

Alignment Between Gait Parameters and Judging of Canter Quality in International Vaulting Horses

Sophie Biau^{1,*}, Elena Pycik¹, Robert de Bruin², Lise Charlotte Berg³, and Isabelle Burgaud¹

¹IFCE (Institut Français du Cheval et de l'Équitation), Saumur Technical Platform, 49400 Saumur, France

²FEI (Fédération Équestre Internationale) Vaulting, 1006 Lausanne, Suisse, Switzerland

³Department of Veterinary Clinical Sciences, University of Copenhagen, Agrovej 8, DK-2630 Taastrup, Denmark

* Author to whom any correspondence should be addressed; Email: sophie.biau@ifce.fr

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Abstract

Like most aesthetic sports, judging performance in equestrian vaulting is subjective. The complexity of judging often exceeds human cognitive capacities and can give rise to bias. The horse score makes up 25% of the total score, including the general quality of the canter and training level of the horse (A1 score), the execution of the performance and the horse's willingness and behavior (A2 score), and the quality of the lunging. The aim of this study was to compare the 6 scores of A1 (average of rhythm, relaxation, connection, impulsion, straightness, and collection) and the A2 score (vault-ability) from judges with 10 measured locomotor parameters. Thirty-three international-level vaulting horses were equipped with an inertial measurement unit (128 Hz) fixed to the sternum to calculate positions and movements in the sagittal and transverse planes and to calculate a quality index from a Fast Fourier Transform of the dorsoventral accelerometric signal. The head and neck were positioned with side reins, and the horses were filmed under competitive conditions at a left-lead canter from the judge's point of view, outside of the circle. Five international judges scored relaxation, connection, straightness, impulsion, rhythm, collection, and vault-ability from the videos in random order. The relationship between measurements and judges' scores was analyzed with Spearman's correlation ($P < 0.05$), and a Mann–Whitney U test ($P < 0.05$) was performed to distinguish locomotor parameters of horses judged correct and incorrect, distinguished by a k-means method. A horse that had at least one good score received good scores in all evaluated elements, each consistently associated with the same locomotor parameters. The group of correct canters, determined by the judges' scores using the k-means method, was characterized by good elevation (14 ± 1 vs. 13 ± 2 cm; $P = 0.013$), good propulsion (6.7 ± 1.4 vs. 5.7 ± 1.7 m/s²; $P = 0.005$), and good regularity of the three beats (0.016 ± 0.004 vs. 0.019 ± 0.004 m/s³; $P = 0.018$). Horses were slightly inclined to the inside of the circle and balanced on their hindlimbs. These measures can guide judge training and scoring system improvements.

Keywords

Judge; score; kinematic; locomotion; circle; lunger

1. Introduction

Vaulting is one of the seven equestrian disciplines recognized by the Fédération Équestre Internationale (FEI). This discipline consists of gymnastic elements performed on a horse at a canter. During a FEI Vaulting Competition, one judge evaluates the horse's performance (Judge A), including

the general quality of the gait and training level of the horse (A1, 60%), the vault-ability (A2, 25%), as well as the quality of the lunging (A3, 15%). The total horse score accounts for 25% of the final score of the test [1].

The canter is an asymmetric gait with synchronization of the movements of the diagonal pair of limbs separated by

a suspension phase [2]. A correct canter has a well-defined beat with a clear moment of suspension. On a circular line, centripetal forces affect the horse, and the horse will lean toward the inside of the circle (inclination). The hooves push outward against the ground, and the resultant force moves toward the inside. It is mainly the front limbs that do this work, while the forces of the hind limbs provide propulsion [3]. It is expected that the horse shows a degree of collection to carry the vaulter.

Faults are sometimes difficult to identify with the naked eye. Judging aesthetic disciplines is a very complex task, which can exceed human cognitive capacities [4]. Over the past few years, there has been an increasing number of scientific studies investigating sports refereeing. Studies have looked at objective measures of horses' performance [5], but less frequently at the quality of the canter, and, as far as we know, none have studied the quality of the canter on a circle. A few studies have investigated the link between the kinematic performance of the horse and the judges' scores [6,7]. These studies reveal that the most useful predictors of equestrian performance are asymmetry of trunk movements for dressage and the distance of landing, elevation of the body, and lifting of the front limbs for jumping performance. No similar study has been conducted for the discipline of vaulting. This would make it possible to identify one or more indicators of canter quality in order to better judge it and improve training. Consequently, it would be interesting to identify any correlations between kinematic measurements of the vaulting horse and judges' scores.

