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Head–Neck Positions in Ridden Horses: Defining Degrees of Flexion and Their Impact on Equine Behavior and Welfare

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Abstract

Horse sports face public scrutiny, particularly regarding concerns about horse welfare. Understanding how the physical positioning of the horse's head and neck while being ridden affects behavior is crucial for improving welfare standards. This study aimed to investigate the influence of head–neck position (HNP) in ridden horses–specifically, the vertical and poll angles–on conflict behavior (CB). Furthermore, it aimed to identify a critical threshold at which HNP significantly affects behavioral outcomes. Elite dressage horses were observed during warm-ups and tests at competitions, and horses presented in educational videos were analyzed to examine the relationship between HNP and CB. A total of 191 rides were analyzed, HNP parameters (angle to the vertical of nasal plane, poll angle, and shoulder angle) and CB indicators (e.g., unusual oral behaviors and tail swishing) were recorded over 3-minute intervals using Observer XT (Noldus). Data were analyzed using general linear mixed-effects models, with CB (sum of all behaviors) as the response variable and horse-rider-ID as a random effect. Both poll and vertical angles had significant negative effects on CB, indicating that horses exhibited more CB when these angles decreased ($p < 0.001$, $df = 139.64/137.28$, respectively). Shoulder angle also had a significant impact on CB in one model ($p = 0.014$, $df = 136.61$). A vertical angle of -7.5° behind the vertical was identified as the cut-off value associated with an increase in CB. Stallions exhibited more CB than mares and geldings ($p < 0.001$, $df = 73.16$). The models demonstrated good fit, with consistently non-significant effects of age, breed, and bit type. Optimizing HNP during riding is crucial for enhancing behavioral well-being and the overall welfare of dressage horses in competitive settings.

Keywords

Head–neck position; equine; behavior; riding; hyperflexion; Rollkur

1. Introduction

Horse sports are in the spotlight of public debate because of serious concerns about horse welfare. Ultimately, these concerns jeopardize the sports' social license to operate **[1,2]**. Public critique is directed toward numerous equestrian disciplines, including dressage, and the horse industry itself has called for urgent welfare improvements to ensure the long-term sustainability of the sport (e.g., **[3]**). Scientific data support this negative image, showing that an alarmingly high number of horses compete with mouth injuries **[4–7]** and exhibit conflict behaviors such as mouth opening or tail swishing **[8–11]**, which likely indicate discomfort, stress, and/or pain. Other studies have frequently reported the use of controversial head–neck positions (HNPs) during riding, where horses are subjected to 'rollkur' or 'hyperflexion' or the so-called 'low, deep, and round' (LDR) posture. These techniques involve over-flexion of the horse's neck and head and most likely lead–regardless of riders' skill levels–to reduced welfare **[12]**.

Yet, despite national competition rules–for example, those of the German Equestrian Federation [13], Equestrian Australia [14], and Swiss Equestrian [15]–and international rules of the Fédération Équestre Internationale [16] that clearly define acceptable HNPs (i.e., with the nasal plane slightly in front of or at the vertical), scientific studies have consistently reported that two-thirds of observed competition horses are ridden with the nasal plane behind the vertical [8,9,17–21]. Moreover, despite these regulations, such HNPs are frequently rewarded with higher competition scores [19,22].

Undesirable or unwanted changes in behavior, such as so-called 'escape' or 'avoidance' behaviors, can be summarized under the umbrella term 'conflict behavior.' These behaviors (e.g., shying, bolting, bucking, rearing, head-tossing, tail swishing, mouth opening, putting the tongue out of the mouth, or over the bit) typically indicate conflicting motivations between the horse's interests (e.g., freedom from pain) and the rider's demands [23,24]. They may result from frustration, confusion due to competing signals given by the rider [25], or discomfort and/or pain [26,27]. Consequently, horses exhibiting conflict behaviors are likely experiencing difficulties in coping with mental and/or physical discomfort [28]. Evidence links different conflict behaviors and facial expressions to negative emotions [29–32]. For example, numerous studies provide evidence that tail swishing and oral behaviors are indicators of stress and potential pain [7,20,26,33–36].

It has been shown that horses subjected to riding techniques that position the nasal plane behind the vertical exhibit signs of discomfort, reflected in various conflict behaviors [12,22,33]. In contrast, horses ridden with conventional poll flexion, where the nasal plane predominantly remains in front of the vertical, show fewer signs of conflict behaviors [8,12,33]. Horses not only express higher levels of conflict behavior when ridden in rollkur/hyperflexion, but also avoid rollkur when given the choice [37,38]. Scientific studies further suggest that flexion of the neck can compress the ventral neck structures, including the pharynx, larynx, and parotid glands [39–43], potentially leading to negative physiological effects. Additionally, the space between the neck and head, known as the gullet, can be quantified by the poll angle. A smaller poll angle reduces the available space, thereby restricting the function of the ventral respiratory and digestive organs [12].

One key structure in the ventral neck is the *m. brachiocephalicus*, a muscle that plays a role in head flexion. Research has indicated that this muscle alters its natural activity pattern and exhibits increased activity when the horse's neck is put in a hyperflexed position [8]. This finding supports earlier work [44] that observed increased single fiber activity in the *m. serratus ventralis* (a muscle that suspends the trunk between the forelimbs) during hyperflexion.

Furthermore, a restricted vision has been proposed as a contributing factor to the increased discomfort experienced during rollkur. This restriction may lead to heightened levels of fear responses attributed to elevated arousal or anxiety in horses subjected to rollkur compared to those ridden with normal poll flexion [33,38]. Interestingly, relatively minor flexion of the horse's head and neck resulting in a nasal plane at 10° behind the vertical results in increased conflict behavior and elevated physiological parameters (e.g., lactate, pleural pressure, upper airway tract abnormalities), compared to when the nasal plane is slightly (5°) in front of the vertical [36]. In response to evidence highlighting the negative impacts of rollkur on horse welfare, Switzerland has introduced the first legal measures to prevent the "excessive bending of a horse's neck or back" [45] and has explicitly prohibited rollkur [46]. However, enforcing this legislation in practice is challenging due to the lack of precise definitions of what constitutes 'excessive flexion,' resulting in the absence of any officially announced sanctions against riders competing in Switzerland under this law since its implementation.

This study examined the influence of HNP on behavior by analyzing the full range of head–neck positions used in practice, based on direct angle measurements without categorization, in a sample of horses ridden in dressage during warm-up for competitions, in competition tests, and in educational videos. The aim was to assess their potential impact on equine welfare as reflected in the occurrence of conflict behaviors. Recognizing the need for a comprehensive industry standard, this study also aimed to objectively define the critical angles at which HNP may jeopardize equine welfare to support riders, judges, and other stakeholders in making evidence-based decisions about horse welfare when evaluating training and competition practices.

It was hypothesized that:

1. The degree of head–neck flexion, specifically at the vertical and poll angles, influences behavioral parameters, implying that greater flexion correlates with increased prevalence of conflict behavior.

2. The poll angle was expected to have more influence on conflict behavior than the vertical angle of the nasal plane.

3. The smaller the shoulder angle or the higher the head is held, the greater the negative impact of flexion on the frequency of conflict behavior.

4. There is a critical 'cut-off value' for the negative influence of neck flexion on a horse's well-being, suggesting that once the vertical and poll angles exceed a certain threshold, conflict behavior increases significantly.

2. Materials and Methods

2.1. Horses and Riders

This study involved no experimental manipulation or rider instruction; it relied solely on unobtrusive video recordings of actual events at publicly accessible competition venues. Data were collected at dressage competitions at three locations: 1) in Aachen (Germany) during warm-up and competition tests, 2) in Bern (Switzerland) during warm-up, and 3) in Avenches (Switzerland) during warm-up and competition tests. Additionally, 4) educational rides were studied from videos via the online platform WeHorse (www.wehorse.com), demonstrating dressage training.

A total of 191 rides were included in this study (Table 1). Details (e.g., sex, age, and breed) for the majority of horses were specified in the competition start lists. The horses were on average 12.9 years old (SD ± 3.5).

The rider-horse pairs were either competing at low to medium levels (levels A, L, and M) or up to the highest levels (levels S and Grand Prix Special) in dressage, or they were ridden in dressage by renowned competitors to showcase training methods for educational and demonstration purposes. In the latter case, the performance level was assigned according to the movements and exercises classified in the German competition guidelines **[13]**, as shown in the respective video. Young horses up to 6 years old were only studied in levels A to M, as they are restricted to lower competition classes until they reach the required age for higher levels.

Background details on the sex, age, and breed of the horses were obtained through the start lists published by the competition organizers, but this information was not available for the 24 horses showcased for educational purposes. However, some background details could be found via the internet due to the popularity of some of these riders and their horses. Mares could be identified in these samples, but stallions and geldings could not be distinguished. One of the WeHorse platform's rides was part of a high-level (S) competition, so it was classified as a competition rather than education. In the dataset, 46 riders appeared twice, 5 riders three times, 9 riders four times, and 3 riders five times. For horses, 62 appeared twice, 2 appeared four times, and 2 appeared five times.

