Applied Animal Behaviour Science 272 (2024) 106202

Contents lists available at ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

Comparison of head–neck positions and conflict behaviour in ridden elite dressage horses between warm-up and competition

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ARTICLE INFO

Keywords:
HNP
Head neck position
Horse
Behaviour
Dressage
Hyperflexion

ABSTRACT

The use of specific head–neck positions (HNPs) in horse riding have been identified to directly affect wellbeing of horses. In the rulebook of the International Equestrian federation (FEI), HNPs with the nasal plane in front of the vertical are mandatory, as well as ensuring horses to be "happy athletes". Deviations from this should be reflected in the scoring of dressage competitions. We investigated ridden elite dressage horses in warm-up areas and during competition, and hypothesised a relationship between the HNP, behavioural indicators and the scores. Forty-nine starters (83%) of an international dressage competition (Grand Prix Special (CDIO5*) at CHIO (Aachen (Germany) in 2018 and 2019) were examined. We analysed HNPs (angle at vertical, poll angle and shoulder angle) as well as conflict behaviour (CB), e.g. unusual oral behaviour (OB) and tail swishing (TS), in the warm-up area and during competition in 3 min-videos (6571 frames). Conflict behaviour was evaluated using the Observer XT with the focus animal method according to an ethogram. Scores given by judges in the competition were noted. Data were analysed with six linear mixed effects models, where phase of competition and year (both factors with two levels) were fixed effects, and the horse was a random effect. Dependent variables were poll angle, angle at vertical, shoulder angle, TS, OB and total CB. Further, we evaluated another three models to evaluate if the vertical angle affected the response variables (TS, OB or CB). Hereby, angle at the vertical (continuous) and year (factor with two levels) were fixed effects, and the horse was considered as a random effect. The horses' nasal plane was behind the vertical more often during warm-up than during competition (-11° vs. -5°; $P<.01$). Further, the poll angle was larger during competition than during warm-up (28° vs. 24°; $P<.01$). Horses showed more total CB and OB during warm-up than during competition (count: 163 and 107 vs. 120 and 78; $P<.01$). Horses tended to show more CB and OB when their nasal plane was behind the vertical. Tail swishing was not affected by angle at the vertical. Scores given by the judges correlated with HNPs during competition ($R = 0.38$; $P<.05$). These results undermine animal welfare concerns during world class dressage competitions.

1. Introduction

In recent years, horse riding at an elite level has come under increased scrutiny because of animal welfare concerns (McGreevy, 2007; Ladewig et al., 2022). In the Olympic discipline of dressage, the discussion of whether riding in certain head–neck positions (HNPs) may compromise the welfare of horses has been ongoing (van Weeren, 2013; König von Borstel and McGreevy, 2014). Official federations regularly state the importance of a sound and happy athlete (Fédération Equestre Internationale, 2019). In practical application, more attention should be paid to equine welfare during equestrian competitions. In numerous studies, the influence of HNPs on various parameters of health and

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https://doi.org/10.1016/j.applanim.2024.106202
Received 2 October 2023; Received in revised form 14 February 2024; Accepted 15 February 2024
Available online 17 February 2024

welfare of horses has been evaluated (van Breda, 2006; Rhodin et al., 2009; Waldern et al., 2009; Cehak et al., 2010; Elgersma et al., 2010; Becker-Birck et al., 2012; Berner et al., 2012; Kienapfel et al., 2014; Kienapfel and Preuschoft, 2016). In nearly all these studies, the hyperflexed position stood out as being extreme. Increased heart rate, cortisol concentrations, or decreased heart rate variability, were physiological indicators showing that this HNP was associated with distress and compromised welfare (König von Borstel et al., 2009; Ludewig et al., 2013; Zebisch et al., 2013a; Hall et al., 2014; Kienapfel et al., 2014; Smiet et al., 2014). In addition, some studies detected impaired breathing (vanErck, 2011; Sleutjens et al., 2012; Zebisch et al., 2013b) and potentially detrimental occurrences in the neck (Clayton et al., 2010; Elgersma et al., 2010; Fjordbakk et al., 2013; Kienapfel, 2014; Nestadt et al., 2015) when horses were ridden with the noseline behind the vertical.

In elite dressage competitions, the directive is clearly defined. According to the Fédération Equestre Internationale (FEI) dressage rules, the noseline has to be at or slightly in front of the vertical at all times (Internationale, 2019a). Hyperflexion as a form of 'aggressive' riding in terms of the FEI is forbidden officially, according to the rules, while not being defined in more than the most extreme form where the chin of the horse is almost touching its chest (Internationale, 2019b) (see the official video of the FEI). In competitions, adherence to these rules must be essential, not only for achieving high scores, but also for ensuring the welfare of the horse during ridden exercise. Even if the ideal HNP is not achieved constantly at all times (e.g., while warming up), it should of course be the final goal. Therefore, we chose world class riders to assure the best possible research results of skilled and experienced horse–rider pairs. We expected to find the whole range of HNPs, knowing from discussions of the last 10 years that the ideal HNPs are not always reached in practical application. However, following the FEI statement 'the welfare of the horse is paramount', the occurrence of hyperflexion is expected as a rare event, with desirable riding to be present most of the times in elite sports (Dyson and Pollard, 2021a).

The primary objectives of this study were to:

1. Examine the prevalence and characteristics of HNPs, including the angle at the vertical, poll angle, and shoulder angle in elite dressage horses during warm-up sessions and competition among different years.
2. Assess conflict behavior (CB) in the form of unusual oral behavior (OB) and tail swishing (TS) in warm-up areas and during competition, with a focus on identifying any differences between these phases.
3. Investigate the correlation between judges' scores and observed HNPs during competition, with the aim of understanding how these positions may affect competition outcomes.

2. Methods

2.1. Study sample

We investigated HNPs and behaviours indicative of conflict of 49 horse-rider pairs competing in the highest possible dressage level, a Grand Prix Special (CDIO5*), during the warm-up and competition phase of a professional dressage competition (CHIO "Concours Hippique International Officiel" Aachen, Germany) (Table 1). All horse-rider pairs were scored for their dressage performance on a scale from 0% to 100% according to the FEI guidelines by five judges during the competition phase. Horses were not scored during the warm-up phase. The data were anonymized. Breed, age and sex of the horses were provided by the organisers of the competition. The mean age of the horses was 13.2 years. All horses were warmbloods. Because the same competition was evaluated in two consecutive years, four riders appeared twice in the dataset with the same horse, and five riders were observed twice but with different horses, so 45 horses and 40 riders were uniquely observed. One of the riders received no scores for his competition ride (eliminated because of the "blood rule" according to the score sheet) but is otherwise fully included in the dataset. According to the world ranking list of the FEI (data.fei.org), 42% (n = 22) of the starters were in the 'Top 20' of the world during the respective year of the data collection, and 86% in the 'Top 100', resulting in a sample of the best riders in the world according to the FEI. In 2018, 73% and in 2019, 93% of the starters were evaluated in both situations: warm-up and competition. In total, 90% of all starters of this particular two Grand Prix Specials were included in the study. The missing 10% of riders were due to organisational reasons because the riders were following their own usual warm-up routine. The warm-up was sometimes earlier than expected, or (in rare cases) the riders did warm up in another place where spectators had no access. Horse–rider pairs were not selected. Every available pair was filmed. During warm-up, gaits and dressage movements were chosen by the riders.

