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Journal of Equine Veterinary Science xx (2017) 1–9

Contents lists available at ScienceDirect

Journal of Equine Veterinary Science

journal homepage: www.j-evs.com

Original Research

The Interplay of Performing Level and Conformation—A Characterization Study of the Lipizzan Riding Stallions From the Spanish Riding School in Vienna

Thomas Druml*, Maximilian Dobretsberger, Gottfried Brem

Department for Biomedical Sciences, Institute of Animal Breeding and Genetics, University of Veterinary Medicine Vienna, Vienna, Austria

A R T I C L E I N F O

Article history:
Received 6 February 2017
Received in revised form 16 June 2017
Accepted 20 June 2017
Available online xxxx

Keywords:
Dressage
Performance level
Rater reliability
Shape regression
Geometric morphometrics

A B S T R A C T

Classical dressage and the schools above the ground as performed in the Spanish Riding School (SRS) in Vienna, require special psychological and physical properties from riding horses. To document the training and performing level of the Lipizzan riding stallions from the SRS in Vienna, we analyzed the horses' performance traits retrieved from chief riders' evaluations in relation to training levels and age classes and we studied the interplay of performing status with the horses' body shape. In total, the mean age of all 80 riding stallions was 11.9 years (min 4 years, max 26 years). Completely trained stallions (competition level S and higher) were on average 15.6 years old (min. 10 years and max. 26 years). From 10 recorded performance traits (five physical traits and five psychological traits), walk, trot, and collection ratings showed significant differences for levadeurs, caprioleurs, and courbetteurs; the psychological traits reactability, diligence, and sensibility showed significant differences between age class (3–4 years, 5–8 years, 9–16 years, >16 years) and number of flying gallop changes. Further we found that 80% of the chief riders' ratings of physical performance traits reached significant levels in the shape regressions, indicating an association of their ratings with body shape variation. The resulting mean body shapes from the significant regressions illustrated the requirements of the school above the ground and the classical dressage on the horses' conformation. We showed that the evaluation of subjective ratings on valuating scales applying shape regressions can help to optimize the quality of scoring data in equine performance traits.

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1. Introduction

The Spanish Riding School (SRS) in Vienna, which was founded in 1672 and built in 1735, is the only one equestrian institution worldwide that has a continuous line of development from the very first beginning of equestrian arts in renaissance times up to nowadays. Although comparable schools were spread all over Europe, they were closed during the 19th and the early 20th century. Another characteristic is the focus of this equestrian institution on classical dressage (champagne school) and on schools above the ground [1,2], following the principles of a horse-adequate and age-adequate training method. Together with the Federal Austrian stud farm in Piber, the SRS represents a complex, where both the breeding of horses and the equestrian part interact with each other. The aim of the stud farm is to deliver adequate riding stallions, whereas the school acts like a testing station interacting with selection decisions in breeding matters. Up to now, the equestrian part and the Lipizzan

Conflict of interest statement: No conflict of interest.

Ethical approval statement/Animal care and welfare statement: This study was discussed and approved by the institutional ethics and welfare committee in accordance with GSP guidelines and national legislation (Number: ETK-06/05/2015).

* Corresponding author at: Druml Thomas, Department for Biomedical Sciences, Institute of Animal Breeding and Genetics, University of Veterinary Medicine Vienna, Veterinärplatz 1, A-1210 Vienna, Austria.

E-mail address: thomas.druml@vetmeduni.ac.at (T. Druml).

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http://dx.doi.org/10.1016/j.jevs.2017.06.003

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stallions' performance have not been subject of systematic description and analysis. Horse breeding concepts firmly rely on expert classifications of conformation and performance. Such judgments are often made in environments that are both stressful and subject to rigid time constraints. This can force judges to use heuristics that draw on prior experience in the decision-making process to enable quick cognitive integration. This process can expose decisions to undefined bias and influence not related to the animal's performance [3]. We were able to detect such bias in previous works concerning rater-agreement and rater-consistency of conformational ratings in Lipizzan mares and stallions [4,5]. In these studies, type trait–related ratings resulted in reasonable associations with body shape variation of the horses. However, functional trait ratings and locomotion trait ratings were characterized by a low inter-rater agreement and missing association to the horses' phenotypes. To address these ambiguities and to take the "*Gestalt* principle" cited by Hawson et al [3] in relation to phenotypic equine evaluation into account, we involved the chief riders of the SRS into the evaluation process of their riding stallions' performance. Hence, they train the horses over years, their decisions are based on the characteristics of the individual stallions over time. So, they do not rely on cognitive information not related to the individual animals.

In this article, we aimed to document the training and performing levels of the Lipizzan riding stallions from the SRS, Vienna, in relation to their age and we studied the demands which are put on the horses' conformation by the riders, that is, the classical dressage (champagne school) or schools above the ground. We further analyzed the horses' performance traits retrieved from chief riders' evaluations in relation to training levels and we studied the interplay of performing status with the horses' phenotypes. Therefore, we applied conventional statistical tools as correlation analysis, principal component analysis, and general linear models, but also methods from image analysis and shape analysis called geometric morphometrics.

