DOI: 10.1590/1809-6891v24e-75434E

Ciência Animal Brasileira
Brazilian Animal Science

e-ISSN 1809-6891

Section: Animal science
Research article

Genetic parameters for jumping performance in Brazilian Sport Horses

Parâmetros genéticos para desempenho de salto em Cavalos Brasileiro de Hipismo

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Abstract
This study aimed to estimate genetic parameters for jumping measures in the Brazilian Sport Horses breed, looking to see which jump characteristics can be evaluated early and that present favorable genetic correlations (ϒg) with measures of later sports performance. Data were available for the results of jumping competitions on the Brazilian Sport Horses. Two traits were calculated: Classification (CLASS) of the animal (taking into consideration obstacle height, number of competitors, type of competition (regional, national, international) and final score (SCOREF) taking into consideration the weight of the competition, height of the obstacles and score for the placement and type of event. Heritabilities were low for the full database (0.00 and 0.07 for CLASS and SCOREF, respectively), but higher when only young horses were considered (0.09 and 0.67, respectively). Genetic correlations between these traits and subjective functional traits (using a scale of 0 to 10) measured at stallion approval for reproduction showed that Power was favorable for indirect selection for both traits (-0.85 for CLASS and 1.00 for SCOREF). Jump also showed a favorable correlation for SCOREF (0.53) but unfavorable for CLASS (1.00). Considering the importance of Temperament and the absence of unfavorable genetic correlations between it and competition results it was concluded that this trait can be maintained among the selection objectives of Brazilian Sport Horses. Suggestions are made for further genetic studies with this breed, and possible modifications in the evaluation regulations to improve data quality.
Keywords: competition; final score; genetic correlations; heritability; temperament

Resumo
Este estudo estimou parâmetros genéticos para avaliações de salto em cavalos da raça Brasileiro de Hipismo, buscando características passíveis de serem avaliadas precocemente e que estejam geneticamente correlacionadas (ϒg) com resultados posteriores em competições esportivas. Para os resultados de competições de salto duas características foram consideradas: Classificação (CLASS) do animal (considerando alturas dos obstáculos; número de competidores; tipo de competição: regional, nacional ou internacional) e escore final (SCOREF) (considerando peso da competição, altura dos obstáculos e escore para a colocação e tipo de evento). Herdabilidades foram baixas (0,00 e 0,07 para CLASS e SCOREF, respectivamente) quando o banco de dados foi considerado como um todo. Foram mais elevadas quando apenas a categoria Cavalos Novos foi considerada (0,09 e 0,67, respectivamente). Correlações genéticas entre estas características e avaliações funcionais subjetivas (em escala de 0 a 10) tomadas em aprovações de garanhões para reprodução mostraram relação genética favorável à seleção indireta entre Potência e resultados de competição (-0,84 para CLASS e 1,00 para SCOREF). Salto também apresentou correlação favorável com SCOREF (0,53), porém desfavorável com CLASS (1,00). Considerando a importância do Temperamento e ausência de correlações genéticas desfavoráveis desta com resultados de competição, conclui-se que esta característica deve ser mantida entre os objetivos de seleção de cavalos Brasileiro de Hipismo. Sugestões de estudos genéticos futuros para a raça e para possíveis modificações no regulamento das avaliações, foram feitas visando a melhoria da qualidade dos dados.
Palavras-chave: competição; escore final; correlações genéticas; herdabilidade; temperamento

Received: March 1, 2023. Accepted: July 3, 2023. Published: September 20, 2023.

https://revistas.ufg.br/vet/index

1. Introduction

The Brazilian Sport Horses (BSH) breed is selected for the equestrian sports of Show Jumping, Dressage, and Eventing Competitions. This breed, recognized by the World Breeding Federation for Sport Horses (WBFSH), is an open population, which allowed, until 2011, the entry of genetic material from any breed recognized by the WBFSH, and from the so-called warm-blooded sport breeds: English Thoroughbred (PSI), Arab, and their crosses.

The Brazilian Sport Horses Breeders Association (ABCCH) defines the Breed Standard as well as selection criteria, with minimum requirements for reproduction. Currently, all mares from BSH and the formative breeds registered with the Genealogical Registry Service (SRG) are admitted as dams. Male sire candidates are publicly presented at annual events entitled "Breeder Approval"[1], where they are evaluated according to morphological, functional, and genealogical criteria described in the breed regulation[2]. Candidates are ranked according to their mean score and, to be approved as a stallion, the candidate must obtain a mean score equal to or higher than 8.0 (0-10).

The success of jumping horse breeders is measured by the performance of their products at the highest levels of sports competition. However, results in this type of competition are usually assessed late in the animal's life, and their heritability estimates (h^2) are low to moderate[3,4,5,6]. Thorén Hellsten et al.[7] stated that selection programs based only on the performance of animals in high-level events would result in reduced genetic gains, due to long generation intervals. The subjective evaluation of the free jumping of foals has been adopted by many breeder associations as a predictor of future performance in the jumping modality. Thus, the study of genetic correlations between traits evaluated early with jumping results in official championships becomes essential in establishing selection programs.

The estimation of specific genetic parameters for a Brazilian equine population, with great sporting potential and international relevance, allows the targeting of selection programs based on possible response criteria. Such studies are extremely relevant for the maintenance and continuity of the genetic improvement of the national sport horse.

The hypothesis of this study is that traits subjectively evaluated at "Breeder Approval" events are favorably genetically correlated to competition results later in life. Therefore, this study aimed to estimate genetic parameters for jumping competition results in the Brazilian Sport Horses breed, in efforts to define which jump characteristics can be evaluated early and that exhibit favorable genetic correlations (ϒg) with measures of later sports performance.

2. Materials and methods

2.1 Horse data

ABCCH[8] supplied pedigree data (34,393 horses), from 1977 until 2011, and Stallion approved subjective evaluations of 294 horses. Those were evaluated by an oscillating number of judges over the years, resulting in an average of 4.26 (± 0.96) judges between 2000-2011. Pedigree information was published in MEDEIROS et al.[9], while stallion approval (Approval) data was published in MEDEIROS et al.[1].

