Can computer vision “see” the rider’s and surface’s effect on the horse’s symmetry?

Using SLEIP AI^{TM} to monitor horses’ locomotor asymmetry

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Summary

Background: Objective assessment of equine locomotor asymmetry is increasingly important for improving lameness detection and monitoring horse welfare. Markerless computer vision systems may provide a practical alternative to traditional gait assessment, although the effects of rider experience and surface type remain unclear.

Objective: To investigate whether a markerless computer vision system (SLEIP AI™) can detect the effects of rider and surface type on locomotor asymmetry and to quantify between-horse variability.

Methods: Four horses were evaluated under six conditions combining rider presence (no rider, novice and experienced rider) and footing type (hard and soft surfaces). Locomotor asymmetry was measured using a smartphone-based system. Linear mixed-effects models assessed the effects of rider and footing, with horse included as a random effect. Intraclass correlation coefficients (ICC) and Fleiss' kappa were used to evaluate variability and asymmetry consistency.

Results: Footing had no significant effect on asymmetry. Rider significantly affected forelimb impact asymmetry ($p = 0.030$), with greater asymmetry under the novice rider. Between-horse variability explained 36–37% of forelimb asymmetry but only 3–8% of hindlimb asymmetry. Agreement in asymmetry sidedness was moderate overall.

Conclusions: Rider experience influenced locomotor asymmetry more than surface type. Markerless computer vision appears to be a practical tool for objective gait assessment, lameness evaluation and training monitoring.

Keywords: horse locomotion; asymmetry; rider; surface; forelimbs; hindlimbs; push-off; impact; computer vision.

Resumo

Introdução: A avaliação objetiva da assimetria locomotora em equinos tem assumido uma importância crescente na melhoria do diagnóstico de claudicações e na monitorização do bem-estar animal. Os sistemas de visão por computador sem marcadores constituem uma alternativa promissora aos métodos tradicionais de avaliação da marcha, embora a influência da experiência do cavaleiro e do tipo de piso nas medições permaneça insuficientemente esclarecida.

Objetivo: Investigar se um sistema de visão por computador sem marcadores (SLEIP AI™) é capaz de detetar os efeitos do cavaleiro e do tipo de piso na assimetria locomotora de cavalos, bem como quantificar a variabilidade entre indivíduos.

Métodos: Foram avaliados quatro cavalos em seis condições resultantes da combinação da presença do cavaleiro (sem cavaleiro, cavaleiro inexperiente e cavaleiro experiente) e do tipo de piso (superfície dura e superfície macia). A assimetria locomotora foi quantificada através de um sistema baseado em smartphone. Foram ajustados modelos lineares mistos para avaliar os efeitos do cavaleiro e do tipo de piso, considerando o cavalo como efeito aleatório. A variabilidade entre indivíduos foi avaliada através do coeficiente de correlação intraclasse (ICC) e a consistência da lateralidade da assimetria pelo coeficiente kappa de Fleiss.

Resultados: O tipo de piso não teve efeito significativo em nenhuma das medidas de assimetria. O cavaleiro influenciou significativamente a assimetria de impacto dos membros anteriores ($p = 0{,}030$), verificando-se maior assimetria com o cavaleiro inexperiente. A variabilidade entre cavalos explicou 36–37% da assimetria dos membros anteriores e apenas 3–8% da dos membros posteriores. A concordância da lateralidade da assimetria foi moderada.

Conclusões: A experiência do cavaleiro influenciou mais a assimetria locomotora do que o tipo de piso. A visão por computador sem marcadores revelou-se uma ferramenta prática para a avaliação objetiva da marcha, podendo constituir um apoio útil no diagnóstico de claudicações e na monitorização do treino.

Palavras-chave: locomoção equina; assimetria; cavaleiro; tipo de piso; membros anteriores; membros posteriores; propulsão; impacto; visão por computador.

