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Findings in 261 cardiac examinations of warmblood sport horses and their association with performance

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Summary: The prevalence of cardiac findings and their influence on the performance potential of warmblood sport horses is widely debated. This paper evaluates the frequency and correlation of valvular regurgitations, dimensional changes, and arrhythmias in 261 warmblood sport horses retrospectively. These horses were examined because of clinical complaints (e.g., poor performance) or due to murmurs or arrhythmias detected as an incidental finding. Frequency analysis showed that mitral valve regurgitation was the most common valvular regurgitation in our population (n = 194), followed by regurgitations of the aortic valve (n = 46). Dimensional changes of the left atrium were associated with an increased risk of atrial fibrillation (OR = 3.18, p = 0.05). Furthermore, their possible influence on performance was assessed. If the heart was detected as the cause of an exercise intolerance by exclusion of other pathologies (n = 39), atrial fibrillation was the most frequent finding. Other cardiac findings discovered frequently in horses with poor performance were severe MVI, severe TVI, AVI, and ventricular and supraventricular premature complexes. However, most horses presented for cardiac examination did not show any clinical signs of cardiac disease (n = 176), and the pathologies described were in most cases incidental findings. Therefore, we can state that mild and moderate valvular regurgitations are in most cases of little clinical relevance. However, valvular regurgitations are associated with an increased risk for the development of dimensional changes. The latter are associated with the development of atrial fibrillation, which is the cardiac finding most associated with a reduced performance potential of the horse affected.

Keywords: equine, cardiology, valvular regurgitation, arrhythmia, poor performance

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Introduction

While orthopedic and respiratory problems are the most common reasons for poor performance in horses (*Martin* et al. 2000, *Martin* et al. 2004) cardiac disease can also have a negative effect on performance (*Martin* et al. 2004, *Gehlen* et al. 2007, *Reef* et al. 2014) by limiting the oxygen supply to the skeletal muscle system through an insufficient cardiac output (*Schwarzwald* 2013). However, arrhythmias and murmurs due to valvular regurgitations are very likely to occur in performance horses because of structural and functional changes due to intensive training and the size of the equine heart and are not always of clinical importance (*Zucca* et al. 2010, *Reef* et al. 2014). The examination of a poorly performing horse poses a major challenge, as it is difficult to determine whether a valvular regurgitation or arrhythmia detected is the reason for the performance problems or just an accidental finding (*Birks* et al. 2004, *de Solis* 2016, *Jago* and *Keen* 2019). Studies in racehorses have found that many murmurs are of minor importance and no difference in the racing performance of horses with or without valvular regurgitations have been found (*Kriz* et al. 2000, *Martin* et al. 2000, *Young* et al. 2008). Some authors claim this to be true for arrhythmias as well (*Physick-Sheard* and *McGurrin* 2010, *Navas de Solis* et al. 2014), while others describe these as a common performance-limiting condition in the racehorse (*Martin* et al. 2000, *Fraipont* et al. 2011, *Reef* et al. 2014). Studies on warmblood horses regarding the frequency of findings and the effect of cardiac disease on sporting performance are rarer. Results from studies conducted on racehorses should not be transferred onto warmblood sport horses, because the age structure of the population is different (*Maré* et al. 2017). Therefore, other cardiac findings may be present. Furthermore, the effect these findings may have on performance in the rather low intensity riding disciplines cannot be compared with the cardiovascular demands of the high intensity racing disciplines.

However, some studies exist indicating that sport horses with arrhythmias may perform normally in jumping or dressage (*Barbesgaard* et al. 2010, *Buhl* et al. 2010) and that many valvular regurgitations have no clinical implication whatsoever (*Verdegaal* et al. 2002, *Gehlen* et al. 2003). On the other hand valvular regurgitations and arrhythmias have also been described as a cause of poor performance in warmblood horses (*Gehlen* et al. 2007). Due to these inconsistencies in this

specific field, we aim to clarify what kinds of cardiac pathologies exist in a large group of warmblood horses and attempt to evaluate the effect of different kinds of cardiac disease on performance. This contributes to the better assessment of cardiac findings and their potentially performance-limiting effects in the warmblood sport horse.

We hypothesize that cardiac findings in our population of warmblood horses differ from findings found in racehorses regarding the frequency of different valvular insufficiencies and arrhythmias, because of the different age structure of the populations. Moreover, we think that warmblood sport horses are less likely to be negatively affected by different cardiac findings than racehorses. However, eventers and high-level sport horses probably suffer more often from poor performance due to cardiological problems than horses starting at a lower level or in other disciplines due to the higher demands on the cardiovascular system.

Material and methods

Horses

Warmblood sport horses presented for initial cardiac examination in an equine referral center in northern Germany between January 2000 and May 2020 are included in the study. The horses are from the same population of horses that has already been described in a previous paper (*Hövener* et al. 2021). However, this time only the 261 warmblood horses listed as competing by the German riding federation (FN) at the time of the examination have been included, compared to a total of 822 warmblood horses included in the other manuscript. Only horses with at least one finding in Echocardiography or ECG were included in the study. No control group was included. Results from follow-up examinations were not included, therefore each horse appears only once in the study. A detailed report of all examinations was saved in the patient file with the owner's permission. Relevant information includes age, sex, breed and presenting complaint as well as findings of the clinical examination, auscultatory findings and results of echocardiographic and electrocardiographic examinations.

Reasons for examination: The presenting complaint of each horse was reviewed, and horses were divided into three groups. Horses of group 1 were presented because of an auscultatory finding during a prepurchase examination or a routine examination. Group 2 included all horses with a complaint of poor performance. Group 3 included horses with any other cardinal clinical signs that may indicate an underlying cardiological problem. These were syncope, cyanosis, epistaxis, poor general health or ventral edema.

Clinical examination: All horses underwent a thorough clinical examination upon arrival at the clinic. All horses with a complaint of poor performance also underwent an orthopedic and respiratory examination. Moreover, a special examination of the cardiovascular system was performed as described by *Keen* (*Keen* 2019). A cardiac auscultation in a resting position and one immediately after intensive exercise and at fixed intervals during the recovery period were conducted. All findings were recorded in the patient file.