Results from the official jump championships of the Brazilian Sport Horses Confederation (CBH) and state federations (years 2006-2013) were obtained from the ABCCH[10]. The Performance database consisted of the following variables: animal name, registration number, date of birth, sex, event name (EVENT), event year (YEAR), animal classification in the event (CLASS), number of competitors the horse has competed against (NOCOMP), score (SCORE), weight of the championship to which the event was linked (WT.COMP), weight of the height of obstacles on the course (WT.HT) and final score (SCOREF). No information regarding the castration of male horses was available; thus, castrated, and uncastrated animals were grouped into the same category. The classification of an individual competitor was established according to the table used for each competition[11]. The score was established considering the classification of the animal and the number of competitors in the event[2] (Table 1).

The following championships were considered: State Jumping Championship, Brazilian Jumping Championship, National Jumping Championship, and International Jumping Championship. Each of them was assigned a weight (WT.COMP) by the ABCCH[12] ranging from 1 to 5, according to the degree of difficulty. ABCCH[12] also attributed weight to the height of the obstacles on the course (WT.HT) that the animal covered, these being: 1.00 m (weight 0); 1.10 m (weight 1); 1.20 m (weight 2); 1.30 m (weight 3); 1.40 m (weight 4), and 1.50 m (weight 5). The final score (SCOREF) was used by ABCCH[12] as a criterion for classifying animals in the "BSH Circuit Ranking", and the animal with the highest final score sum at the end of each year was the ranking winner. Thus, a final score (SCOREF) was calculated by ABCCH[12] for each EVENT using the following formula:

$$SCOREF = (WT.COMP+WT.HT)*SCORE$$

EVENTs with less than five observations were removed from the database. The exact date of each EVENT was not available in the database, so the age of each animal for each test was calculated by the difference, in years, between its birth date and August 1st of the year of the event, known as the beginning of the birth season for the southern hemisphere. The day adopted for the calculation marks the beginning of the birth season of each

Table 1. Scoring system adopted by ABCCH, considering the classification of the animal (CLASS) and the number of competitors the horse has competed against (NOCOMP)

CLASS	NOCOMP															
	16+	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
1st	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5
2nd	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	
3rd	15	14	13	12	11	10	9	8	7	6	5	4	3	2		
4th	13	12	11	10	9	8	7	6	5	4	3	2	1			
5th	12	11	10	9	8	7	6	5	4	3	2	1				
6th	11	10	9	8	7	6	5	4	3	2	1					
7th	10	9	8	7	6	5	4	3	2	1						
8th	9	8	7	6	5	4	3	2	1							
9th	8	7	6	5	4	3	2	1								
10th	7	6	5	4	3	2	1									
11th	6	5	4	3	2	1										
12th	5	4	3	2	1											
13th	4	3	2	1												
14th	3	2	1													
15th	2	1														
16th	1															

Source: ABCCH[12].

year and is regulated as a calculation basis for the age of the animals competing in the BSH Circuit for Young Horses[13].

The entire Performance database included 1,596 animals, that came from the mating of 386 stallions with 1,109 mares. Each of the 529 events had an average participation of 36.76 (±38.25) horses and 2.81 (±1.71) courses covered by each horse. Each horse, in turn, participated in 33.32 (±25.04) courses in total.

2.2 Statistical model

The CLASS and SCOREF variables in the Performance database were subjected to a mixed model (PROC MIXED) analysis to examine the significance of fixed effects (Phenotypic Models). The fixed effects tested for the models were: event (within a year). Covariates included the number of competitors, horse age, weight of the competition, and height of obstacles. Lower CLASS values were considered as a measure of the greater capacity of the animal to win the event in which it participated, while higher SCOREF values indicated a greater ability of the animal to score in events with a greater number and quality of competitors, and/or greater height of obstacles.

These were performed using SAS® v.9.4 (Statistical Analysis System Institute, Cary North Carolina), considering the individual as a random effect. The effects that were not significant (P>0.05) were removed from the final model for each variable analyzed. The original model was:

Model 1: Phenotypic Model for Performance

$$Y_i = \mu + g_i + r_i + w_i + e$$

where = dependent variable: sports performance results in official competitions organized by CBH; μ = overall mean of the trait; g_i = random animal effect on each result; r_i= random effect associated with each repeated measure of individual i; w_i= sum of known environmental effects (fixed effects) that influence the trait; e = residual effect on the trait.

The model considered most suitable for each trait was the one that encompassed the following characteristics: obtained convergence criterion, significance (P<0.05) in all effects, and lowest value for Akaike's Information Criteria (AIC)[14].

2.3 Estimation of genetic parameters

The components of variance and covariance and estimates of genetic parameters were obtained using an Animal Model, via the Derivative Free Restricted Maximum Likelihood, using MTDFREML[15]. The significant fixed effects in the statistical models were maintained for estimating genetic parameters. The variance components were estimated for each trait individually, using as priors the individual and residual variances resulting from statistical models. The model included, in addition to the additive genetic random effect, the random maternal genetic and animal genetic effects. The latter was included to estimate the magnitude of the sum of non-additive genetic effects and other permanent environmental effects, intrinsic to the individual.

Model 2:

$$Y = X\beta + Z_1\,\beta\alpha + Z_2 m + Z_3 p + e$$

where: Y = vector of observations: sports performance results in official competitions; X = incidence matrix of fixed effects of influence on the trait; β = vector of fixed effects influencing the trait; Z_1 = incidence matrix of additive genetic random effects; α = vector of additive genetic random effects; Z_2 = maternal genetic random effects incidence matrix; m = vector of maternal genetic effects (random); Z_3 = incidence matrix of random effects intrinsic to the animal (non-additive genetics and permanent environment); p = vector of random effects intrinsic to the animal (non-additive genetics and permanent environment); e = influence of the residual effect on the trait.