Introduction

Lameness in horses has posed challenges to riders, trainers and veterinarians for a very long time. In recent years, the generalized use of social media and growing awareness about animal welfare have raised scrutiny on equestrianism and controversial practices that can potentially inflict suffering to horses are decreasingly tolerated. To keep a social licence to operate, the equestrian industry is obliged to adopt the best practices and assure the horses' welfare.

Lameness examination includes visual observation of the horse trotted in hand, among a comprehensive set of procedures that can include imaging exams and nerve blocks (Baxter e Stashak, 2020), to reach a diagnostic. Lameness diagnostics is complex and time-consuming, and this has led to the development of several technological tools, designed to help recognising lameness and identifying the lame limb or limbs. Lately, applications using computer vision associated with machine learning became commercially available, and increasing sophistication of such systems will probably revolutionize not only lameness diagnostics but also training and rehabilitation monitoring.

Many factors can affect the manifestation of lameness, or locomotor irregularity, including the type of surface where horses are being observed. Lameness and the phase of lameness manifestation can vary between track surfaces, and some horses show impact lameness on soft ground and elevation lameness on hard ground (Azevedo et al., 2015). Pfau et al. (2014) reported a significant effect of surface type (hard/soft) on forelimb-lame horses trotted on the lunge. When comparing ridden horses on three different surfaces, greatest movement asymmetry was recorded during trotting on the least firm (softer) surface (Barstow et al., 2019).

The rider and their individual features also play a part in the locomotor irregularities of horses. The rider's weight has implications in the biomechanics of the thoracolumbar spine (Clayton et al., 2023), causing its extension (hence, the hollowing of the back). Even though an increase of 15% to 25% in the rider's weight had no effect on horses behavioural and physiological parameters (Christensen et al., 2020), there is evidence that if the rider's weight exceeds 15% to 25% of the horse's weight, the rider can induce temporary lameness and behavioural signs of musculoskeletal pain in the horse (Dyson et al., 2019).

Another factor that can interfere with the horse's locomotor regularity is the rider's experience. An experienced rider manages their weight distribution and body movements during predictable gait patterns and reacts quickly to unexpected responses from the horse. To achieve this, the rider's pelvis moves in coordination with the horse's back and the saddle, while the trunk stabilizes the upper body over the pelvis. Both innate and learned asymmetries are common in riders and horses and tend to persist across different gaits (Clayton et al., 2023).

The aim of this study was to investigate whether a smartphone-based computer vision system can detect the effects of rider and surface on locomotor asymmetry at trot and quantify the contribution of interindividual variability. In the future, it is expected that knowledge of these factors will increase exponentially, contributing to a better understanding of horse-rider interaction, ultimately benefiting equine welfare.

Materials and Methods

Four horses, used daily for riding lessons with elementary level riders, were selected for this study. A general characterization of each horse is presented in table 1. Horses were deemed sound or mildly lame before the study. All horses were shod with conventional steel shoes, except for horse 2, which was unshod in the hindlimbs.

Table 1. Age, height and estimated weight of horses

Horse	Age (yrs)	Height (cm)	Estimated weight (kg)
1	14	172	565
2	14	155	522
3	14	167	553
4	9	150	420

The horses' locomotor asymmetries were assessed using a markerless, smartphone-based, computer vision technology that tracks over 100 anatomical key points to quantify equine gait asymmetry and detect lameness, SLEIP AI™ (Lawin et al., 2023; SLEIP AI AB., 2024). Video recordings were acquired using an iPad™ 13 Pro. Each horse was trotted back and forth on a 30 m track on a hard (crushed sand) and a soft (silica + textile fibres) surface, led in-hand (no rider), ridden by an elementary level male rider (rider 1) and an experienced male rider (rider 2). Overall, each horse was trotted 6 times. The riders' age, height and weight are presented in table 2.

Table 2. Age, height and weight of riders

Rider	Age (yrs)	Height (cm)	Weight (kg)
1	20	185	71.5
2	56	182	90

In-hand trot-ups were performed at a comfortable speed, consistent with the conditions used in lameness examinations. In ridden trot-ups, riders were asked to exert minimal interference. Both riders spontaneously adopted posting trot, although no instructions on trotting rider position were given. To assess the presence of baseline lameness, a threshold of >0.5 on the absolute measures of asymmetry when horses were conducted in-hand at trot on a hard surface was considered as clinically relevant (Meistro et al., 2025).