Echocardiography: An echocardiographic examination was performed in all horses including an examination in B-Mode, M-Mode and a Color Doppler-Echocardiography of all four valves from right and left parasternal views (*Gehlen* 2010, *Schwarzwald* 2019). Valve morphology was assessed in 2D-Echocardiography. If regurgitations or VSD were present in Doppler Echocardiography, severity was estimated as described in literature (*Bonagura* and *Reef* 2004, *Reef* et al. 2014) The maximal size of the atria and chambers was measured in millimeters and recorded (*Reef* 1990, *Gehlen* et al. 1998, *Schwarzwald* 2019). As only adult warmblood horses were included in the study and body weight was not recorded for many horses Cut-off values were used for grading of dimensional changes of the compartments of the heart. Values were chosen according to recommendations in literature (*Gehlen* et al. 1998, *Al-Haidar* et al. 2013, *Maarse* 2014, *Huesler* et al. 2016, *Decloedt* et al. 2017, *Vernemmen* et al. 2020, *Berthoud* and *Schwarzwald* 2021). A grading scheme based on these values is presented in Table 1. Any other abnormal findings were additionally recorded in the patient file. The pictures and videos taken during the examination were reviewed from the video archive and were reevaluated by an experienced clinician.

Electrocardiography (ECG): A resting ECG was performed using a standard base-apex lead (*Mitchell* 2019) in all horses. Exercising ECG was performed if auscultation after exercise revealed an irregular heartbeat or in the case of unexplained poor performance. A telemetric ECG system was used. Electrodes are placed in a modified base-apex configuration on the left and right hemithorax and sternum (*Chope* 2018,

Table 1 Grading scheme for the severity of dimensional changes of the heart in warmblood sport horses. Cut-off values are presented in millimetres for adult warmblood horses. Values were adapted according to *Berthoud* et al (2021), *Al-Haidar* et al. (2013) and *Huesler* et al. (2016) for the left atrium and left ventricle and according to *Vernemmen* (2020), *Maarse* (2014), *Gehlen* (2010) and *Decloedt* (2017) for the right atrium and right vetricle. | *Einstufungsschema für den Schweregrad von Dimensionsveränderungen des Herzens bei Warmblutsportpferden. Die Cut-off-Werte werden für erwachsene Warmblutpferde in Millimetern angegeben. Die Werte wurden nach Berthoud et al (2021), Al-Haidar et al. (2013) und Huesler et al. (2016) für den linken Vorhof und die linke Herzkammer und nach Vernemmen (2020), Maarse (2014), Gehlen (2010) und Decloedt (2017) für den rechten Vorhof und die rechte Herzkammer angepasst.*

	Left Atrium	Left Ventricle	Right Atrium	Right Ventricle
Normal	110–130 mm	107–127 mm	60–70 mm	55–65 mm
Mild Changes	130–140 mm	125–137 mm	70–80 mm	65–75 mm
Moderate Changes	140–150 mm	135–147 mm	80–90 mm	75–85 mm
Severe Changes	150–160 mm	145–157 mm	90–100 mm	85–95 mm

Mitchell 2019). The electrodes are secured under a girth and connected to a transmitter box on the surcingle. This sent data via Bluetooth to a computer that was equipped with an appropriate software for analysis. Horses were then exercised at the lounge line, according to their usual level of exercise. All abnormal findings were recorded in the patient file and ECG-Protocols were reviewed by an experienced clinician. Findings are defined as described by *van Loon* (*van Loon* 2019). Ventricular and supraventricular premature contractions were considered pathological if more than 2 were present at peak exercise or if pairs, paroxysms or more than 5 isolated premature contractions were present during recovery (*Martin* et al. 2000).

Performance: All horses, without major orthopedic problems or other severe systemic illnesses underwent an exercising examination. Horses were exercised at the lunge line by an experienced handler. After a warm-up period, horses were exercised at gallop. The duration and intensity of exercise depended on the equine's level of training but consisted of at least ten to fifteen minutes of intensive galloping. Horses were driven at least until the onset of intensive breathing. If the horse showed shortness of breath, intense sweating or was unwilling to work this was recorded in the patient file. Horses were then stopped, and the heart rate was recorded immediately upon halting. 120 to 180 beats per minute were regarded as physiological (*Bonagura* and *Reef* 2004). If heart rate was below these values right after exercise, exercising was continued, and intensity was increased. Heart Rate was closely monitored during the recovery period. Recovery was considered physiological if heart rate was below 100 beats per minute within five minutes after the end of the exercise and at the resting level after thirty to forty minutes (*Allen* et al. 2016). Moreover, heart rhythm was closely monitored during the recovery period to detect any post-exercise arrhythmias. Exceptionally high heart rates (>250/min), a relatively increased heart rate or a prolonged recovery period were considered as indicative of performance problems (*Allen* et al. 2016).

If the clinical impression, exercising heart rate and post-exercise heart rate recovery indicated an exercise intolerance, the most probable cause was considered. If horses had only mild to moderate cardiac disease but severe orthopedic or respiratory disease, these were more likely the performance limiting disease (*Knight* and *Evans* 2000, *Martin* et al. 2000, *van Erck* et al. 2006, *Fraipont* et al. 2011, *Melkova* et al. 2016). If no or only mild orthopedic, respiratory or other disease were present and moderate to severe cardiac findings were present, heart rate after exercise was elevated above the normal rate and heart rate recovery was prolonged the cardiac finding was assumed to be the performance limiting condition.

Furthermore, each horse was looked up in the database of the German Federation of Equestrian Sports (Federation national/FN), in which all competition results in Germany since 1976 are recorded to be better able to judge the horse's level of performance at the time of the examination. We used the UELN (Unique equine life number) to search for the horse in the database. Horses were then divided into groups depending on the discipline (Dressage, Show-jumping, 3-Day-Eventing) and the level of performance (low-level, medium-level, high-level). The level of performance was assessed following the FN's different levels of performance as follows: Low Level = FN Level novice (A) and beginner (E), medium = FN level easy (L) and medium (M) and high Level = FN Level Difficult (S).