2. Material and Methods

We analyzed 10 performance traits (Suppl. Table 1) from 80 riding stallions and morphometric traits (492 shape coordinates) from 69 mature riding stallions of the SRS, Vienna. Thirty-five stallions were "in training" (which is equivalent to Novice level according to Fédération Equestre Internationale Rules for Dressage, FEI), 45 horses were "completed" (equivalent to Grand Prix level, according to FEI). For the definition of the stallions' performance level, a structured interview based on a questionnaire was led with two chief riders of the SRS, and the horses' morphometric traits were derived from standardized images applying Generalized Procrustes Analysis. The collection of the data was performed in the second half of the year 2014 and in the first half of 2015.

2.1. Ethical Review

This study was discussed and approved by the institutional ethics and welfare committee in accordance with GSP guidelines and national legislation (Project Number: ETK-06/05/2015).

2.2. Data Collection

2.2.1. Questionnaire Chief Riders

The structured interview was led by the stud farm director of Piber/Austria with the two chief riders on basis of a questionnaire comprising 18 questions. These included the evaluation of 10 performance traits scored on a Likert scale ranging from 1 to 5 and the characterization of eight descriptive traits which were relevant for our research question (Suppl. Table 1). The performance traits were walk, trot, gallop, collection, strength, diligence, sensibility, intelligence reactability, and performability; and the descriptive traits defined levels of training in the champagne school and schools above the ground. The champagne school represents the pre-Olympic schooling of riding horses, and includes basic elements of riding as well as movements like flying changes, pirouette, piaffe, and passage. In the flying change, the horse performs a lead change at the canter while in the air between two strides. In so called tempi changes, the horse is asked to perform flying changes every stride (one tempis), every two strides (two tempis), three strides (threes), or four strides (fours). A horse which successfully passed the champagne school and/or the school above the ground is called "completed" in the SRS. Within the context of the principles of classical equestrian arts, which are preserved in the SRS, the schools above the ground represent the top level of horses' education comprising movements called capriole, courbette, and levade. In the levade, the horse is asked to put its weight on the hind legs and to lift its forequarter above the ground and to hold this position approximately 30° from the ground. In the courbette, the stallion jumps on its hind legs forward without touching the ground with its forelegs; and in the capriole, the stallion jumps from a raised position of the forehand straight up into the air and kicks out with the hind legs when the body axe reaches the horizontal. In these lections, the horse leaves the ground, and they can be performed on long reins, at the hand or below the saddle.

2.2.2. Imaging and Morphometric Traits

Standardized digital images were taken from 69 mature stallions performing in champagne and/or school above the ground by the author. The resulting photographs were used for the definition of the horse body shapes via digitization of coordinates (landmarks). Images were recorded using a DSLR camera where the distance between horse and camera was 18 meters, the focal width of camera lens was 100 mm and the camera focus was set at the center of gravity of the horse (height of camera set at 110 cm in a 90° angle approximately onto the position of the animal's heart). The horses were presented by a groom in so called open posture: left foreleg standing vertical; hoof of the right foreleg one to two hoof lengths behind the left foreleg; cannon bone of the right hind leg near to the vertical; hoof of the right hind leg is located two to three hoof lengths before the left hind leg. Imaging process was repeated several times and a minimum of two line-ups was performed per horse. For the selection of finally used pictures, an optimal fit criterion regarding the stance of the horse was applied [4,5].

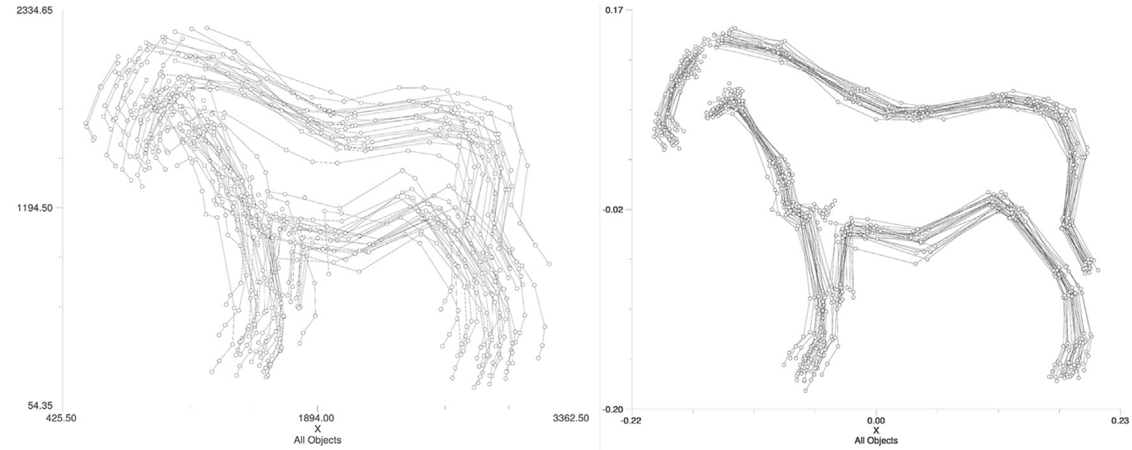

Fig. 1. Digitized data set (test data) before applying the Procrustes fit (on the left) and optimal superimposed specimens of unit size and minimum distance to the sample mean (on the right).

For describing the body shape, a horse model suited to study shape variation with regard to conformational criteria was developed [4,5]. This model combines the outline of the horse and 31 somatometric landmarks (Fig. 1; [4]). Outline curves were transformed to single coordinates and further defined as sliding semilandmarks to minimize the bending energy and result in homologous-like points along a curve [6]. The horse model finally comprised 246 landmarks (31 somatometric landmarks and 215 sliding semi-landmarks).