Data resulting from the SLEIP AI™ analysis were retrieved. The numerical asymmetry values represent the mean of all valid strides recorded by the application, with an average of 30.58 strides for the forelimbs (range: 15-52) and 23.46 strides for the hindlimbs (range: 15-31). For forelimbs, a unitary value (1) represents the inter-diagonal difference in vertical head displacement, expressed as a proportion of the horse's withers height, corresponding to 2.5% of that height. For hindlimbs, a unitary value (1) represents the inter-diagonal difference in vertical pelvic displacement, also normalized to withers height, corresponding to 1.4% of that height (SLEIP AI AB., 2024).

To evaluate the effects of rider and footing on asymmetry magnitude (absolute value of asymmetry measurements), four linear mixed models were fitted, with Forelimb Push-Off, Forelimb Impact, Hindlimb Push-Off, and Hindlimb Impact as dependent variables. In each model, rider and footing (and their interaction) were included as fixed effects, and horse was included as a random intercept:

$$Y_{ij} = \beta_0 + \beta_1 \text{Rider}_{ij} + \beta_2 \text{Footing}_{ij} + \beta_3 (\text{Rider} \times \text{Footing})_{ij} + u_j + \varepsilon_{ij}$$

The contribution of the random effect of horse was assessed using the intraclass correlation coefficient (ICC), calculated from the estimated variance components.

Individual horse's asymmetry plots were built using Ms Excel graphs from Microsoft Office 325™. The asymmetry values were considered as negative when associated with the left limbs, and positive when associated with the right limbs. Consistency in sidedness of the affected limb was evaluated using Fleiss' kappa coefficient (κ), Kappa values were calculated for each condition (forelimb and hindlimb; push-off and impact phases) as well as across all conditions combined.

The strength of agreement was interpreted according to standard benchmarks (values ≤0 indicating no agreement, 0.01-0.20 slight, 0.21-0.40 fair, 0.41-0.60 moderate, 0.61-0.80 substantial, and >0.80 almost perfect agreement). Approximate 95% confidence intervals (95% CI) for κ were computed using asymptotic standard errors. Statistical significance of agreement was assessed by testing the null hypothesis of κ = 0 using a z-test. All statistical analyses were conducted with significance set at $p < 0.05$. Statistical analysis used IBM SPSS Statistics for Windows, Version 27.0 (IBM Corp., 2020).

Results

Baseline of registered lameness

The absolute measures of asymmetry when horses were conducted in-hand at trot on a hard surface (i.e., the conditions which are usually considered for lameness inspection) are presented in table 3.

Table 3. Asymmetry values at in-hand trot in a hard surface. Negative values point to left limb; positive values point to right limb.

Horse	Forelimb Push-Off	Forelimb Impact	Hindlimb Push-Off	Hindlimb Impact
1	-0.5	-0.1	0.1	-0.3
2	0.3	0	0.8	0.5
3	0.1	0.1	0.9	-0.1
4	0.3	0.4	0.7	0.2

Thresholds for asymmetry severity defined for the SLEIP AI™ software (Meistro et al., 2025) are as follows: very mild (0.2-0.49), mild (0.5-0.9), moderate (1.0-1.49), and severe 1.5-2.0). According to this classification, horse 1 exhibited mild forelimb asymmetry, and the remaining horses exhibited mild hindlimb asymmetries.

Effect of the rider and the type of surface

Table 4 summarises the fixed effects tests in the four linear mixed models. No significant effects of rider, footing or their interaction were detected for forelimb push-off, hindlimb push-off or hindlimb impact asymmetry measures ($p>0.05$). For forelimb impact, a significant effect of rider was observed ($p=0.03$). Bonferroni-adjusted pairwise comparisons revealed a significant difference between the 'No Rider' and 'Rider 1' conditions, with lower values observed in the 'No Rider' condition (*M*diff = -0.200, SE = 0.067, $p=0.029$). No significant differences were found between 'No Rider' and 'Rider 2' ($p=0.251$) or between 'Rider 1' and 'Rider 2' ($p=0.852$).