A second analysis was performed using only data from young Horses. This category was regulated by the Brazilian Sport Horses Confederation[16] and aimed at young horses at the beginning of their sporting career, where they compete within the same age group and with a progressive increase in the height and difficulty of the jump course. This second analysis was carried out to determine the magnitude of random effects under more uniform environmental conditions. The 396 animals that participated in the 12 events aimed at the Young Horses category were offspring of 142 stallions and 324 mares and produced 1,730 results for this analysis.

Estimates of genetic correlations of early evaluated traits with sports performance results were obtained by joining the Approval and Performance databases. The components of covariance and genetic correlations were estimated in two-trait analyses between the CLASS/SCOREF and the functional aspects evaluated during the Stallion Approval. The variances obtained in the individual analyses were used as priors in the two-trait models.

3. Results

Table 2 details the descriptive statistics for the Performance traits of the official championships promoted by CBH. The comparison of the maximum classification (CLASS) in the database with the maximum number of competitors (NOCOMP) of each event showed the absence of some results. Thus, animals that were not classified in each course were not included in the database, probably because they did not score for the Ranking.

The fixed effect of the event within each year was significant (P<0.0001) for both CLASS and SCOREF (Table 3), while the sex of the animal did not influence the results of the sports competitions.

Table 2. Descriptive statistics for variables included in the PERFORMANCE database for Brazilian Sport Horses

Trait**	Mean	Standard deviation	CV (%)	Minimum	Maximum
WT.COMP	3.40	1.11	32.64	1	5
WT.HT	2.08	1.23	59.32	0	5
CLASS*	6.23	4.69	75.28	1	17
NOCOMP	26.95	18.71	69.42	1	116
SCORE	9.77	6.23	63.76	0	20
SCOREF+	51.51	39.24	39.25	0	200
AGE (years)	9.10	3.17	34.71	4	32.5

*Classification in each event by the horse (CLASS); + Final score considering classification (SCOREF), number of competitors (NOCOMP), championship weight (WT.COMP), and weight of the height (WT.HT) of obstacles on the course; **54,852 observations for each trait.

Table 3. Models obtained from the analysis of mixed models considering only phenotypic data of PERFORMANCE

Trait	Indidual cov*+ (P<0.0001)	Residual σ²* (P<0.0001)	Model** (P<0.034)
Classification (CLASS)	2.74 (0.16)	17.32	*Y= 0.65 + EVENT + 0.21*(**AGE**) + 0.02*(NOCOMP) + 0.29*(**WT.COMP**)*
Final score (SCOREF)	9.48 (0.10)	90.88	*Y = -36.76+EVENT +8.43*(**WT.COMP**) + 9.18*(**WT.HT**) - 0.30*(CLASSI) + 5.35*(SCORE)*

*Individual Covariance (Individual Cov) and Residual (σ² Residual) estimates were used as initial priorities for the estimates of genetic parameters; ** The two covariates in bold, for each trait, were the most influential and were included in the models for the estimation of genetic parameters; + The proportion of individual covariance about σ² Residual was demonstrated between relatives, along with each Cov.

The level of competitors was implied by the weight attributed to the championship (WT.COMP) to which the event was linked. The effect of WT.COMP was significant (P<0.0001) in the Phenotypic Model for CLASS and, as expected, for SCOREF. The height of the obstacles (WT.HT) of the course represented another indication of the degree of difficulty of the event. This effect was not significant for CLASS, since the animals competed with each other within the same height of obstacles. Courses with obstacles at 1 meter high (Table 4) had a more regionalized character (smaller WT.COMP) and fewer competitors (NOCOMP) when compared to other heights. The average age of the competitors was 9.10 (±3.17) years. The age of the competitors at each event was calculated approximately and therefore deviations of at most 11.9 months may have occurred.

Therefore, the ability of some individuals to win competitions (CLASS) decreased over time (P<0.05) (Table 3), while the ability to obtain high scores (SCOREF) in more competitive events did not show the same effect (P>0.05) (Table 4). Possibly, this occurred because many animals have started their sporting careers in courses with high obstacles (Table 3) and were able to improve their performance over time, as suggested by the effect of the age of CLASS (Table 4).

Table 4. Number of observations (No Obs.), age range and averages for age, classification (CLASS), the final score (SCOREF), number of competitors (NOCOMP), and championship weight (WT.COMP) for each level of obstacle height in PERFORMANCE, in Brazilian Sport Horses.

Obstacle height (m)	Nº Obs.	Age interval (Years)	Mean age (years)*	Mean CLASS*	Mean SCOREF*	Mean WT.COMP*	Mean NOCOMP*
1.00	6,074	4.03 – 26.27	10.02^{b}	6.14^{cd}	27.87^{f}	3.02^{f}	21.28^{c}
1.10	12,348	4.03 – 31.60	8.87^{de}	5.97^{d}	42.77^{e}	3.21^{e}	26.48^{b}
1.20	16,126	4.49 – 26.12	8.66^{e}	5.93^{d}	57.46^{d}	3.45^{d}	28.33^{a}
1.30	13,015	4.54 – 22.57	9.05^{d}	6.35^{c}	62.06^{c}	3.53^{c}	28.37^{a}
1.40	6,478	4.69 – 32.52	9.55^{c}	7.03^{b}	67.24^{b}	3.64^{b}	26.68^{b}
1.50	888	7.17 – 19.90	10.82^{a}	8.13^{a}	80.88^{a}	4.12^{a}	28.54^{a}

*Different letters in the same column indicate significantly (p>0.05) different means by the Tukey test.