In the context of international dressage competitions (Grand Prix Special, CDIO 5*) in Aachen, Germany, all horses were vetted by veterinarians as 'fit to compete' according to international FEI rules **[16]**. In the context of national dressage competitions (low to high-level A–S in Avenches and Bern, Switzerland), random veterinary checks were undertaken according to the national rules. Stewards (during warm-up) or judges (during competition) were always present and had the authority to remove horses suspected of injury. Only horse-rider pairs that passed the veterinary checks or were not called out by stewards or judges were allowed to participate in the competition. Thus, all horses included in this study had been judged to be healthy. In the context of online video footage (WeHorse platform), the scientific observer, highly experienced with horses, made a subjective evaluation, excluding any horse from the analysis if signs of lameness were visible, though this was not necessary for the current sample. Hence, only horses deemed sound were included in the dataset. No information was available on other potential health issues, such as oral discomfort or subclinical conditions, for any of the included horses.

Equipment was recorded in terms of whether the horse was wearing a snaffle or double bridle. However, there was no information available on the tightness of the nosebands, except that Swiss rules require a 1.5 cm gap between the nasal bridge and the noseband, while FEI rules stipulate that two fingers should fit between the noseband and the side of the horse's mouth. It is unknown whether these rules were adhered to in practice.

Table 1: Overview of study-specific details, including study location and number of rides analyzed at each location (n = 191), breed and sex of horses, equipment used, and level of performance.

Category	Description	Total (n)
Location	Aachen (GER)	99
	Bern (CH)	16
	Avenches (CH)	52
	WeHorse	24
Situation*	Warm-up	100
	Competition	68
	Education	23
Level	Elite (CDIO5*)	100
	High (S)	40
	Medium (Young horses, M)	39
	Light (Young horses, L)	12
	Beginner (Young horses, A)	9
Breed	Royal Dutch Sport Horse (KWPN)	29
	German Warmblood	62
	Iberian Breeds (Pura Raza Española, Lusitano)	11
	Swiss Warmblood	56
	Other Warmblood	15
	Unknown**	18
Sex	Stallion	49
	Gelding	103
	Mare	23
	Unknown**	16
Bit used	Double bridle	139
	Snaffle	52

*Situation refers to the condition under which the sample was taken: at the warm-up area before the competition (warm-up), the competition itself (competition), or from videos provided at the online platform for educational purposes (education).

**Recorded material without information provided about horses and riders was also studied.

2.2. Data Collection

The video samples were obtained between the years 2018 and 2021. To ensure the analysis of a broad spectrum of HNPs **(Figure 1)**, samples were collected from horses at different levels of competition and training, the latter being analogous to competition levels. The aim at each competition location was to film every rider on each starter list. However, this was not always possible due to time constraints, multiple riders in the warm-up area, and visibility issues when horse-rider pairs were frequently hidden behind other competitors and spectators during filming. For the educational videos, the selection was based on renowned trainers (n = 10) known for dressage riding at the highest levels. Every suitable video of these trainers was included if it met the study criteria: a minimum duration of three minutes at trot and canter, with rein contact maintained during the working phase.

During warm-up at competitions, two observers filmed at the same time with handheld video cameras (Sony FDR-AX53, Sony HDR-CX625, recordings in HD quality at 25 frames per second), filming different horse-rider pairs in the publicly accessible warm-up arenas. Horses were always filmed from the short side of the arena from a 10 m distance. The cameras were held at shoulder height with the cameras' internal image stabilizer activated, allowing for flexibility in camera handling and positioning along the short side due to the presence of other horses/riders and spectators.

During competitions, the observers did not film any tests, but videos were obtained from the event organizers, who made the video footage publicly available. In contrast to the videos from the warm-up, one rider-horse pair was visible at a time from consistent angles in the competition test videos. This also applied to the educational videos (WeHorse), where individual horses were fully visible without any obstructions.

2.3. Data Selection

After reviewing all obtained videos in Adobe Premiere Pro (versions 2020–2023) for recording quality, minimum lengths of continuous observation, and excluding horses deemed unfit to be ridden, a complete dataset of 191 rides was acquired.

The criteria for selecting video footage from the warm-up required each rider-horse pair to be filmed for at least six to seven minutes, allowing the extraction of a 3-minute riding segment for analysis. Phases of walking and standing still were cut out because these are often used for relaxation with long reins or for adjusting equipment. Thus, only footage showing the beginning of the working phase in trot (defined as the start of the sitting trot, in contrast to rising trot where the rider stands up and sits down in the rhythm of the trot) and canter sequences during the warm-up remained for subsequent analysis. Furthermore, sequences in which other horses or spectators crossed in front of the observed rider-horse pair were also cut out. The films were cut using Adobe Premiere Pro (versions 2020 and 2023).

The same principles of cutting the videos from the warm-up at competitions applied to the videos available from the dressage tests and the educational training videos, i.e., only the working phases were included by removing walking and standing. After reviewing and editing all obtained videos, rider and horse identities were anonymized to comply with ethical research standards and to ensure unbiased analysis.

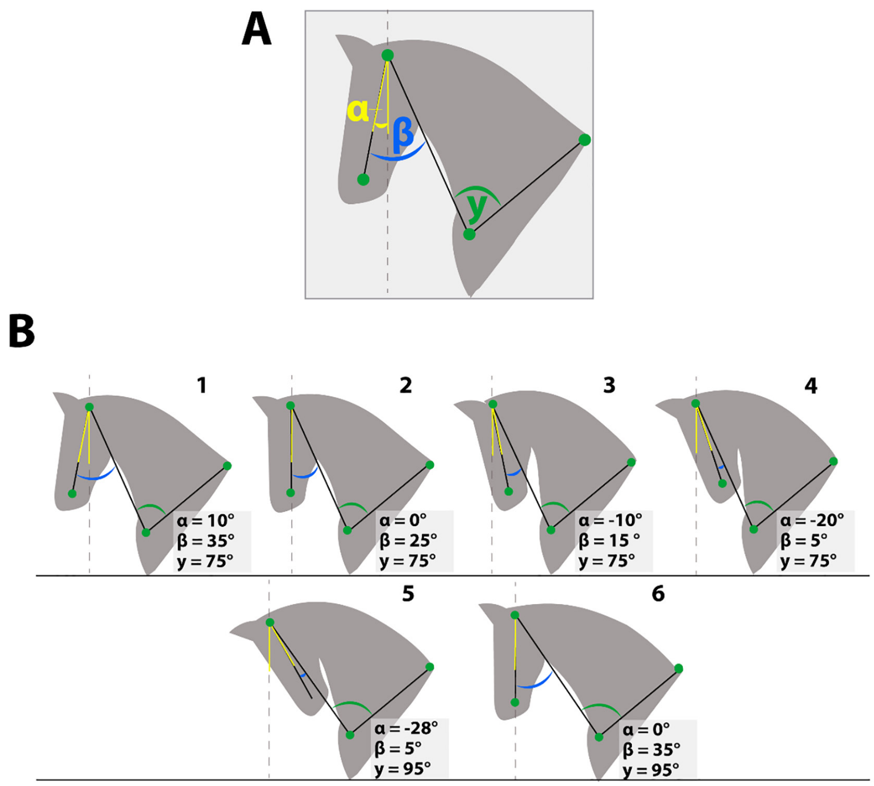

Figure 1: A) Anatomical markers (green dots) were used to measure the vertical angle (α), the poll angle (β), and the shoulder angle (γ). B) Six examples illustrating the three angles and resulting HNPs. Images 1-4: same shoulder angle but different vertical and poll angles. 1: nasal plane in front of the vertical, 2: nasal plane at the vertical, 3: nasal plane clearly behind the vertical, 4: nasal plane strongly behind the vertical, 5: larger shoulder angle and same poll angle as (4), resulting in a nasal plane strongly behind the vertical, 6: same shoulder angle as in (5) but with a larger poll angle (same as in image 1, resulting in a nasal plane at the vertical).

2.4. Data Analysis

2.4.1. Determination of Head–Neck Position

From the videos, every single frame showing a clear profile view of the horse was analyzed to determine the HNP. All video recordings were reviewed to identify scenes where the horse appeared in profile view. Using JavaScript, these segments were isolated and decomposed as individual frames, displayed at a rate of three frames per second. The observer then annotated four anatomical markers in each frame, following a consistent order **(Figure 2)**. These anatomical markers were: the corners of the mouth, poll (directly behind the ears), shoulder joint, and saddle button directly above the withers. From the connections of these anatomical markers, three angles were calculated in each frame **(Figure 1)**: 1) the angle of the nasal plane in relation to the vertical (vertical angle (α), 2) the poll angle (β), and 3) the shoulder angle (γ) **(Figure 1A)**. JavaScript was used to automatically compile this information into a table along with frame numbers, timestamps, and coordinates of each annotated point. This process served solely to streamline the workflow by generating as many individual frames as possible. The program itself did not perform any independent actions, resulting in a total of 13,553 annotated frames and an average of 70.6 ± 36.8 (SD) frames for each sampled ride. An angle with the nasal plane in front of the vertical was defined as $\alpha \geq 0$, and behind the vertical as $\alpha < 0$, implying that the angles behind the vertical were given negative values (examples in **Figure 1B**, 3–5). The mean angles for each horse from these single frames over the 3-minute sequences were calculated and subsequently analyzed statistically.

To assess inter-rater agreement for the angular measurements, Pearson correlation coefficients were calculated based on annotations from two observers across 10 recordings, corresponding to 656 key frames for the angles α, β, and γ. The results indicated excellent agreement for α ($r = 0.959$, $p < 0.0001$) and good agreement for β ($r = 0.869$, $p < 0.001$). In contrast, γ showed a moderate correlation ($r = 0.699$, $p < 0.01$), suggesting greater variability in either the annotation process or the calculation of this specific angle.

