0-0.5) [6]	0 (0-0.04) [3]	Control [7]	20 (16.1-21.9)	0 (0-0.1) [3]	0 (0-0.06) [3]		
Peak season	Eventing [17]	20.3 (17.1-23.8)	0.1 (0-1.8) [14]	0 (0-0.3) [4]	Endurance [7]	21 (14.4-22.8)	0.04 (0-0.2) [4]	0 (0-0.08) [2]		
	Control [8]	22.3 (15.2-23.8)	0.1 (0-0.3) [4]	0 (0-0.1) [1]	Control [7]	21.9 (8.4-22.8)	0.02 (0-0.1) [3]	0 (0-0.04) [1]		

Number of premature complexes and readable hours reported as: median (minimum and maximum) of abnormal beats or hours [number of horses with abnormal beats]. All variables showed no significant changes throughout the season. n, number of horses. SVPC, supraventricular premature complex; VPC, ventricular premature complex.

training progressed in Standardbred [7,32] and Thoroughbred racehorses [8,9]. It is possible that the stimulus of one training season for eventing or endurance horses is not sufficient to induce similar changes. The current horses in this study were adults that had been in training for years, and the competitive level of the horses was heterogeneous. It is plausible that results in a population of young eventers or endurance horses with a more intense training stimulus or monitored for a longer period of time would be different. Statistical changes observed in endurance control horses did not follow prospective hypotheses, were small in magnitude, and were considered clinically irrelevant.

The number of horses included was small, and the number of variables examined was large, predisposing the study to type I error. The sample size for the comparison of eventing and endurance horses with their respective control group varied between seven and 22 horses per group. This study has several other limitations, resulting from the use of privately owned horses in training and competition. A lack of precise information quantifying the exercise schedules and the variable off-season before the first examination may have caused changes in fitness to be less marked compared with studies where untrained horses were recruited and more intense, and homogeneous training programs were implemented [8,32]. Some horses did not complete all examinations, but the rate and the reasons for withdrawal were analogous to previous reports [33]. In addition, 24-h continuous ECGs were sometimes incomplete because of training schedules. The population was heterogeneous, and horses were competing at different levels and ridden by amateurs and professionals, reflecting variability faced by clinicians. Cardiovascular examinations that include a rigorous exercise test cannot be performed at any time, as adequate timing is needed to avoid injuries and respect competitive goals. 'Within 4 weeks of the time of competition' was chosen as a time period unlikely to allow significant changes. It is possible that cardiovascular changes occurred in this period, but longer times are expected to cause cardiovascular changes associated with detraining in most scenarios in other species [34]. Tests were analyzed and interpreted on the day of the examination, and the clinician investigator had all the clinical information available to provide riders with real-time assessment. The electrocardiographic and echocardiographic data could have been re-analyzed by a blinded observer to decrease the possibility of bias, and this is a limitation of the

study. The low number and the variable intensity of the standardized exercise test in the endurance group is another important limitation of the study. Evaluating larger groups of homogenous competitive levels could help further define the potential cardiovascular effects of different workloads in horses performing eventing and endurance exercise.

Conclusions

The study describes cardiological variables of eventing and endurance horses with no clinical signs of poor performance throughout a competition season. Data collected from a larger number of subjects from more homogenous groups would be useful to further investigate cardiovascular examination findings and adaptations to training and competition in sport horses.

Conflicts of Interest Statement

None of the authors of this article have a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper.

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