Statistical analysis

Data was collected from the patient file as described above. Horses were divided into groups depending on their presenting complaint and their level of performance. Data were stored in an Excel spreadsheet (IBM Excel© Version 2017, Microsoft Corporation, Redmont, WA, USA). Statistical analysis was conducted using IBM SPSS statistical software version 27 (SPSS Inc., Chicago, Illinois, USA). Frequency tables as well as mean, median, standard deviation, 95%-confidence intervals and boxplots were used for the presentation of descriptives.

The presenting complaint was compared to the clinical presentation at the day of the examination regarding the performance of the horse using a Cohen's Kappa Test. The level of agreement was assessed according to *McHugh* (*McHugh* 2012) as follows: 0 = Poor; 0.01–0.2 = slight; 0.21–0.4 = fair; 0.41–0.6 = moderate; 0.61–0.8 = substantial and 0.81–1.0 = almost perfect. Frequency analysis was used to determine how common different cardiological findings were in our group of horses. Associations between different cardiac findings were determined using a Chi-Squared-Test. Association was considered significant if the p-value was smaller than 0.05. Odds Ratios (OR) including 95% CI were calculated to evaluate whether certain findings presented a risk of the presence of other findings. OR were also calculated to evaluate whether horses competing in different disciplines and at different performance levels were at a higher risk of having performance deficits due to cardiological problems. The risk was considered significantly enhanced if the OR was above 1.00 and the p-value was significant.

In order to test, whether different age groups were affected by different valvular regurgitations, a Mann-Whitney-U Test was used to determine, whether a significant difference in age existed between horses affected by AVI, MVI or TVI. This was considered the case if the p-value was below 0.05.

A multivariable binomial logistic regression model was used to determine the probability of showing a cardiologically caused performance problem depending on potential influence factors. Thirteen variables were entered into the model. These were presence of mild MVI, mild AVI, mild TVI, moderate MVI, moderate TVI, moderate AVI, severe MVI, severe AVI, severe TVI, mild VSD, AF, SVPCs and VPCs. These variables were included in the full model and eliminated backwards until only variables with $p < 0.1$ were included. Nagelkerke's R-squared was 0.509 in the full model and 0.441 in the final model. Influence was considered statistically significant if the p-value was below 0.05 and the risk was considered enhanced if the OR was above 1.00. The 95% CI was also calculated. The model impact was assessed by Nagelkerke's R squared.

Results

Horses: A total of 288 warmblood horses presented for cardiological examination in the period mentioned above. 27

horses did not have any cardiac findings. Therefore, they were excluded from the study. 261 active sport horses with cardiac findings were included. The age range was between 3.0 years and 21.0 years. The mean age was 8.7 years. The largest group of horses were Holsteins (n = 89), followed by Hanoveranians (n = 75), Oldenburgs (n = 28), German Sport Horses (n = 25) and Trakehners (n = 21). Most horses presented were geldings (n = 159), while mares (n = 82) and stallions (n = 20) were presented less commonly.

Reasons for examination

The majority of horses (n = 176/67%) presented for cardiological examination due to an incidental finding of a murmur or arrhythmia. 97 (37%) were detected during a prepurchase examination and 85 (33%) during a routine examination. Only 32% of horses (n = 85) showed clinical signs, indicating a possible cardiac disease, such as exercise intolerance, syncope, cyanosis or ventral edema. Most of them (n = 67/26%) were presented because of a complaint of poor performance. Seventeen (6%) horses showed other clinical signs.

Echo- and electrocardiographic findings

An echocardiographic examination was conducted in all 261 horses, revealing a pathology in 238 cases. Regurgitations or congenital abnormalities were present in 229 cases. Most of these were due to an isolated MVI (n = 154/59%) (Tab. 2) and the majority was graded as mild (n = 202/72%) (Tab. 3). Dimensional changes were present in 32% (n = 83) of horses examined. The LA was most affected, with LA enlargement being present in 59 horses (22%) (Tab. 4). 78 horses were diagnosed with valvular regurgitations and dimensional changes. This implies that 94% of dimensional changes were accompanied by valvular regurgitations. The risk of LA enlargement was more than three times higher (OR = 3.14, CI = 1.35–7.31, p < 0,01) if horses were affected by MVI than in horses without this finding. AVI was not significantly associated with LA enlargement (p = 0.21). The probability of having LV enlargement on the other hand was thirteen times higher in horses with AVI (OR = 13.1, CI = 5.61–30.35, p < 0.01) than in horses without this regurgitation. No significant association existed between MVI and LV enlargement (p = 0.11). No significant association could be detected between VSD and LA enlargement (p = 0.13) or LV enlargement (p = 0.31). A RA enlargement was found twenty-eight times (OR = 28.46, CI = 7.36–110.10, p < 0,01) more frequently in horses with TVI than in those without this finding. RV Enlargement was also significantly associated with TVI (OR = 20.36, CI = 2.60–201.59, p = 0.09).

Regarding the age of the horses, findings varied between MVI, TVI and AVI. (Tab. 5). 56% of horses with AVI were over 10 years of age, while 73% of horses with MVI and 75% of horses with TVI were younger than 10 years. The Mann-Whitney-U Test showed that significant differences in age structure exist between horses with and without AVI (U = 3072.0; p < 0.001). The same was true for horses with and without MVI (U = 4731.50; p = 0.001).