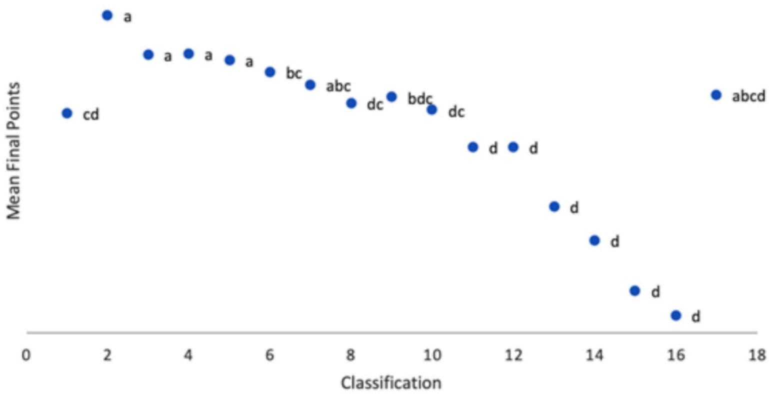

Figure 1. Final score averages (SCOREF) for each classification obtained in the various events considered for the Brazilian Sport Horses (BSH) breed. Letters after the dots indicate means are different using the Tukey test (P<0.05).

Table 5. Number of observations (N Obs.), age range and means for age, classification (CLASS), final score (SCOREF), number of competitors (NOCOMP), and weight of the championship (WT.COMP), for each height level in events for Young Horses.

Obstacle height (m)	N Obs.	Age range (Years)	Mean age (years)*	Mean CLASS*	Mean SCOREF*	Mean WT.COMP*	Mean NOCOMP*
1.00	58	4.27 - 8.63	5.36^{e}	5.72^{bc}	42.62^{c}	4.00^{a}	14.21^{c}
1.10	461	4.14 - 8.73	5.03^{e}	2.56^{d}	67.88^{ab}	3.15^{bc}	45.57^{ab}
1.20	445	4.64 - 8.87	5.96^{d}	3.58^{cd}	82.02^{a}	3.24^{b}	48.90^{a}
1.30	466	4.54 - 11.73	6.91^{c}	5.23^{c}	78.64^{ab}	3.08^{bc}	37.50^{b}
1.40	284	7.06 - 14.22	8.07^{b}	8.03^{a}	61.51^{b}	2.99^{c}	22.36^{c}
1.50	16	8.41 - 12.65	9.84^{a}	7.44^{ab}	71.31^{ab}	2.00^{d}	16.00^{c}

*Different letters in the same column indicate significantly (p<0.05) different means by the Tukey test.

Figure 1 shows that an increase in SCOREF is not necessarily related to a better classification in the test. This is because animals winning in easy tests may have received the same score as those ranked 17th in tests with higher jumps, greater number of competitors, or level of the championship.

PERFORMANCE one-meter courses were marked by the presence of horses almost as experienced (Age) as those in the 1.50-m competitions (Table 4). Moreover, the average age of horses in the 1.20- and 1.30-m courses was similar to those in the 1.10-m category, showing that a gradual increase in the level of difficulty was denied to a significant number of animals. Thus, a reduction in variation due to age effects (Table 5) was achieved by analyzing the subset of data referring to the Young Horses category.

The variance components for classification (CLASS) and final score (SCOREF) were derived from the same models applied to the Performance and Young Horses datasets (Table 6). Comparing the variance components estimated from Performance and Young Horses data reveals a decrease in the environmental component due to age, and possibly rider, consistency within the Young Horses data subset. Furthermore, environmental effects played a role in CLASS (both datasets), especially when an animal showed impeccable jumping technique but did not receive a good classification. The maternal effect showed a reduced genetic influence for this trait, with it approaching insignificance, despite substantial environmental variability and reduced additive genetic variation.

Table 6. Variance components for classification (CLASS) and final score (SCOREF) in official jump competitions (A) and for young horses (B)

Trait	σ^2 Additive genetic	σ^2 Genetic maternal	σ^2 Permanent environmental	σ^2 Environmental	σ^2 Phenotypic	Additive genetic (h^2)+*	Maternal genetic+*	Permanent environmental+*	Environmental+*
A. All horses									
CLASS	0.034	0.381	2.715	17.580	20.590	0.00 (0.01)	0.02 (0.01)	0.13 (0.01)	0.85 (0.01)
SCOREF	78.280	62.400	105.460	931.200	1132.000	0.07 (0.01)	0.06 (0.02)	0.09 (0.01)	0.82 (0.01)
B. Young horses									
CLASS	1.937	0.000	10.888	8.291	21.120	0.09 (0.09)	0.00 (0.075)	0.520 (0.090)	0.39 (0.025)
SCOREF	961.100	12.896	0.003	482.600	1444.000	0.67 (0.12)	0.009 (0.066)	0.000 (0.108)	0.33 (0.027)

+Values expressed as a proportion of the total variation; * Standard error of the estimate shown in parentheses.

The estimation of permanent environment effects allowed the calculation of repeatability from the proportion of total variation attributed to genetic and permanent environment effects, resulting in a value equivalent to 0.15 for CLASS and 0.21 for SCOREF in Performance. Proportionally higher repeatability (r) was also obtained for CLASS (r=0.60) and SCOREF (r=0.67) for Young Horses results. Here, a high proportion of phenotypic variance is attributed to permanent environment effects in CLASS and additive genetic effects in SCOREF, amidst estimates of higher standard errors (Table 6). This suggests a need for caution in interpreting the results for Young Horses.

3.1 Genetic correlations

Due to the change in methodology for the evaluation of jumping aptitude indicators, only 58 had information on Performance and scores for the Jump trait, adopted until 2006. The remaining 78 animals underwent the new detailed system of evaluation of the jumping movement. An individual's highest rankings consisted of the lowest values assigned to the CLASS for each competition. Thus, genetic correlations between functional measures evaluated during the Stallion Approval and CLASS considered favorable were those with a negative sign and absolute value closer to one.