Table 1
Number of starters, age, breed and sex of the horses in the sample.

Parameter		2018	2019	Total
Number of starters		25	27	52
Eliminated, retired or not started (n)		2	1	3
Included in analyses (n)		23	26	49
Age (±SD) (years)		13.76 (±1.75)	12.74 (±2.18)	13.23 (±2.04)
Breed	Other	6	7	13
	KWPN*[1]	10	6	16
	Hanoverian	6	4	10
	Westphalian	1	3	4
	Lusitano	1	5	6
	Trakehner	1	2	3
Sex	gelding	11	16	27
	mare	3	3	6
	stallion	11	8	19

*[1]Koninklijk warmbloed Paard Nederland

In the present study, the recent situation in dressage riding of elite horses was evaluated in one selected typical competition during two consecutive years. Typically, in dressage competitions the horse-rider pairs have to complete one predefined, well-known test in front of one or more judges, which are sitting on the short side and (if 5 or more judges are present) in the middle of the long sides. In the highest classes, very specific and difficult movements, such as piaffe (a slow elevated trot without moving forward and without floating phase), are to be shown. Additionally, at international elite levels, equine health and management are set at very high standard. In the context of elite competitions, the horses are vetted as 'fit-to-compete'. In the warm-up area and during competition, the riders are always under scrutiny of experts (stewards and judges), and clearly lame horses are to be excluded, therefore we can confirm, that we analysed visually sound horses. The aim of the study was the evaluation of the relationship of HNP and behavioural parameters at warm-up and competition and the scores given by the judges for the competition ride. Furthermore, the relationship between the HNP used in the warm-up area and the HNP used in the competition was studied.

2.2. Data collection

Horses were monitored during warm-up and competition as described below.

2.3. Warm-up

During warm up, all horses were filmed by two videographers either with a Sony FDR-AX 53 or a Sony HDR-CX625 camera in at 25 frames per second with a resolution of 1280×720 pixels (HD). In the warm-up area, horses were filmed from the short side of the arena at a 10-m distance to the short side in the same position in both years. The cameras were handheld at shoulder height with the cameras internal image stabiliser switched on because the presence of spectators around the riding area required flexibility in camera handling.

2.4. Competition

Videos of the competition were provided by an Internet video platform, again with 25 frames per second and a resolution of 1920×1080 pixels (Full HD). Horses were on camera continuously, resulting in all angles being present (front, profile and hind views; for HNP evaluation, only the profile view was used, see below). The footage of the competition was collected by a professional company for every horse–rider pair, standardized with the same angles in each ride.

2.5. Data selection

For each horse–rider pair, the HNPs and the conflict behaviours (Table 2) were analysed for 3 minutes each in the warm-up area and during the competition by using the Observer XT software v.15 (Noldus, Wageningen, The Netherlands; www.noldus.com). Footage of the warm-up was cut in sections of continuous riding of three consecutive minutes if available after the beginning of the working phase (defined as the start of sitting trot in contrast to the rising trot, where the rider stands up and sits down in the rhythm of the trot). The selection of three minutes was made for the purpose of analysis, and it has been found to be long enough for comprehensive assessments and short enough for practical application in field trials (e.g. Kienapfel et al., 2014). To gain these three minutes of consecutive riding, 6–10 minutes of "raw" warm up need to be filmed, as every rider warms up individually without giving notice on their warm up program. Phases of walk, standing or other horses crossing in front of the observed pair were cut out. Walk and standing were excluded to ensure comparability, as these are often used as relaxation or adjusting phases in warm-up. No other selection was made. The competition footage was analysed for a duration of 3 consecutive minutes after 1 minute of beginning the competition ride to ensure comparability with the warm up. Walk was also removed in competition data.

Table 2
Ethogram of observed conflict behaviours.

Behaviour	Explanation
Rearing	The horse's forebody and forelimbs rise, such that the weight is carried by the hindlimbs while standing. Each leaving of the ground was counted as one event.
Unusual oral behaviour (all deviations from a still and closed mouth or chewing with closed lips)	The horse opens the mouth so a gap between the upper and lower jaw is visible, showing the teeth or tongue for more than 1 second, chewing movements with visible separation of upper and lower jaw or moving the lower jaw opposite to the upper jaw while chewing. The total time of these behaviours was taken and counted as one event per second.
Tail swishing	The horse moves the tail in a fast motion in a vertical, horizontal or combined direction. Each act was counted as one event independent of the vigour of the movement.
Headshaking	The horse moves the head quickly up and down or from side to side or both. Each act was counted as one event.
Crabbing	Hindlimbs of the horse do not follow the track of the forelimbs. The total time of this behaviour was taken and counted as one event per second.
Errors in rhythm	Insertion of rider induced additional steps resulting in a clear loss of the rhythm. Bucking (throwing the hindquarters up simultaneously), kicking with one leg and every other hopping movement outside the specific gait while moving was included here. Each deviation from the gait-specific rhythm was counted as one event.
Nose tilting	The horse tilts its nose to one side. The duration of this action was taken and counted as one event per second.
Going-against-reins	The horse pulls the head up, pushes against the reins and breaks the line between elbow of the rider and rings of the bit. Each act was counted as one event.
Ear movement	Analysed in another study (in prep)
Ear position	Analysed in another study (in prep)hnp