A resting ECG was performed in all 261 horses. Heart rate at rest ranged from 28 to 60 beats per minute and mean resting heart rate was 36.3 ± 4.2 beats per minute. Resting ECG revealed an arrhythmia in 54 horses. The most common

Table 2 Frequency of different cardiac findings in 261 sport horses that underwent echocardiographic examinations in the equine clinic in Bargteheide. | *Häufigkeit verschiedener Herzbefunde bei 261 Sportpferden, die in der Pferdeklinik Bargteheide echokardiographisch untersucht wurden.*

MVI	154 (65%)
AVI	22 (9%)
MVI+TVI	20 (9%)
MVI+AVI	13 (6%)
TVI	11 (5%)
More than 2 R	4 (2%)
AVI+PVI	2 (1%)
MVI+VSD	2 (1%)
AVI+TVI	1 (0,5%)
PVI	1 (0,5%)
VSD	1 (0,5%)
Total	214 (100%)

Abbreviations: R.= Regurgitation, MVI = Mitral valve regurgitation, AVI = Aortic valve regurgitation, TVI = Tricuspid valve regurgitation, PVI= Pulmonic valve regurgitation, VSD= Ventricular septal defect | *Abkürzungen: R. = Regurgitation, MVI = Mitralklappenregurgitation, AVI = Aortenklappenregurgitation, TVI = Tricuspidalklappenregurgitation, PVI = Pulmonalklappenregurgitation, VSD = ventrikulärer Septumdefekt*

Table 3 Frequency and severity of valvular regurgitations in 261 horses that underwent echocardiographic examination in the equine clinic in Bargteheide between 2000 and 2020. | *Häufigkeit und Schwere von Klappenregurgitationen bei 261 Pferden, die zwischen 2000 und 2020 in der Pferdeklinik Bargteheide echokardiographisch untersucht wurden.*

	MVI	AVI	TVI	PVI	VSD	Total
Mild	140 (72%)	27 (59%)	25 (69%)	3 (100%)	3 (100%)	198 (70%)
Moderate	47 (24%)	14 (30%)	8 (22%)	0 (0%)	0 (0%)	69 (24%)
Severe	7 (4%)	5 (11%)	3 (8%)	0 (0%)	0 (0%)	15 (5%)
Total	194 (100%)	46 (100%)	36 (100%)	3 (100%)	3 (100%)	282 (100%)

Abbreviations: MVI = Mitral Valve Regurgitation, AVI = Aortic Valve Regurgitation, TVI = Tricuspid Valve Regurgitation, PVI = Pulmonal Valve Regurgitation, VSD = Ventricular Septal Defect | *Abkürzungen: MVI = Mitralklappenregurgitation, AVI = Aortenklappenregurgitation, TVI = Tricuspidalklappenregurgitation, PVI = Pulmonalklappenregurgitation, VSD = ventrikulärer Septumdefekt*

finding was AF affecting 12 % of all horses examined (n = 32), followed by second-degree AV-Block (5 %/n = 12) and SVPCs (3 %/n = 9) and VPCs (0,5 %/n = 1). A total of 69 horses underwent an exercising electrocardiographic examination. Maximum heart rate during exercise ranged between 122 and 310 beats per minute. Mean value was 175.3 ± 33.3 beats per minute. Exercising ECG revealed a finding in 24 horses. Fifteen horses (6 %) were affected by AF. 2 had SVPCs (1 %), 6 had SVPCs and VPCs (2 %) and one had a sinus arrhythmia.

A significant association could be established between a LA enlargement and the occurrence of AF. Horses with dilatation of the LA were three times more likely (OR = 3.18, CI = 1.47–6.87, p = 0.05) to be affected by AF. The risk of AF increased with the severity of the dimensional changes of the LA. Therefore, only 9 % of horses with normal LA dimensions were affected by AF. 10 % of horses with mild dimensional changes and 25 % of horses with moderate changes of LA dimensions were affected by AF (OR = 2.85, CI = 1.15–7.04, p = 0.04). Ultimately, 57 % of horses with severe changes of LA dimensions were affected by AF (OR = 10.77, CI = 2.29–50.58, p = 0.05). We could not find that presence of mild or moderate MVI and TVI was significantly associated with AF. However, we found a significant association between severe MVI (OR = 10.76, CI = 2.29–50.58, p = 0.05) and severe TVI (OR = 15.20, CI = 1.34–172.73, P = 0.04) with AF.

Association with poor performance

A total of 67 horses (26 %) presented for a cardiological exam due to a complaint of poor performance. Upon examination, 67 (26 %) horses showed signs of poor performance. In 58 of these horses (86 %), the presenting complaint and the clinical exercising examination agreed. This means that agreement between the presenting complaint and the findings from the exercising examination was almost perfect (Kappa 0.82). Presenting complaint and exercising examination were significantly associated. (OR = 132.47, CI = 50.22–349.40, p < 0.001)). A total of 194 (74 %) of the 261 horses with a cardiac finding showed no clinical signs of decreased performance during the exercising examination. Mean heart rate measured right after intensive exercise was 151.5 ± 1.1 beats per minute in horses considered fit. 181.9 ± 3.4 was the mean heart rate in poor performers. In horses, that had cardiologically caused performance problems mean heart rate was even 196.5 ± 1.2.

Table 4 Frequency and severity of cardiac dimensional changes in 261 horses that underwent echocardiographic examination in the equine clinic in Bargteheide between 2000 and 2020. | *Häufigkeit und Schwere der kardialen Dimensionsveränderungen bei 261 Pferden, die zwischen 2000 und 2020 in der Pferdeklinik Bargteheide echokardiographisch untersucht wurden.*

	Left Atrium	Left Ventricle	Right Atrium	Right Ventricle
Mild	20 (34 %)	8 (27 %)	7 (54 %)	2 (33 %)
Moderate	32 (54 %)	17 (57 %)	1 (8 %)	1 (17 %)
Severe	7 (12 %)	5 (17 %)	5 (38 %)	3 (50 %)
Total	59 (100 %)	30 (100 %)	13 (100 %)	6 (100 %)

Other organ systems were detected as the cause of the clinical problems in 23 poorly performing horses (34 %). The heart was determined as the only performance limiting condition in 29 cases. In another 10 horses cardiologic findings together with findings in other organ systems were responsible for the poor performance of the horse affected. In 5 horses no reason for the exercise intolerance could be detected (Tab. 6). AF was the cardiac finding most found responsible for poor performance. It was found in 51 % of horses with cardiologically caused poor performance. In 85 % of these cases AF was accompanied by valvular regurgitations (Tab. 7). Moreover, 63 % (n = 20) of horses with AF were performing poorly. This was only true for 14 % of horses with valvular regurgitations. Logistic regression showed that AF was significantly associated with poor performance (OR = 22.77, CI = 7.47–69.41, p < 0.001) This finding was supported by absolute numbers as 63 % of all horses diagnosed with AF were performing poorly. In total, more than half of all horses performing poorly due to a cardiological problem (51 %) were affected by AF, either as an isolated finding or combined with other pathologies. Another finding significantly associated with poor performance was SVPCs (OR = 7.36, CI = 1.51–35.96, p = 0.01). In absolute numbers, 50 % (n = 4) of horses