The aim of this study was to identify objective indicators to help judge canter quality. We hypothesized that propulsion, balance, and inclination are indicators of vaulting canter quality. To this end, 33 international-level vaulting horses were evaluated by five international judges under similar conditions to those of a competition. The horse cantered on a constant circle with a minimum diameter of 16 m and was equipped with side reins, with or without an elastic insert, fixed to a surcingle. The vaulter performed a series of compulsory exercises. The judges' scores were compared with measured locomotor parameters of canter obtained from an inertial measuring unit (IMU) fixed to the horse's sternum. This comparison enabled us to analyze and discuss the current scoring system.

2. Materials and Methods

2.1. Animals

A total of 33 high-level vaulting horses (13 ± 4 years of age with 4 ± 3 years of international experience) were included in the present study. All horses had previously competed at the international level. There were 29 geldings, two mares, and two stallions. They were lunged by 19 lungers familiar to the horses, with 9 ± 4 years of international experience. Participants were recruited on a voluntary basis following a presentation of the project at an FEI vaulting seminar. All participants signed an informed consent form beforehand.

2.2. Study Design

The study was carried out between December 2021 and February 2023 as a multicenter study at six different test centers in four countries (France, the Netherlands, Denmark,

and Finland). The test area was a 22-m circle enclosed by a low fence or other suitable material, with the lunger in the center. A vaulter performed a series of predetermined exercises in the following order: Mount on, Basic seat, Stand, Jump from forward stand, Forward swing, Backward swing, Ground jump to the inside, Ground jump to the outside, Sideways prince on the neck, Forward kneeling on the croup, and Handstand in the grips [1].

All tests were recorded with a camera (GoPro Hero 8, GoPro, Inc., 3025 Clearview Way, San Mateo, CA 94402, USA) attached to the front of the lunger. Another camera (Sony HDR CX625, Sony Europe B.V., The Heights, Brooklands, Weybridge, Surrey, KT13 0XW, United Kingdom) was installed outside the circle in a position that simulated the position of the judge in a competition (Figure 1). This camera filmed each performance from the mount-on of the vaulter until the completion of the final exercise.

The horses wore their regular equipment used for vaulting. As in competition, the horse presented itself with a correctly adjusted bridle and the correct position of the surcingle and a pad. With the side reins properly adjusted, the horse can carry its nose correctly on or slightly in front of the vertical [1]. The side reins were adjusted in accordance with the FEI's Vaulting Rules ("With the side reins properly adjusted, the horse can carry its nose correctly on or slightly in front of the vertical."). In order to allow the horse to bend on the circle, as usual, the lungers adjusted the inside rein to be slightly shorter than the outside rein. The difference in length between the two sides was at the discretion of the lunger.

In order to ensure the quality of the reins' adjustment, an experienced investigator analyzed the images from the camera fixed on the lunger to evaluate the head-neck and neck-trunk angles with the Kinovea® software.

They were also fitted with an inertial measuring unit (IMU) (Opal sensor, 6 g, APDM Wearable Technologies Inc., 7204 SW Durham Road, Suite 800 (Bldg. Q), Portland, OR 97224, USA) attached to the surcingle against the sternum. The sensor included a 3-axis accelerometer, a 3-axis gyroscope, and a 3-axis magnetometer. The sampling frequency was 128 Hz, and the accelerometers were configured in a high-6-g mode. The horses were warmed up before entering the arena for the test. Before starting the recording, the horse/lunger combination had one minute to acclimatize to the arena and the type of side reins. All horses were recorded with two types of side reins in a randomized design. The side reins joined the bit ring and the surcingle. They were either all-leather side reins ("Without elastic"), made entirely of leather, or side reins with a small elastic part ("With elastic"), made of leather with an elastic piece measuring 6 cm. The two rein types are both permitted in competition. Between each rein type, the horses' mouths were checked for lesions, and the horses were hand-walked for five minutes without side reins.

A duration of 1 min 30 s of left-lead canter without a vaulter was recorded. The left-lead canter was the gait most commonly chosen by competitors. The horses worked on a circle with a lunge line measuring 14 ± 1 m in length. The mean speed of the left-lead canter was 4 ± 0.5 m/s, and the mean stride frequency was 1.6 ± 0.1 strides/s.

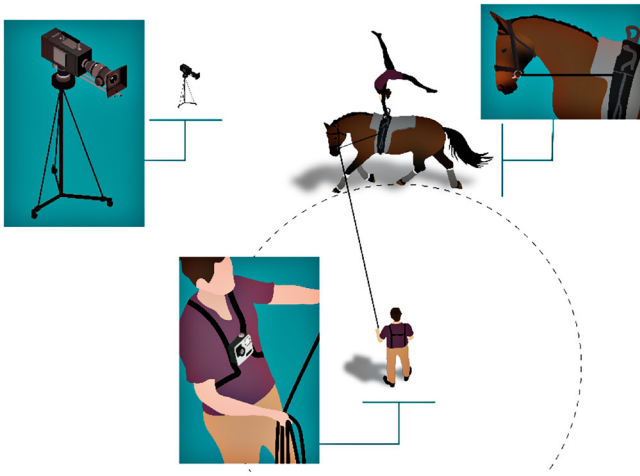


Figure 1: Diagram of the experimental setup. The lungers wears a camera (GoPro Hero 8) attached to a harness around the chest. A tripod-mounted camera (Sony HDR CX625) is positioned outside the circle, in the judge's location during a competition. The horse is equipped with side reins connecting the bit and the surcingle on a pad, which is standard equipment required for competition. An IMU is fixed to the surcingle against the horse's sternum.

