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Left Ventricular Adaptations in Herding Dogs

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ABSTRACT

***Background*:** Athlete's heart syndrome comprises a set of functional and anatomic cardiac changes secondary to intense and prolonged physical exercise in humans and animals. The heart adapts to the type of activity performed, and Doppler echocardiography is the best tool for identifying these changes. Speckle tracking echocardiography (STE) has provided new data on cardiovascular adaptations secondary to physical exercise in humans, information that conventional echocardiography cannot provide. Although physical activity and work in dogs are well documented, there are few studies on cardiovascular adaptations secondary to exercise in dogs, and no studies to date evaluated these adaptations using STE.
***Materials, Methods & Results*:** A total of 31 dogs of the Border Collie and Ovelheiro Gaúcho Brasileiro breeds were divided into two groups: a herding group (HG, n = 15), which performed herding activity five to six times a week for at least 4 months, and a sedentary group (SG, n = 16), with no history of physical activity in the past twelve months. All dogs were previously subjected to electrocardiography and blood pressure measurement. After that, the animals underwent echocardiographic examination at rest at a single time point. The data were analyzed by two-way multivariate analysis of variance (ANOVA) at a level of significance of 5% ($P < 0.05$) and a trend at 90% ($P < 0.1$). The dogs of the HG had higher values for left-ventricular end-systolic diameter (LVESD) and systolic volume (SV), and lower values for left-ventricular myocardial performance index (Tei index) and systolic septal movement. STE results indicated that the HG presented lower values for strain and strain rate in some myocardial segments in the radial, circumferential, longitudinal, and transverse directions.
***Discussion*:** The increase in LVESD is justified by the increase in preload (volume) required to meet the increased oxygen demand, whereas SV is directly related to the Frank-Starling mechanism. The lower Tei index in the HG indicates better systolic-diastolic performance, explained by a shorter isovolumetric relaxation time and isovolumetric contraction time and by an increase in left ventricular (LV) ejection time. Similar results were not observed in LV systolic wall motion. Therefore, we believe that the most likely explanation is a higher systolic efficiency, associated with lower energy demand at rest. According to STE criteria, the lower strain and strain rate in the HG in some myocardial segments in all directions suggest less need for myocardial deformation and lower deformation velocity in order to maintain systolic function. In conclusion, conventional echocardiography and STE were complementary and fundamental to understand cardiovascular adaptations in herding dogs.

Keywords: echocardiography, canine, physical activity.

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INTRODUCTION

The term "athlete's heart" is often used to define major cardiac adaptations to physical exercise [19,36], including the increase in internal diameter, wall thickness, and mass of the left ventricle (LV) [31,36]. However, different types, intensities, durations, and frequencies of physical activity result in distinct cardiac adaptations [19,29].

In this context, Doppler echocardiography stands out as a useful tool to evaluate these cardiac adaptations in animals [1,27,40,49] and humans [4]. Recent techniques of tissue velocity imaging (TVI) and speckle tracking echocardiography (STE) have brought new knowledge about myocardial deformation [12], contributing significantly to sports medicine [17,30].

STE allows determining the strain (ST) and strain rate (STR) of LV myocardial deformation in orthogonal planes in the radial, longitudinal, and circumferential directions, and in tangential planes, caused by the sliding of muscle layers from the endocardium to the epicardium [18]. Although these variables have been validated in dogs [9,11,50] and have been used to evaluate heart diseases [15,38,43], the behavior of these variables relative to adaptations promoted by physical activities like snow sled pulling [40] agility competitions [34], running competitions [27] and herding [2,5,22,41,51] remains unknown.

Therefore, aiming to better understand the herding activity in dogs and its hemodynamic consequences, the objective of this study was to present the behavior of morphological and functional echocardiographic variables, as well as variables related to the systolic function of the LV, both conventional and current (TVI and STE), compared to sedentary dogs.