2.6. Determination of head–neck position

Every single frame of the videos with visible profile view of the horse was analysed with the help of a newly developed annotation tool (Group 'Computer Vision', Institute of Informatics, Humboldt University of Berlin, Germany), which has been validated in a pilot study prior to application within this research. This tool worked as described in the following sentences: The relevant sequences in profile view were provided as single frames from the video footage (selected by the researchers as time codes) with 3 frames per second, allowing for efficient manual annotation. From this footage, the tool stored all frames in profile view on a server and the researcher annotated each individual frame manually (Fig. 1). Hereby, the researcher annotated four anatomical markers in each frame following the same order (Fig. 1). These anatomical markers were mouth, neck, shoulder and withers. Out of these data points, the tool calculated three angles in each frame and saved them in a table for further processing. The three angles calculated were: The angle of the noseline in relation to the vertical (α), the poll angle (β) and the angle between the shoulder and withers (shoulder angle, γ) (Fig. 2). Additionally, the X and Y coordinates of each marker were saved. Each single frame was numbered specifically, so all information was present for every frame and could be relocated in the video. The tool allowed for an automated measuring of angles in still frames from manually determined markers. Therefore, the tool sped up the workflow considerably, but did not automatically extract any angles from the video footage, nor did it any other manipulation of data. Ultimately, 540 frames were recorded for each horse in each condition (see supplementary table ST1, whereof 33 ± 12 (SD) single frames during

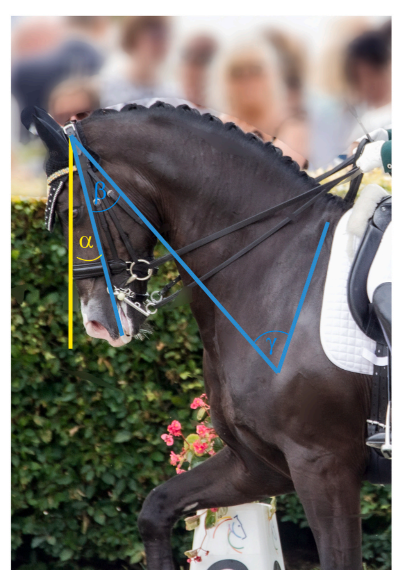

Fig. 1. Studied angles: α = angle at the vertical, β = poll angle, γ = shoulder angle.

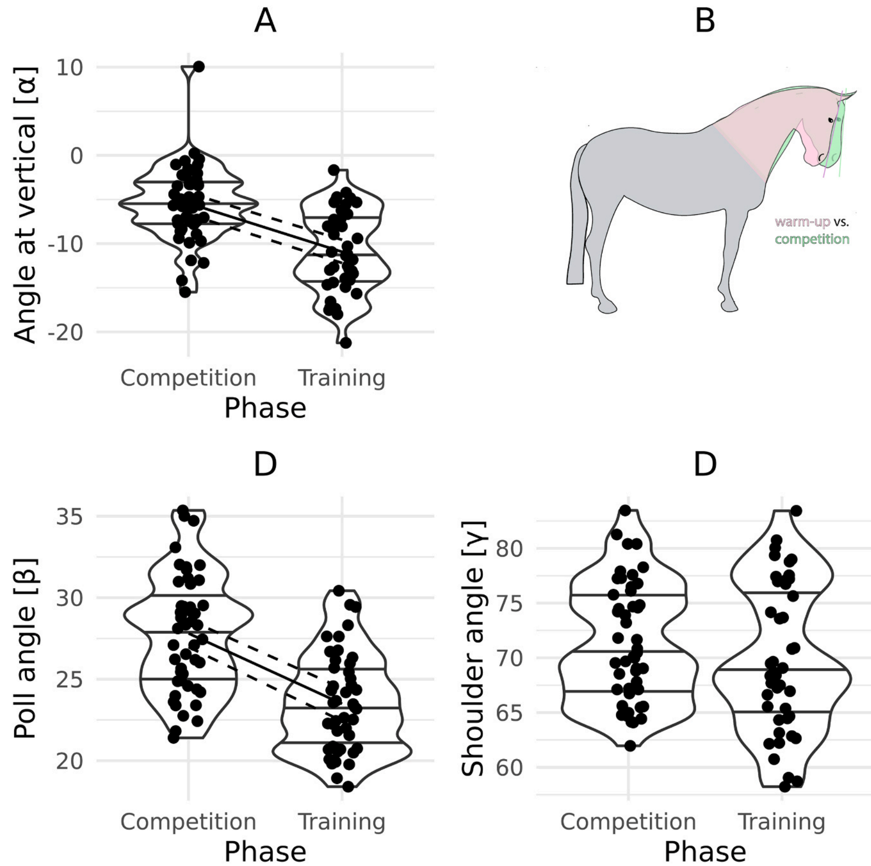

Fig. 2. Angle at vertical in 93 observations (a) and a visualisation of the angle at the vertical with a median of −11,34° behind the vertical in warm-up and −5,54° behind the vertical in competition (b), shoulder angle (c) and poll angle (d). Poll angle (BIC_w: 0.903) and angle at vertical (BIC_w: 0.878) were larger during competition than during training. No such effect was found in the shoulder angle (BIC_w: 0.652). The violin plots show the distribution of the data, where the three lines show the 25th, 50th and 75th percentiles. The solid line between competition and training phase shows the model prediction, whereas the dashed lines show the upper and lower confidence intervals. Model prediction is only presented where an effect was found.

warm-up and 103 ± 24 single frames during competition were in profile view and therefore analysed (total: 6571 individual frames; Table 3). A cranial angle in front of the vertical was defined as $\alpha > 0$, behind the vertical as $\alpha < 0$, implying that the angles behind the vertical were given as negative values. We calculated the mean angles for each horse from these single frames. The mean angles per horse were then statistically analysed. Owing to technical problems, the HNPs of two horses in the warm-up area and of one horse in the competition rides were missing, so the calculation of three angles at the vertical, three poll angles and two shoulder angles was not possible. Summed up, 46 data points for the training, and 47 data points for the competition were included in the final data set.

2.7. Behaviour

All behaviours indicative of conflict were analysed in the Observer XT software v.15 (Noldus) using the focus animal method (as in Kienapfel et al., 2014). Every occurring behaviour was noted following the ethogram adapted from König v Borstel et al., 2009, listed in Table 2.

Table 3
Number of analysed single frames.

Year	Situation	Total number of frames	Frames per horse (±SD)
2018	Warm-up	736	37 (±15)
	Competition	2007	96 (±24)
2019	Warm-up	750	28 (±10)
	Competition	3078	109 (±24)
Total		6571	135 (±18)

Oral behaviour was not always visible because the riders were freely moving in the warm-up area with a fixed position of the camera (as explained above). Subsequently, to minimise an effect of the visibility of the mouth on oral behaviour, it was tracked in Observer XT, and results were extrapolated on 3 minutes of mouth visibility, in relation to the whole sequence. For tail swishing, unusual oral behaviour and all other behaviours the videos were evaluated individually, resulting in viewing each video at least 3 times while scoring in the Observer. If some individual behaviours occurred more often, another observation was performed. The final scores and ranking for each competition ride were provided online by the organisers of the competition. As end result, nose tilting, crabbing and unusual oral behaviour could have maximum values of 1/s, resulting a maximum value of 180 counts. All other behaviours could have unlimited values in theory as they were counted on occurrence.