2.4.2. Behavior

For annotating behaviors, the entire 3-minute video was observed by one observer highly experienced in observing ridden horse behavior. All occurrences of behaviors indicative of conflict according to the ethogram in **Table 2** were recorded as frequencies via the Observer XT software (Noldus, version 15) using the focal animal method **[47,48]**. Periods during which the horse's mouth was not visible due to the filming angle were labeled as "out of sight," and the duration of these phases was summed. To account for differences in mouth visibility resulting from individual horses performing different routines, the recorded frequencies of oral behaviors were proportionally adjusted to reflect full (100%) visibility throughout the observation period using a rule-of-three calculation.

Each video was watched at least three times by the same observer to annotate tail swishing separately from unusual oral behavior and from all other behaviors **(Table 2)**. If multiple other behaviors were observed at the same time, another annotating round was performed for that behavioral category. Some behaviors, such as unusual oral behavior, were exhibited as sustained patterns rather than discrete events (unlike tail swishing, for example), and were converted from durations to frequencies **[48]** to obtain comparable data (1 s = 1 count). As a result, head or nose tilting, crabbing, and unusual oral behavior could have maximum values of 180 (3 × 60) counts. All other behaviors could have unlimited values in theory as they were counted as occurrences (see **Table 2** for explanation).

An inter-observer reliability (IOR) test was performed to validate the standardization of the behavioral data extraction from the video material. The IOR was conducted using behavioral data recorded by an additional observer from 49 horses and resulted in a Spearman's Rank Order Correlation of 0.95 ($p < 0.01$) and a Kendall's Tau Coefficient of 0.82 ($Z = 8.32$, with a Kendall's Tau Correlation). Due to the nature of the data, it was not possible to completely blind the observers to the horses' situation and HNPs.

2.5. Statistical Analysis

All statistical analyses were conducted in RStudio Pro (version 2024.04.0+735) with R (version 4.3.3.). First, descriptive statistics on the raw data were conducted, generating histograms for the three measured angles, i.e., the vertical angle (α), the poll angle (β), and the shoulder angle (γ), as well as for the sum of all combined behaviors, labeled as 'conflict behavior.' The median and interquartile range (IQR) for each angle and behavioral parameters were calculated. Second, correlations between the three angles were assessed using Spearman rank correlations. Third, correlations between the vertical angle and conflict behavior were also examined using Spearman rank correlations.

Subsequently, factors such as sex, age, breed, and performance level were investigated to determine their influence on the prevalence of conflict behaviors. Among the behaviors listed in the ethogram, only tail swishing, unusual oral behavior, head shaking, and gait irregularities were observed. None of the other behaviors were present in the sample.

Figure 2: Still image (one single frame) from warm-up video, showing a horse in profile view. Anatomical markers (green circles) were placed on each single frame to calculate the vertical, the poll, and the shoulder angles (see **Figure 1**).

Table 2: Ethogram of recorded conflict behaviors (adapted from **[8,38,49]**). Each behavior was counted as one event; exceptions are indicated with superscript.

Behavior	Definition
Unusual oral behavior*	Includes all deviations from a still and closed mouth or chewing with closed lips, i.e., the horse opens the mouth so a gap between the upper and lower jaw is visible, shows the teeth or tongue for more than 1 second, makes chewing movements with visible separation of upper and lower jaws, or moves the lower jaw opposite to the upper while chewing.
Head or nose tilting*	The horse tilts its head or nose to one side.
Headshaking	The horse moves the head quickly up and down, from side to side, or both.
Going-against-reins	The horse pulls against the reins and breaks the line between the rider's elbow and the rings of the bit.
Rearing	The horse's forebody and forelimbs lift off the ground, with the hindlimbs supporting its weight while standing.
Bucking	The horse lowers the head and neck and raises the hindlimbs off the ground while standing with both front legs on the ground. While moving, see 'gait irregularities'.
Tail swishing	The horse moves the tail rapidly in vertical, horizontal, or combined directions. Each movement was counted separately, regardless of its intensity.
Crabbing*	The horse's hindlimbs do not follow the track of the forelimbs without intention from the rider.
Gait irregularities	Insertion of an additional step resulting in loss of rhythm. Bucking (throwing the hindquarters up simultaneously), kicking with one leg, and other hopping movements outside the specific gait while moving were included. Each deviation from the gait-specific rhythm was counted as one event.

*The total time of this behavior was recorded and counted as one event per second.

To ensure comparability of the observed behaviors, their scale was adjusted using the 'norm_scale' function, which assigns values between 0 and 1. Here, 0 represents no behavioral count and 1 represents the maximum observed count for that behavior. This adjustment was necessary because gait irregularities (n = 61) and head shaking (n = 9) were observed substantially less frequently compared to tail swishing (n = 6,461) and unusual oral behavior (n = 18,678). This scaling ensured that gait irregularities and head shaking were proportionally represented relative to the two more frequently observed behaviors.

Then, a new variable 'total_conflict_behavior' was created by merging these scaled behaviors (i.e., tail swishing, oral behavior, gait irregularities, and head shaking). The 'scale' function in R was used to transform the continuous variables (i.e., vertical angle, shoulder angle, poll angle, and age). This process centered the variables to their mean values and standardized them to units of one phenotypic standard deviation. This involved subtracting the mean of the variable and dividing the result by the standard deviation, resulting in data with a mean of 0 and a standard deviation of 1. All further statistical analyses were based on conflict behavior (sum of all recorded behaviors).

Seven linear mixed-effects models (LMMs, Models 0–6) were built using the function 'lmer' from the lme4 package. Five models were used to test Hypotheses 1, 2, and 3, and two additional models were used to test Hypothesis 4. To test Hypotheses 1–3, 'conflict behavior' was used as the response variable (continuous factor) in each of the five models, and sex (categorical factor with three levels), age (continuous factor), breed (categorical factor with 15 levels, summarized in **Table 1**–for example, Westphalian, Hanoverian, Trakehner, Oldenburger as 'German Warmblood'), performance level (categorical factor with five levels), and type of bit (categorical factor with two levels) as fixed effects. Horse-rider ID was added as a random effect. The factor 'situation' could not be included in the models as it generated an error, likely because the 'education' group was too small for modeling. As a result, this variable was excluded from all models, and its results are presented descriptively.

In Model 0, the above-described variables and fixed effects were included, along with the vertical angle (continuous factor) and the poll angle (continuous factor) as fixed effects. Additionally, an interaction with the shoulder angle (continuous factor) was included to examine the influence of the vertical and the poll angle on conflict behavior. This model represents the complete analysis of all parameters. In Model 1, only the vertical angle was added as a fixed effect to account for influences of this angle on conflict behavior alone. In Model 2, the vertical angle with an interaction with the shoulder angle was used as a fixed effect to test the influence of the height of the head. The third model had the poll angle as a fixed effect to test the impact of the neck angle, and the fourth model had an interaction between the poll angle and the shoulder angle as a fixed effect to isolate the effect of head height on poll angle.

To test our fourth hypothesis, i.e., to determine a cut-off value of the vertical angle at which signs of conflict behavior significantly increase, another two models were built with the same fixed effects as for Model 1, but with the vertical (Model 5) and poll (Model 6) angles transformed into categorical variables. All vertical and poll angles were transformed by grouping the data into four categories of similar size (n = 48 or 47) using the function 'cut_number'. For the vertical angle, the following four categories were created: 1) -31.03° to -11.40°; 2) -11.36° to -7.48°; 3) -7.47° to -4.05°, and 4) -3.57° to 10.93°. For the poll angle, these categories were created: 1) 17.60° to 24.58°; 2) 24.59° to 28.12°; 3) 28.24° to 31.63°; 4) 31.73° to 40.12°. The number of categories was chosen to maximize their application of these categories in riding practice. Consequently, Model 5 had the vertical angle as a categorical variable with the four categories as fixed effect, and Model 6 had the poll angle as a categorical variable with the four categories as fixed effect. Sex, age, breed, performance level, and type of bit were added as fixed effects, and horse-rider-ID as a random effect.

All model residuals were inspected for normal distribution using diagnostic Quantile-Quantile Plots (Q-Q Plots) and Kolmogorov-Smirnov tests (all model residuals: $p > 0.05$). An ANOVA (Type I, sequential) was performed to determine *p*-values for each of the seven models.

3. Results

3.1. Descriptive Statistics

3.1.1. Head and Neck Positions

The distribution of the three measured angles in the sample is shown in **Figure 3**. In total, 178 horses were ridden with their nasal plane behind the vertical, i.e., 63 horses were ridden with a vertical angle between -20° and -10°, while 112 horses were ridden with a vertical angle between -10° and 0°. No horse was ridden precisely at a 0° vertical angle. Only 13 horses were ridden with a vertical angle between 0° and 10°, indicating an HNP with the nasal plane in front of the vertical. Median and interquartile range (IQR) are shown in **Table 3**.