The head and neck positions showed a head–neck angle of $91^\circ \pm 9^\circ$ and a neck–trunk angle of $178^\circ \pm 9^\circ$. These values were measured from the zygomatic arch, the withers, and the base of the tail using still images obtained from the camera worn by the lungers during a canter stride. The angles were evaluated using Kinovea® software for each image of a complete stride. The selected angle value was the average of each value during a stride. As described in the FEI rules, the nose was near the front of the vertical axis, with a mean angle of $-2^\circ \pm 9^\circ$.

2.3. Ethical Statement

The study was approved by the FEI (Vaulting) and did not require study-specific permission, given that this research was non-invasive and the test setup corresponded to a regular training session. The reins tested were part of the horses' normal equipment. The behavioral observations of the horses were carried out in compliance with the ethical guidelines of the International Society for Applied Ethology. This research was non-invasive.

Chief trainers of the testing stations, as well as the owners, the lungers, and the vaulters, volunteered their horses to participate in the study. They all signed an informed consent form beforehand. If the participant was a minor, one of the two parents signed. No personal data were collected. The age and number of years of practice were collected from the FEI website (<https://www.fei.org/vaulting/athletes>) [8]. The data were anonymized for analysis.

2.4. Mouth Examination

An examination of the horse's mouth before and after each test was carried out by a qualified FEI veterinarian equipped with disposable gloves. The examination consisted first of palpating the upper and lower bars, looking for sensitivity or injuries, and secondly, with the mouth open and the tongue

held in place, checking for injuries to the mandibular bars, the lips, the corners of the mouth, and the tongue. These examinations ensured respect for the physical integrity of the horse and the quality of the data collection. A form was filled out for each test, and the results were communicated immediately. No oral injuries were reported during the study.

2.5. Data Collection

2.5.1. The Judges' Scores

A total of 66 videos (33 horses/two types of side reins) were obtained. Five international judges scored the videos in a randomized order without knowing the name of the horse, the vaulter, or the nationality. Complete blinding was not possible. For each video, the judges gave seven scores (scores ranged from 0 to 10, with 10 indicating the highest level; one decimal place was allowed). The parameters were scored as defined by the FEI Vaulting Guidelines (Table 1).

2.5.2. Locomotor Parameters

The IMU was taped to the surcingle at the level of the sternum. It was the preferred position for estimating movements of the center of gravity that affect the distribution and intensity of loads on the horse [5,9]. From a biomechanical point of view, the trunk segment is considered to be a non-deformable segment.

The sensor records acceleration data on the z-axis (dorso-ventral direction of movement pointing upward), the x-axis (horizontal direction of movement pointing backward), and the y-axis (lateral direction of movement pointing to the right), as well as rotation angles around the three-dimensional axes (roll, pitch, and yaw angles). For each of the 66 tests, the measurements described in Table 2 were calculated from the IMU recordings.

2.6. Statistical Analysis

The statistical analysis was carried out on 65 recordings, including two recordings per horse (one with each type of side rein) and the seven scores from each judge for each recording. One horse was recorded with only one type of side rein.

Descriptive statistics were carried out for the variables, and after a normality test (Shapiro–Wilk test), Spearman's correlation analyses were used to assess the linear relationships between each variable, IMU sensor measurements, and judges' scores. Results were considered statistically significant at $P < 0.05$. Correlation coefficients with $|r| > 0.6$ were interpreted as indicating moderate to strong correlations, and as very strong when $|r| > 0.8$; as fair when $0.3 < |r| < 0.5$; and as poor when $0.1 < |r| < 0.2$.

A classification using the k-means method on the canter (A1) + Vault-ability (A2) score was carried out (Supplementary Materials) [10]. The horses in one group were the highest-scored horses ("correct canter group"), and the horses in the second group were the lowest-scored horses ("incorrect canter group"). A Mann–Whitney U test ($P < 0.05$) was performed to determine whether there was a significant difference in locomotor parameters between the two groups without multiple post hoc comparisons. All statistical analyses were performed using XLSTAT 2023.3.0 (Lumivero, 2025), an XLSTAT statistical and data analysis solution. <https://www.xlstat.com/fr> with a significance level of $P < 0.05$.