In total, 16,482 two-dimensional landmark coordinates were extracted from 69 standardized individual digital images using the software packages tpsDig version 2.17 [7] and tpsUtil, version 1.58 [8].

2.3. Image and Shape Analysis

Before proceeding to statistical analyses of image data, a reference system in which one coordinate position on a specimen can be assigned to the homologue position on another specimen is established. We generated this reference system by means of a Generalized Procrustes superimposition, which scales, rotates and centers every single specimen onto the mean configuration of the sample. This statistical procedure eliminates non–shape-associated variation by superimposing landmark configurations using least-squares estimates for translation and rotation parameters. First, the centroid of each configuration is translated to the origin, and configurations are scaled to a common, unit size. The centroid is defined as the mean of all x and y values from all coordinates. Each shape is characterized by its size, called centroid size. This variable is the square root of the sum of all squared distances from each landmark to the centroid. If all x and y coordinates of the landmarks are divided through centroid size, the resulting specimens are of unit size 1. Finally, the configurations are optimally rotated to minimize the squared differences between corresponding landmarks, which is also called Procrustes distance *d* [9]. The process is iterated to compute the mean shape. At the end of this procedure, the original coordinate data have been replaced by substitute Cartesian coordinates (shape coordinates [10]), as they vary around their own sample mean, and are corrected for effects of scale (centroid size), orientation, and location of the original specimens (Fig. 1).

For testing the subjectively scored performance traits (walk, trot, gallop, collection, strength, diligence, sensibility, intelligence, reactability, and performability) for rater-consistency, we applied so called shape regressions, where shape coordinates are regressed onto the scores from the evaluation protocols. For significant shape regressions (the rating of a performance trait was consistent and in association with body shape variation), we recalculated the trait score–associated mean Lipizzan horse shapes along the regression curve for (1) an unfavorable score of five and (2) a favorable score of one. Using this technique, it is possible to visualize the trait-associated aspects of shape encoded in classifier ratings. Shape coordinates were calculated using the program tpsRelw v1.53 [11], shape regressions and shape visualizations were calculated with the program tpsRegr v1.40 [12] and SAS [13]. For further information and details concerning shape regressions and geometric morphometrics, see Refs. [4–6,9,10,14].

Table 1
Training level and mean age of 80 riding stallions from the SRS, Vienna.

Training Level	Stallions	%	Mean Age, y	Min–Max Age, y
In training	35	43.75	7.17	4–13
Completed	45	56.25	15.64	10–26

Abbreviation: SRS, Spanish Riding School.

2.4. Statistical Analyses

Descriptive statistics for performance traits were calculated using the procedures proc freq and proc means of the SAS software packages, version 9.1 [13]. The interclass correlations between the traits were calculated with the SAS procedure proc corr adjusted to the formula of

Table 2
Training level and mean age for the disciplines of the champagne school for 80 riding stallions from the SRS, Vienna.

Training level	Flying Changes	Age, y	Pirouette	Age, y	Piaffe	Age, y	Passage	Age, y
Not yet performed[a]	24	11.13	22	8.82	22	9.46	26	9.23
In training	16	7.25	25	10.60	25	9.96	21	10.29
Completed	40	14.30	33	15.03	33	15.09	33	15.12

Abbreviation: SRS, Spanish Riding School.
[a] In this category, horses which are in the basic training levels and horses which have been specialized for en air schools and therefore did not pass single steps of the champagne school are summarized.

Spearman. For visualization purpose, a principal component analysis based on the correlation matrix was performed using the SAS procedure proc princomp. To analyze the differences of the horses' performance traits according to their training and specialization levels, we applied following generalized linear model:

$$Y = y + \text{age}_i + \text{flying\_changes}_j + \text{pirouette}_k + \text{piaffe}_l + \text{passage}_m + \text{levade}_n + \text{capriole}_o + \text{courbette}_p + \text{error}_{ijklmnop}$$

where:age_i = effect of four age categories (3–4, 5–8, 9–16, >16 years);$\text{flying\_changes}_\text{j}$ = effect of performing flying changes (one-tempi, two-tempi, and three-tempi flying changes, flying changes basics, not yet performed);$\text{pirouette}_\text{k}$ = effect of pirouette completed, pirouette in training, pirouette not yet performed;piaffe_l = effect of piaffe completed, piaffe in training, piaffe not yet performed;passage_m = effect of passage completed, passage in training, passage not yet performed;levade_n = effect of levade performed, levade not performed;capriole_o = effect of capriole performed, capriole not performed;$\text{courbette}_\text{p}$ = effect of courbette performed, courbette not performed;$\text{error}_\text{ijklmnop}$ = remaining variance.

Multiple pairwise comparisons of mean ratings were adjusted according to the formula of Tukey and Kramer. All statistical analyses and the graphical representations were carried out using the SAS software packages, version 9.1 [13].

3. Results

3.1. Characterization of Performing Levels

From 80 stallions, 45 horses (mean age of 15.64 years) were completed, that is, they successfully passed the training of champagne school and/or school above the ground, and 35 stallions of a mean age of 7.17 years still were in training (Table 1).

Table 3
Training level and mean age for schools above the ground (en air) for 80 riding stallions from the SRS, Vienna.

Training level	En Air	Mean Age, y	Levade	Capriole	Courbette
Not yet performed	58	—	75	69	72
In training	9	9.00	2	4	4
Completed	13	15.54	3	7	4

Abbreviation: SRS, Spanish Riding School.