2.8. Validation and quality assurance

To ensure reproducibility, the current study evaluated video material that was collected in a standardised way (see "data collection"). Further, we performed an inter observer reliability (IOR) test to validate the standardisation of the data extraction from the video material. The IOR test was performed for the total behavioural observations with two observers and 39 horses and resulted in an IOR of 0.91, thus assuring the quality of extracted data (Supplementary Figure S1). For minimising the potential observer bias further, behaviour and head-neck position were analysed by two different observers. All data are available upon request to ensure repeatability of data analysis. Statistical methods are well established and cited appropriately in the section "*Statistical analysis of results*". Equations are described as text to improve readability.

2.9. Statistics

The data were evaluated in R version 4.2.2. The data collection during competition or warm-up was defined as a factor with 2 levels and is hereafter referred to as "phase". The r-code is supplied in Supplementary Material S1.

We performed nine linear mixed effects models with the package "nlme" (Pinheiro and Bates, 2000). Residuals were checked for normal distribution and met the assumption of homogeneity using the "*simulateResiduals*" function from the "*DHARMa*" package (Hartig, 2019). The target variable of three models was sqrt transformed to meet this assumption (indicated below).

2.10. Angles during competition

1. Vertical angle affected by phase of riding: Vertical angle (continuous) was considered the dependent variable, whereas the phase of riding (factor with two levels) and the year (factor with two levels) were considered as fixed effects. The horse-rider pair was considered as a random effect.
2. Shoulder angle affected by phase of riding: Shoulder angle (continuous) was considered the dependent variable, whereas the phase of riding (factor with two levels) and the year (factor with two levels) were considered as fixed effects. The horse-rider pair was considered as a random effect.
3. Poll angle affected by phase of riding: Poll angle (continuous) was considered the dependent variable, whereas the phase of riding (factor with two levels) and the year (factor with two levels) were considered as fixed effects. The horse-rider pair was considered as a random effect.

2.11. Behaviour

4. Total conflict behaviour affected by phase of riding: Total conflict behaviour (continuous) was considered the dependent variable, whereas the phase of riding (factor with two levels) and the year (factor with two levels) were considered as fixed effects. The horse-rider pair was considered as a random effect.
5. Unusual oral behaviour affected by phase of riding: Sqrt(Unusual oral behaviour) (continuous) was considered the dependent variable, whereas the phase of riding (factor with two levels) and the year (factor with two levels) were considered as fixed effects. The horse rider pair was considered as a random effect.
6. Tail swishing affected by phase of riding: Sqrt(tail swishing behaviour) (continuous) was considered the dependent variable, whereas the phase of riding (factor with two levels) and the year (factor with two levels) were considered as fixed effects. The horse-rider pair was considered as a random effect.

2.12. Behaviour in relation to angles

7. Total conflict behaviour model: Total conflict behaviour (continuous) was considered the dependent variable, whereas vertical angle (continuous) and year (factor with two levels) were considered as fixed effects and the horse rider pair was considered as a random effect.
8. Unusual oral behaviour model: Unusual oral behaviour (continuous) was considered the dependent variable, whereas vertical angle (continuous) and year (factor with two levels) were considered as fixed effects and the horse rider pair was considered as a random effect.
9. Tail swishing model: sqrt(Tail swishing) (continuous) was considered the dependent variable, whereas vertical angle (continuous) and year (factor with two levels) were considered as fixed effects and the horse rider pair was considered as a random effect

All models, including all possible interactions, were evaluated via automated model selection with the dredge function from the MuMin package in R (Bartoń, 2013). Restricted maximum likelihood was set to false, and although all models were run with the Bayesian Information Criterion (BIC) and the Aikaike Information criterion (AIC), the BIC was chosen as the main result. Model selection via AIC or BIC present an alternative to frequentist p-value testing. Hereby, the AIC favours the model that best fit the data, whereas the BIC penalises complex models. Due to the requirement of stronger effects we chose to focus on the BIC, but to also report AIC. Hereby, the AIC can deliver information on causal relationships that can be of further interest to test in larger datasets. The model weight (BICw or AICw) can be interpreted as the probability that a specified model is optimal given the data in the set of models considered, where the model weights of all models in a given set add up to 1 (Symonds and Moussalli, 2011). If the difference in BIC or AIC (delta) between the best and the second-best model is below 2, the simpler model should be chosen. The Evidence Ratio (ER) describes the fold of how much better the best model is in comparison to the next best model. If the ER is below 1, the simpler model was chosen due to a delta below 2. (Chakrabarti and Ghosh, 2011))

Prediction models were calculated by bootstrapping with the package "boot" (Canty and Ripley, 2022). Dependant variables that needed to be transformed were back transformed for model estimate presentation and plotting.

Ultimately, the "stargazer" function from the "stargazer" package was used to indicate the *P*-values of all selected models (Hlavac, 2022).

Correlations between HNP and scores were calculated. The data was not normally distributed (Shapiro Wilk test, $p > 0.05$), so Spearmans Rank Correlation tests were used. The parameters "Competition Ranking" and "World Ranking", "poll angle" "shoulder angle" and "angle at the vertical" in relation to "score" were tested.

We evaluated the distribution of the final scores from the five judges placed around the arena on positions E, H, C, M and B, and visualised them in violin plots based on their position. The inter-rater reliability between the scores was estimated using ICC analysis with the R package irr (Gamer et al., 2012).

3. Results

The fixed effects presented best describe the data and explain the dependent variable (Table 4). The effect sizes of the best chosen models are described in Tables 5 and 6, and the associated figures showing model prediction estimates and confidence intervals.

3.1. Angles during warm-up and competition

The descriptive statistics of the raw data are presented in in Table 7. In most cases, the horses' nasal plane was held behind the vertical. The nasal plane was behind the vertical more often during warm-up (−10.95 [α]) than during competition (−5.43 [α]; see Tables 4 and 5 as well as Fig. 2). Further, the poll angle was larger during competition (27.81 [β]) than during warm-up (23.51 [β]; sees Tables 4 and 5, as well as Fig. 2). There was no difference of the shoulder angle between these two situations (70.67 [γ]; see Tables 4 and 5, as well as Fig. 2).