Table 1: Judges' score definitions.

Parameter	Definition
Rhythm	The characteristic sequence of footfalls and timing of a pure canter with a clear beat and a clear moment of suspension.
Relaxation	The horse's mental state (calmness without anxiety or nervousness), as well as its physical state (the absence of negative muscle tension).
Connection	Through the body to the contact on the side reins (acceptance of the bit (or cavesson) through acceptance of the aids), when the energy generated in the hindquarters by the driving aids flows through the whole body of the horse and is received in the side reins and lunge line, referred to as the "bridge of engagement."
Impulsion	The transmission of an eager and energetic, yet controlled, propulsive thrust generated from the hindquarters into the athletic movement of the horse. Impulsion is associated with a phase of suspension. It is measured by the Horse's engagement of its hind legs and desire to carry itself forward with a lowering of the croup, elasticity of its steps, suppleness of its back, and increased lightness of the forehand.
Straightness	The horse is straight when the footfalls of the forehand and the hindquarters are appropriately aligned and when its longitudinal axis is in line with the track on which it is lunged.
Collection	The horse lowers and engages its hindquarters and shortens and narrows its base of support, resulting in lightness and mobility of the forehand and self-carriage.
A1	The average of the six subscores listed above makes up Score A1. A1 represents 60% of the total score for the horse.
Vault-ability (A2)	The horse must give the impression of carrying out the test of its own accord and maintaining true balance and self-carriage. There is an impression of harmony and lightness throughout the test. A2 represents 25% of the total score for the horse.

Table 2: Canter calculated variables.

Variable	Biomechanical definition	Requirement described in the judging guidelines
Mean longitudinal balance: LgB (°)	Mean trunk angle in the sagittal plane (relative to the position before the start). It represents the average balance between the shoulders and the hips of the horse per stride, as reflected by the trunk segment as a non-deformable segment; positive values represent flexion of the trunk ("balance on the shoulders"), and negative values represent extension of the trunk ("balance on the hips"). (Figure 2).	This mean posture is linked to balance on the shoulders if the horse's trunk is in flexion, with the withers as the lowest point, or to balance on the hindquarters (collection) if the trunk is in extension, with the withers as the highest point.
Mean lateral balance: LaB (°)	Mean trunk angle relative to the position before the start. It represents the average left/right balance of the horse per stride; negative values represent a lean to the left, and positive values represent a lean to the right.	Position and movement in the horizontal plane most closely correspond to the straightness score. The guidelines describe an observation of the mean lateral balance at an almost vertical body angle. The results should therefore show a link between straightness and mean lateral balance.
Roll body lean angle: Roll (°)	Roll angle of the rotation around the longitudinal axis.	
Pitch body angle: Pitch (°)	Pitch angle of the rotation around the mediolateral axis.	The guidelines describe stability in balance; therefore, a low pitch value is expected.
Elevation (cm)	Range of vertical displacement of the horse's trunk per stride (using the method for deriving displacement [11]).	Clear moment of suspension. Suppleness through the back.
Propulsion (m/s ²)	Mean vector of propulsion during the stance phase (when dorsoventral acceleration was negative and longitudinal acceleration positive).	The guidelines describe a canter with energetic strides and clear impulsion from the engaged hindquarters.
Braking (m/s ²)	Mean vector of braking during the stance phase (when both accelerations were negative).	
Braking time (s)	Mean time spent braking during the support phase per stride.	
Propulsion time (s)	Mean time spent in propulsion during the support phase per stride.	
Canter quality index (m/s ³)	Integral of a Fast Fourier Transform of the first two harmonics ($\pm$ frequency/2) (Figure 3). The lower the value, the more regular the three beats. A high value could represent a diagonal dissociation, i.e., a short temporal separation of the limbs of the diagonal pairs at contact and/or lift-off.	Regularity and a clear three-beat canter.

3. Results

The distribution of the judges' scores is shown in **Figure 4**. Only Collection and Connection were normally distributed (Shapiro–Wilk test). A few scores were far from the median. Descriptive statistics for locomotor parameters are presented in **Table 3**.

3.1. Correlation

Results of the correlation tests between the variables are shown in **Figure 5**. The correlation analysis showed that all the scores were highly correlated. All the scores were correlated with the same locomotor parameters, and the quality index was inversely correlated with all the scores. Correlations for each of the scores with the locomotor parameters are described in **Table 4**.

Analysis of the correlations between selected locomotor variables revealed a statistically significant relationship close to the significance threshold, with a low correlation coefficient. Although statistically significant, this relationship remains poor and should therefore be interpreted with caution because it is of limited practical relevance. A horse in extension was more stable ($r = -0.247$, $P = 0.047$), with more propulsion ($r = -0.246$, $P = 0.049$), and the more the horse propelled, the higher the elevation ($r = 0.284$, $P = 0.022$). Obviously, propulsion and braking are linked: the more time the horse spends braking, the less time it spends propelling.