Table 4. Type III tests of fixed effects (F.E.) in the four models

F.E - Forelimb Push-Off	df1	df2	F	p-value
• Rider	2	15	1.439	0.268
• Footing	1	15	0.154	0.700
• Rider x Footing	2	15	1.320	0.297
F.E. – Forelimb Impact	df1	df2	F	p-value
• Rider	2	15	4.482	0.030
• Footing	1	15	0.366	0.554
• Rider x Footing	2	15	0.640	0.541
F.E. – Hindlimb Push-Off	df1	df2	F	p-value
• Rider	2	15	0.159	0.854
• Footing	1	15	0.110	0.745
• Rider x Footing	2	15	0.478	0.629
F.E. – Hindlimb Impact	df1	df2	F	p-value
• Rider	2	15	0.016	0.984
• Footing	1	15	0.147	0.707
• Rider x Footing	2	15	2.106	0.156

The proportion of variance attributable to differences between horses varied across models (table 6). For forelimb variables, the horse accounted for a substantial proportion of the variance (Forelimb Push-Off: 36.1%; Forelimb Impact: 36.9%). In contrast, for hindlimb variables, the contribution of the horse was considerably smaller (Hindlimb Push-Off: 3.0%; Hindlimb Impact: 7.6%), indicating that most of the variability in these outcomes was explained at the observation level rather than between horses.

Table 5. Variance components and intraclass correlation coefficients (ICC) for each model

Stride phase	Horse (τ^2)	Residual (σ^2)	ICC (%)
Forelimb Push-Off	0.055	0.098	36.1
Forelimb Impact	0.011	0.018	36.9
Hindlimb Push-Off	0.004	0.136	3.0
Hindlimb Impact	0.002	0.026	7.6

The asymmetries registered in each individual horse were plotted to allow for visual interpretation of each individual horse.

Figure 1 presents the values obtained for horse 1. Both in-hand trot-ups point to a push-off asymmetry in the left forelimb. This asymmetry accentuates with both riders, as well as a right hindlimb push-off asymmetry, more pronounced over soft footing.

Horse 2 (figure 2) presents a consistent right hindlimb push-off asymmetry, more apparent in the hard track surface and combined with a very mild right forelimb push-off asymmetry. However, and depending on the rider and track, this horse also presents inconsistent forelimb and hindlimb impact asymmetries in both left and right limbs.

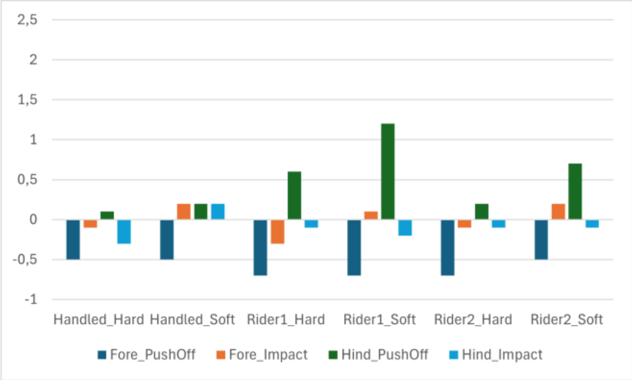

Figure 1. Registered asymmetries for horse 1

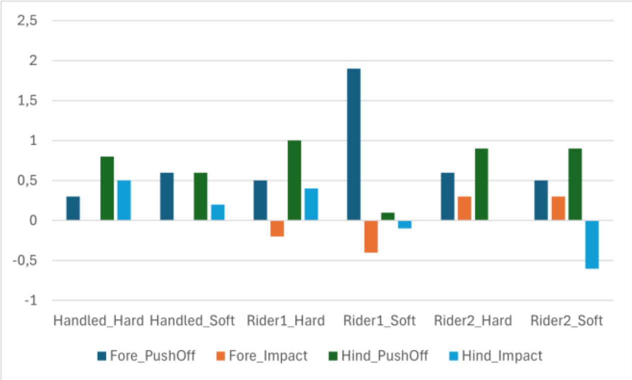

Figure 2. Registered asymmetries for horse 2

Horse 3 (figure 3) presents a right hindlimb push-off asymmetry at in-hand trot, coupled with a right forelimb impact asymmetry on hard footing. The magnitude of the hindlimb asymmetry decreases under both riders. Inconsistent forelimb and hindlimb impact asymmetries appear under rider in the right limbs.