Table 7. Covariance components (Cov) and phenotypic (p), genetic (g), and environmental (e) correlations (ϒ) obtained in two-trait analyses between the functional measures evaluated during the Approval and the classification (CLASS) and the final score (SCOREF) in Performance by the Brazilian Sport Horses (BSH) breed

Trait *	CLASS						SCOREF					
	Cov_p	Cov_g	Cov_e	Υ_p	Υ_g	Υ_e	Cov_p	Cov_g	Cov_e	Υ_p	Υ_g	Υ_e
Walk (0.36)	9.50E-03	4.70E-04	8.90E-03	0.00	0.00	0.00	9.00E-03	5.00E-03	-4.40E-03	0.01	0.04	-0.01
Trot (0.53-0.54)	2.60E-02	0.158-01	-7.00E-03	0.02	0.02	0.00	7.20E-03	-6.00E-03	7.20E-03	0.01	-0.04	0.02
Canter (0.35)	0.17	5.50E-02	6.30E-02	0.12	0.09	0.03	1.80E-02	1.50E-02	4.00E-03	0.02	0.12	0.01
Jump (0.17-0.75)	8.70E-02	0.17	-8.00E-02	0.00	1.00	-1.00	3.60E-02	9.70E-02	-6.00E-02	0.04	0.53	-0.26
Attitude (0.09-0.17)	1.30E-02	1.40E-02	-3.20E-03	0.19	0.20	-0.01	1.00E-02	5.20E-03	-1.00E-17	0.01	0.07	0.00
Impulsion (0.22-0.36)	-9.90E-03	2.00E-02	-3.00E-02	0.20	0.30	-0.1.	5.70E-03	5.40E-03	2.30E-04	0.01	0.06	0.00
Power (0.09-0.11)	3.50E-03	-3.80E-02	3.60E-02	0.00	-0.85	0.13	4.30E-02	3.70E-02	2.00E-03	0.04	1.00	0.01
Amplitude (0.25)	3.10E-03	1.90E-02	-1.60E-02	0.20	0.25	-0.05	4.10E-02	1.50E-06	4.10E-02	0.04	0.00	0.15
Temperament (0.42-0.43)	0.25	-1.70E-02	0.26	0.50	-0.11	0.61	4.80E-02	5.80E-05	4.80E-02	0.05	0.00	0.13
FOREL.MEC (0.37-0.38)	-5.80E-03	4.20E-02	-5.50E-02	-0.01	0.31	-0.14	-1.50E-02	-3.30E-02	3.60E-02	-0.02	-0.26	0.10
HINDL.MEC (0.34-0.36)	-3.50E-02	-1.60E-02	-4.90E-03	-0.04	-0.13	-0.01	6.50E-02	4.50E-02	1.20E-03	0.06	0.39	0.00
Flexibility (0.20)	-5.30E-03	-1.00E-02	-3.60E-03	-0.01	-0.12	-0.01	0.33	-3.90E-04	0.33	0.32	0.00	1.00
Respect (0.29-0.30)	5.60E-02	-2.20E-02	7.80E-02	0.06	-0.24	0.24	6.80E-03	1.60E-02	-9.20E-03	0.01	0.20	-0.03
Regularity (0.24)	0.25	-2.10E-02	0.27	0.25	-0.20	0.62	2.70E-02	8.40E-03	1.90E-02	0.03	0.08	0.05

*Range of heritability estimates obtained in all analyses are in parentheses. Forelimb mechanics (FOREL.MEC), hindlimb mechanics (HINDL.MEC).

Table 7 shows the covariance components and correlations between these traits. For the final score, contrary reasoning was adopted considering that the highest SCOREF values represented the best performances.

The two-trait analysis involving Jump demonstrated some instability in its heritability estimate. The addition of information about the animal's classification in field competitions reduced its estimate from the 0.74 obtained in the single trait analysis to 0.17.

Such instability seems to have been especially affected by the genetic correlation between Jump and CLASS, where the evaluation carried out in Approval proved to be a poor indication of the animal's phenotypic capacity to win an event (ϒp=0), and inversely proportional to their genetic potential for such a feat (ϒg=1). On the other hand, the heritability for Jump remained stable in the two-trait analysis with SCOREF.

The ambiguous character of the Jump trait was once again evident by comparing its genetic correlations with CLASS and SCOREF. One would expect such correlations to follow a similar criterion of favoring indirect selection. However, the perfect Jump technique presented before the Approval judges displayed an unfavorable genetic correlation with CLASS (ϒg=1.00) and a favorable correlation of moderate magnitude with SCOREF (ϒg=0.53). It is believed that the animals that received lower evaluations in Jump were later subjected to differentiated training, as indicated by the environmental correlation with CLASS being equal to -1, resulting in a phenotypic correlation equal to zero. Those animals well evaluated in Approval may have been subjected early to courses with high obstacle height (WT.HT) in important competitions in the official calendar (WT.COMP), possibly with challenges beyond their capacity at that time. Thus, these animals would have been systematically harmed in their SCOREF by environmental factors (ϒe=-0.26), which would have reduced its phenotypic correlation (ϒp=0.04). Such handling would have allowed these good horses to obtain significantly high SCOREF but without visible reflections on its CLASS (ϒp=0). These horses may even have shown certain genetic superiority to compete in more important events (ϒg with SCOREF = 0.06 - 0.07), but had little genetic (ϒg=0.20 – 0.30) or phenotypic (ϒg=0.19-0.20) potential to win them (CLASS). Other traits that exhibited divergent relationships with different performance measures in sports competitions were Attitude and Impulsion, which demonstrated poor genetic correlation with CLASS and a slightly favorable correlation with SCOREF.

Subjective evaluations of Amplitude did not demonstrate any potential benefit for indirect selection for SCOREF (ϒg=0.00). Instead, such selection would worsen the genetic values for CLASS (ϒg=0.25) in the current competition circuit. The Temperament trait was contrary to indirect selection for CLASS (ϒp=0.50). Genetically, their relationship was low but favorable (ϒg=-0.11), although it was null (ϒg=0.00) with SCOREF. Considering its environmental correlation with SCOREF (ϒe=0.13), it is believed that animals of good Temperament were also subjected to great heights of obstacles early on, which strongly influenced their CLASS in such events (ϒe=0.61).