3.1.2. Behavior

The frequencies of conflict behavior (sum of all recorded behaviors) varied from 0 to 362 during three minutes, with a median frequency of 129.17 (IQR: 33.95–224.38; **Figure 4**). The most frequently recorded behaviors were oral behavior (median: 101.7, IQR: 19.22–184.17; **Figure 4B**) and tail swishing (median: 23, IQR: 12.54–58.56; **Figure 4C**). Gait irregularities were observed in 35 horses (total: 61 counts; median: 0, IQR: 0–5), and head shaking was very rarely observed (in 9 horses, total: 12 counts; median: 0, IQR: 0–3). All other behaviors were not observed in this sample **(Table 4)**.

3.1.3. Scaling of Behaviors

Figure 5 illustrates the assigned values of both raw behavioral data and scaled data. The linear relationships demonstrate that one count of unusual oral behavior was equivalent to one count of tail swishing, as both behaviors shared the same scaling with a maximum of 180 on the y-axis. In contrast, one count of gait irregularities corresponded to 36 counts (180/5) of tail swishing or oral behavior, as reflected by the y-axis value of 5 for gait irregularities. This scaling allowed for a balanced contribution of different behaviors to the overall analysis.

The prevalence of conflict behavior and the vertical angle in the different situations is shown in **Figure 6**. The smallest vertical angles were measured in the warm-up, followed by competition, and education. For conflict behavior, the order was reversed: the highest frequency was recorded in the warm-up, followed by the competition, with the lowest levels observed in education.

3.1.4. Correlation of HNP Angles

The vertical and poll angles were significantly moderately correlated (rho = 0.54, $p < 0.001$), meaning the smaller the poll angle, the more the nasal plane was behind the vertical. The vertical and the shoulder angles were significantly but weakly correlated (rho = -0.34, $p < 0.001$), indicating that as the head height increased, the vertical angle decreased. This means that the nasal plane was positioned further behind the vertical, i.e., closer to the horse's chest. The poll and the shoulder angles were not correlated (rho = 0.11, $p > 0.05$).

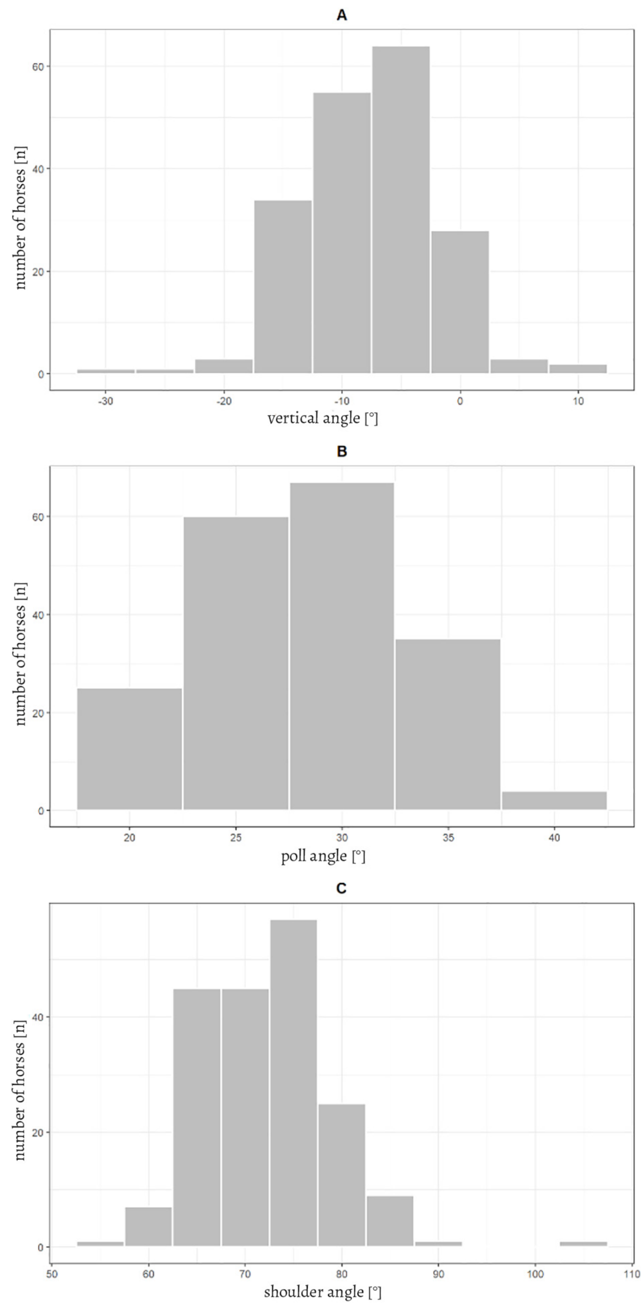

Figure 3: Histograms showing the distribution of the three measured angles across all 191 horses in each situation (warm-up, competition, and education): A) vertical angle, B) poll angle, and C) shoulder angle. The vertical angle reflects the position of the horse's head relative to the vertical plane, with negative values indicating behind-the-vertical positions.

Table 3: Median and interquartile range (IQR) of the three measured angles (in degrees).

Angle	Median [°]	IQR	
		min	max
Vertical angle (α)	-7.48	-15.06	0.10
Poll angle (β)	28.11	21.02	35.21
Shoulder angle (γ)	71.95	62.60	81.30

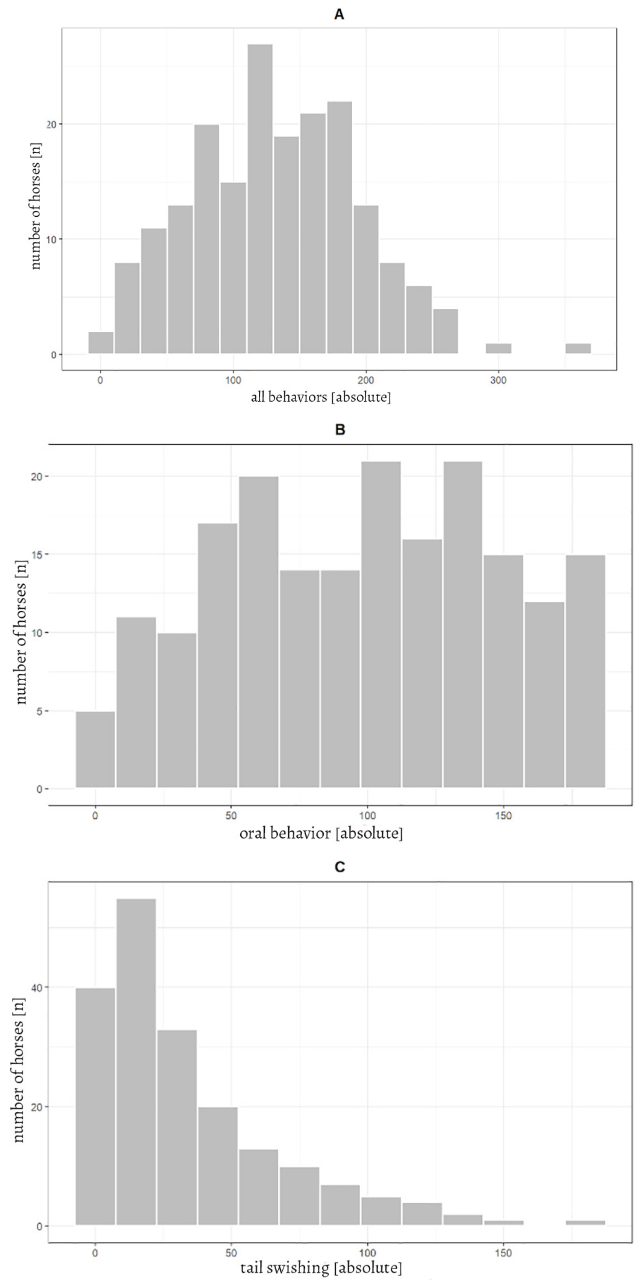

Figure 4: Histograms showing the distribution of conflict behaviors observed in 191 horses across all situations (warm-up, competition, and education): A) all observed behaviors combined into a new category labeled as 'conflict behavior'; B) unusual oral behaviors; and C) tail swishing. The counts represent absolute frequencies per horse.

3.1.5. Correlation of HNP and Conflict Behavior

There was a low negative correlation between the vertical angle and conflict behavior (rho = -0.30, $p < 0.001$; **Figure 7A**). This indicates that the smaller the vertical angle (indicating that the horses were ridden more behind the vertical), the higher the prevalence of conflict behavior. There was also a low negative correlation between the poll angle and conflict behavior (rho = -0.38, $p < 0.001$; **Figure 7B**), indicating that as the poll angle decreased, the prevalence of total conflict behavior increased.

Table 4: Median and interquartile range (IQR) of all behaviors (conflict behavior: unusual oral behavior, tail swishing, gait irregularities, and head shaking) summed over a 3-minute observation period. The latter two behaviors were rarely displayed; therefore, all values are 0.