3.2. Analysis of Variance

An analysis of variance (Mann–Whitney U test) on the two groups formed from a k-means test on A1 + A2 scores differentiated higher-scoring horses ("Correct canter" group) and lower-scoring horses ("Incorrect canter" group) by elevation (14 ± 1 cm vs. 13 ± 2 cm, $P = 0.013$), propulsion (6.7 ± 1.4 m/s² vs. 5.7 ± 1.7 m/s², $P = 0.005$), and a clear regularity of the three beats (0.016 ± 0.004 m/s³ vs. 0.019 ± 0.004 m/s³, $P = 0.018$) (**Figure 6**).

4. Discussion

Many sports, such as gymnastics, diving, ski jumping, and figure skating, use judges' scores to determine the winner

of a competition. These judges use discipline-specific rating scales when judging performances (for example, 0.000–10.000). This is the case for vaulting judges, and one judge (out of four judges) is responsible for scoring the Rhythm, Relaxation, Connection, Impulsion, Straightness, and Collection of the canter with scores between 0 and 10; one decimal place is allowed. The average of the six scores constitutes A1. This A1 score is combined with the vault-ability (A2) of the horse, which represents 25% of the horse's final score, and the Lunging score, which represents 15%, for a total Horse Score. A3 was not scored by the five judges in this study, as the aim only concerned judging horse locomotion.

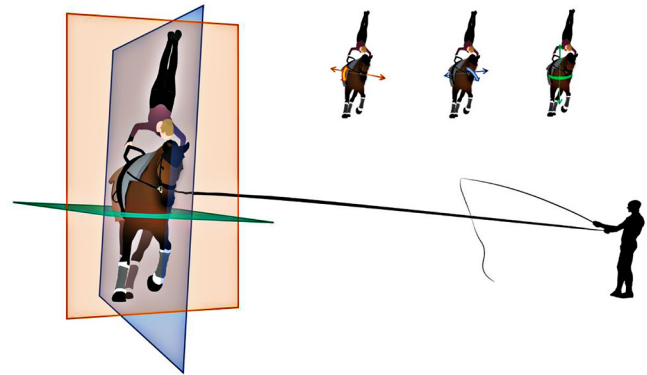


Figure 2: Representation of the three planes: Frontal plane in orange: This plane divides the trunk into front and back parts. In this plane, the horse performs movements of inclination, and the oscillation around the longitudinal axis of the trunk is rolling. Sagittal plane in blue: This plane divides the trunk into right and left parts. In this plane, the horse performs movements of flexion (movement of the trunk downward) and extension (movement of the trunk upward), and the oscillation around the mediolateral axis is pitching. Transversal or horizontal plane in green: This plane divides the trunk into upper and lower parts. In this plane, the horse performs movements to the left and right, and the oscillation around the vertical axis of the trunk is yawing.

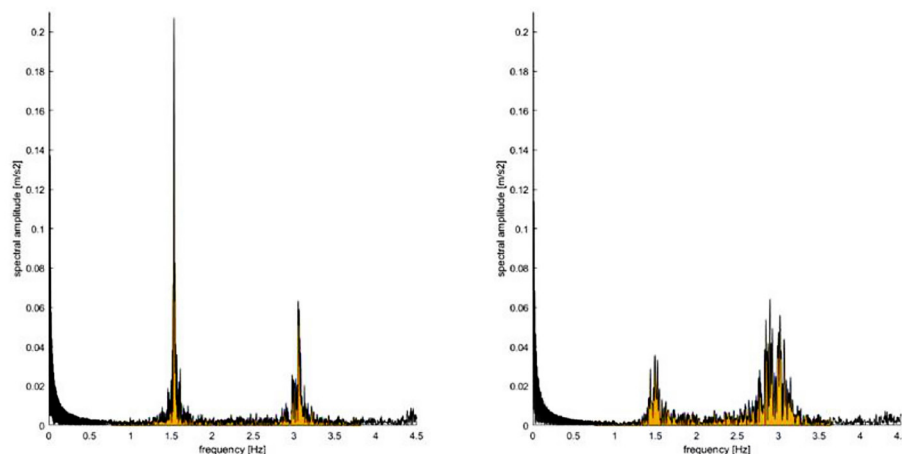


Figure 3: Fast Fourier transform of a correct canter quality index on the left and an incorrect one on the right. The yellow area represents the calculation of the canter quality index. The larger the area, the more irregular the canter.