3.2. Behaviour during warm-up and competition

Median and interquartile range of conflict behaviours are shown in Table 8. Horses showed more total conflict behaviour,unusual oral behaviour, and tail swishing during warm-up (162[s], 107[s], and 35.75 [s], respectively) than during competition (78[s], 120[s], and 29[s], respectively; see Tables 4 and 5, as well as Fig. 3). Although BIC selected a model without phase of riding (competition vs. warmup) for number of

Table 4
Results of all calculated linear mixed effect models. The fixed effects describe the dependent variable best and are considered the model outcome. The model weight (w_i) based on the Bayesian information criterion (BIC) and the Akaike information criterion (AIC) describes the model weight, where 1 is the sum of all models calculated. The evidence ratio (ER) reflects how much better the model is compared to the next best model. Each model was calculated with 93 observations. Phase is either warm-up or competition.

Model	Dependent variable	AIC			BIC		
		Fixed effects	wi	ER	Fixed effects	wi	ER
Phase of riding + Year	Vertical angle	Phase	0.671	2.040	Phase	0.878	7.197
	Shoulder angle	-	.292	1.136	-	.0652	4.025
	Poll angle	Phase	0.723	2.610	Phase	0.903	9.309
	Total conflict behaviour	Phase	0.652	1.880	Phase	0.869	6.685
	Sqrt(Tail swishing)	Phase	0.578	2.627	-	0.428	0.900
	Sqrt(Unusual oral) behaviour	Phase	0.486	0.951	Phase	0.486	0.372
Vertical angle + Year	Sqrt(Tail swishing)	-	0.510	2.372	-	0.808	8.417
	Unusual oral behaviour	Angle Vertical	0.459	1.120	-	0.254	0.477
	Total conflict behaviour	Angle vertical	0.594	2.041	-	0.268	0.442

Table 5
Fixed effect model estimates and upper and lower confidence intervals (CI) of fixed effects for the best models selected by BIC, or in the case of tail swishing by AIC during WarmUp and Competition (Comp.). Further P values are presented to indicate level of significance. (n.s. =not significant).

	Behaviour					
Dependant variable	Oral behaviour [s]		Conflict behaviour [s]		Tail swishing [s]	
	Warmup	Comp.	Warmup	Comp.	Warmup	Comp.
Estimate	107.13	78.30	162.79	120.48	35.75	28.64
Upper CI	124.09	91.86	179.44	137.38	45.51	37.92
Lower CI	91.66	65.07	144.18	103.53	26.04	20.69
P	<.01		<.01		<.1	
	Angles					
Dependant Variable	Vertical angle [α]		Poll angle[β]		Shoulder angle [γ]	
	Warmup	Comp.	Warmup	Comp.	Warmup	Comp
Estimate	-10.95	-5.43	23.51	27.81	70.67	70.67
Upper CI	-9.71	-4.24	24.44	28.74	71.94	71.94
Lower CI	-12.12	-6.65	22.56	26.95	69.38	69.38
P	<.01		<.01		n.s.	

Table 6
Fixed effect model estimates of behaviours (tail swishing, unusual oral behaviour and total conflict behaviour) and angle at the vertical, as well as level of significance level. Standard error is given in brackets.

	Dependent variable		
	Tail swishing	Unsual oral behaviour	Total conflict behaviours
	-1	-2	-3
Vertical angle		-2.197*	-2.026*
		(0.874)	(0.856)
Constant	31.97**	80.007**	113.848**
	(0.152)	(8.787)	(8.963)
Note:	**P<0.05;**P<0.01*		

tail swishes during warm-up and competition, the AIC selected a model with phase as a fixed effect, where horses showed more tail swishing during warmup (36[s] than during competition 29[s] (see Tables 4 and 5, as well as Fig. 3). Errors in rhythm and headshaking were rarely observed, especially during competition in only a few horses. The other behaviours listed in the ethogram were never observed.

3.3. Behaviour in relation to angles

Horses showed more total conflict behaviour and unusual oral behaviour when their nasal plane was behind the vertical (see Tables 4 and 6, as well as Fig. 4). This effect was only evidenced in the model selection via AIC, but not in the BIC. Tail swishing on the other hand was not affected by angle at the vertical, as the null model was the best model (see Tables 4 and 6, as well Fig. 4).

Table 7
Descriptive statistics of all measured angles during warm-up and competition. Observed were the angle of the noseline in relation to the vertical (α), the poll angle (β) and the angle between the shoulder and withers (shoulder angle, γ).

Situation		Angle at the vertical (α) [°]	Poll angle (β) [°]	Shoulder angle (γ) [°]
Warm-up	median	-11.34	23.19	69.07
	IQR	7.02	4.79	11.62
	maximum	-21.24	30.43	83.43
	minimum	-1.66	18.41	58.23
Competition	median	-5.54	28.22	70.29
	IQR	4.48	4.63	8.89
	maximum	-15.49	35.35	83.47
	minimum	10.06	21.40	61.96

[1]IQR: interquartile range

3.4. Scores

The scores given ranged between 59% and 87% with possible scoring of 0–100%. The judges' total scores correlated strongly among each other ($R > 0.96$; $P < 0.001$; Fig. 5). The inter-rater reliability of the judges was high, with an ICC=0.99 and a 95% confidence interval ranging from 0.98 to 0.99). Furthermore, the scores were weakly to moderately correlated with the angle α ($R = 0.38$; $P < 0.05$). The more the horses' nasal plane was behind the vertical, the higher was the chance for a higher score.

The parameter 'world ranking' was strongly correlated with the 'competition ranking' in both years (2018: $r = -0.69$; $P < 0.05$; 2019: $r = -0.76$; $P < 0.05$), meaning the higher the riders were ranked in the FEI world ranking (short notion for data interpretation: lower numbers in world ranking mean a better rank, resulting in a negative sign here), the higher were their scores in the competition.

Furthermore, the 'world ranking' parameter was correlated weakly with the amount of unusual oral behaviour ($r = -0.30$; $P < 0.05$), weakly to moderately with the angle of the noseline behind the vertical ($r = -0.37$; $P < 0.05$) and moderately with the poll angle ($r = 0.43$; $P < 0.05$). So, the horses of riders higher in the FEI world ranking tended to show more unusual oral behaviour and a noseline more behind the vertical resulting in a smaller poll angle.

4. Discussion

The current study provides an insight into the current riding practices during warm-up and competition during international dressage sport. We found that horses were ridden with the nasal plane more

Table 8
Median and IQR of conflict behaviours observed during warm-up and competition in 3 minutes (only observed behaviour categories are listed).