Behavior	Median	IQR	
		min	max
All behaviors	129.17	33.95	224.38
Tail swishing	23.00	12.50	58.50
Unusual oral behavior	101.70	19.22	184.17
Gait irregularities	0	0	0
Head shaking	0	0	0

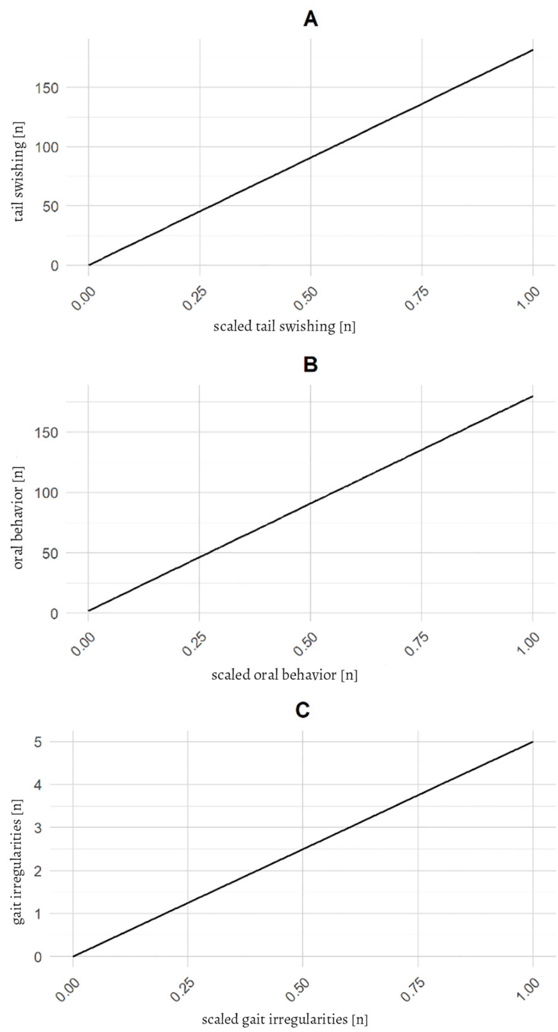

Figure 5: Comparison of raw and scaled behavioral data. A) tail swishing, B) oral behavior, and C) gait irregularities are shown with both raw counts (y-axis) and scaled values (x-axis). For example, tail swishing (A) and unusual oral behavior (B) were roughly equivalent on the y-axis, whereas gait irregularities occurred less frequently compared to the other two variables. For practical application, approximately one count of gait irregularity could be equivalent in value to about 36 counts of tail swishing and/or oral behavior.

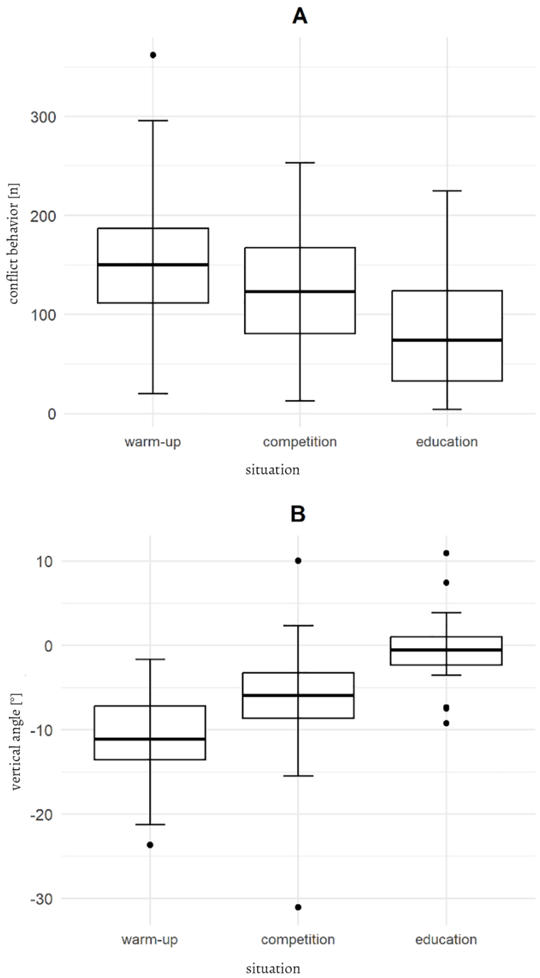

Figure 6: Boxplots showing the effect of the situation (warm-up, competition, and education) on A) the frequency of conflict behaviors (e.g., tail swishing, unusual oral behavior), and B) the vertical angle of the head–neck position (HNP), measured in degrees. Each box represents the interquartile range (IQR), with the horizontal line indicating the median. Whiskers extend to 1.5× IQR, and black dots represent outliers.

3.2. Modeling Results

The results of the linear modeling are shown in **Table 5** for all seven models. All models found a significant effect of sex ($p < 0.01$), with stallions showing more conflict behavior compared to mares and geldings (**Table 5**, **Figure 8**). Age, breed, and type of bit showed no significant effects on conflict behavior in any of the models.

Model 0, which included all aspects (with the vertical and the poll angle as fixed effects and an interaction of the shoulder), revealed a significant negative effect of the poll angle on conflict behavior ($p < 0.001$), meaning that horses showed more conflict behaviors when the poll angle decreased. The model had a good fit with an AIC of -132.70 and a BIC of -39.52.

Model 1 (with the vertical angle as a fixed effect) had a significant negative effect of the vertical angle on conflict behavior ($p < 0.001$), indicating that horses showed a higher number of conflict behaviors when the vertical angle decreased. The level of dressage had significant negative effects on conflict behavior for level 3 (M level [medium], $p < 0.05$) and level 5 (A level [beginner], $p < 0.05$), indicating less conflict behavior in lower classes. The model had a good fit, with an AIC of -149.46 and a BIC of -68.71.

Model 2 (with the vertical angle and an interaction of the shoulder angle as a fixed effect) had a significant negative effect of the vertical angle on conflict behavior ($p < 0.001$). Also, there was a significant negative effect of the shoulder angle on conflict behavior ($p = 0.014$). Level 3 ($p < 0.05$) and level 5 ($p < 0.05$) had significant negative effects on conflict behavior, too. The model had a good fit, with an AIC of -137.54 and a BIC of -50.57.

Model 3 found a significant negative effect of the poll angle on conflict behavior ($p < 0.001$), indicating that horses showed more conflict behaviors when the poll angle decreased. The model had a good fit, with an AIC of -168.61 and a BIC of -87.86.

Model 4 detected a significant negative effect of the poll angle on conflict behavior ($p < 0.001$). The model had a good fit, with an AIC of -150.10 and a BIC of -63.13.

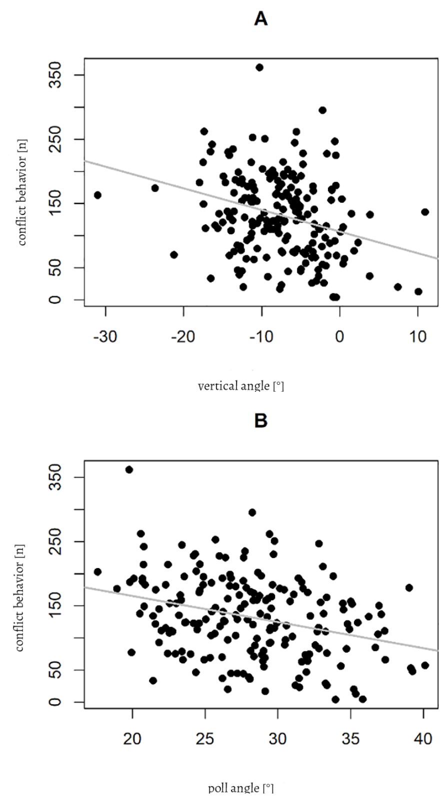

Figure 7: Scatterplots showing the relationship between the angular measurements of head positions and the frequency of conflict behavior in absolute numbers observed in 191 horses across all situations (warm-up, competition, and education). A) Correlation of the vertical angle [°] and conflict behavior (rho = -0.30, $p < 0.0001$), and B) Correlation of the poll angle [°] and conflict behavior (rho = -0.38, $p < 0.0001$). The gray lines represent the linear regression fit for each relationship.

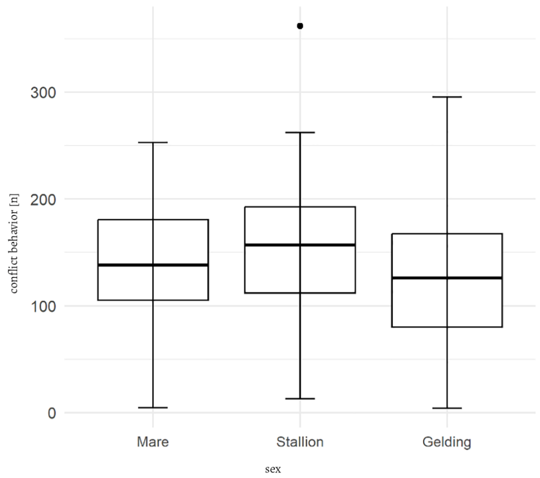

Figure 8: Boxplot showing the total number of conflict behaviors (e.g., tail swishing, unusual oral behavior) in mares, stallions, and geldings. Each box represents the interquartile range (IQR), with the horizontal line indicating the median. Whiskers extend to 1.5 × the IQR, and black dots indicate outliers. Stallions exhibited significantly more conflict behaviors than mares ($p < 0.01$, results from lmer and ANOVA). No significant difference was observed between mares and geldings.

Overall, all models exhibited similar significant effects, indicating the importance of certain variables such as the vertical angle (Models 1 and 2), the poll angle (Models 0, 3, and 4), and the sex of the horses (all models, **Figure 8**) in predicting conflict behavior. Model 0 showed a slightly better fit, based on AIC and BIC values, compared to the other models. The non-significant effects of age, breed, and type of bit used remained consistent across all models.