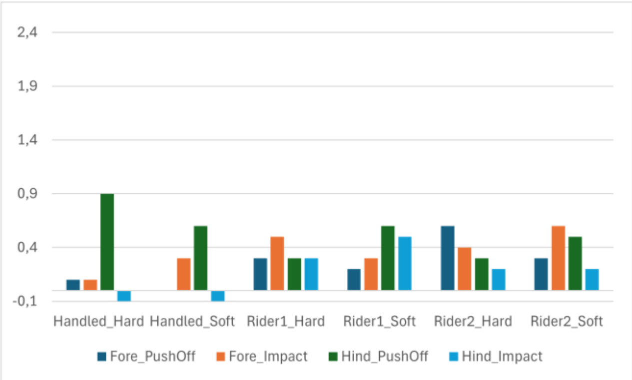

Figure 3. Registered asymmetries for horse 3

Horse 4 (figure 4) presents a push-off right hindlimb asymmetry in in-hand trot, coupled with a right forelimb impact asymmetry. With rider 1, the right hindlimb push-off asymmetry disappears, and the right forelimb impact asymmetry accentuates and with rider 2, both asymmetries decrease when compared to handled trot. No substantial differences are observed between hard and soft footing.

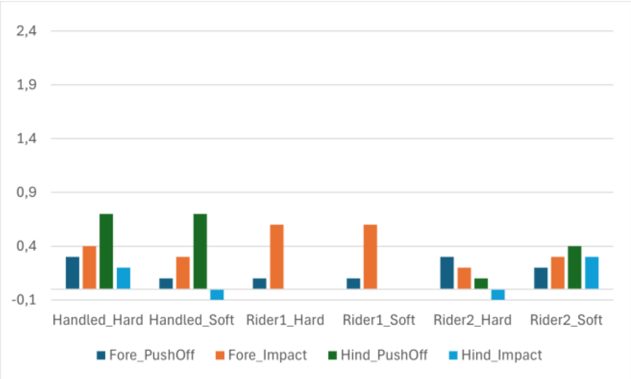

Figure 4. Registered asymmetries for horse 4

Consistency in asymmetry sidedness

For consistency analysis, asymmetry values up to 0.1 (absolute value) were considered negligible (indicating absence of asymmetry). Data are shown in table 6 and Fleiss k values, confidence intervals and p-values in table 7.

Table 6. Observations in asymmetry sidedness

Stride Phase	Horse	Left	None	Right
Forelimb Push-Off	Horse 1	6	0	0
	Horse 2	0	0	6
	Horse 3	0	2	4
	Horse 4	0	3	3
Forelimb Impact	Horse 1	1	3	2
	Horse 2	2	2	2
	Horse 3	0	1	5
	Horse 4	0	0	6
Hindlimb Push-Off	Horse 1	0	1	5
	Horse 2	0	1	5
	Horse 3	0	0	6
	Horse 4	0	3	3
Hindlimb Impact	Horse 1	2	3	1
	Horse 2	1	2	3
	Horse 3	0	2	4
	Horse 4	0	4	2

Table 7. Fleiss k values, confidence intervals and p-values

Stride phase	Kappa	CI 95%	p-value
All	0.41	0.28-0.54	<0.0001
Forelimb Push-Off	0.53	0.30-0.76	0.0002
Forelimb Impact	0.28	0.05-0.51	0.028
Hindlimb Push-Off	0.49	0.26-0.72	0.0004
Hindlimb Impact	0.22	0.00-0.44	0.058

The results show a moderate overall agreement between observations. Consistency in asymmetry sidedness can be interpreted as moderate in forelimb and hindlimb push-off phases, and as fair in forelimb and hindlimb impact phases. K value for hindlimb impact phase was borderline non-significant (p=0.058).