	Warm-up			Competition		
	Number of horses showing this behaviour	Median number of events observed in 3 minutes	IQR of conflict behaviour observed in 3 minutes	Number of horses showing this behaviour	Median number of events observed in 3 minutes	IQR of conflict behaviour observed in 3 minutes
Unusual oral behaviour	49/49	110.4	80.4	49/49	81.5	61.5
Tail swishing	49/49	33.0	64.3	49/49	26.5	43.5
Headshaking	4/49	0	0	0/49	0	0
Errors in rhythm	27/49	1.0	2.0	1/49	0	0
Total number of conflict behaviour events	49/49	165.4	62.9	49/49	120.5	83.8

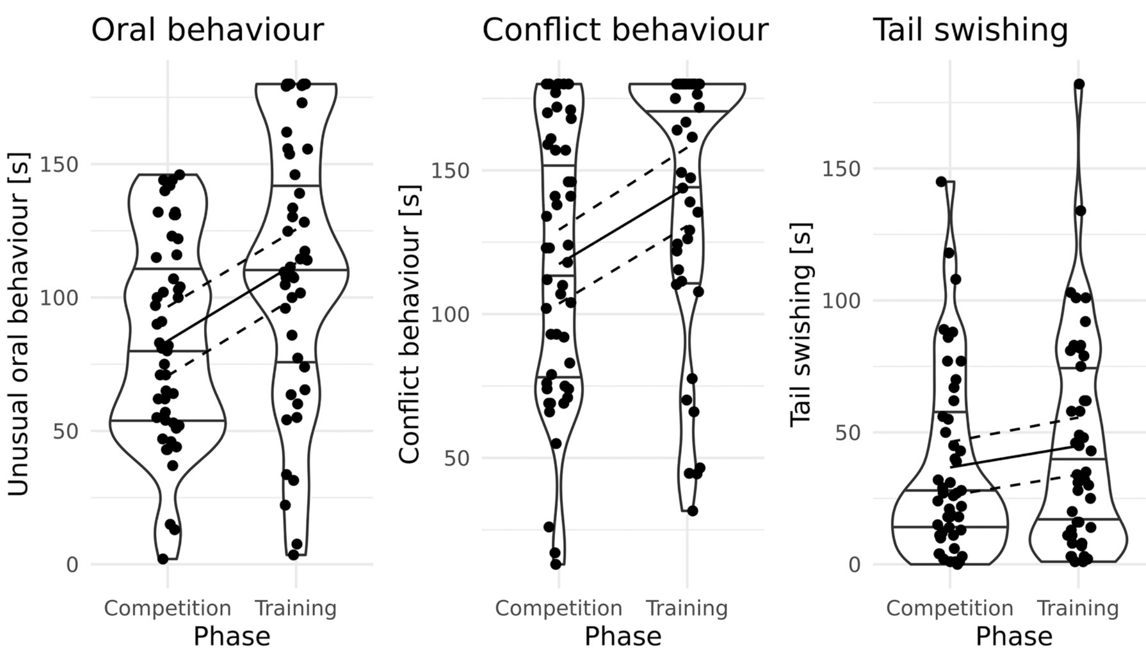

Fig. 3. Horses displayed more conflict behaviours, especially unusual oral behaviours during competition than during training ($BIC_{w:}$ 0.869 and $BIC_{w:}$ 0.486, respectively). This effect was only found for tail swishing with AIC, but not BIC (BIC_w: 0.762, AIC_w: 0.578). The violin plots show the distribution of the data, where the three lines show the 25th, 50th and 75th percentiles. The solid line between competition and training phase shows the model prediction, whereas the dashed lines show the upper and lower confidence intervals. Model prediction is only presented where an effect was found.

behind the vertical during the warm-up than during the competition phase. This practice is not in accordance with FEI guidelines. As conflict behaviour correlates with HNP, with more conflict behaviour occurring when the horse is ridden more behind the vertical, we suggest that there is a need to monitor practices in the warm-up area of competitions to always ensure the welfare of horses on the competition grounds. We have also found that the more horses were ridden behind the vertical in the competition, the higher was the probability of good scores by the judges, which should not be the case according to the rules.

During the competition, the horses showed less conflict behaviour than in the warm-up area. Kienapfel at al. (2014) found similar results by comparing these two situations in horses that started at a lower performance level in small national competitions in Germany (Kienapfel et al., 2014). One possible shortcoming of our study might be the impossibility to select representative portions for the whole warm-up process as the latter was not performed in a standardised way. The ridden programme in warm-up was chosen freely by the riders. We tried to address this limitation by selecting the same warm-up phase for each rider, which nonetheless may not be fully representative for the whole warm-up process of each individual rider. However, other studies assessing warm-up situations used similar approaches (Kienapfel et al., 2014; Dyson and Ellis, 2020). In general, the method of choosing a restricted random portion of a video sequence for behavioural studies is necessary to acquire a comparable and manageable database. The aim of this study was to generate an overview of the recent state of the art in dressage riding.

A vast majority of the observed conflict behaviour was unusual oral behaviour and tail swishing. No difference in tail swishing could be found between the two studied situations. Tail swishing as one of the most frequently observed behaviours was also found in other studies (Kienapfel, 2011; Christensen et al., 2014; Kienapfel et al., 2014; Górecka-Bruzda et al., 2015; Dyson and Pollard, 2021a; b). Generally, high frequencies of conflict behaviour were also seen in the study by Hamilton et al. (2022), who found it in nearly all studied movements at competitions in novice and elementary classes. In other studies, specifically looking at the influence of different HNPs, conflicting results were found. Some studies found a difference in tail swishing depending on the HNP categories (König von Borstel et al., 2009; Kienapfel, 2011; Kienapfel et al., 2014), another study did not (Christensen et al., 2014). However, we did not directly compare the influence of HNP on the behaviours. Although the HNP was changed in the competition (as compared with the warm-up), the level of tension in horse and rider might increase in the competition situation, where the demonstration should be the best possible because the final performance is being