When transforming the vertical angle and the poll angle into categorical variables and incorporating these into Model 5 (vertical angle) and 6 (poll angle), it was found that horses displayed more conflict behaviors starting at a vertical angle of -7.5° and lower **(Figure 9)**, and at a poll angle of 24.5° and lower. Stallions were again connected with showing more conflict behavior ($p < 0.05$). Sex, age, breed, performance level, and bit had no effect on conflict behavior. Model 5 had an AIC of -131.93 and a BIC of -44.97. Model 6 had an AIC of -146.37 and a BIC of -59.40.

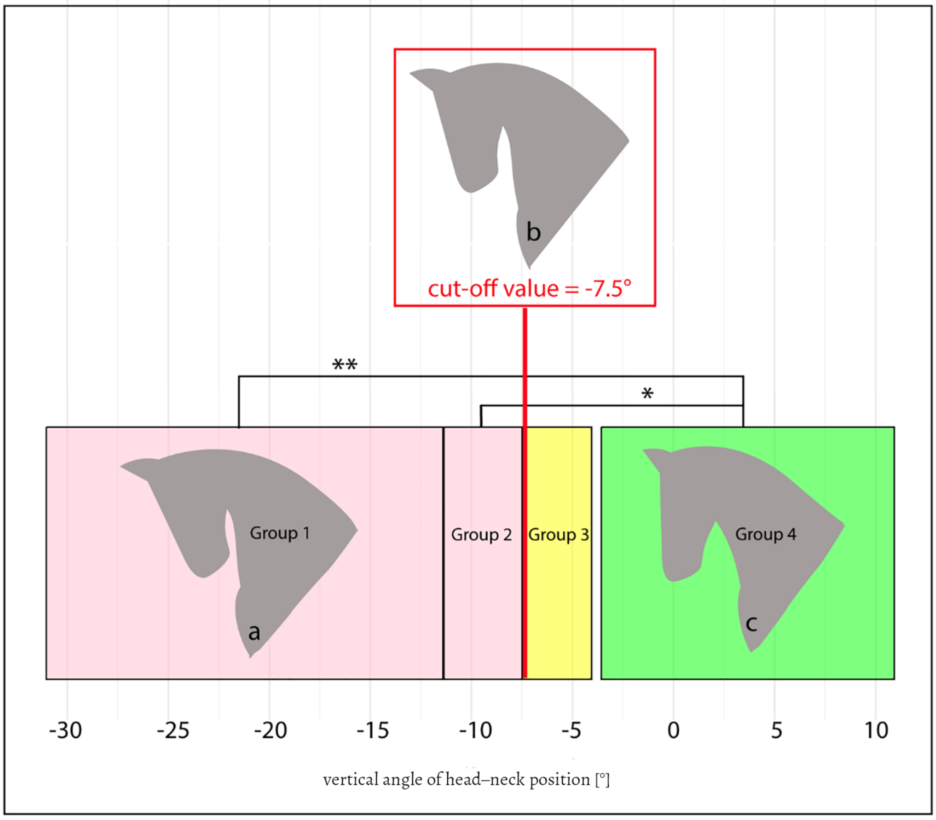

Figure 9: Results of Model 5 (vertical angle as a categorical variable with 4 groups) and subsequent ANOVA. Group 1: -31.03 to -11.4°; Group 2: -11.36 to -7.48°; Group 3: -7.47° to -4.05°; Group 4: -3.57° to 10.93°. Groups 1 and 2 are significantly different from group 4, with no other significant differences detected. Significance levels: *** $p = 0$, **$p = 0.001$, *$p = 0.05$. Colors indicate the authors' suggestions for practical implication with the green zone (group 4) connected to low conflict behavior, yellow (group 3) to intermediate conflict behavior, and red (groups 3 and 4) with the highest conflict behavior in relation to the HNP position. (a) Shows a vertical angle of -20°, (b) a vertical angle of -7.5° representing the recommended limit of flexion, and (c) shows a vertical angle of 0°.

Table 5: Results of Models 0–6 (lmer). All models had conflict behavior as the response variable, with sex, age, breed, performance level (A, L, M, S), and type of bit as fixed effects, and horse-rider-ID as a random effect. Model 0 was the complete model and included the vertical angle (continuous factor) and the poll angle (continuous factor) as fixed effects. Additionally, an interaction with the shoulder angle (continuous factor) was included. Model 1 had the vertical angle as a fixed effect; Model 2 included an interaction between the vertical angle and the shoulder angle; Model 3 included the poll angle; and Model 4 included the poll angle with an interaction with the shoulder angle. Models 5 and 6 both had conflict behavior as the response variable, with sex, age, breed, performance level, and type of bit as fixed effects and horse-rider-ID as a random effect. Model 5 had the vertical angle as a categorical variable with four categories as a fixed effect, and Model 6 had the poll angle as a categorical variable with four categories as a fixed effect. Only significant factors are shown. Sex 'gelding' and performance level 'Grand Prix Special' were the intercepts in all models, respectively.

Model	Term	Estimate	Std. Error	t-value	df	*p*-value
Model 0	(Intercept)	0.256	0.078	3.291	59.317	0.001
	Vertical angle	-0.018	0.013	-1.328	130.329	0.185
	Poll angle	-0.049	0.013	-3.798	136.999	0.000
	Shoulder angle	-0.012	0.011	-1.136	131.790	0.258
	Mare	0.059	0.029	2.067	70.399	0.040
	Stallion	0.074	0.023	3.273	73.164	0.001
Model 1	(Intercept)	0.285	0.076	3.772	58.635	0.000
	Vertical angle	-0.034	0.009	-3.691	139.640	0.000
	Mare	0.054	0.028	1.919	70.415	0.059
	Stallion	0.074	0.023	3.275	75.759	0.002
	Level S	-0.035	0.041	-0.847	106.978	0.399
	Level M	-0.113	0.055	-2.060	97.878	0.042
	Level L	-0.063	0.079	-0.804	93.016	0.423
	Level A	-0.165	0.077	-2.152	83.900	0.034
Model 2	(Intercept)	0.285	0.076	3.772	58.635	0.000
	Vertical angle	-0.034	0.009	-3.691	139.640	0.000
	Mare	0.054	0.028	1.919	70.415	0.059
	Stallion	0.074	0.023	3.275	75.759	0.002
	Level S	-0.035	0.041	-0.847	106.978	0.399
	Level M	-0.113	0.055	-2.060	97.878	0.042
	Level L	-0.063	0.079	-0.804	93.016	0.423
	Level A	-0.165	0.077	-2.152	83.900	0.034
Model 3	(Intercept)	0.250	0.078	3.215	60.811	0.002
	Vertical angle	-0.051	0.011	-4.854	125.246	0.000
	Shoulder angle	-0.026	0.010	-2.479	136.607	0.014
	Mare	0.057	0.029	1.966	72.671	0.053
	Stallion	0.077	0.023	3.388	75.690	0.001
Model 4	(Intercept)	0.270	0.076	3.564	59.326	0.001
	Poll angle	-0.059	0.010	-6.064	137.275	0.000
	Shoulder angle	-0.002	0.008	-0.248	138.964	0.805
	Mare	0.063	0.028	2.268	69.592	0.026
	Stallion	0.071	0.022	3.221	73.516	0.002

Model	Term	Estimate	Std. Error	t-value	df	*p*-value
Model 5	(Intercept)	0.321	0.080	4.033	56.038	0.000
	Vertical.Class1-2	-0.029	0.022	-1.306	121.645	0.194
	Vertical.Class1-3	-0.050	0.024	-2.038	137.591	0.043
	Vertical.Class1-4	-0.099	0.027	-3.635	136.032	0.000
	Mare	0.057	0.029	1.929	66.773	0.058
	Stallion	0.075	0.023	3.203	73.768	0.002
Model 6	(Intercept)	0.348	0.080	4.376	60.709	0.000
	Poll.Class1-2	-0.083	0.022	-3.752	136.450	0.000
	Poll.Class1-3	-0.109	0.022	-4.858	127.397	0.000
	Poll.Class1-4	-0.135	0.028	-4.896	135.174	0.000
	Mare	0.056	0.029	1.922	69.740	0.059
	Stallion	0.066	0.023	2.877	75.345	0.005

4. Discussion

This study explored the full range of head–neck positions (HNPs) used in dressage horses during warm-up, competition, and educational situations to assess their impact on equine welfare, as indicated by conflict behaviors. It aimed to identify critical angles associated with welfare risks to provide evidence-based guidance for riders, judges, and other stakeholders in evaluating training and competition practices.

Our first hypothesis proposed that the degree of flexion would influence behavioral parameters, particularly conflict behaviors. The data fully supported this hypothesis. A greater degree of ventral head flexion was associated with a higher total frequency of conflict behaviors. Although the correlation coefficient values for head angle and conflict behavior were moderate ($r = -0.3$ for the vertical angle and $r = -0.38$ for the poll angle), it was statistically significant, indicating a meaningful association between HNP and conflict behavior. However, the moderate strength of the correlations also suggests that HNP is not the sole explanatory variable. Other factors not captured in this study may also contribute to the occurrence of conflict behaviors. The horse-rider system is inherently multifactorial, influenced by aspects such as training methods, rider skill, saddle fit, and individual horse temperament. Nevertheless, our data highlight HNP as one of the key factors that should be considered when aiming to improve equine welfare. The predominant manifestations of conflict behavior comprised unusual oral behavior and tail swishing. Gait irregularities and head shaking were shown less frequently.