Thirty-three stallions successfully passed their training in the champagne school, 25 to 21 horses still were in training and 22 to 26 stallions were at basic training levels (Table 2) or did not perform in champagne school movements. The average age of completely finished horses (completed) ranged from 14.3 to 15.1 years, horses in training were between 7.3 and 10.6 years old. As not all stallions get finished in the champagne school, because they directly can proceed to schools above the ground or to lections on long reins according to their physical and psychological ability, the mean age of horses in the category "not yet performed" is between 8.8 and 11.1 years. Regarding the schools above the ground, which were shown by 22 stallions, five horses were performing the levade, 11 horses the capriole, and eight horses the courbette (Table 3).

In Fig. 2, the proportions of stallions performing en air schools structured by birth year, are shown. Stallions performing in schools above the ground concentrate in the birth years 2008 to 1993, which is equivalent to an age spectrum from 7 to 22 years. From these 64 stallions, 42 (68%) are champagne riding horses, 22 are performing movements above the ground. In total, nearly one third of the riding stallions from the SRS could be trained for schools above the ground within this 15-year window.

3.2. Evaluation of Ratings by Shape Regression

Shape regressions are statistical tools, which can be used for the evaluation of the consistency of subjective classifier ratings [4,5]. Furthermore, this method enables the analysis of the relationship between scored traits and morphometric traits. The 10 recorded performance traits can be separated in two groups: physical traits comprising the descriptors of walk, trot, gallop, collection, and strength; and psychological traits comprising the descriptors of diligence, reactability, sensibility, intelligence, and performability. However, shape regressions on psychological performance traits did not result in significant curves, a result we had expected, we found significant equations for four of the five physical performance traits (Table 4).

The highest amount of shape variability explained by the regressions was found in ratings for collection and trot (3.1% and 2.2%), which is comparable with findings in equine conformation traits [4,5] and in ratings of human face shape [15]. In Fig. 3, favorable and unfavorable model horses for significant regressions are shown. Regarding the trait collection, we found the following morphological

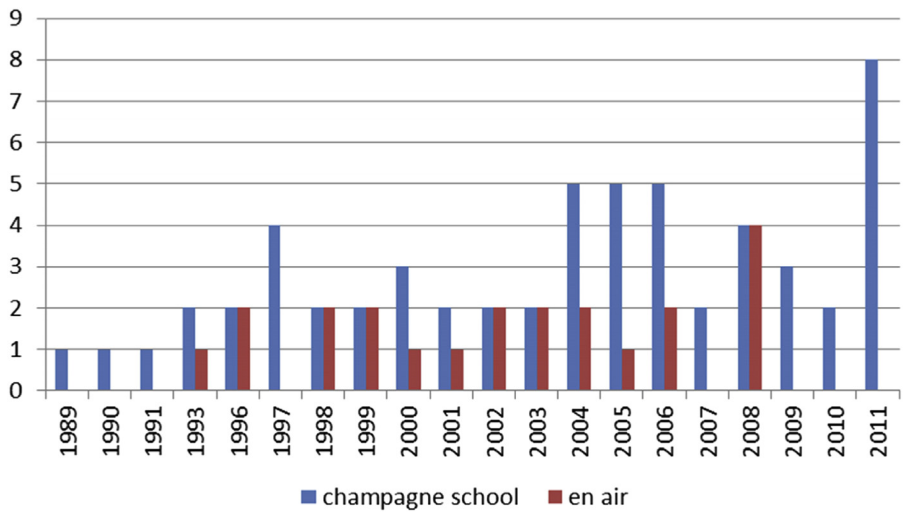

Fig. 2. Distribution of riding stallions by birth year (blue = champagne school, red = en air; y axis = number of stallions, x axis = birth years).

differences: horses with unfavorable ratings are characterized by deviations from the optimal conformation as they are overbuilt, showing less withers, a deeper set back, and backward set front legs. Further they tend to a rectangular format of body and are characterized by a stiff head–neck connection.

Stallions ranked favorable for trot show a well formed top line, a longer croup, a longer and well-set neck with good head–neck connection. In the case of walk rankings, favorable horses are characterized by a similar conformation as documented in the shape differences of trot rankings. Physically, strong horses do not vary much from the mean configuration of the population, horses ranked unfavorable differ in stance and harmony from the mean, for example, favorable horses. At the same time, walk, trot, and collection differentiated significantly between levadeurs, caprioleurs, and courbetteurs (Table 5).

3.3. Analysis of Performance Ratings

Testing the effects of performing levels on the 10 performance traits in a linear model, we found no differences for training levels in piaffe and passage. In the traits, intelligence, performability, and strength, no significant effects of training levels were detected. Regarding physical performance traits, in general, horses performing schools above the ground, differed in walk, trot, gallop, reactability, and collection from horses performing in champagne schools or training (Table 6). Especially, stallions performing the courbette were scored significantly better in the traits trot, gallop, and reactability (Table 5).

The mean scores for the 10 performance traits varied from 1.7 to 2.45; whereas in psychological traits, higher scores were given than in the physical traits (mean scores varying from 2.14 to 2.45). Overall, the evaluations by the chief riders showed a tendency toward better scores, than the mean of the scale would one let expect.