Table 5 Age structure in years in horses diagnosed with MVI, AVI or TVI in the equine clinic in Bargteheide between 2000 and 2020. | *Altersstruktur in Jahren bei Pferden mit Diagnose MVI, AVI oder TVI in der Pferdeklinik Bargteheide zwischen 2000 und 2020.*

	MVI	AVI	TVI
Total	194	46	36
Mean	8.23	11.05	8.41
Median	7.55	10.66	8.00
Minimum	3.0	4.3	3.3
Maximum	18.0	21.0	13.1

Abbreviations: MVI = Mitral valve regurgitation, AVI = Aortic valve regurgitation, TVI = Tricuspid valve regurgitation | *Abkürzungen: MVI = Mitralklappenregurgitation, AVI = Aortenklappenregurgitation, TVI = Tricuspidalklappenregurgitation*

Table 6 Reasons for poor performance in sport horses that were presented for a cardiac examination because of a complaint of poor performance in the equine clinic in Bargteheide between 2000 and 2020. | *Gründe für die Leistungsschwäche bei Sportpferden, die aufgrund dieser in der Pferdeklinik Bargteheide zwischen 2000 und 2020 zur Herzuntersuchung vorgestellt wurden.*

	Reason for Poor Performance
Heart	29 (36 %)
Airways	24 (30 %)
Heart, Airways	7 (9 %)
No Reason found	6 (8 %)
Orthopedic	6 (8 %)
Heart, Orthopedic	3 (4 %)
Other	2 (3 %)
Airways, Orthopedic	2 (3 %)
Total	79 (100.0 %)

Table 7 Cardiac findings in warmblood sport horses with cardiologically caused performance problems examined in the equine clinic in Bargteheide. | *Herzbefunde bei Warmblutsportpferden mit kardiologisch bedingten Leistungsproblemen – untersucht in der Pferdeklinik Bargteheide.*

	Findings	Max. HF	Level of performance
1	Mild AVI	182/ min	Medium Level Showjumping
2	AF, severe TVI	188/min	Medium Level Dressage
3	AF, moderate TVI	189/min	Medium Level Showjumping
4	Moderate AVI	189/ min	Low-Level Showjumping
5	Moderate AVI	181/min	Low-Level Showjumping
6	Severe AVI	188/ min	Medium Level Showjumping
7	AF, severe AVI	179/ min	Medium Level Showjumping
8	Moderate MVI	188/ min	Medium Level Showjumping
9	AF, moderate MVI	232/ min	Low-Level Dressage
10	Severe TVI	188/ min	Medium Level Showjumping
11	Severe MVI	182/ min	Medium Level Dressage
12	Moderate MVI	189/ min	Low-Level Showjumping
13	Mild AVI	200/ min	Medium Level Showjumping
14	AF, Mild AVI	184/min	Medium Level Showjumping
15	AF, Mild MVI	184/ min	Medium Level Showjumping
16	AF, Mild MVI, Moderate AVI, Severe TVI	184/ min	Medium Level Dressage
17	AF	191/ min	Medium Level Showjumping
18	Severe MVI, Mild TVI	191/min	Medium Level Showjumping
19	Severe MVI	182/ min	Medium Level Dressage
20	AF, Mild MVI	189/ min	Medium Level Showjumping
21	Moderate AVI	191/ min	Medium Level Dressage
22	AF, Severe MVI	188/ min	Medium Level Dressage
23	AF	194/ min	Medium Level Showjumping
24	AF, Severe MVI	248/ min	Low Level Dressage
25	AF, Moderate MVI	199/ min	Low Level Eventing
26	AF, Mild MVI	299/ min	High Level Showjumping
27	Moderate MVI	184/ min	Low Level Showjumping
28	AF, Mild MVI	180/ min	Low Level Dressage
29	Moderate MVI, Moderate AVI	189/ min	Low Level Dressage
30	SVPCs	188/ min	Low Level Dressage
31	Moderate AVI	194/ min	Medium Level Dressage
32	Moderate MVI, SVPC	187/min	Medium Level Dressage
33	AF, Mild MVI, mild AVI	248/ min	Medium Level Showjumping
34	SVPCs	182/ min	High Level Showjumping
35	SVPCs, VPCs	181/ min	Low Level Showjumping
36	AF	180/ min	Medium Level Showjumping
37	AF, Moderate MVI	228/ min	Medium Level Showjumping
38	AF, Mild MVI	230/ min	Medium Level Showjumping
39	AF, Moderate MVI	199/ min	Medium Level Showjumping

Abbreviations: MVI = Mitral Valve Regurgitation, AVI = Aortic Valve Regurgitation, TVI = Tricupid Valve Regurgiation, AF = Atrial Fibrillation, VPCs = Ventricular Premature Contractions, SVPCs = Supraventricular Premature Contractions | Abkürzungen: MVI = Mitralklappenregurgitation, AVI = Aortenklappenregurgitation, TVI = Tricupidklappenregurgiation, AF = Vorhofflimmern, VPCs = ventrikuläre Frühkontraktionen, SVPCs = supraventrikuläre Frühkontraktionen

with SVPCs were performing poorly. MVI was also significantly associated (p = 0.002). However, only severe MVI had an increased risk for poor performance (OR = 4.65, CI = 0.58–37.07), while mild (OR = 0.19, CI = 0.07–0.57) and moderate (OR = 0.33, CI = 0.09–1.10) MVI were not associated with an increased risk. In absolute numbers only 5% (n = 7) of horses with mild MVI and 15% (n = 7) of horses with moderate MVI were poor performing. Many of these also had other findings. 71% (n = 5) of horses with severe MVI were performing poorly. AVI was also a common finding in poorly performing horses, as 22% (n = 6) of mild AVI, 21% (n = 3) of moderate AVI and 40% (n = 2) of severe AVI were found in horses with exercise intolerance. Some other findings were primarily found in poorly performing horses as well. 67% of VPCs (n = 4) and 100% (n = 3) of severe TVI were diagnosed in poor performers.