Tail swishing, noted as one of the prevailing behaviors in competition horses, has been consistently documented across various studies **[20,22,26,33,50,51]**. Yet, investigations into the influence of different HNPs on the movements of the tail have yielded disparate findings. While some studies have reported significant variations in the frequencies of tail swishing based on HNP categories **[8,38,50]**, others have not **[33]**. Despite this, frequent tail swishing is widely regarded as an undesirable behavior during riding, as emphasized in previous research **[8,26,33,38]**. This behavior is often associated with discomfort, irritation, or stress, making it a relevant welfare indicator. In line with this, major equestrian governing bodies, including the FEI **[52]**, the German Equestrian Federation **[13]**, and Swiss Equestrian **[15]**, categorize excessive tail swishing as a reason to downgrade performance in competition. The German Equestrian Federation particularly emphasizes that a relaxed and slightly swinging tail indicates suppleness and relaxation during riding **[53]**. The frequent tail swishing observed in our study aligns with these standards, indicating that horses were displaying undesirable behavior as recognized by both equestrian federations and researchers.

Along with the frequent tail swishing, an increase in unusual oral behavior was also observed. Again, rulebooks explicitly require a horse "chewing the bit with a quiet, sensitive mouth" during riding **[52]**. Yet, research has shown that these conflict behaviors are very common **[8,11,22,26,36]**. Deviations from a closed mouth, such as chewing with an open mouth, sticking the tongue out, or 'flapping' the lips, are interpreted as signs of discomfort, stress, and/or pain **[54,55]**. Considering that nearly 10% **[4]** and 45% **[7]** of Danish competition horses, and 52% of Finnish event horses **[5]** examined after competitions had mouth lesions, it is reasonable to expect that some of these ridden horses may exhibit signs of pain and/or discomfort. Moreover, the increased occurrence of oral behavior during transitions, as reported in another study, may be linked to heightened rein contact **[9]**, potentially offering a plausible explanation for oral lesions observed in some horses. However, further research is needed to confirm this association, as other factors may also contribute to the development of such lesions. Additionally, a recent study proposed that oral 'defensive' behavior can also serve a functional role: horses may learn, through trial and error, to use specific mouth movements to reduce aversive stimuli such as rein tension **[55]**.

The findings from our study suggest that oral behavior is also directly related to HNP, whereas tail swishing, when examined in isolation, does not necessarily correlate with HNP **[22]**. Instead, tail swishing is more likely linked to other aversive stimuli, such as those from the rider or equipment, like spurs **[22,26,56]**.

Our second hypothesis proposed that a smaller poll angle would have a more restrictive impact on the horses' conflict behavior and, consequently, their welfare compared to the vertical angle. When analyzed separately, both the vertical angle and the poll angle significantly influenced conflict behavior. However, when both angles were analyzed together in one model, the influence of the poll angle became more prominent, overshadowing the effect of the vertical angle. This suggests that the poll angle has a greater influence on the horses' behavior compared to the vertical angle. This may be attributable to the direct correlation between a tight poll angle and restrictions of the laryngopharyngeal system, i.e., the anatomical structures involved in the upper respiratory tract that play a critical role in breathing, swallowing, and vocalization. Several studies found a decrease in pharyngeal diameter with increased neck flexion **[36,39,40,42]**. This finding supports our observation that the poll angle had a stronger impact on conflict behavior, which, in turn, has more profound consequences for the horse's overall welfare. However, under field conditions, the poll angle is practically undetectable during live scoring, as the naked eye of any observer lacks reliable reference points to estimate a reasonably accurate angle. This is not the case for the vertical angle. Vertical lines are common in the riding environment, such as fence posts, walls, lampposts, or doors, all of which can serve as reference lines for assessing the vertical angle of the horse's nasal plane. This makes it easier for observers, such as stewards, judges, or riders, to gauge alignment and posture in relation to these fixed points. In a field study without video recordings **[8]**, as well as in standardized experimental studies **[36,57]**, horses with a vertical angle of -10° were categorized as being consistently behind the vertical. Horses with vertical angles between 0 and -10° were classified as borderline cases **[8]**. The vertical angle is well established as a reference in equestrian regulations and continues to be recommended for this purpose. Once precise measurements are available, the current study also advocates for the documentation of the poll angle, as it appears to have a more detrimental impact on the horse.

Our third hypothesis focused on the influence of the height of the head on the occurrence of conflict behavior. This factor is represented by the shoulder angle, measured between the poll, shoulder, and withers **(Figure 1)**. Our results showed that the higher the head was held, the smaller the angle of the shoulder and neck. No interaction of the vertical or poll angle with the shoulder angle was found in any model. Instead, in model 2, there was a significant negative influence of the shoulder angle on conflict behavior, meaning the smaller the shoulder angle and, therefore, the higher the head was held, the higher the prevalence of conflict behavior.

Surprisingly, the poll angle had no such influence on the shoulder angle. Given that the poll angle influenced behavior more than the position of the nasal plane (Model 0), an increase in conflict behavior with a higher head was expected. Yet, the results make sense insofar as a tight poll angle is detrimental in any case, regardless of head height, unlike the vertical angle. A small vertical angle (e.g., -20°, **Figure 1B**) automatically results in a smaller poll angle (e.g., -5°) with a high head, while the same vertical angle with a low head leaves more space for the lower neck structures. In summary, across all seven models, the shoulder angle had no significant influence on conflict behavior. Therefore, smaller head angles appeared to increase conflict behavior, regardless of head height, with a tendency for conflict behavior to increase with a higher neck position (a smaller shoulder angle).

Our fourth hypothesis aimed to define a cut-off value for flexion, beyond which the horse's conflict behavior is significantly negatively affected by the degree of flexion. Defining this value is essential for practical applications of existing laws **[45]** and competition rules **[13,52]**. Current recommendations are limited to the requirement for the position of the nasal plane to be at or slightly in front of the vertical **[13–15]**.

An important consideration is how angle specifications are interpreted across different regulatory standards. Terms such as "slightly" (in front of the vertical) or "extreme" (flexions) can vary widely in meaning, depending on individual perspectives shaped by personal experiences, riding knowledge, and ethical considerations. It is imperative that more precise definitions are developed and standardized to allow for greater objectivity, thereby enhancing validity and consistency. Relevant federations are encouraged to address this issue, as doing so would minimize future debates and increase transparency for all stakeholders.

To our knowledge, only Switzerland currently has regulations regarding the use of specific HNPs. Since 2014, rollkur has been prohibited by law: "Additionally, prohibited for equines are [...] methods that induce hyperflexion of the equine neck or back (Rollkur) **[45]**." Nevertheless, no sanctions related to this regulation have been officially recorded since its implementation **[15]**, despite the results of this study suggesting that the prevalence of riding with the nasal plane behind the vertical in Switzerland may be comparable to levels observed internationally, where no such law exists. Obviously, implementing this law has proven difficult, as the definition "Attributes of Rollkur, an especially in dressage riding used method of Hyperflexion (overbending), are a particularly deep head–neck position and an overstretched back, forced through violent interaction of the rider's hands and/or through equipment" **[46]** leaves room for interpretation, particularly regarding what constitutes a 'deep' position. Attributes such as 'particularly deep' and 'violent interaction' are subjective descriptions prone to individual interpretation.

To investigate a potential limit for HNP from a scientific perspective, two additional models (Model 5 and Model 6) were included in the analyses, transforming the continuous variable of the vertical angle into a categorical variable. This categorization divided all measured vertical angles into four equally sized groups based on the number of rides in each category to assess their impact on conflict behavior. The ANOVA results revealed a significant difference between groups 1 and 2 compared to group 4, but not to group 3, with groups 1 and 2 ranging in vertical angles from -31° to -7.5°. Based on these findings, a 'traffic light' system is proposed to categorize the different HNP: green zone (group 4) connected to low conflict behavior, yellow or amber zone (group 3) associated with intermediate conflict behavior, and red zone (groups 2 and 1) indicating the highest amount of conflict behavior in relation to head position. As a result of our analysis, a vertical angle of -7.5° is suggested as the absolute limit of tolerated flexion for safeguarding horse welfare while riding. Group 2, ranging from -7.47° to -4°, is recommended as a yellow zone, with no significant differences observed compared to other groups. However, closely monitoring horse-rider pairs is advised within this range, and observing the horses' behavior is essential to ensure their well-being, as riding with a nasal plane behind the vertical poses a risk to animal welfare **[12]**. It appears that the transitions from flexion that raise welfare concerns to only mild discomfort related to neck flexion occur in group 2. All vertical angles greater than -4° would be categorized within the green zone, indicating minimal conflict behavior and a lower risk to welfare.

The result of a limit of -7.5° fits reasonably well into the existing literature **[8]**, showing significant differences in conflict behavior in ridden horses with a nasal plane more than 10° behind the vertical compared to all other positions. Additionally, a correlation was found that horses ridden with their nasal planes at a vertical angle of -10° behind the vertical showed significantly more conflict behavior compared to horses ridden 5° in front of the vertical **[36]**. In addition, a meta-analysis confirmed the vertical angle as a valid threshold, with positions of the nasal plane behind the vertical being correlated with stress and/or pain in most studies investigating the influence of head flexion on horses **[12]**. Both national and international rulebooks, as well as current scientific literature, widely support the recommendation that the nasal plane should be at (or in front of) the vertical. However, based on the results of our study, this widely acknowledged standard is problematic: a majority of horse-rider pairs would face sanctions if the strict vertical angle of 0°, as outlined in all competition rules, were enforced. To enable the practical application of sanctions in a reasonable manner, a more realistic limit of -7.5° behind the vertical is proposed in this study, which better reflects current riding practices.