Additional traits related to the horse's personality are Respect and Regularity. Both showed favorable correlations with the results of sports performance in competitions. Subjective Respect scores were genetically correlated with CLASS (ϒg=-0.24) and SCOREF (ϒg=0.20), without, however, the occurrence of phenotypically perceptible reflexes. Additionally, environmental effects contrary to genetic effects were demonstrated between classification in jumping competitions and Respect (ϒe=0.24) and Regularity (ϒe=0.62) scores, possibly for reasons similar to those discussed for Temperament. Poor relationships were observed between subjective evaluations of forelimb mechanics (FOREL.MEC) and official competition results, including CLASS (ϒg=0.31) and SCOREF (ϒg=-0.26). Therefore, hindlimb mechanics (HINDL.MEC) showed a subtly favorable genetic correlation for CLASS (ϒg=-0.13) and a genetic correlation of greater magnitude for SCOREF (ϒg=0.39).

4. Discussion

The lack of information on disqualified animals has been reported as a frequent problem in analyses involving competition results[5,17,18] but has been estimated to have a small impact on genetic parameters[18]. Conflicting reports have been made regarding the influence of sex on competition data. Some identified the superiority of the performance of males over females through accumulated points and accumulated classification in the sports career, without considering castration in males[18,19]. Similar data confirmed the effect of sex for results accumulated over the life of the animal, while results accumulated in young animals were not influenced by sex[5]. Otherwise, a non-significant tendency of stallions to perform better than females, and females better than geldings, was reported for the jumping phase in one-day eventing[20], and explained by the fact that stallions already constitute a selected portion of the population and, therefore, their superior performance would be expected. A common reason for neutering male horses in sports is to obtain animals with a more stable temperament and possibly more work-focused. On the other hand, when considering the occurrence of animals at advanced ages (14 years) in the Approval of Stallions, it is understood that some owners may have kept their animals uncastrated solely to maintain the possibility of approving it as a sire in a remote future, hoping to maintain a certain financial value added to the animal. Thus, not all non-castrated males have gone through a selection process, so their average performance would not necessarily be superior to that of castrated animals.

It was understood that national and international championships attracted more skilled competitors than those state or regional events. Among the wide range of ages observed, only 2,817 (5.13%) results were from animals older than 15 years. The average agreed with a period reported in the literature as being the peak of the sporting career for showjumping(4,21), and the jumping phase of the event(20,22). A curvilinear relationship between age and performance was reported(4,20), where animals improve their performance as they age, peaking at the elementary level at age 10, Intermediate level at 14, and Advanced level competitions at 16 years of age(20). Nonetheless, the best horses seem to reach their peak between the 9th and 11th year, with their performance declining from this point onwards(21).

Article 132 of the General Regulations of the CBH provides that horses registered in national competitions must have their age established in the regulations of each sport, considering the requirements of the events in which they will participate. Such instruction was prepared with a view to the conservation and development of the animal's physical and mental integrity(11). Nevertheless, only championships with national and international coverage presented age limitations for the horses(13). Thus, the choices regarding competitions (WT.COMP) and height of obstacles (WT.HT) of the events in which the animals competed were influenced by the owner of the animal and the expertise of its rider and did not necessarily reflect the horse's maximum athletic potential.

The ability of some individuals to win competitions (CLASS) decreased over time, while the ability to obtain high scores (SCOREF) in more competitive events was not influenced over time. Possibly, this occurred because many animals have started their sporting careers in courses with high obstacles and were unable to improve their performance over time, as suggested by the effect of age in CLASS. Thus, the gradual increase in performance reported previously(4,20,22) was not observed in BSH horses. Swedish and Dutch Equestrian Federations adopt a score similar to SCOREF to indicate to the owner at what level the animal should compete, limiting the participation of horses with a certain score in competitions where they had already demonstrated sufficient skill(5,19,23), thereby forcing them to face new challenges. Under these conditions, a 26-year-old animal would rarely be participating in 1-m courses in those countries, as shown in BSH. The repeated measures analysis of CLASS and SCOREF (not shown) revealed better adequacy of the model under the residual covariance structure of the first-order autoregressive type, reflecting the homogeneous interdependence between the results of successive competitions of each individual. Thus, ratings and consequently final scores obtained in sequence were more similar to each other than those more distant in time, leading to the assumption that, if the environmental conditions were similar, the athletic evolution reported in the literature could be observed in BSH. The effects of early exposure of young animals to tests of high physical demand on the sporting career of jumping horses should be investigated.

The winning set (horse and rider) in a jumping competition is the one that completed the course with the fewest penalty points and met the time criterion established for the event, outperforming the other competitors(12). Therefore, a set that has not knocked down any obstacle or incurred any other foul may have received a classification other than the first place. Such a set would have demonstrated sporting ability without having achieved the best time, thus receiving a SCOREF corresponding to their performance. The SCOREF composition justifies the significant effects of this trait. Curiously, CLASS was not the factor with the greatest influence on SCOREF.

Regulations for the CBH(16) Young Horse Championship state that an animal must undergo courses of progressively greater difficulty and height until reaching its maximum or sub-maximum performance. Such competitions were included in a second analysis as they display greater standardization of many environmental conditions since the animals compete with each other within the same height of obstacles and age. The age range established by the regulation(16) for each height of obstacles was not obtained possibly due to the inclusion of courses open to other categories in the events identified as Young Horses. Even so, a lower age range was achieved along with the gradual increase in the height of the obstacles. Greater homogeneity of riders was also expected in such competitions, where only riders in the Senior (>18 years) or Junior (14 to 18 years) categories are eligible to participate. Members of these categories can be professional riders or anyone who feels capable of competing with them. The 12 events that presented the term “Young Horses” in their nomenclature were considered in this analysis.

Among environmental factors that contributed to the jumping performance of young horses, age (2.40%) and rider (8.28%) were considered the most important sources of variation(24). The proportion of variance due to the rider was reported to increase with the degree of difficulty, ranging from 4% for entry to 10% for advanced levels(22); and to be about 10% after 6.8 years of age(4). Removing the effect of the rider led to the partition of this fraction of the variance between additive genetic and permanent environmental effects(4), and an overestimation of heritability and repeatability(6,18). Recently, the stability of the horse-rider relationship was proven to have a positive influence on a horse's performance, as the best performance was achieved by those with a maximum of two riders over the course of their career(21). The importance of the rider in competitions involving BSH (Brazilian Sport Horse) horses at a young age, when there is substantial learning, physical conditioning, and the onset of the sports career, might be greater than what has been previously documented in the literature. Therefore, the addition of information regarding the rider/owner would greatly clarify the real nature of the permanent environmental effects that seem to be so important to the winning ability of animals in Young Horse competitions. On the other hand, the analysis of results of this nature was a useful tool to demonstrate the possibility of reducing the strong environmental influences observed in Performance and increasing additive gene expression for individual competition results.