Stallions completed for the levade had better rankings in the trait collection and stallions showing the capriole were ranked worse in the trait walk than horses not performing in this school above the ground. Interestingly, the age effect became significant only for the traits reactability and collection. In elements of the champagne school (FEI Grand Prix level), it could be shown that horses in higher performing levels in the pirouette were classified lower for the trait walk, whereas the number (tempi) of flying gallop changements is linked to higher evaluations to the traits diligence and sensibility. In total, the linear model used explained from 9% (strength) up to 44% (collection) of the variance observed in 10 performance traits.

The subjective ratings of the 10 performance traits also were analyzed by use of Spearman rank correlations to search for relationships between the scoring traits and between physical and psychological trait complexes. The correlations found ranged from −0.02 (sensibility/strength) to 0.69 (trot/gallop) (Table 7). In general, the correlations were at a medium to low level, but the correlation structure as shown in Fig. 4 allows for a differentiation between complexes of performance traits.

Table 4
Significance levels ($P < .05$) for shape regressions of 10 subjectively scored performance traits, proportion of shape variance explained by the ranking score, mean score and standard deviation (Se) of scores.

Trait	Type	*P* Value	% Variance Explained	Mean Score	Se
Walk	Physical	.0008	1.78	2.42	0.90
Trot	Physical	.0024	2.32	2.26	0.87
Gallop	Physical	n.s.	—	2.45	0.98
Collection	Physical	.0001	3.13	2.14	0.86
Strength	Physical	.0001	1.97	2.16	0.98
Diligence	Psychological	n.s.	—	1.70	0.88
Sensibility	Psychological	n.s.	—	2.00	1.06
Intelligence	Psychological	n.s.	—	1.75	0.91
Performability	Psychological	n.s.	—	1.77	0.79
Reactability	Psychological	n.s.	—	2.42	0.95

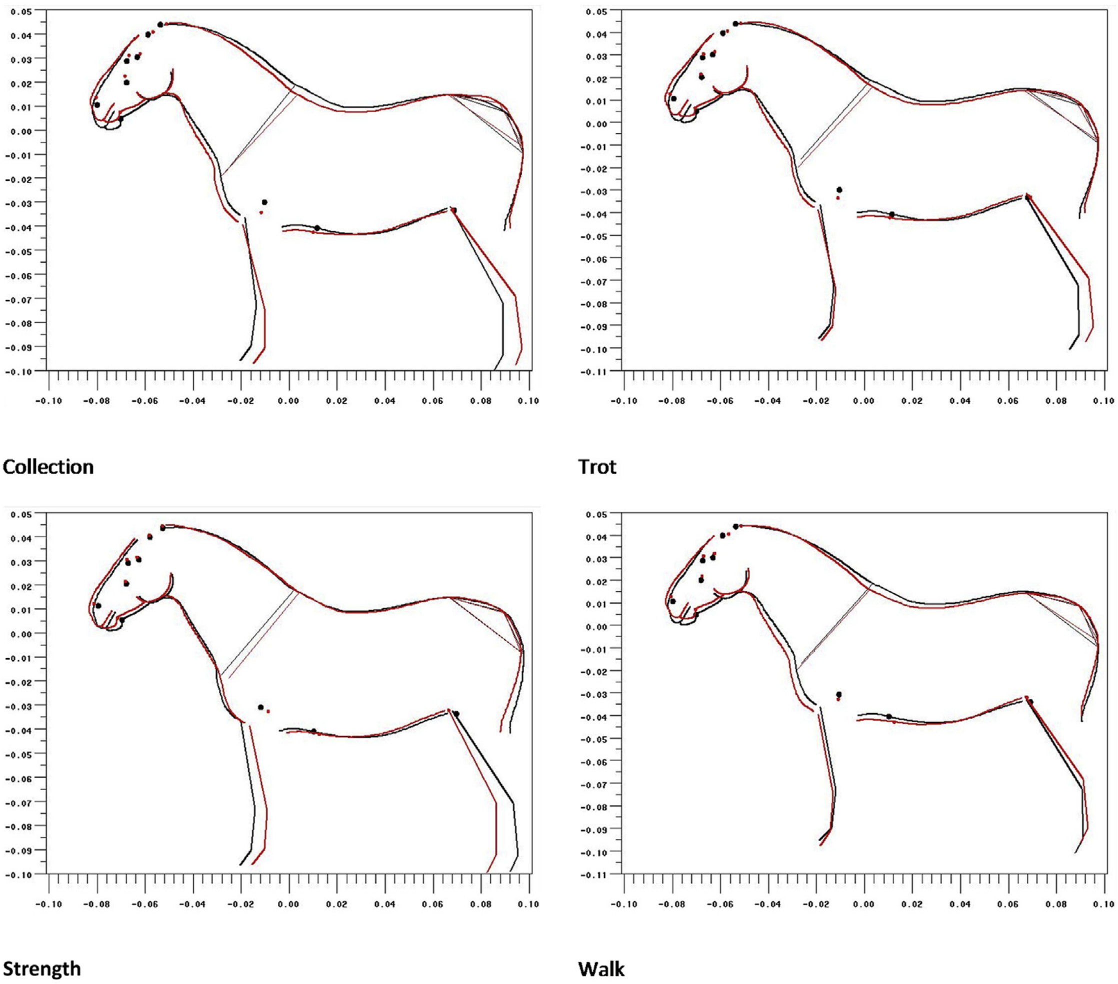

Fig. 3. Graphical representations of averaged model horses according to favorable ratings (score of 1; black figure) and unfavorable ratings (score of 5; red figure) along the regression curves for the traits collection, trot, walk, and strength.