Sporting performance

At the time of the examination, all horses examined were used as sport horses in Germany. 119 horses started in dressage competitions. Of these 60 were low-level, 52 in medium level and 7 high-level sport horses. 116 horses were showjumpers. Of these 35 started in low-level, 63 in medium-level and 18 in high-level competitions. Another 26 horses were eventers, of which 15 were low-level, 10 medium-level and 1 high level sport horses. A total of 18% (n = 23) of showjumpers, 12% (n = 15) of dressage horses and 7% (n = 2) of eventers were performing poorly due to a cardiological finding, while the rest were not affected negatively at the time of the examination. The level of performance of horses with a cardiologically caused performance problem was most commonly at a medium level, with 24 horses being affected, which equals 17% of all horses performing at that level and 63% of all horses performing poorly. OR revealed a significant association between discipline and level of performance with cardiologically caused poor performance only in medium-level showjumpers (OR = 1.98, CI = 0.95–4.09, p = 0.05), compared to the other horses examined.

Discussion

Valvular regurgitations occur in different frequencies in warmblood horses and racehorses. There is a high prevalence of TVI in racehorses, while other valvular regurgitations are found less commonly (*Patteson* and *Cripps* 1993, *Kriz* et al. 2000, *Young* et al. 2008, *Young* and *Wood* 2010, *Zucca* et al. 2010, *Leroux* et al. 2013). The prevalence of TVI increases significantly with intensive training in these horses (*Buhl* et al. 2005, *Young* and *Wood* 2010). The low prevalence of TVI (13%) in this population of warmblood horses could be related to the lack of high intensity training at a young age. On the other hand, MVI is described as the most common valvular regurgitation in warmblood horses (*Verdegaal* et al. 2002, *Gehlen* et al. 2007, *Leroux* et al. 2013). It has been hypothesized in literature that larger horses have a predisposition for developing MVI (*Leroux* et al. 2013), which may explain the high prevalence of MVI in our population (74%) and other populations of warmblood horses (*Verdegaal* et al. 2002, *Gehlen* et al. 2007, *Leroux* et al. 2013). AVI is very rarely seen in racehorses (*Patteson* and *Cripps* 1993, *Kriz* et al. 2000, *Young* et al. 2008) but can be found more frequently in warmblood horses (*Verdegaal* et al. 2002, *Gehlen* et al. 2007, *Leroux* et al. 2013) We found that AVI is significantly more common in older horses and AVI is described to be a pathology of the older horse in other studies as well (*Else* and *Holmes* 1972, *Leroux* et al. 2013). This could be a reason why it is so rarely seen in the generally very young racehorse population. The least common valvular regurgitation in warmblood horses (*Verdegaal* et al. 2002, *Gehlen* et al. 2007, *Leroux* et al. 2013), as well as in racehorses (*Young* et al. 2008, *Zucca* et al. 2010) was PVI. The latter was also rarely diagnosed in our population. Other than AVI, MVI and TVI were more commonly found in younger horses in our population and other populations of horses (*Leroux* et al. 2013). This may explain why these findings are more common in the very young racehorse population than AVI.

We found significant associations between MVI and LA enlargement, as described in literature (*Gehlen* et al. 2003, *Gehlen* et al. 2007, *Gehlen* et al. 2007, *Reef* et al. 2014). However, we cannot determine an association between MVI and LV enlargement contrary to what is stated in the latest consensus statement (*Reef* et al. 2014). This could, however, be due to the low number of severe MVI in this population of horses. The described associations between AVI and LV enlargement and TVI and RA enlargement are also described in literature (*Reef* and *Spencer* 1987, *Gehlen* et al. 2003, *Gehlen* et al. 2007, *Gehlen* et al. 2007, *Reef* et al. 2014). The latest consensus statement describes AVI as a risk factor of LV and LA enlargement (*Reef* et al. 2014). In this context, we could not detect an association between AVI and LA enlargement. This, again, may be due to the fairly low number of horses with severe AVI (11%).

We found AF to be the most diagnosed arrhythmia in our population of horses, which is supported by other studies (*Gehlen* et al. 2007, *Gehlen* 2010, *Leroux* et al. 2013). In general, AF is described as the most common pathological arrhythmia in the horse (*van Loon* 2019). In racehorses AF often is paroxysmal (*Deem* and *Fregin* 1982, *Ohmura* et al. 2003), which is probably caused by the extremely high demands placed upon the cardiovascular system during racing. Most horses with AF (78%) in our population had an underlying heart disease. This goes along with findings in other studies on large populations of non-racehorses (*Leroux* et al. 2013). Cardiovascular demands placed upon warmblood sport horses in general are lower, potentially explaining the low prevalence of AF without underling heart disease in our population. Especially LA enlargement is described to increase the risk of AF (*Gehlen* and *Stadler* 2002, *Gehlen* et al. 2007, *Reef* et al. 2014). This is strongly supported by the results of this study. MVI and TVI are sometimes also described to increase the risk of AF (*Reef* et al. 1988, *Leroux* et al. 2013, *Onmaz* et al. 2019). We could not find that the presence of atrioventricular valvular regurgitations in general was associated with AF. The lack of a direct association between TVI and MVI and AF in general is most likely due to the low number of severe MVI and TVI in this population. If only severe MVI and TVI were considered, a significant association between regurgitations of these valves and AF could be established. This makes sense as severe MVI and TVI includes severe enlargement of the LA

or RA, which present an increased risk for AF, as discussed above (*Reef* et al. 2014)

Other studies found, VPCs and SVPCs to be a common finding in horses (*Vibe-Petersen* and *Nielsen* 1980, *Martin* et al. 2000, *Barbesgaard* et al. 2010, *Buhl* et al. 2010, *Onmaz* et al. 2019). These arrhythmias were rather rare findings in our population. The majority of VPCs and SVPCs are diagnosed by exercising ECG, during exercise or in the recovery period (*Martin* et al. 2000, *Barbesgaard* et al. 2010, *Buhl* et al. 2010). The very low number of SVPCs and VPCs in our population could be due to the relatively small number of exercising ECGs performed. Even though an auscultation was performed right after exercise and during the recovery period SVPCs and VPCs may have been missed without an exercising ECG. This certainly presents an important limitation to the results presented in this study.