Heritability estimates reported in the literature for measurements of official contest results were generally low and influenced by the variable considered and form of analysis. Studies carried out with the subdivision of data into levels of difficulty and analysis as distinct characteristics commonly revealed higher values in heritability for more difficult routes[3, 4,5,6,22]. Some reported estimates similar to those obtained for SCOREF in Performance[3,4]. Higher values ($h^2 = 0.08 – 0.23$) were obtained by the inclusion of the effect of the rider[22] or other variables as performance measures. For the best classification achieved by the animal, the estimate was 0.14[25]. For points accumulated over certain age groups, heritabilities ranged between 0.24 and 0.28[5]. Studies that adopted cumulative results over the entire sporting career or part of it[19,26,27] reported heritability estimates ranging from 0.19 to 0.27. However, such a data structure resulted in only one or a few phenotypes per animal, and none of these studies considered the permanent environmental effect in their analyses, which may have resulted in deviations in the estimates of additive genetic variance.

The maternal genetic effect has been overlooked in literature reports regarding the performance of jumping horses. Since it represented less than 1% of the phenotypic variance for CLASS even in more homogeneous competition environments for BSH animals, together with the previous description of European competition systems, the effect was supposed to be negligible for this trait. Even so, for SCOREF, it was almost as important as additive effects in Performance (all horses). The professional level of the riders in European and Young Horses shows was likely responsible for “hiding” maternal genetic effects, which proved to be less influential in this type of competition. Skilled riders may be able to overcome possible behavioral difficulties manifested by their mounts and influenced by the phenotype of their mothers. Thus, it was concluded that the effect of the dam on the offspring's phenotype, supposedly behavioral in nature, was durable and evidenced in heterogeneous environmental conditions, such as those routinely found in Brazilian show jumping competitions (Table 6).

4.1 Genetic correlations

Among the 294 breeding candidates evaluated, 134 horses displayed competition results in Performance and morphological and gait evaluations in Approval[1]. As mentioned for Heritability estimates, genetic correlations between competition results and evaluations of gaits are also influenced by the variable used as a measure of sports performance[19]. Assessment methods of such subjective gait evaluations also have a great impact on these estimates[23,28]. Even so, a general trend towards the greater predictive capacity of canter for genetic values of competition results in the jumping modality was observed in most studies[5,19,23]. This was also true for SCOREF in BSH. Those reports also show strong and favorable genetic correlations between subjective assessments of gaits and results of competitions in Dressage competitions, indicating that indirect selection for dressage may be carried out by selecting for gait.

Literature reports have historically reported positive, strong, and favorable genetic correlations between subjective jumping evaluations in young horses and competition results[7]. Estimates consisted of values above 80%[5,23,27,28]. Thus, the considerable difference between these reports and the estimates of genetic correlations with SCOREF and CLASS presented here was probably due to the systematic environmental deviation resulting from the owners' anxiety towards see their horses competing in high-level difficulty tests in a short period.

The ineffectiveness of the Jump evaluation was possibly perceived by the ABCCH through the phenotypic correlations with results of competitions close to zero. This might have been the reason for the change in the way of evaluating the jumping ability of breeding candidates. As previously discussed in MEDEIROS et al.[1], a favorable Attitude was found in animals that were able to maintain Impulsion. Thus, selection through subjective assessments of Attitude and Impulsion would result in an impact opposite to that desired for CLASS performance in the current system of jumping competitions adopted in the country.

Although Power has shown low heritability[1], it had strong and favorable genetic correlations for indirect selection for both performance measures in national jumping competitions. These results were similar to the reports of genetic correlation between this trait, evaluated in foals under three years old jumping in freedom, and the highest classification achieved by the animal in its sporting career ($\Upsilon g=0.85$), by Ducro et al.[28]. However, the phenotypic correlation found by the authors ($\Upsilon p=0.23$) was higher than that reported between Power and SCOREF ($\Upsilon p=0.04$) and between Power and CLASS ($\Upsilon p=0.00$).

While Stallion Approval was held only once a year and involved a small proportion of animals born, all applicants were assumed to have undergone some degree of jumping training. This training led to more efficient jump trajectories with less energy expenditure[29]. Since all horses cleared the fence, Power consisted of its ability to jump beyond what was necessary for the imposed obstacle, also indicating some aspect of the animal's temperament and reactivity to a stimulus; and not only of its physical capacity to project its body upwards[1]. Thus, a calm and less reactive animal would demonstrate less power due to its personality and training, not necessarily to inferior physical or technical skill. This behavioral aspect may be an important factor in the relationship between Power and sports competition results.

Animal personality, the result of temperament being modulated by life events (such as training), is an important factor to be considered when breeding and using domestic horses[30]. Its assessment in farm animals is of growing scientific and practical interest. Different theoretical frameworks and methodological approaches have been proposed[31]. In horses, it has been objectively evaluated by its dimensions, such as fearfulness, reactivity towards humans, locomotor activity, gregariousness, or tactile sensitivity. Heritability estimates in young horses were elevated ($h^2 > 0.50$) for fearfulness measures and moderate ($h^2 = 0.35$) for tactile sensitivity measures[32]. No phenotypic link was found between them and subsequent jumping performance, although this was influenced by some behaviors during breeding shows, such as whinnies, main gait when entering, evasive behaviors, and posture during conformation evaluation[30].