On the correlation circle in Fig. 4, we clearly see the accumulation of psychological traits on the upper left corner (diligence, sensibility, intelligence, performability; *r* ranging from 0.44 to 0.62). On the upper right, riding traits group together (trot, gallop, collection, reactability; *r* ranging from 0.39 to 0.69), whereas walk and strength

Table 5
Multiple comparisons of trait means where the effects of performing levels were significant in the linear model.

Walk	Pirouette in training 1.99^{a}	Not yet performed 2.76	Pirouette completed 3.54^{b}		
	Capriole performed 3.26^{a}	Capriole not performed 2.26^{b}			
Trot	Courbette performed 1.68^{a}	Courbette not performed 2.41^{b}			
Gallop	Courbette performed 1.25^{a}	Courbette not performed 2.24^{b}			
Diligence	Flying change one tempis 1.79	Flying change two tempis 2.29^{a}	Flying change three tempis 0.67^{b}	Not yet performed 0.95^{b}	Flying change—lead change basics 1.33
Sensibility	Flying change one tempis 1.15^{a}	Flying change two tempis 2.31^{b}	Flying change three tempis 1.40	Not yet performed 1.22	Flying change—lead change basics 1.09
Collection	Levade performed 1.00^{a}	Levade not performed 1.91^{b}			
Reactability	Courbette performed 1.44^{a}	Courbette not performed 2.22^{b}			

Superscripts of small letters indicate significant ($P < .05$) differences in means.

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Table 6
Levels of significance for training levels on 10 performing traits as derived from the linear model.

Traits/Effects of Training Level	Walk	Trot	Gallop	Collection	Strength	Reactability	Diligence	Sensibility	Intelligence	Performability
Age	ns.	ns.	ns.	0.001	ns.	0.005	ns.	ns.	ns.	ns.
Flying changes	ns.	ns.	ns.	ns.	ns.	ns.	0.002	0.037	ns.	ns.
Pirouette	0.017	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Piaffe	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Passage	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Levade	ns.	ns.	ns.	0.039	ns.	ns.	ns.	ns.	ns.	ns.
Capriole	0.029	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Courbette	ns.	0.051	0.018	ns.	ns.	0.048	ns.	ns.	ns.	ns.
R^2	0.25	0.34	0.33	0.44	0.09	0.38	0.34	0.27	0.18	0.22

represent different, mostly antagonistic traits in relation to the others.

4. Discussion

The duration of competitive life time in sport horses is a fundamental issue with ethical and economic impact. Wallin et al [16] estimated a median length of life in 983 Swedish Warmblood riding stallions, ranging from 13.9 to 16.0 years, at a mean of 14.7 years. Friedrich et al [17] estimated longevity for dressage horses in Germany and New Zealand. In this study, the median survival time in sports ranged from 3 years (New Zealand) to 6 years (Germany), whereas the factors breed, age, and competition level had significant effects on the duration of competitive life. Similar values for longevity ranging from 2 to 5 years were found by Woehlk and Bruns [18], Lindner and Offeney [19], and Ducro et al [20]. The highest impact on life time that is survival time in dressage sport was documented for the factor competition level. The median survival time in dressage sport for higher competition levels (S, Intermediare II, Grand Prix, Advanced) ranged from 6 years (New Zealand [17]) over 6.5 years (Great Britain [21]) to 10 years (Germany [17]). When we compare these data with the mean age of different performing levels of Lipizzan stallions from the SRS, we see that completed stallions (eq. to competition level S and higher) were on average 15.6 years old (min. 10 years and max. 26 years). In total, the mean age of all 80 riding stallions was 11.9 years (min. 4 years and max. 26 years). This age spectrum in comparison with survival data from dressage horses illustrates that the principles of equestrian arts, that is, an adequate duration of the training period, is a fundamental part to produce riding stallions with a high longevity and still is a characteristic of equestrian tradition in the SRS.

Hence, performing status is highly associated with age, a significant effect of age on the Lipizzan stallions' performance traits could be proven for collection and reactability, traits that are supposed to improve by time during a horse's education. Nevertheless, the effects of performing level on performance traits mostly were relevant for the discrimination of horses going in air above the ground and for the figures pirouette and flying changes. Interestingly, the applied linear model did not deliver information concerning piaffe and passage performing levels and the traits intelligence, performability, and strength. Because subjective ratings of traits on a valuating scale do not rely on biological measures or empirical scales, analysts are confronted with a "black box" problem. Therefore, we evaluated the chief riders' ratings by use of shape regressions to recompose the morphological aspects, which were encoded in their ratings.

Taking into account that 80% of the chief riders' ratings of physical performance traits reached significant levels in the shape regressions, their consistency and reliability of visual perceivements were higher than in ratings of expert conformation classifiers. Here, the percentage of significant individual ratings of six type-related conformation traits varied from 0% to 83%, at a mean of 41% in 102 Lipizzan stallions [5]. In 11 conformational traits of 44 Lipizzan mares, the percentage of significant regressions was 27% [4]. A reason for the higher accuracy in subjective classifications in the SRS is the different point of perspective—the chief rider possesses long-term accumulated information regarding the individual horses, whereas conformation classifiers mostly rely on their temporal restricted visual

Table 7
Spearman rank correlation matrix of 10 performance traits from 69 riding stallions of the SRS.