MATERIALS AND METHODS

Animal selection

The present study was approved by the Animal Research Ethics Committee of the Federal University of Pampa under Protocol No. 038/2015. Thirty-five dogs of the Border Collie and Ovelheiro Gaúcho Brasileiro breeds were previously evaluated by electrocardiography, Doppler echocardiography, peripheral blood pressure measurement, and clinical assessment to ensure that only healthy animals were included in the study. Two dogs with canine visceral leishmaniasis, one with myxomatous mitral valve disease and another with a high level of stress during echocardiographic evaluation, were excluded from the study, totaling 31 dogs, and these animals were subdivided into a sedentary group (SG) and a herding group (HG) according to the level of physical activity.

The SG consisted of 16 dogs with no history of physical activity or work for at least 12 months, whereas the HG included 15 dogs that performed physical activity 5 to 6 times a week for at least 4 months (29.46 ± 25.44 months). The HG performed its daily activities in a morning shift (3.44 ± 0.88 h) and an evening shift (3.88 ± 0.92 h), totaling an average of 5.2 ± 2.33 h of daily activity. Further information on the breed, gender, weight, and age of the study groups is shown in Table 1.

Echocardiographic examinations

Two-dimensional (2D), one-dimensional (M-mode), and Doppler (spectral and color) echocardiography, TVI, and STE scans were acquired using an MyLab Twice Vet ultrasonographic[1] device with multi-frequency transducers (3-5 MHz and 4-11 MHz). Index electrocardiograms were also obtained, without sedation or anesthesia, according to the recommendations of authors (6,13). The morphological and systolic function variables were analyzed offline using a MyLabDesk platform[1] and were measured three times by a single evaluator blind to group allocation.

For morphological analysis, the LV internal diameter (LVID) thickness, LV free wall (LVFW) thickness, and interventricular septum (IVS) thickness at end-systole and end-diastole were obtained in the right parasternal view in the chordal plane in M-mode. In the same image, the ejection fraction (EF) [26], shortening fraction (SF) [45], stroke volume (SV), LV mass, and LV mass index were calculated [46]. The diameter of the left atrium, aorta, and the left atrium to aortic diameter ratio were measured in the right parasternal view in the two-dimensional mode [21].

The isovolumetric relaxation time, isovolumetric contraction time, and aortic flow ejection time were obtained in the apical five-chamber view, allowing the later calculation of the LV's global myocardial performance index (Tei index) [44]. Similarly, the LV septal and parietal TVI were obtained in the apical four-chamber view [14].

STE was used to determine LV systolic myocardial deformation (ST and STR) in the radial, circumferential, longitudinal, and transversal directions, according to literature recommendations [9]. The myocardial musculature was tracked by automatically demarcating the endocardial and epicardial borders at end-systole using the Aided Heart Segmentation system, and was later adjusted by the evaluator to optimize speckle tracking in the images.

ST and STR values were obtained for the anterior-septal, anterior, lateral, posterior, inferior, and septal segments in the circumferential and radial directions, and for the basal-septal, basal-lateral, medial-septal, medial-lateral, apical-septal, and apical-lateral segments in the longitudinal and transversal directions. The ST and STR values of the epicardial and endocardial borders were also separately evaluated in the longitudinal and circumferential directions.

Statistical analysis

All statistical analyses were performed by pairwise analysis of variance (ANOVA) using SPSS software version 20.0 (IBM SPSS Statistics) at a 5% level of significance ($P < 0.05$) and a trend of 10% ($P < 0.1$).

RESULTS

The ANOVA results indicated the absence of significant differences in body weight, age, and breeds between the SG and HG ($P > 0.05$) [Table 1]. Similarly, gender did not significantly affect the echocardiographic parameters in the two groups ($P > 0.05$). With respect to heart morphology-related variables (Table 2), LVID was significantly larger in the HG than in the SG ($P < 0.05$), but there were no significant intergroup differences in LVFW and IVS thickness.

The systolic function indicator variables (SV and Tei index) were significantly different between the groups ($P < 0.05$) [Table 3]. The SV was significantly larger in the HG than in the SG, whereas the Tei index was significantly lower in the HG than in the SG ($P < 0.05$) [Table 3].

EF and SF were not significantly different between the groups (Table 3). In turn, the septal peak systolic velocity (Sm) was significantly lower ($P < 0.05$) in the HG than in the SG (Table 3).