Given the genetic relation of Power and performance results, its personality component, the wide age range observed in Approval, and the known effects of training on this trait, it was concluded that the attempt to reduce the environmental variation by restricting the age of the animals would contribute to an increased heritability reported for this trait[1], improving the effectiveness of indirect selection for CLASS and SCOREF. Furthermore, many characteristics evaluated in Approval were not described in the literature, and an even smaller number had their relationship described to competition results, making it difficult to compare the estimates currently reported for Attitude, Impulse, Amplitude, and Regularity with other populations.

Considering that the ideal jump consists of executing a trajectory in the form of a parabola, where the proper amplitude depends on the height of the obstacle, and that training gives animals the ability to calculate their trajectory to overcome the obstacle with less effort[29], fractionating the jump trajectory in two assessments (Power and Amplitude) may have contributed to this unfavorable genetic correlation. Literature reports involving subjective assessments of jump amplitude were not found, possibly because it is not a feature of interest to other sports horse breeds. However, this fractionation revealed the potential value of Power for performance selection.

Much more favorable genetic correlations between temperament scores and accumulated points (0.93) and ranking (0.91) in jumping competitions have been reported for Swedish horses. The environmental correlations, in turn, were considerably smaller (0.11-0.09)[19]. Even so, genetic correlation estimation with competition results proved that the ideal moment for evaluating temperament in jumping horses was in fact during the jump evaluations (Υg=0.88), rather than gait (Υg=0.16)[5], as applied at Stallion Approval. Thus, it is believed that the great divergences in literature reports are due to the differences described between the competition systems and the anxiety of Brazilian owners to obtain results quickly. Thus, selection for Temperament in BSH horses should reflect the genetic potential of CLASS in the selected population. However, gains will only manifest phenotypically under proper management.

Similarly, the relationship between the care taken by horses during the jump and the maximum classification in a sporting career[23] demonstrated a stronger genetic correlation than those reported here (Υg=0.80), but with reduced phenotypic reflexes (Υp=0.14). The importance of aspects related to the animal's personality for users of sport and leisure horses[33] and the high to moderate heritabilities estimated for objectively measured personality traits early in life[32] justify the inclusion of any temperament-related trait with favorable or zero genetic relation to performance in the selection objectives for the BSH, such as Power, Temperament, Respect, Regularity. Yet, more accuracy is needed in defining the theoretical concepts, terms, and measures used for each trait.

Only Ducro et al.[23] estimated genetic correlations between subjective scores of the jump biomechanics and competition results (Υg=0.67), showing potential for indirect selection for the highest ranking obtained in an animal's career. On the contrary, poor relationships were observed in the present study between subjective evaluations of forelimb mechanics (FOREL.MEC) and official competition results in CLASS and SCOREF, indicating the need for an urgent review of the FOREL.MEC assessment methodology.

The ability to flex the forelegs close to the body during jumping is commonly considered a great predictor of jumping capacity and is heavily influenced by training[34]. Thus, it is believed that the large age variation observed in Approval exerted an even more important influence than that detected by the Phenotypic Model of FOREL.MEC. Therefore, older animals had longer training, making it impossible to distinguish between the fraction of the recoil capacity of the forelegs due to training and that fraction due to the animal's genetic superiority. Such training effect would have improved the FOREL.MEC of some animals without visible reflections on competition results, introducing bias into the assessments. Conversely, hindlimb mechanics (HINDL. MEC) showed a subtly favorable genetic correlation for CLASS and of greater magnitude for SCOREF. This was considerably lower than that reported (Υg=0.80)[23] but in the same direction. Thus, HINDL.MEC was the second-best way to predict the genetic potential for the final score obtained in the results of sports competition in BSH horses, second only to Power.

There is a strong and positive genetic correlation (0.52) between the highest classification achieved in a horse's sports career and its back technique during free jumping[23]. Impulsion and Flexibility both involve the movement of the spine during the jump[1]. However, none showed that favorable relationship for indirect selection for jumping competitions, meaning that animals with good Impulsion and Flexibility of the spine were not always superior in performance. Although the evaluation of these two traits did identify genetically superior animals when performed separately[1], the combined process did not allow for the manifestation of this superiority to result in the current national competition system.

The Stallion Approval process carried out in recent years has included the evaluation of some traits that would allow indirect selection for results of sports competition in the jumping modality. Power, Respect, Regularity, HINDL.MEC, Flexibility, and Temperament exhibited, in descending order, response potential in the case of indirect selection for CLASS. Power, HINDL. MEC, and Respect are traits potentially favorable for selection to improve SCOREF. The possibility of the negative impact of Impulsion, Attitude, and to a lesser degree, Canter, on CLASS indicates a need for caution in choosing these as selection criteria.

5. Conclusion

Specific aspects of Brazilian show jumping competitions were reported, indicating the need for further studies, possibly including information on male castration and the random effect of the rider, in the estimation of genetic parameters for competition results. Traits that may be favorable for indirect selection for improvements in SCOREF without unfavorable impact on CLASS include Power, Hindlimb mechanics, Respect, and Regularity. Some traits showed conflicting relationships with the selection for sports performance, possibly due to the fragmentation of important features in more than one subjective assessment. Considering its importance, Temperament can be maintained among the selection objectives of Brazilian Sport Horses due to the absence of unfavorable genetic correlations between this trait and competition results.

Conflict of interest

The authors confirm that they have no conflicts of interest concerning the work described in this manuscript.

Author contributions

Conceptualization: B. R. Medeiros, P. Garbade and C. M. M. Pimentel. *Data curation:* B. R. Medeiros and C. M. M. Pimentel. *Investigation:* B. R. Medeiros, P. Garbade, V. Peripolli, L. T. Dias and C. M. M. Pimentel. *Project management:* B. R. Medeiros. *Supervision:* P. Gabarde and C. M. M. Pimentel. *Writing (original draft):* B. R. Medeiros. *Writing (review and editing):* B. R. Medeiros, P. Garbade, V. Peripolli, L. T. Dias and C. M. M. Pimentel.

Acknowledgments

To CAPES (Coordenação de Aperfeiçoamento de Pessoal do Nível Superior) and CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico), Brazil for scholarship support.

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