Traits	Walk	Trot	Gallop	Collection	Strength	Diligence	Sensibility	Intelligence	Performability
Trot	0.35								
Gallop	0.34	0.69							
Collection	0.08	0.41	0.39						
Strength	0.03	0.14	0.08	0.21					
Diligence	0.10	0.45	0.29	0.22	0.28				
Sensibility	0.07	0.45	0.46	0.33	−0.02	0.57			
Intelligence	0.18	0.36	0.41	0.42	0.12	0.58	0.54		
Performability	0.10	0.36	0.25	0.40	0.21	0.57	0.44	0.62	
Reactability	0.21	0.52	0.56	0.56	0.06	0.27	0.47	0.41	0.33

Abbreviation: SRS, Spanish Riding School.

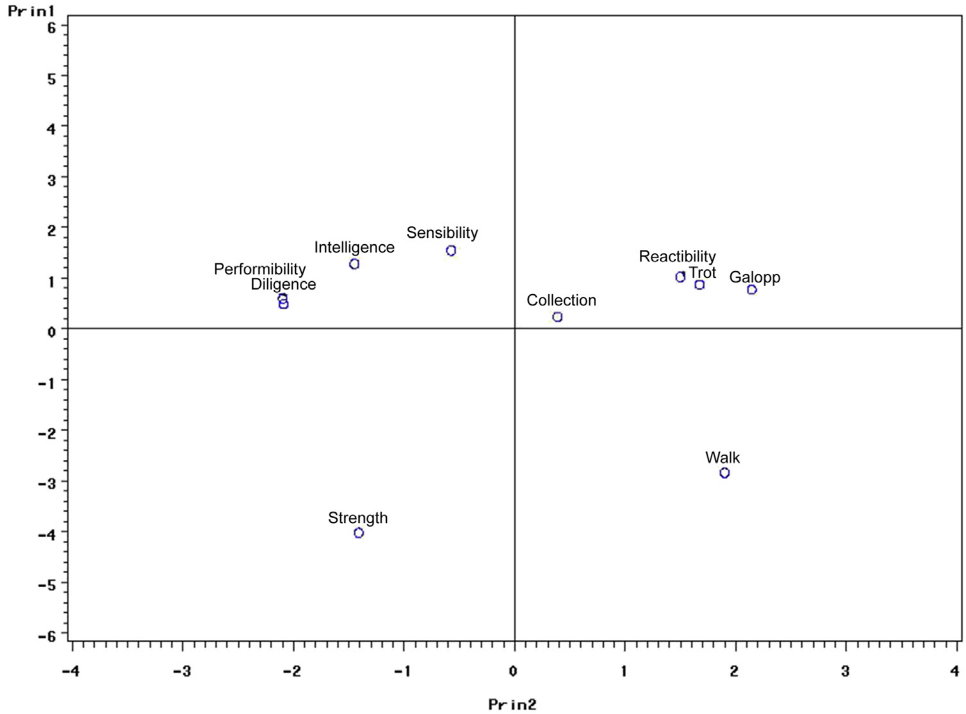

Fig. 4. Correlation circle of 10 performance traits expressed by the first two principal components of the Spearman correlation matrix.

impressions alone. The significant ratings presented in this paper explained between 3.1% and 1.8% of total shape variation within the morphometric data of 80 stallions. These findings are comparable with previous studies in horses, where ratings of type-related conformation traits in Lipizzan stallions and mares explained between 0.8% and 5.2% of body shape variation [4,5]. In human studies of face shape variability, these coefficients reached values of 7.3% for attractiveness, 8.0% for masculinity [15], 1.7% for aggressiveness, 1.9% for body weight, and 6.5% for fighting success [22]. However, these individual visual assessments reflect attributes like attractiveness, aggressiveness, and masculinity; in our case, the ratings of physical equine performance traits should be in association with body shape variation related to specific performing abilities. The graphical representations of un-/favorable horse shapes along the regression curves for the traits collection, strength, walk, and trot, all showed aspects related to the theory of conformation classification (interpretative anatomy [23]). Compared with equine shape regressions on type traits, where sexual dimorphism, breed type or format were encoded in the ratings [5], we found in the analysis of performance data encoded information associated with functional characteristics like: head–neck connection (stiff vs. regular), top-line (forward–upward vs. straight), formation of hind quarter (overbuilt vs. regular; deep set tail vs. regular; long, medium sloping croup vs. flat and short croup), stance (backward stance of front legs and forward stance of hind legs vs. regular; backward stance of hind legs vs. regular), and backline (weak longer back vs. shorter and strong back).

5. Conclusions

In this study, we were able to show that an expanded training phase of Lipizzan stallions up to an age from 10 to 15.6 years, which is in accordance to the principles of classical equestrian arts, still is characteristic for the SRS. Further, we demonstrated by use of geometric morphometric methods that subjective ratings of performance traits can be evaluated for rater consistency and for association with perceived equine conformation. By means of four significant physical performance traits, the requirements of the school above the air and the classical dressage on the horses' conformation could be illustrated, which is an important issue, as the aptitude for classical dressage in the SRS represents the official breeding goal for Lipizzans in the Austrian state stud breeding program. We also could show that substantial differences in rating consistencies in different samples and studies exist, and that the evaluation of subjective ratings by means of shape regressions thus can help to optimize the quality of conformation scoring data in horses.

Acknowledgments

This work was supported by the Austrian Research Promotion Agency (FFG) and Xenogenetik (Contract number 843464).