Segmental and total ST and STR were significantly different between the groups in the four directions using the STE technique. In the radial direction, the STRs of the septal and anterior-septal segments were significantly higher in the SG than in the HG ($P < 0.05$) [Table 4]. Similarly, in the circumferential direction, the STR of the lateral, inferior, posterior, septal, and total (average of all segments) segments was significantly higher in the SG than in the HG ($P < 0.05$) [Table 5]. However, in the epicardial and endocardial borders, the systolic STR of the anterior-septal, anterior, and total segments, the systolic STR of the anterior segment, the global ST, and the ST of the inferior segment showed a trend to higher values in the SG relative to the HG ($P < 0.1$).

In the longitudinal direction of myocardial deformation, the ST values of the basal-septal and medial-septal segments of the epicardium were higher in the SG than in the HG ($P < 0.05$), and there was a trend to a higher global mean in the SG compared with the HG ($P < 0.1$) [Table 6]. Similarly, in the transversal direction, the ST values of the basal-septal and medial-septal segments were higher in the SG than in the HG ($P < 0.05$) [Table 7].

DISCUSSION

The results on the structural parameters of the heart (LVID, IVS, and LVFW) indicated that the herding activity performed by dogs resulted in a predominantly isotonic adaptation [40], similar to what was observed in rats subjected to swimming programs [20] and in human marathonists [32]. The isotonic activities promote an increase in venous return (preload) to meet the greater oxygen demand in the muscles. In the long term, this volumetric overload induces eccentric hypertrophy of the LV to maintain a constant parietal stress and adequate SV [30,48].

The highest SV found in the HG was similar to that found in human athletes practicing isotonic activities, such as swimming, running, soccer, and basketball for 15 to 20 hours a week for longer than four years compared with an SG [7]. The SV is intrinsically correlated with preload, and thus the volumetric overload imposed by the herding activity induced an increase in SV, according to the Frank-Starling mechanism [7,39].

In a study involving human sprinters and marathoners, the lower Tei index in athletes was due to a reduction in isovolumetric relaxation and contraction times, and to an increase in the LV ejection time [48], indicating better myocardial function [23]. Therefore, it was hypothesized that the variables that compose this index were affected by physical conditioning resulting from herding practices, leading to improved overall cardiovascular (systolic and diastolic) efficiency.

Table 1. Characterization of the study groups regarding the animal breed, gender, weight, and age.

	Characteristics	Sedentary dogs	Herding dogs
Breed	Ovelheiro Gaúcho - n (%)	7 (58.33)	5 (41.66)
	Border Collie - n (%)	9 (47.36)	10 (52.63)
Gender	Male - n (%)	5 (33.33)	10 (67.67)
	Female (%)	11 (66.67)	5 (33.33)
Weight	Mean (kg) ± standard deviation	18.9 ± 0.86	20.22 ± 1.06
Age	Mean (years) ± standard deviation	3.94 ± 0.60	4.38 ± 0.57
Total	Animals n (%)	16 (51.61)	15 (48.38)

Table 2. Structural echocardiographic variables in herding and sedentary dogs.

Variable	Herding dogs	Sedentary dogs	*P*-value
LVDd (cm)	3.98 ± 0.12	3.73 ± 0.12	0.147
LVDs (cm)	2.72 ± 0.09	2.43 ± 0.06	0.031*
IVSd (cm)	0.87 ± 0.04	0.85 ± 0.04	0.762
IVSs (cm)	1.17 ± 0.05	1.09 ± 0.05	0.325
LVFWd (cm)	0.77 ± 0.04	0.85 ± 0.04	0.168
LVFWs (cm)	0.99 ± 0.06	1.04 ± 0.06	0.532
LA/AO ratio	1.41 ± 0.05	1.42 ± 0.05	0.862
LVM (g)	114.65 ± 10.65	100.94 ± 10.48	0.672
LVMI (g m²)	158.65 ± 12.08	131.56 ± 11.90	0.122

LVDd= end-diastolic left ventricular diameter; LVDs= end-systolic left ventricular diameter; IVSd= end-diastolic interventricular septum thickness; IVSs= end-systolic interventricular septum thickness; LVFWd= end-diastolic left ventricular free wall thickness; LVFWs= end-systolic left ventricular wall thickness; LA/AO= ratio between the left atrial diameter and the aortic diameter; LVM= left ventricular mass; LVMI= left ventricular mass index; *= significantly different at $P < 0.05$.