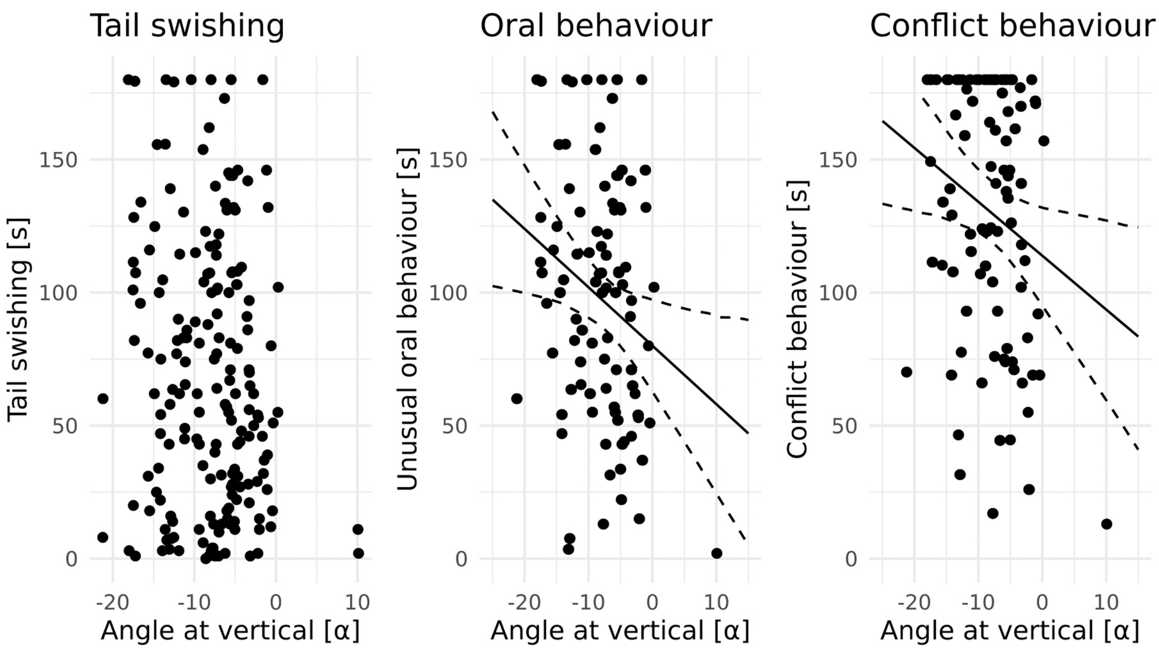

Fig. 4. Horses displayed more conflict behaviours, especially unusual oral behaviours when their nasal plane was behind the vertical (AIC_w: 0.653, AIC_w: 0.459, respectively). No such effect was found for tail swishing (AIC_w: 0.510). The violin plots show the distribution of the data, where the three lines show the 25th, 50th and 75th percentiles. The solid line between competition and training phase shows the model prediction, whereas the dashed lines show the upper and lower confidence intervals. Model prediction is only presented where an effect was found.

judged. The missing difference in tail swishing in the two situations points to a possible correlation of other factors causally influencing tail swishing more than HNP alone. In addition, sequences of tasks such as piaffe, passage and pirouettes are demonstrated in the competition situation more often than in the warm-up, possibly resulting in greater physical stress. However, frequent tail swishing is generally seen as an undesirable signal while riding, as stated in previous studies (König von Borstel et al., 2009; Christensen et al., 2014; Kienapfel, 2014; Kienapfel et al., 2014; Dyson and Pollard, 2021a) and in the general riding rules of the FEI (Internationale, 2019a). Further investigations are therefore required to determine the influence of specific ridden tasks on the occurrence of tail swishing in elite dressage horses.

The occurrence of unusual oral behaviour differed significantly between both analysed situations, and the same was true for the used HNPs. At competition, the horses were presented with larger poll angles and therefore a noseline less strongly behind the vertical. The unusual oral behaviour seems to be closely related to the HNP and could be a useful indication for the rider to acknowledge a necessary change in the selected HNP.

Another significant weak to moderate correlation in this study is the relationship between the judges' rating and the HNP. Conflict behaviour was not correlated with the scoring. The more the horses held the noseline behind the vertical during competition, the higher was the probability of a good ranking. This is surprising as the national and international regulations require an HNP with the noseline at or slightly in front of the vertical (Internationale, 2019a). The correlation coefficient is in this case between "weak" and "moderate" with $p<0.05$ (Alsaqr, 2021). These results should be considered as what they are- multifactorial, but an association of the parameters nonetheless. This specific variable is not the only factor in this correlation, but important in a range of others. In this example of score and HNPs, not only HNPs account for scores, but of course the performance itself is another (if not the main) factor. If there are big mistakes in piaffe or pirouettes and other performance problems, of course the score will be low independent of HNPs. But we could see, if the score is high (so performance was good in the first place), there was also an increased probability of a noseline behind the vertical. This association shouldnt́ be present according to the rules. It has been found that judges tend to focus on the forehand (head, neck and shoulder area) of the horse (Wolframm et al., 2013), so this relatively easily visible indicator should be taken into account. The extremely high ICC (0.99) in this study was consistent with findings that the agreement between judges scoring elite competitions, with better known riders and horses, was higher than between judges scoring novice riders (Stachurska and Bartyzel, 2011). This may be due to the judges having higher qualifications at the elite level, implicating more experience, an implicit bias for specific, easily recognisable horse–rider pairs, or a combination of both, which could not be considered statistically in the ICC. The high scores up to 87% were also reflective of the world ranking level of the competitions considered in this study, as the highest scores are awarded to the best horse–rider pairs in dressage.

However, while the scoring agreement between judges was excellent, the high ICC does not necessarily imply that the judges were "right", as the higher scores were positively correlated to HNPs behind the vertical, which should in theory be penalised. This rule-contradicting result of higher scores correlating with HNPs held more strongly behind the vertical was also found in another study (Lashley et al., 2014). We found no association between the given scores and the shown conflict behaviour, which is, as well as a noseline behind the vertical, in contrast to the rules of the FEI (Internationale, 2019a). Apparently, the undesirable or missing correlations indicate the failing of following own internal rules, which has to be based on other factors than inter-rater agreement. The results of our study revealed a discrepancy between FEI rules and scores in relation to objectively measured kinematic and behavioural parameters. The authors suggest to address this discrepancy to improve equine welfare at the highest levels of the sport.