Discussion

Baseline lameness assessment

The horses included in this study were previously deemed as sound or mildly lame by riders (equestrian pupils and instructors). The registered measures point to mild asymmetries in all horses, with potential clinical relevance of hindlimb asymmetries in horses 2, 3 and 4. This points to the need of a more comprehensive examination, to assess the eventual presence of injury that could compromise the horses' welfare on their daily ridden routines. Even though asymmetry is not always associated with pain (Marunova et al. 2025), it has been established that subjective assessment of equine lameness by owners, and even by veterinarians, can be unreliable and contrast with objectively assessed asymmetry levels (Greve & Dyson, 2014; Müller-Quirin et al., 2020). Additionally, establishing the presence of lameness based solely on straight line, in-hand trot-ups may prove insufficient, and lungeing and ridden work observation can contribute with valuable information for a complete assessment (Dyson, 2014).

Effects of the footing and the rider

Surface properties influence hoof-ground interactions and impact loading. Hard surfaces increase impact forces and vibration, whereas more compliant surfaces reduce these effects, partly by prolonging the braking phase following impact (Parkes & Witte, 2015). In this study, the hardness of the footing's effect on registered asymmetries was non-significant. This agrees with previous studies that assessed the effect of surface type on push-off and impact asymmetries in trotting horses (Azevedo et al., 2015; Marunova et al., 2024).

One of this study's aims was to investigate the relevance of rider's weight on the horses' locomotor asymmetries. Hence, the two male riders were selected based on their biometrics, as both had approximately the same height, but rider 1 had a substantially lower body weight than rider 2. Paradoxically, the only significant effect detected in the study was that of rider 1, who aggravated forelimb impact asymmetry. Rider 2's body weight exceeded rider 1's in 20.6%, falling within the range previously determined to produce no significant effects (Christensen et al., 2020). The rider/horse bodyweight ratios in this study varied between 12.39% (rider 1/horse 1) and 21.43% (rider 2/horse 4), under the maximum acceptable value of 25% from which the rider can induce temporary lameness and behavioural signs of musculoskeletal pain in the horse (Dyson et al., 2019). Roost et al. (2020) reported differences in magnitude and distribution of pressures among riders according to their bodyweight, which may have contributed to the development of musculoskeletal pain, but acknowledged that the differences might also have been influenced by saddle fit and riders' positions. We can speculate that the results in this study can be due to the other factor that distinguishes both riders, i.e., experience. Rider 1 is an elementary level, 20-year-old student with under 5 years of riding experience, while rider 2 is an advanced level riding instructor, with over 40 years of riding experience. Rider 2's experience may have contributed to a better balance and greater ability of the rider to adjust to the horses' motion, hence having a lower effect on gait asymmetry, as can be inferred from the observation of plots in figures 1 to 4. A previous study reported that horses showed significant differences, namely in hindlimb lameness, when ridden, even though the influence of the rider could not be predicted for an individual horse and recommended that the level of training of the rider should be taken into consideration (Licka et al., 2010).

Another factor to consider is the fact that horses were ridden in posting trot. Lameness can be altered by the diagonal on which the rider sits; usually in horses with hindlimb lameness it becomes more apparent when the rider sits on the diagonal of the lame(r) limb. Forelimb lameness may also be affected, but in a less predictable way (Dyson, 2014). During posting trot, maximum croup height becomes asymmetrical, likely because of rider-induced downward forces when rising from the saddle. This can mimic hindlimb push-off lameness and results in increased asymmetry of back movement compared with in-hand trotting (Clayton et al., 2023). Visualizing the videos recorded with SLEIP AI™ allowed noticing that rider 1 sat consistently on the right forelimb/left hind diagonal (probably due to being less experienced), while rider 2 systematically changed diagonals. This may help to explain why with horse 4, rider 1 apparently caused the "disappearance" of right hindlimb asymmetry (as he was consistently exerting downward forces in this limb's diagonal, when rising, hence masking the asymmetry). According to Persson-Sjodin et al. (2018), a push-off hindlimb lameness is expected to increase when the rider sits during the lame hindlimb stance, whereas an impact hindlimb lameness is expected to decrease.