Table 3. Echocardiographic variables related to systolic function in herding and sedentary dogs.

Variable	Herding dogs	Sedentary dogs	*P*-value
EF (%)	60.60 ± 1.397	62.69 ± 2.037	0.161
SF (%)	31.70 ± 1.42	34.45 ± 1.40	0.179
CO (L/min)	3.81 ± 0.395	3.76 ± 0.456	0.626
PFV (m/s)	0.95 ± 0.046	0.90 ± 0.395	0.574
AFV (m/s)	1.24 ± 0.059	1.28 ± 0.048	0.630
Sm par (m/s)	0.17 ± 0.01	0.18 ± 0.01	0.479
Sm sep (m/s)	0.13 ± 0.01	0.15 ± 0.01	0.044*
LV Tei index	0.37 ± 0.03	0.46 ± 0.03	0.030*
CI (L/min/m²)	5.42 ± 0.557	5.1 ± 0.537	0.949
SV (mL)	28.89 ± 2.394	22.11 ± 1.528	0.049*

EF= ejection fraction; SF= shortening fraction; CO= cardiac output; PFV= pulmonary flow velocity; AFV= aortic flow velocity; Sm par= parietal peak systolic velocity; Sm sep= septal peak systolic velocity; LV Tei index= left ventricular global myocardial performance (Tei) index; CI= cardiac index; SV= stroke volume; *= significantly different at $P < 0.05$.

Table 4. Strain (ST) and strain rate (STR) in the radial direction obtained by speckle tracking echocardiography in herding and sedentary dogs.

Segment	Variable	Herding dogs	Sedentary dogs	*P*-value
Anterior-septal	ST (%)	23.294 ± 3.832	34.24 ± 3.774	0.750
	STR (s^{-1})	2.202 ± 0.250	2.958 ± 0.246	0.041*
Anterior	ST (%)	29.722 ± 3.900	32.887 ± 3.840	0.568
	STR (s^{-1})	2.531 ± 0.256	2.718 ± 0.252	0.607
Lateral	ST (%)	30.439 ± 3.812	31.319 ± 3.754	0.871
	STR (s^{-1})	2.535 ± 0.229	2.381 ± 0.226	0.637
Posterior	ST (%)	26.610 ± 3.633	30.539 ± 3.578	0.448
	STR (s^{-1})	2.231 ± 0.194	2.178 ± 0.191	0.848
Inferior	ST (%)	21.157 ± 3.748	29.771± 3.691	0.113
	STR (s^{-1})	2.056 ± 0.162	2.382 ± 0.160	0.163
Septal	ST (%)	20.416 ± 3.905	31.574 ± 3.846	0.720
	STR (s^{-1})	2.111 ± 0.169	2.670 ± 0.184	0.043*
Global average	ST (%)	25.439 ± 3.458	31.574 ± 3.406	0.217
	STR (s^{-1})	2.277 ± 0.179	2.548 ± 0.176	0.293

*= significantly different at $P < 0.05$.

The EF and SF values found in this study were similar to those found in sled dogs trained for five months [40]. However, higher SF values were found in race greyhounds trained for three months compared with sedentary animals [27]. The absence of significant differences between the two groups may be because the contractility indexes are directly affected by the preload, afterload, and/or heart rate [13].

A previous study reported that Sm values were higher in human athletes practicing marathon and canoeing than in sedentary individuals [47]. However, there was no significant difference between athletes practicing marathon, weightlifting, swimming, soccer, basketball, martial art, windsurfing, and a control group [16]. It was hypothesized that a higher systolic efficiency associated to a lower energy demand at rest were the main contributing factors for this difference. Therefore, the decrease in this variable in the HG indicates lower cardiovascular energy consumption and better performance when associated with a better systolic function, demonstrated by the SV and Tei index. However, although there were no difficulties in angulation, such errors should be considered as a source of variation [10].