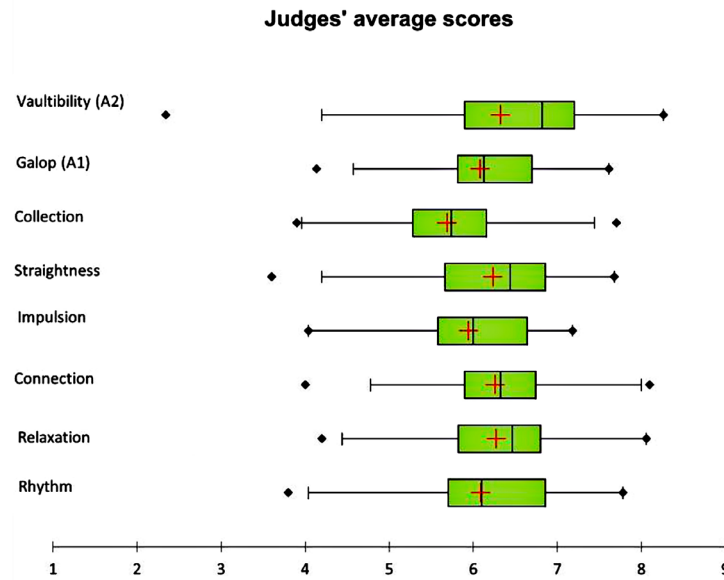


Figure 4: Box plot of the judges' scores.

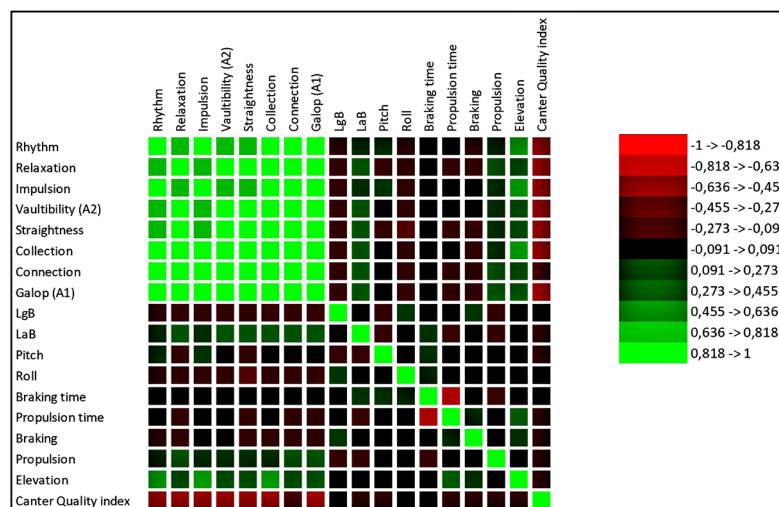


Figure 5: The Correlation plot displays significant correlations between the judges' scores and the locomotor parameters. Positive correlations are shown in green, and negative correlations are shown in red. Black indicates no correlation.

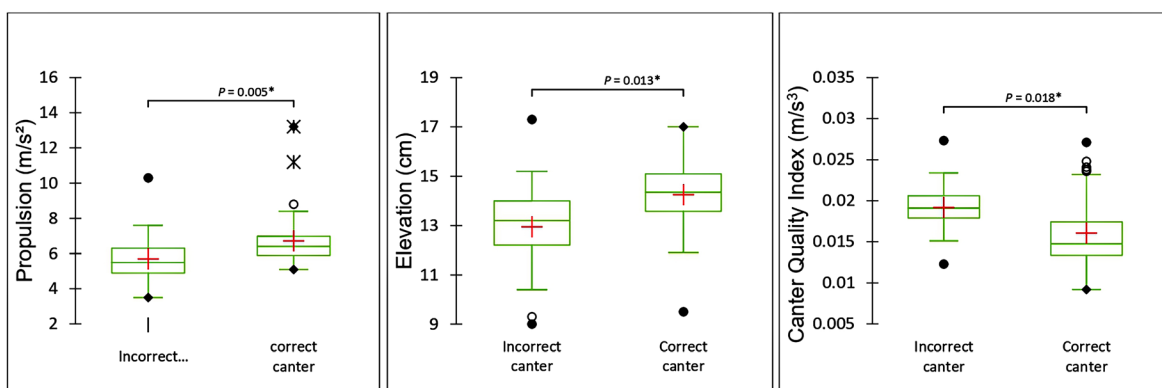


Figure 6: Boxplot of the three locomotor parameters that distinguished correct canter quality from incorrect canter quality. A correct canter was characterized by greater propulsion and elevation compared with an incorrect canter, and a lower quality index, indicating a better canter.

Table 3: Mean $\pm$ sd of locomotor parameters. Values in brackets are mean (95% CI).