Furthermore, we tried to determine which cardiological conditions are associated with exercise intolerance in competing warmblood sport horses. As in other studies, we found a large portion of horses (44 %) performing poorly, because of a respiratory or orthopedic problem (*Knight* and *Evans* 2000, *Martin* et al. 2000, *van Erck* et al. 2006, *Richard* et al. 2010, *Fraipont* et al. 2011, *Melkova* et al. 2016, *Hövener* et al. 2020). This number is slightly smaller than that of horses performing poorly, due to cardiac problems (49 %). However, there probably exists a bias because all horses in this study had a cardiac pathology. If taking all poorly performing horses presented to the clinic into account, respiratory and orthopedic problems would most likely be even more common.

Determining the clinical significance of cardiac findings is challenging for veterinarians, as regurgitations and arrhythmias commonly occur in healthy, normal performing horses (*Buhl* et al. 2005, *Young* et al. 2008, *Buhl* et al. 2010, *Physick-Sheard* and *McGurrin* 2010). Indeed, 74 % of horses in our population did not show any clinical signs indicating an underlying cardiac condition, even though all of them had one or more cardiac pathologies. Only 26 % of these horses showed signs of exercise intolerance. Similar results are presented in other studies (*Verdegaal* et al. 2002, *Gehlen* et al. 2007, *Gehlen* et al. 2007, *Barbesgaard* et al. 2010, *Buhl* et al. 2010).

Valvular regurgitations in general are rarely described as clinically relevant findings in warmblood horses (*Verdegaal* et al. 2002, *Gehlen* et al. 2007, *Gehlen* et al. 2007) and racehorses (*Kriz* et al. 2000, *Young* et al. 2008). If they are considered as the cause of performance problems, MVI is described as having the biggest negative influence on a horse's performance in literature (*Patteson* 1995, *Reef* 1995). Other studies, however, have found that MVI is of little clinical significance in racehorses (*Kriz* et al. 2000, *Young* et al. 2008, *Fraipont* et al. 2011) and warmblood horses (*Verdegaal* et al. 2002, *Gehlen* et al. 2007, *Gehlen* et al. 2007). These findings are supported by our study, in which only 10 % of horses with MVI showed signs of poor performance upon examination. TVI is usually described as an incidental finding as well and has been found frequently without clinical implications in a high number of young racehorses (*Patteson* and *Cripps* 1993, *Kriz* et al. 2000, *Young* et al. 2008, *Young* and *Wood* 2010). Data exists, however, that a majority of warmblood horses diagnosed with TVI were poorly performing (*Gehlen* et al. 2007). In our population, on the other hand, 86 % of horses with TVI were performing normally, but a total of 24 % of horses with AVI were performing poorly. AVI is described to have a bigger influence on the performance potential of horses (*Gehlen* et al. 2007, *Reef* et al. 2014). In this context it may be worth noting that AVI was more often moderate to severe than MVI and TVI in our population. However, already 22 % of mild and 21 % of moderate AVI were found in poorly performing horses. This was only the case for 5 % of mild MVI, 4 % of mild TVI, 15 % of moderate MVI and 13 % of moderate TVI. An AVI could lead to a higher risk of performance deficits than regurgitations of the atrioventricular valves, as blood ejected through the aortic valve is supposed to deliver oxygen to the skeletal musculature of the horse (*Bonagura* and *Reef* 2004). If the cardiac output is limited due to an AVI, oxygen supply in the skeletal musculature may be inadequate, which may lead to a reduced performance potential of the horse affected (*Schwarzwald* 2013). However, if regurgitations were severe, they were accompanied by exercise intolerance in most cases. 40 % of severe AVI, 71 % of severe MVI and 100 % of severe TVI were found in poorly performing horses. This strongly indicates that the severity of the regurgitation, coupled with the associated dimensional changes are more relevant for the horse's performance potential than which valve is affected. VSD which are less than 25 mm in diameter are described to be present in performance horses without clinical signs (*Scansen* 2019) and are usually described as not performance limiting in horses not competing in high-intensity sports, as they are not considered haemodynamically important (*Reef* et al. 2014). This is supported by the fact that none of the horses with exercise intolerance in this population had a VSD.

Unlike regurgitations arrhythmias are more commonly described as a reason for performance deficits (*Martin* et al. 2000, *Jose-Cunilleras* et al. 2006, *Schwarzwald* 2013, *Durando* 2019). In general, AF is described as the most common performance limiting cardiac condition in horses (*Deem* and *Fregin* 1982, *Schwarzwald* 2013, *Reef* et al. 2014, *McGurrin* 2015, *Durando* 2019). Moreover, it has been found that induced AF can significantly decrease exercise potential (*Buhl* et al. 2018). A large portion of horses with AF also had a complaint of exercise intolerance in advance (*Reef* et al. 1988, *Reef* et al. 1995, *Gehlen* and *Stadler* 2002). We found that 63 % of horses with AF were exercise intolerant at the time of the examination and AF was significantly associated with poor performance, underlining these findings. Other arrythmias like VPCs and SVPCs have been described as performance limiting, as well (*Martin* et al. 2000, *Fraipont* et al. 2011). However, many other studies have shown horses with SVPCs or VPCs to perform normally and found that these pathologies do not necessarily lead to clinical signs in warmblood horses (*Barbesgaard* et al. 2010, *Buhl* et al. 2010) or racehorses (*Jose-Cunilleras* et al. 2006). However, 50 % of SVPCs and 67 % of VPCs were found in poorly performing horses in this study and SVPCs were significantly associated with poor performance. The general number of SVPCs and VPCs was low in this population. This may be due to the low number of exercising-ECGs performed. Potentially, the high percentages of poor performing horses with SVPCs or VPCs are because exercising ECG was performed only in horses with inexplicable

poor performance or if arrhythmias were auscultable at rest or after exercise. Maybe some fit horses had SVPCs or VPCs during or after exercise but did not undergo exercising ECG. Therefore, these pathological arrhythmias may have remained undetected in a number of horses. This lack of exercising ECG examinations in the majority of horses presents an important limitation to the significance of the results presented.