An important factor to consider is the duration of neck flexion necessary to impair equine welfare. In our study, each measurement was taken over a 3-minute period, and the average HNP values were analyzed. Our data clearly indicate that just three minutes of neck flexion with vertical angles greater than -7.5° behind the vertical has a detrimental effect on horse welfare, as evidenced by a significant increase in conflict behaviors in these positions. Unfortunately, shorter durations were not assessed statistically in this study. However, it is reasonable to hypothesize that neck flexions beyond the vertical may cause discomfort regardless of duration, potentially inducing adverse effects even in the short term. Supporting this assumption, a study on the muscle activity of the flexing neck muscles demonstrated an abnormal activation pattern as soon as the nasal plane was held behind the vertical, both in ridden and unridden horses **[58]**. Additionally, none of the studies included in a recent meta-analysis on the effects of hyperflexion suggested that the duration of neck flexion is a relevant factor in determining its impact. Riding with the nasal plane behind the vertical was shown to have a negative impact on horse welfare, regardless of how long it was maintained **[12]**. From a scientific perspective, it is recommended that warnings be issued promptly after neck flexion exceeds a -7.5° vertical angle to encourage posture adjustments. To safeguard equine welfare, it is recommended that if this position is maintained for approximately three minutes or longer, whether continuously or cumulatively, appropriate sanctions should be considered. Given the potential welfare implications, a precautionary approach is advisable. In line with the principle of "better safe than sorry," the establishment of clear regulatory guidelines would help ensure responsible riding practices.

A question emerging from our results is the lack of explanation for the high incidence of positions with the nasal plane behind the vertical. Of the 191 horses observed, 178 (93%) were ridden with a vertical angle lower than 0°, and 132 horses (69%) had a vertical angle lower than -5° behind the vertical. 96 horses (50.3%) had a vertical angle lower than -7.5° behind the vertical. Consequently, riding with a negative vertical angle seems to be the current standard at competitions, at least in elite classes. In our sample, two models showed an effect associated with the lower competition classes, where a reduced prevalence of conflict behavior was observed. This is supported by another study **[8]**, which found that competition level significantly influenced conflict behavior; i.e., the higher the level, the greater the prevalence of conflict behavior. Interestingly, in that study, a nasal plane behind the vertical was partly penalized by the judges in lower classes but not in higher classes. In contrast, a positive correlation was found between high scores and a nasal plane behind the vertical in elite classes **[22]**. A similar finding was reported in another study focusing on piaffe movements **[19]**. The absence of correlations between low scores and hyperflexed positions may indicate a failure in the application of competition rules.

Research has shown that attitudes and knowledge acquisition in sports can be significantly influenced by the behavior of elite athletes, as indicated by studies on observational learning (e.g., **[59,60]**). Consequently, leisure riders and riders competing at lower levels may look up to elite riders as role models, potentially adopting similar techniques and practices. This highlights the importance of fostering positive role models to promote better practices across all riders. Addressing this inconsistency is proposed to enhance equine welfare at all levels of the sport, ultimately setting the standard for good riding within the broader equestrian community. Notably, while sanctioning riding behind the vertical may discourage undesirable postures, it does not support riders in adopting better alternatives. For meaningful and lasting improvements in equine welfare, it is important to support and educate riders, i.e., raising awareness of the impact of different head–neck positions on horse welfare and promoting training approaches that encourage a more open frame. A combination of education and regulation is likely to be most effective in achieving sustainable improvements in riding practices.

5. Limitations

One limitation of our study is the composition of the sample of ridden horses. To accurately investigate a parameter such as neck flexion and establish appropriate cut-off values for acceptability, it is essential to assess the full range of its manifestations, which typically follow a Gaussian distribution. Failing to consider the entire range of the parameter could result in incomplete or inaccurate conclusions about the appropriate cut-off values. Since most of the measured angles reflected a nasal line behind the vertical, with only a few exceptions, the defined cut-off value of -7.5° likely limits its accuracy. The focus on this narrower range of angles may have skewed the value too far to the left on the x-axis, resulting in smaller cut-off values than might be representative of the full range of head–neck positions. In this case, all degrees of the vertical angle of a ridden horse from -25° up to 25° should have been included in the sample. However, in a field study, the sample is heavily influenced by real-world conditions. Here, the Gaussian distribution exhibited a shift, with the peak not at the expected maximum of approximately 0°, but around -10°. Thus, the defined cut-off angle is likely smaller than it should be. Including more instances where the nasal plane was in front of the vertical would likely have produced a larger cut-off, potentially closer to vertical. This suggests that the current value might underestimate the true impact on the occurrence of conflict behaviors shown by the horse. This may have led to a misrepresentation of angles greater than 0°, as only a small number (13 out of 191 horses, or 6.8% of the sample) were ridden with their nasal plane in front of the vertical. Therefore, the cut-off value should not be regarded as an ideal standard but rather as a pragmatic threshold reflecting current riding practices, which often deviate from generally accepted guidelines. Recognizing this, promoting incremental, achievable adjustments can serve as practical steps toward aligning everyday practices with welfare-oriented standards.

Another potential limitation of our study might be the impossibility of selecting representative portions for the entire warm-up process, as it was not performed in a standardized way. The ridden program in the warm-up was freely chosen by the riders. This limitation was addressed by selecting the same warm-up phase for each rider (the beginning of the working phase), which nonetheless may not be fully representative of the whole warm-up process for each individual rider-horse pair. However, similar approaches have been used in other studies assessing warm-up situations **[8,61]**.

Our HNP analysis measured HNPs across all available single frames captured in profile view. Previous studies have typically analyzed only a few frames to estimate HNPs **[33,58,62]** or relied solely on qualitative analysis, which is prone to subjectivity **[8,9,20,26,38,63]**. Our HNP assessment covered the entire video footage, providing the most accurate estimation possible in accordance with our methodology, which involved filming from outside the riding area, as described previously **[22]**. A total of approximately 13,500 frames were manually annotated and subsequently analyzed, evenly distributed across the sequences to minimize variations related to gait. However, the number of frames acquired for each sequence varied depending on the number of profile views captured for each rider. This limitation must be considered, especially in warm-up areas and educational rides, where only one camera was used.

The competition footage was captured by a professional service with multiple cameras, resulting in a substantially larger number of profile views. There, the best views were selected in a standardized manner for each ride, enhancing the precision of competition data analysis. Yet, achieving the highest level of accuracy would require continuous angle detection, which is only possible by filming from the center of the arena to ensure complete independence from variations in gait and perspective. Unfortunately, this is not feasible in a field setting. Moreover, attaching sensors to horses during field studies to consistently measure HNPs directly as a gold standard, especially in official competitions, is not yet permitted. Nevertheless, future advancements in regulations and technology may enable the implementation of such methods, for example, using AI-based 3D modeling or similar approaches.

6. Conclusions

The present study provides valuable insights into riding practices during warm-up, competition, and education in national and international dressage. Our findings support the hypothesis that increased neck flexion is associated with a higher frequency of conflict behaviors, such as tail swishing and oral behavior, both of which are considered undesirable according to equestrian rulebooks. Furthermore, the study highlights the significant influence of the poll angle, suggesting it plays a more prominent role in inducing discomfort than the more commonly discussed position of the nasal plane. This study also proposes a cut-off of the nasal plane at -7.5° behind the vertical as a practical limit for ensuring equine welfare, balancing scientific findings with current riding practices.

The high prevalence of negative vertical angles observed in competitions raises concerns about current standards. To enhance equine welfare and maintain the sport's social license to operate, stricter enforcement of regulations on head and neck positions is urgently needed in both competition and warm-up areas. While sanctions may reduce harmful postures, lasting welfare improvements require education–promoting more open head–neck positions alongside regulation. Future technological advancements, such as continuous angle detection through sensor-based systems or AI-driven computer vision techniques, may enhance the accuracy and enforcement of these standards.

Authors' Contributions

K. Kienapfel: Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project Administration, Funding Acquisition. E. Hartmann: Writing - Original Draft, Writing - Review & Editing, Visualization. B. Preiss: Validation, Formal Analysis, Writing - Original Draft, Visualization. I. Bachmann: Conceptualization, Resources, Writing - Original Draft, Writing - Review & Editing, Supervision, Funding Acquisition.

Data Availability

The authors confirm that all data underlying the findings are fully accessible without restrictions. Data can be obtained upon request from the corresponding author.

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Conflicts of Interest

The authors declare that there are no conflicts of interest

Ethical Approval

This type of non-invasive behavioral research is approved under the German Animal Protection Act and does not require study-specific permission. The researchers did not interfere in any way with the riding, horses, or riders, and all riding corresponded to the routine competition procedures. No additional actions were undertaken for this study. Data collection was based on the analysis of HNP and horse behavior from video footage obtained from horse-rider pairs. Filming was carried out in publicly accessible areas, ensuring no disruption to the competition environment. No direct interaction with riders or interference in warm-up activities occurred. Where required, permission to film was obtained from the event organizers in accordance with competition regulations and ethical guidelines. In addition, the authors confirm that the study has followed the guidelines of the Declaration of Helsinki. The data were anonymized for both riders and horses.

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