With regard to the STE technique, despite the higher values obtained in the radial and circumferential directions, these values do not reflect higher pumping efficiency, considering that SV values were higher in the HG, indicating the higher systolic efficiency of the dogs from this group. To the best of our knowledge, no studies to date used this echocardiographic modality to evaluate athletic cardiac performance in dogs. However, the ST values in the anterior-septal and septal segments in the circumferential direction were decreased in humans undergoing isotonic and isometric training [3]. It is plausible to consider that the circumferential myocytes of the right ventricle also encompass the IVS region. Therefore, it is also plausible to consider this factor as an influence toward lower ST values in the segments surrounding the IVS region (anterior-septal, septal, and inferior) in the HG.

Another relevant factor is that the right parasternal view in the transversal axis and in the papillary plane, used to acquire the LV transversal image and calculate the ST and STR of the segments, may have limited the tracking of speckles on the epicardial border of the anterior-septal, septal, and anterior segments, because of the proximity of these segments to the echocardiographic probe. This technical limitation may have affected the results of epicardial parameters evaluated in the circumferential direction.

Similar to the radial and circumferential direction, the higher deformation measurements in the longitudinal direction in the SG could not compensate for the larger LV diameter in the HG, resulting in a lower SV in the SG. A controversial result was found

Table 5. Strain (ST) and strain rate (STR) of the endocardium (End) and epicardium (Epi) in the circumferential direction obtained by speckle tracking echocardiography in herding and sedentary dogs.

Segment	Border	Variable	Herding dogs	Sedentary dogs	*P*-value
Anterior-septal	Epi	ST (%)	5.380 ± 0.823	5.831 ± 0.810	0.698
		STR (s^{-1})	0.560 ± 0.072	0.753 ± 0.071	0.065¥
	End	ST (%)	18.65 ± 2.154	23.70 ± 2.121	0.106
		STR (s^{-1})	1.954 ± 0.231	2.413 ± 0.228	0.168
Anterior	Epi	ST (%)	19.74 ± 2.329	24.51 ± 2.294	0.156
		STR (s^{-1})	0.546 ± 0.084	0.764 ± 0.082	0.073¥
	End	ST (%)	19.74 ± 2.329	24.51 ± 2.294	0.155
		STR (s^{-1})	1.924 ± 0.260	2.649 ± 0.256	0.057¥
Lateral	Epi	ST (%)	6.259 ± 1.114	6.863 ± 1.097	0.702
		STR (s^{-1})	0.646 ± 0.084	0.840 ± 0.083	0.112
	End	ST (%)	18.79 ± 2.65	23.78 ± 2.613	0.192
		STR (s^{-1})	1.904 ± 0.277	2.703 ± 0.273	0.049*
Posterior	Epi	ST (%)	7.164 ± 1.082	7.07 ± 1.066	0.951
		STR (s^{-1})	0.721 ± 0.096	0.844 ± 0.095	0.369
	End	ST (%)	17.07 ± 2.307	22.48 ± 2.27	0.105
		STR (s^{-1})	1.847 ± 0.235	2.566 ± 0.232	0.038*
Inferior	Epic	ST (%)	6.297 ± 1.035	6.005 ± 1.019	0.842
		STR (s^{-1})	0.676 ± 0.101	0.816 ± 0.100	0.333
	End	ST (%)	16.04 ± 2.049	21.16 ± 2.018	0.08¥
		STR (s^{-1})	1.688 ± 0.206	2.506 ± 0.203	0.008*
Septal	Epi	ST (%)	5.862 ± 0.884	6.006 ± 0.870	0.907
		STR (s^{-1})	0.681 ± 0.090	0.854 ± 0.089	0.182
	End	ST (%)	17.53 ± 2.06	21.72 ± 2.029	0.158
		STR (s^{-1})	1.806 ± 0.222	2.527 ± 0.219	0.028*
Global average	Epi	ST (%)	5.972 ± 0.762	6.343 ± 0.750	0.731
		STR (s^{-1})	0.638 ± 0.065	0.812 ± 0.06	0.065¥
	End	ST (%)	17.97 ± 2.011	22.89 ± 1.980	0.092¥
		STR (s^{-1})	1.854 ± 0.211	2.561 ± 0.208	0.024*

*= significantly different at $P < 0.05$; ¥= trend ($P < 0.1$).

in human athletes practicing wrestling (isometric) and marathon (isotonic) compared with an SG [37]. However, total ST values in the longitudinal direction were lower in human athletes practicing weightlifting, judo, and jujutsu (isometric) than in sedentary subjects [30]. The opposite was observed in rats subjected to 200 min of swimming five days a week for three months [24].