Compensatory lameness must also be considered when interpreting the results, as Reed et al. (2020) reported that 56.6% of horses presented for lameness evaluation showed combined head and pelvis asymmetries, which in most cases were attributed to compensatory asymmetries. For instance, horse 1 presented a forelimb push-off asymmetry, and an accentuated right hindlimb push-off asymmetry when ridden. Contralateral hindlimb push-off asymmetry is the most common compensatory pattern associated with forelimb lameness – the first law of sides (Reed et al., 2020), and the riders' weight probably accentuated this pattern in horse 1. The second law of sides can probably help explaining the pattern shown by horse 3, where the right hindlimb push-off asymmetry coupled with an ipsilateral forelimb impact (compensatory) asymmetry, accentuated by the riders' weight. Horse 2 is the case where the asymmetry pattern is harder to explain, posing the hypothesis of multi-limb lameness, with a possible influence of hindlimbs being unshod in discrepancies between riders and surfaces. Panos et al. (2023) reported a positive effect on lameness scores and hock angles of shoeing the hindlimbs of previously barefoot horses.

The fact that the study lacked thorough lameness diagnostics limits the ability to explain some of the observed patterns. Nevertheless, inter-individual differences between horses accounted for a substantial proportion of the variance, impacting over 36% of the variance of forelimb asymmetries, although only between 3 and 8% of hindlimb asymmetries. The reasons for a higher inter-individual variance in forelimb asymmetry may involve the fact that head movements are more susceptible to external influences and distractions than those of the pelvis, and that head oscillation pattern is more dependent on active muscular contractions at trot (Clayton et al., 2025).

Consistency in sidedness of asymmetry

In this study, there was a moderate overall agreement between observations, regarding left and right sided asymmetries. Push-off asymmetries exhibited a higher consistency than impact asymmetries. Possible explanations may involve the impact of riders' weight in the weight-bearing phase of the stance associated with sitting or rising trotting position, as well as firmness or compliance of the footing and the effect of compensatory lameness. However, it has been reported that horses regularly switch between small left- or right-sided movement symmetries, although they less frequently switch between more severe left- and right-sided movement symmetries (Pfau et al., 2025).

Limitations of this study include the lack of significance of some of the analysed factors which likely reflects the insufficient statistical power resulting from the reduced number of horses involved and precludes a generalization of conclusions without further confirmation. Additionally, the fact that riders were not instructed to ride in sitting trot adds confusion to an already complex interpretation, and lack of definitive lameness diagnostics prevents a more consistent analyses of primary and compensatory lameness. The findings should therefore be interpreted with caution. The software that was used (SLEIP AI v. 2.8.1) has subsequently been updated, and now includes a feature that uses the motion of the head and the withers to differentiate between primary and compensatory asymmetries (for instance, pointing to primary forelimb issue if the withers moves in the same direction as the head, or compensatory if they move in opposite directions). This feature could have helped in the interpretation of the results in this study and should be used in future attempts.

Nevertheless, the study points to the negligible effect of trotting surface in asymmetry, consistent with previous studies, and the more noticeable effect of the rider, also in agreement with previous reports. Interindividual factors affect forelimb asymmetry more than hindlimb asymmetry. Markerless computer vision technology allows for non-invasive, timeefficient data retrieval of locomotor asymmetry in horses, and machine learning algorithms will likely revert in growing accuracy of these systems, making them a valuable resource in veterinary lameness diagnostics, injury rehabilitation and training monitoring.

Ethical statement: this study involved no procedures on animals, according to the definition stated in the Decree of Law nr. 113/2013 of August 7th.

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