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References

[1] Kugler G, Biehl W. Die Lipizzaner der Spanischen Hofreitschule. Vienna: Pichler Verlag; 2002.
[2] Podhajsky A. Die klassische Reitkunst. Munich: Franckh-Kosmos; 2006.
[3] Hawson LA, McLean AN, McGreevy PD. Variability of scores in the 2008 Olympic dressage competition and implications for horse training and welfare. J Vet Behav 2010;5:170–6.
[4] Druml T, Dobretsberger M, Brem G. The use of novel phenotyping methods for validation of equine conformation scoring results. Animal 2015;9:928–37.
[5] Druml T, Dobretsberger M, Brem G. Ratings of equine conformation - new insights provided by shape analysis using the example of Lipizzan stallions. Arch Anim Breed 2016;59:309–17.
[6] Gunz P, Mitteroecker P. Semilandmarks: a method for quantifying curves and surfaces. Hystrix 2013;24:103–9.
[7] Rohlf FJ. tpsDig, digitize landmarks and outlines, version 2.17. New York, USA: Department of Ecology and Evolution, State University of New York at Stony Brook; 2013.
[8] Rohlf FJ. tpsUtil, file utility program, version 1.58. New York, USA: Department of Ecology and Evolution, State University of New York at Stony Brook; 2013.
[9] Rohlf FJ, Slice DE. Extensions of the Procrustes method for the optimal superimposition of landmarks. Syst Zool 1990;39:40–59.
[10] Bookstein F. Morphometric tools for landmark data: geometry and biology. Cambridge, UK: Cambridge University Press; 1991.
[11] Rohlf FJ. tpsRelw, relative warp analysis, version 1.53. New York, USA: Department of Ecology and Evolution, State University of New York at Stony Brook; 2013.
[12] Rohlf FJ. tpsRegr, shape regression, version 1.28. New York, USA: Department of Ecology and Evolution, State University of New York at Stony Brook; 2013.
[13] SAS Institute. SAS version 9.1. Cary, NC, USA: SAS Institute Inc; 2009.
[14] Slice DE. Geometric morphometrics. Ann Rev Anthropol 2007;36:261–81.
[15] Windhager S, Schäfer K, Fink B. Geometric morphometrics of male facial shape in relation to physical strength and perceived attractiveness, dominance and masculinity. Am J Hum Biol 2011;23:805–14.
[16] Wallin L, Strandberg E, Philipsson J, Galin G. Estimates of longevity and causes of culling and death in Swedish warmblood and coldblood horses. Livst Prod Sci 2000;63:275–89.
[17] Friedrich C, König S, Rogers CW, König v, Borstel U. Untersuchung zur Nutzungsdauer von Dressurpferden – Ein Vergleich zwischen neuseeländischen Sportpferden und Hannoveranern in Deutschland. Züchtungskunde 2011;83:68–77.
[18] Woehlk TC, Bruns E. Analyse der Nutzungsdauer von Reitpferden im Turniersport. 1999, 31–40, In: Göttinger Pferdetage 1999, Zucht und Haltung von Sportpferden, FN Verlag, Warendorf, Germany.
[19] Lindner A, Offeney F. Einsatzdauer, Abgangsraten und –ursachen bei Sportpferden. Dt Tierärztl Wsch 2006;99:39–42.
[20] Ducro BJ, Bovenhuis H, Back W. Heritability of foot conformation and its relationship to sports performance in a Dutch Warmblood horse population. Equine Vet J 2009;41:139–43.
[21] Walters JM, Parkin T, Snart HA, Murray RC. Current management and training practices for UK dressage horses. Comp Exerc Physiol 2008;5:73–83.
[22] Trebicky V, Havlicek J, Roberts C, Little AC, Kleisner K. Perceived aggressiveness predicts fighting performance in mixed-martial-arts fighters. Psychol Sci 2013;24:1664–72.
[23] Kilgore L. Anthropometric variance in humans: assessing Renaissance concepts in modern applications. Anthropol Notebooks 2012;18:13–23.

Suppl. Table 1
Description of the 10 collected performance traits, which were scored by two chief riders of the Spanish Riding School, Vienna on a Likert scale ranging from 1 to 5, one unit increase, scale mean = 3; 1 = excellent, 2 = good, 3 = satisfactory, 4 = sufficient, 5 = nonsufficient.

Trait	Trait Type	Description
Walk	Physical	Following aspects are evaluated: length of steps, rhythm and harmony of movement, impulse of movement
Trot	Physical	Following aspects are evaluated: length of steps, action of steps, impulse of movement, rhythm and harmony of movement
Gallop	Physical	Following aspects are evaluated: rhythm and harmony of movement
Collection	Physical	Following aspects are evaluated: the ability of the horse to collect itself, i.e., to put its hindlegs below the center of gravity
Strength	Physical	Following aspects are evaluated: physical strength of the horse for carrying the rider
Diligence	Psychological	Self-explaining
Sensibility	Psychological	Self-explaining
Intelligence	Psychological	Self-explaining
Performability	Psychological	Self-explaining
Reactability	Psychological	Self-explaining
Training level	Descriptive	The horse is completed or still in training
Flying changes	Descriptive	Following levels were observed: training level lead change basics, one flying change (one tempis), two flying changes (two tempis), three flying changes (threes), not performed
Pirouette	Descriptive	In training, completed, not performed
Piaffe	Descriptive	In training, completed, not performed
Passage	Descriptive	In training, completed, not performed
Levade	Descriptive	In training, completed, not performed
Capriole	Descriptive	In training, completed, not performed
Courbette	Descriptive	In training, completed, not performed