The HNP was analysed with an annotation tool, which enabled the researchers to measure the HNPs in all available profile view frames by hand. Up to now, only few frames were analysed in recent studies to give an estimation of the achieved or used HNPs (Becker-Birck et al., 2012; Christensen et al., 2014; Kienapfel, 2014), or the analysis was done only qualitatively and subsequently prone to be subjective (König von Borstel et al., 2009; Kienapfel et al., 2014; Smiet et al., 2014; Górecka-Bruzda

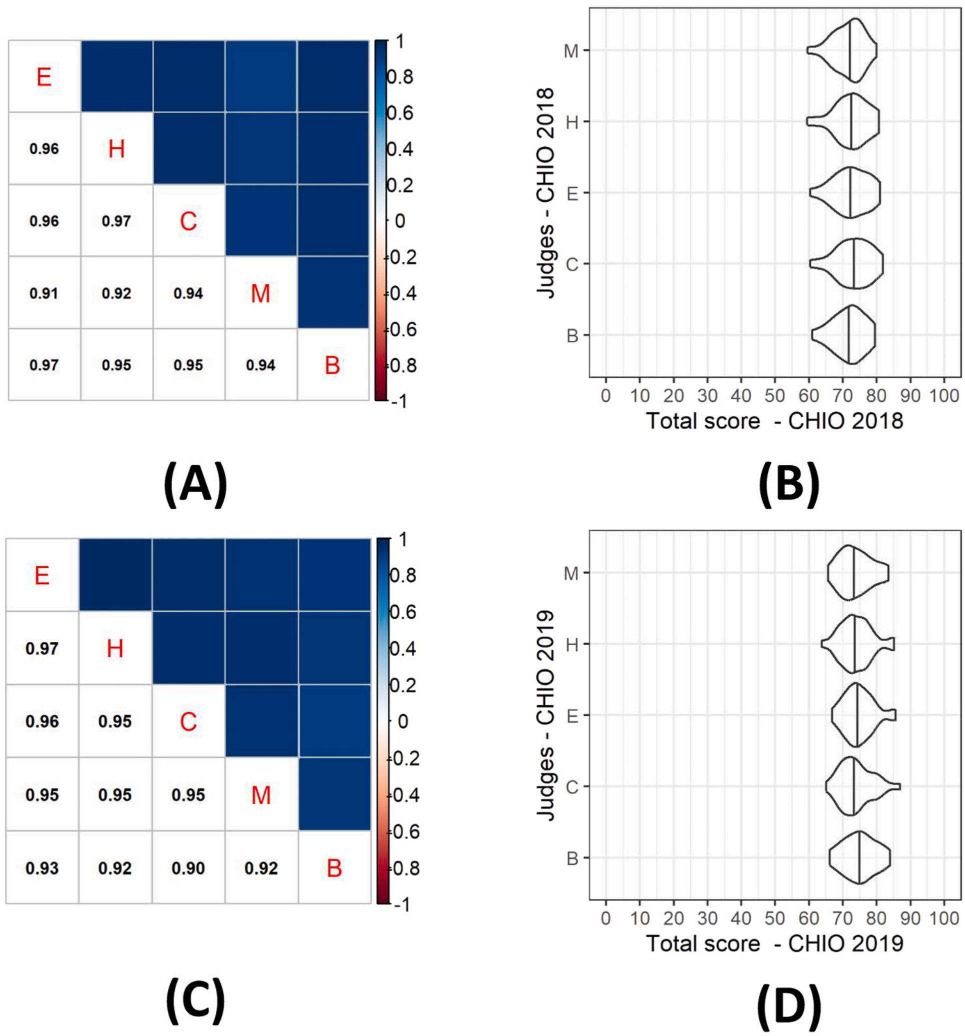

Fig. 5. Cross-correlation matrix of the judges for the total score, 2018 (A) and 2019 (B) by arena position of the five judges, who were placed in the competition arena in the middle of the long side (two judges at the letters E and B), in the front corners (two judges, placed at the letters H and M) and one in the centre (at the letter C), to observe the riders from different angles. (C,D) Violin plots of the scores given by each judge, pooled by position (E, H, C, M and B) in 2018 (C) and 2019 (D).

et al., 2015; Dyson and Pollard, 2021a; Hamilton et al., 2022). Our HNP assessment was carried out across the whole video footage, giving the best possible estimation of HNPs. In total, the three angles were determined for the specification of the HNPs used in each case for 6571 individual frames, evenly distributed over the respective sequences, maximising an independence of gait-related variations. Even so, the frames acquired for each sequence varied depending on the number of profile views of each rider. This limitation must be considered especially in the warm-up area, where every ride was filmed by only one camera. The competition was filmed by a professional service with more than one camera, provided as one video with different camera views, where the best views were chosen in the same standardised way for each rider, resulting in a substantially larger number of profile views. This led to a higher precision of the analyses of the competition data but was only possible because the riders presented a predefined riding programme. For achieving the highest accuracy, it would be necessary to have continuous angle detection to assure full independence of gait and perspective, but this is not possible with current technical instruments in a field situation. Unfortunately, in field studies, especially in official competitions, attaching any sensor to the horse is not permitted. Further technical improvements would be desirable.

5. Conclusion

Horses tended to have their nasal plane (noseline) behind the vertical more often during warm-up than during competition. Poll angle was larger during competition than during warm-up, while there was no significant difference in shoulder angle between the two situations. Horses displayed more conflict behavior and unusual oral behavior during warm-up than during competition. Judges' scores correlated with HNPs during competition. Horses with noselines held further behind the vertical tended to receive higher scores.

The result implies that there might be concerns related to animal welfare and rule compliance. The observed HNPs used by world-class riders in this study appear to contradict the established rules, yet these deviations are not penalised by the judges during competitions.

Ethics approval

This type of non-invasive, behavioural research is approved under the German animal

protection act and does not require a study-specific permission. Filming of the horse-rider-pairs was done in a public area on the competition grounds. Riders of the horses

were not informed about the study as this information might have biased results. Researchers did not handle animals in any way for this study or interfered in any way with riding styles, horses or riders. All riding corresponded to the routine competition procedures without any manipulation or disturbance.

Declaration of Generative (AI) and AI-assisted technologies in the Writing Process

The authors did not use any artificial intelligence assisted technologies in the writing process.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The processed data and statistical models are available on a public data repository (link will be provided here). The video data cannot be shared publicly because of confidential data to protect the identity of the riders. Videos and behavioural data are deposited on a public data repository (contact via KK) with restricted access for researchers who meet the criteria for access to confidential data.

Acknowledgements

Our article has already been published as a pre-print in a slightly different version (Kienapfel et al., 2021).

Financial support statement

This study was funded by the Federal Veterinary Office of Switzerland, by the Haldimann Foundation, Switzerland and by the Central Innovation Program of Small and Medium Sized Enterprises (ZIM), Germany. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Implications

Conflict behaviour increased with decreasing vertical angles of the nasal plane, and correlated with head-neck positions and behaviour in ridden elite dressage horses. As conflict behaviour (i.e., tail swishing and unusual oral behaviour) is considered to indicate stress, pain or discomfort, this suggests an association with compromised welfare. Contradicting to the rules for equestrian competitions, tests with a nasal plane further behind the vertical were more likely to achieve higher scores. As our results indicate welfare concerns, solutions to ensure and enhance animal welfare in dressage sport during both, warm-and competition should be elaborated.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2024.106202.

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