Variable	Mean $\pm$ sd (95% CI)
LgB (°)	-8 ± 5 (-9 , -7)
LaB (°)	-11 ± 5.5 (-13 , -10)
Pitch (°)	13 ± 2 (13 , 14)
Roll (°)	10 ± 2 (9.5 , 10.5)
Braking time (s)	0.18 ± 0.03 (0.17 , 0.19)
Propulsion time (s)	0.14 ± 0.04 (0.13 , 0.15)
Braking (m/s ²)	7 ± 0.8 (6.7 , 7.2)
Propulsion (m/s ²)	6.5 ± 1.5 (6.1 , 6.8)
Elevation (cm)	14 ± 2 (13.5 , 14.3)
Quality index (m/s ³)	0.017 ± 0.004 (0.016 , 0.018)

The results showed a strong correlation between the six scores in A1 (and A2): a horse judged to be correct only received good marks (**Figure 4**). This may suggest that the judges assessed the overall quality of the canter rather than focusing on each of the six specific scores, or that the scores are linked and thus, if one goes up, the other scores follow. This refers to the complexity of judging without numerical data. The high number of canter quality criteria to be scored in one minute by a single judge may give rise to bias [12–14] and requires a great deal of knowledge of horse locomotion. An assessment of seven (or more) scores without any numerical data has been reported to be beyond human cognitive capacity [15]. As in dressage, judges rely on simpler cognitive strategies to make decisions, which can lead to errors of judgment [4], such as breed bias or the fact that some judges systematically give high marks and others low marks.

According to the judges, a correct vaulting horse canter was distinguished from an incorrect one by the activity and the regularity of the three beats. The group of correct canters, determined by the judges' scores using the k-means method, was characterized by good activity and regularity in the three-beat canter. Conversely, the group of incorrect canters, determined by the judges' scores, was characterized by poorer activity and regularity. Moreover, each score was correlated with the elevation and regularity of the three beats. Elevation and propulsion were two canter performance criteria that have already been demonstrated in dressage horses [4].

Balance in the sagittal and frontal planes can also be relevant observables [1]. They correlated well with the judges' scores. The horse has to show collection by lowering and engaging its hindquarters. The forehand is lightened as a result of the better balance; therefore, the horse will be able to move its forelimbs more freely and reach higher and farther forward. The collection of a gait means that forward movements become upward movements. This was demonstrated in the collected trot [3]. Propulsion and elevation were the consequence of good balance.

The horses with a lower leaning angle were scored better. When a horse moves in a circle, its body leans inward due to centripetal forces. This inclination allows the vertical resultant of the ground reaction force to remain outside the circle [16]. The degree of inclination depends on both the circle size and the speed. In this study, at a speed of 4 ± 0.5 m/s on a 16 m diameter circle, the mean inclination angle of the horses was $11 \pm 5.5^\circ$. Like in dressage [6], trained vaulting horses learn to maintain the vertical orientation of their body in order to support the vaulter. This observable was correlated with the straightness score. Indeed, on a left circle, the horse must show lateral bending to the left, developed in the horizontal plane around a dorsoventral axis, which influences hind limb placement and can serve as a visual indicator [17]. Good straightness offers good stability in the mediolateral plane for the execution of the vaulter's exercises [18]. It is also known that horses must stabilize their trunk, neck, and head to maintain a spatial frame of reference [19]. One might therefore have expected a correlation between the straightness score and lateral bending (LaB), but this was not observed in the present study. This could indicate either that the IMU calculation does not accurately reflect whole-body lateral bending, or that the judges did not evaluate it correctly [9].

This correlation between all the scores may reflect the scale of progression proposed in the rules [1], which should make it possible to assess the quality of a performance objectively. The progression is organized into three main phases, the order of which is fundamental. Thus, a horse that is collected, the highest criterion on the scale, is balanced, with impulsion, and regular in its beats. According to this scale, a horse could have a poor score for collection, but a good score for regularity of the beats. However, this was not the case in this study; a horse with a poor collection score had a poor regularity score systematically. In addition, the guidelines specify that scores must be distinct. For example, a horse may show poor rhythm with an unclear three-beat canter (lower A1), but may still work with completely consistent speed and energy (higher A2). It seems unlikely that all 33 horses would have been either good or bad for all six scores, indicating that either the details of the six A1 scores are redundant, or the judges are not able to separate the judging of the scores. The fact that several of the scores were correlated with the same locomotor parameters shows that the assessment of these separately may be redundant and that a simplification, such as reducing the number of scores, might be possible.

The quality index calculated in this study seemed to be of major significance to the judges. This index should reflect the distortions of the dorsoventral accelerometric signal and consequently evaluate the regularity of gait and even modifications of the three beats. During the test with the vaulter, the two major faults in the quality of the canter are a lack of projection and a desynchronization of the diagonal, which must be penalized by the Rhythm score, which inevitably has an impact on the A1 score. This was the case in the study. As the other locomotor parameters were not correlated with this index, an in-depth biomechanical study of these two faults should be undertaken in order to detect them visually.