Baggish *et al*. [3] suggested that the involvement of septal regions of the epicardium in the HG may indicate a role of right ventricle adaptation in the longitudinal deformation of myocytes. The decrease in these values may be related to the lower sympathetic activity and higher parasympathetic activity due to physical training [35]. However, it is not possible to confirm these hypotheses considering only the present results, and further studies are necessary to address this question more conclusively.

No studies to date evaluated myocardial deformation in the transversal direction in dogs. However, ST values were lower in all transversal myocardial segments in handball practitioners undergoing isotonic and isometric training, compared with an SG [8]. In

Table 6. Strain (ST) and strain rate (STR) of the epicardium (Epi) and endocardium (End) in the longitudinal direction obtained by speckle tracking echocardiography in herding and sedentary dogs.

Segment	Border	Variable	Herding dogs	Sedentary dogs	*P*-value
Septal-basal	Epi	ST (%)	15.033 ± 2.010	21.558 ± 1.972	0.031*
		STR (s^{-1})	1.670 ± 0.307	2.364 ± 0.272	0.107
	End	ST (%)	14.483 ± 2.415	19.718 ± 2.370	0.137
		STR (s^{-1})	1.926 ± 0.285	2.314 ± 0.253	0.322
Medial-septal	Epi	ST (%)	11.227 ± 1.527	15.900 ± 1.498	0.040*
		STR (s^{-1})	1.185 ± 0.187	1.803 ± 0.166	0.230
	End	ST (%)	15.411 ± 2.293	19.732 ± 2.250	0.193
		STR (s^{-1})	1.716 ± 0.226	2.153 ± 0.200	0.163
Apical-septal	Epi	ST (%)	5.849 ± 0.802	6.134 ± 0.788	0.802
		STR (s^{-1})	0.706 ± 0.142	0.873 ± 0.126	0.390
	End	ST (%)	15.685 ± 2.395	15.383 ± 2.350	0.929
		STR (s^{-1})	1.596 ± 0.275	1.568 ± 0.244	0.940
Basal-lateral	Epi	ST (%)	16.669 ± 1.987	20.464 ± 1.950	0.187
		STR (s^{-1})	1.958 ± 0.386	2.273 ± 0.342	0.549
	End	ST (%)	14.859 ± 2.422	16.453 ± 2.377	0.796
		STR (s^{-1})	2.648 ± 0.320	2.092 ± 0.284	0.210
Medial-lateral	Epi	ST (%)	11.764 ± 1.687	14.520 ± 1.656	0.257
		STR (s^{-1})	1.958 ± 0.386	2.273 ± 0.342	0.332
	End	ST (%)	13.237 ± 2.037	14.020 ± 1.999	0.643
		STR (s^{-1})	1.800 ± 0.220	1.657 ± 0.195	0.631
Apical-lateral	Epi	ST (%)	6.374 ± 1.019	7.444 ± 1.000	0.462
		STR (s^{-1})	0.641 ± 0.137	0.877 ± 0.121	0.214
	End	ST (%)	13.957 ± 2.298	13.113 ± 2.255	0.796
		STR (s^{-1})	1.590 ± 0.254	1.375 ± 0.226	0.534
Global average	Epi	ST (%)	11.153 ± 1.186	14.337 ± 1.164	0.069¥
		STR (s^{-1})	1.244 ± 0.200	1.645 ± 0.186	0.169
	End	ST (%)	14.605 ± 1.408	16.403 ± 1.452	0.396
		STR (s^{-1})	1.879 ± 0.166	1.860 ± 0.147	0.931

*= statistical significance ($P < 0.05$); ¥= trend ($P < 0.1$).

contrast, human soccer players presented higher global transversal ST values compared with a control group [33]. These authors hypothesized that this difference might be due to the increased volume and the increased number of myocardial cells. Although no histological analysis was conducted in our sample, there was no significant intergroup difference in IVS and LVFW thickness on echocardiography, which decreases the likelihood of involvement of this mechanism in the evaluated dogs.