Finally, we hypothesized that eventing horses and high-class performance horses suffer most from cardiac disease. Because considering the three Olympic disciplines eventing is the one with the highest demands on the cardiovascular system of the horse and higher-class tournaments generally require more cardiac output (*Bitschnau* et al. 2010, *Munsters* et al. 2014). Contrary to this we found medium-level showjumpers most commonly suffering from cardiologically caused performance deficits. The low number of eventers in general may have contributed to them being underrepresentated. Furthermore, eventers are described as having a higher cardiac capacity in general (*Bitschnau* et al. 2010) and, therefore, might be better and longer able to compensate for pathologies limiting cardiac output. The cardiovascular demands placed upon horses in dressage competitions, on the other hand, are comparatively low. This may explain, why these horses rarely are presented because of a poor performance due to a cardiac problem. *Pedersen* et al. (*Pedersen* et al. 2018) hypothesized that horses with gastric ulcerations may never reach high-class performance level because this illness may cause subclinical performance limitations. This could also be true for horses with cardiac disease. Therefore, these horses may have a subclinical performance deficit and would never compete well enough to be considered for starting in eventing or higher-class tournaments due to their mild cardiac findings. This may be a reason why high-level performance horses and eventers do not suffer the most from cardiac disease. However, we have the limiting factor that only horses starting in national tournaments were considered. Including horses competing at international tournaments could also alter the results.

In general, our data was taken from a population of warmblood horses that was very diverse regarding age, breed, and sex of the animals and included sport horses from all performance levels. Therefore, the horses in this study could be seen as representative for warmblood sport horses with cardiac conditions in Germany and even Central Europe. On that note we do not see a reason for a significant bias. However, our study differed from other studies, as the evaluation of such a large number of cardiological examinations on performing warmblood horses has not yet been conducted to the best of our knowledge. Some limitations of the present study should be underlined, nonetheless.

Data used in the study has been collected over a period of almost 20 years. Due to technological progress, ultrasound technology and image quality have improved during the time of our study and new methods of examinations developed, which may have altered results. However, case files and images were reviewed by the same person. Technology was already very advanced in the early twentyfirst century and very well suited to identify and grade valvular regurgitations and cardiac dimensions and to diagnose arrhythmias. Moreover, the base frame of the cardiologic examination was generally the same over the period described and for all examining veterinarians. Of course, the examination was still adapted to recommendations of renowned experts in the field of equine cardiology. We did not note any differences regarding frequency or severity of findings, neither between different examiners, nor between different periods when reviewing the case files and images. Moreover, a Chi-Square test was performed for each cardiac condition and no significant differences were observed, neither between different examiners, nor between different times. Therefore, we suppose that the findings from different years and from different veterinarians can be compared with each other.

Moreover, the lack of a control group remains a limitation, especially when OR are calculated. The OR would probably be even higher, if horses with a certain cardiac finding were compared to a healthy population instead of horses with other cardiac conditions.

The lack of allometric scaling, when grading cardiac dimensions can also be named as a limitation to the results of this study, as some exceptionally small or large horses could have been graded incorrectly when using cut-off values for the grading of their cardiac dimensions. However, all horses were adult warmblood horses, therefore physiological cardiac dimensions should not vary excessively.

Finally, as always when examining the poorly performing horse, the only way to determine the cause of the problem is by diagnosis of exclusion. This is because the clinical complaint described can be caused by pathologies in almost all organ systems (*Niederhofer* and *Müller* 2017). Determining an accurate diagnosis and finding the cause of the exercise intolerance was attempted by conducting a very thorough examination of all horses presented because of a complaint of poor performance, including an examination of all organ systems commonly described as being responsible for performance deficits in the sport horse, especially an orthopedic and respiratory examination. A strict recorded exercise test including an exercising ECG was not performed in this population of horses. This could have altered results regarding the performance of the horses. However, all horses underwent an exercising examination and were closely monitored during the recovery period especially regarding heart rate and heart rate recovery. Moreover, most horses assessed as poor performing by the examining veterinarian were also presented because the rider noted a decrease in the horse's performance. This indicates that the horse was not performing as it used to at its usual level of training. At last, exercise examination, exercising heart rate and heart rate recovery was analyzed to make sure that any present cardiac finding was only declared as the cause of the exercise intolerance, if no other performance limiting pathologies could be found, heart rate after exercise was elevated above a physiological level and heart rate recovery was prolonged.

Conclusion and clinical implications

We found valvular regurgitations to be a common, but rarely clinically relevant finding in a group of 261 warmblood sport

horses. Contrary to studies on racehorses which are mostly affected by TVI, we found MVI to be the most common valve affected, followed by AVI. The latter was especially common in older horses. We found a significant association between presence and grade of left atrial enlargement and the presence of AF. The latter was the most common arrhythmia in our population and the finding most often associated with exercise intolerance. Other arrhythmias were less common. AF was significantly associated with poor performance, as were SVPCs and severe MVI. To sum up, we can say that valvular regurgitations on their own rarely cause performance problems. However, they are associated with dimensional changes of the heart, which are associated with AF. This finding can be detrimental to a horse's performance potential.

Abbreviations

AF = Atrial Fibrillation
AVI = Aortic Valve Regurgitation
CI = Confidence Interval
LA = Left Atrium
LV = Left Ventricle
mm = Millimeters
MVI = Mitral Valve Regurgitation
OR = Odd's Ratio
PVI = Pulmonary Valve Regurgitation
RA = Right Atrium
RV = Right Ventricle
SVPC = Supraventricular Premature Complex
TVI = Tricuspid Valve Regurgitation
VPC = Ventricular Premature Complex
VSD = Ventricular Septal Defect

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