Table 4: Correlations between scores and locomotor parameters. Only significant correlations ($P < 0.05$) are reported.

	Rhythm	Relaxation	Connection	Impulsion	Straightness	Collection	Canter (A1)	Vault-ability (A2)
Quality index	-0.550 (<0.0001)	-0.502 (<0.0001)	-0.441 (<0.0001)	-0.513 (<0.0001)	-0.467 (<0.0001)	-0.441 (<0.0001)	-0.504 (<0.0001)	-0.564 (<0.0001)
LgB	-0.269 (0.030)	-0.258 (0.038)	-	-0.266 (0.033)	-	-	-0.252 (0.043)	-
LaB	0.245 (0.050)	0.303 (0.015)	0.372 (0.002)	-	0.384 (0.013)	0.324 (0.009)	0.330 (0.008)	0.360 (0.003)
Elevation	0.529 (<0.0001)	0.301 (0.015)	0.377 (0.002)	0.525 (<0.0001)	0.276 (0.027)	0.456 (<0.0001)	0.411 (0.001)	0.369 (0.003)
Propulsion	-	0.305 (0.014)	0.322 (0.009)	-	0.269 (0.030)	0.251 (0.044)	0.279 (0.025)	-
Roll	-	-	-	-	-0.282 (0.002)	-	-	-

4.1. Limitations

The main limitation in the current study design is that the scoring was done using videos. We know that the visual angle from which the sporting situation is perceived influences judgment. Even if the camera was placed in the same place as a judge's table, the information perceived visually is limited, particularly when it comes to assessing the speed of movements [12]. In addition, the potential public pressure, which is part of the judging process, is not taken into account here. Scores can also be biased by the automation of certain evaluation routines, especially for a large number of videos, with an effect of the order in which the performances are viewed [13]. As in the case of live judging, the participating judges were international-level expert judges, and we know from previous studies in other disciplines that there is a risk of bias among expert judges, such as overpersonalized expectations of some athletes highlighted in, e.g., gymnastics [14]. The videos provided were not nominative, but the fact that they were international judges and international athletes made anonymizing impossible. These biases were illustrated by the results of the interjudge agreement analysis, particularly the more severe assessment by one of the five judges.

Measurements of canter quality were carried out with the vaulter, as in competition, in this study. To extend this analysis, it would be relevant to compare the locomotor parameters of the canter with and without the vaulter. As with the rider–horse interaction, the vaulter probably has an impact on locomotion, whether beneficial or not [20,21].

5. Conclusion

The FEI rules propose six distinct scores to assess the quality of the canter: rhythm, relaxation, connection, impulsion, straightness, and collection, and a separate score for vault-ability. They were all correlated and therefore non-discriminatory, and several were correlated with the same locomotor parameters. On the basis of the results, a simplification of the number of scores can be discussed. The results showed that, for judges, a correct quality of canter was a canter with propulsion, elevation, and good regularity of the three beats. Balance in the sagittal and mediolateral planes should be retained as an observable measure of performance. All of these observables seem to be decisive and sufficient to assess the quality of the canter and are interesting

from the point of view of decision support within the framework of the initial and ongoing training of judges.

Supplementary Materials

Supplementary Materials present details of the k-means classification of canters based on the combined A1 and A2 judges' scores, including cluster validation metrics.

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Authors' Contributions

S.B.: Conceptualization, Methodology, Formal analysis, Resources, Data curation, Writing – original draft, Writing – review & editing, Supervision, Project administration. E.P.: Conceptualization, Formal analysis, Resources, Data curation, Writing – original draft, Writing – review & editing. R.DB.: Conceptualization, Resources, Writing – original draft, Writing – review & editing. L.C.B.: Conceptualization, Resources, Writing – original draft, Writing – review & editing. I.B.: Conceptualization, Methodology, Project administration. All authors have read and agreed to the published version of the manuscript.

Data Availability

The authors confirm that all data underlying the findings are 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

The study was approved by the FEI (Vaulting) and did not require study-specific permission. The data were anonymized for lungers, vaulters, and horses.

Consent to Participate

Chief trainers of the testing stations, as well as the owners, the lungers, and the vaulters, volunteered their horses to participate in the study. They all signed an informed consent form beforehand. If the participant was a minor, one of the two parents signed. No personal data were collected.

Declaration of Generative AI and AI-Assisted Technologies

During the preparation of this work, the authors used DeepL Translator to improve the translation of the text. Following the use of this tool, the authors reviewed and edited the content as needed and take full responsibility for the final version of the publication.

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