It is of note that the left parasternal and apical four-chamber views used to acquire the longitudinal image of the LV presented technical limitations. The longitudinal movement of the myocardium resulted

Table 7. Strain (ST) and strain strain (STR) in the transversal direction obtained by speckle tracking echocardiography in herding and sedentary dogs.

Segment	Variable	Herding dogs	Sedentary dogs	*P*-value
Basal-septal	ST (%)	11.338 ± 6.358	34.101 ± 6.239	0.018*
	STR (s^{-1})	2.764 ± 0.570	3.526 ± 0.559	0.351
Medial-septal	ST (%)	17.842 ± 5.636	36.621 ± 5.531	0.027*
	STR (s^{-1})	2.213 ± 0.403	3.063 ± 0.395	0.147
Apical-septal	ST (%)	27.840 ± 4.887	30.325 ± 4.796	0.720
	STR (s^{-1})	9.971 ± 3.616	2.297 ± 3.549	0.145
Lateral-basal	ST (%)	12.573 ± 13.86	36.833 ± 13.599	0.225
	STR (s^{-1})	2.386 ± 0.857	4.301 ± 0.841	0.126
Medial-lateral	ST (%)	16.901 ± 12.45	34.098 ± 12.220	0.336
	STR (s^{-1})	2.059 ± 0.771	3.505 ± 0.757	0.195
Apical-lateral	ST (%)	24.691 ± 7.764	29.872 ± 7.619	0.639
	STR (s^{-1})	2.165 ± 0.491	2.658 ± 0.482	0.482
Medial total	ST (%)	18.531 ± 5.762	33.64 ± 5.654	0.075¥
	STR (s^{-1})	3.593 ± 0.732	3.225 ± 0.718	0.723

*= statistical significance ($P < 0.05$); ¥= trend ($P < 0.1$).

in the displacement of points to positions out of the imaging plane, preventing the proper tracking of the myocardium and consequently reducing the reliability of the data for some segments. Similar results were found in humans [25] and other animals [28].

Cardiovascular adaptations in herding dogs usually agree with Morgaroth's theory [31, 35], in which isotonic or dynamic exercises tend to promote LV hypertrophy, characterized primarily by an increase in the LVID. The decrease in ST and STR values in the HG suggests improved conditioning of myocardial muscles, due to the reduced need to shorten myocardial fibers in order to maintain or improve systolic function parameters. Our STE results were similar to those found in human athletes practicing isotonic or isometric activities [30,33,42,48] considering segmental and global values of ST and STR. However, interspecies differences and the type of training performed should also be considered.

The limitations of this study include the difficulty in acquiring images of the epicardial border of some animals in the apical four-chamber view. This limitation decreased the reliability of the measurements and even prevented adequate speckle tracking of these segments, which culminated in the exclusion of some images from the analysis. This difficulty was also reported by Carnabuci [9] and Mantovani [28]. Another limitation was the difficulty in standardizing the herding activity in different farms, which limited the accurate quantification of the volume and intensity of the activities performed by each animal. Furthermore, the greater number of males in the HG reflects the reality of rural properties in the southern region of Brazil where the study was conducted. However, despite the differences in gender between the groups, the results of multivariate ANOVA indicated that gender did not significantly affect the studied variables.

CONCLUSION

The results suggest that the physical activity performed by herding dogs resulted in structural cardiovascular adaptations, reflected by a larger LVID and functional adaptations, namely a higher SV, lower Tei index, and lower Sm sep, characterizing a predominance of isotonic activity. STE results demonstrated that ST and STR values were lower in herding dogs in the radial, circumferential, longitudinal, and transversal directions in some myocardial segments, particularly in the IVS, suggesting a reduced need for myocardial deformation to maintain systolic function in herding dogs at rest, when compared with sedentary animals. Therefore, the conventional (structural and functional) and tissue echocardiographic findings obtained by tissue Doppler and speckle tracking were complementary and fundamental to understanding cardiovascular adaptations in herding dogs.

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Ethical approval. All procedures, treatments and animal care were in compliance with the guidelines of the Italian minister of health for the care and use of animals (D.L.27/171992 325 n.116) and UE (Directive 86/609/CEE).

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