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Difference in radiographic findings and gait analysis between horses that are freshly shod and at the end of their shoeing period

Matthew Benn[1], *Stéphane Montavon*[1] *and Anton Fürst*[2]

[1] Veterinary Department of the Swiss Armed Forces, Bern, Switzerland
[2] Equine Department, Vetsuisse-Faculty, University of Zurich, Zurich, Switzerland

Summary: The aim of this study was to determine how a horse's gait changes over an eight-week shoeing period and if these changes could be picked up by a single sensor inertial measurement unit (IMU) fitted with a GPS receiver chip. The device employed in this study was the ALOGO Move ProTM. It was also of interest to measure the radiographic changes throughout this period to determine if these physical changes were tied to the kinematic parameters measured by the sensor. The study was performed using 21 Swiss Warmblood horses belonging to the Swiss Armed Forces and consisted of two rounds of testing. Each round was comprised of balance radiographs of all four feet (dorsopalmar/-plantar and lateromedial projections) and dynamic tests, both in hand and on a 20 m lunging circle. Round one invariably began on the day the horse was shod with the second round following eight weeks later. The measured variables were separated into four categories: dynamic values (stride height, stride length and strike power), balance values (longitudinal and lateral balance), radiographic values (palmar/plantar angle and toe length) and the height at the withers. Palmar/plantar angles decreased over the eight-week period but were only significant in the hind feet (average difference 1.81°). Stride length was significantly greater in round two in all measurements at the trot (average difference 16.48 cm) and canter (average difference 33.56 cm), and stride height was significantly greater in the second round for one of the tests performed at the trot (trot on right rein) (average difference 0.66 cm) and both tests at the canter (average difference 1.00 cm). Bigger horses were found to lean more towards the inside of the circle near the end of their shoeing period. In addition, a horse's height at the withers and its longitudinal balance showed a negative correlation towards the end of the shoeing period. There were also similar correlations between a horse's stride length and its longitudinal balance shifting towards the front, when horses reach the end of a shoeing period, those with longer strides will lean even further forwards than others. It is important to note that although these changes happen gradually over an eight-week period, the inverse changes happen instantly when the horses are trimmed and shod. These results complement previous research showing that horses tend to carry more weight on their forelimbs when traveling at higher speeds, as a horse's velocity and stride length are directly correlated. This study demonstrates that the ALOGO Move ProTM device can accurately measure changes in a horse's gait over the course of an eight-week shoeing interval. This device could be therefore used in further studies and tests, and, with enough data, there might be potential for this sensor to learn and identify evolving patterns within a shoeing period. This could result in the capacity of the device to be able to inform the rider or trainer when the optimal time to have the horse reshod is, based on how the horse's balance evolves over time.

Keywords: horse, gait analysis, shoeing, radiography, foot balance, GPS sensor, IMU, longitudinal balance, lateral balance

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Correspondence: Matthew Benn, Veterinary Department of the Swiss Armed Forces, Worblentalstrasse 36, 3063 Bern, Switzerland; matthewbenn23@yahoo.com

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Introduction

The subjectivity of describing and attributing a grade to lameness is widely discussed amongst veterinary practitioners and usage of the well-defined AAEP Lameness Scale illustrates differing opinions amongst colleagues, particularly for mild cases (*Keegan* et al. 2010). Therefore, devices that allow for objective gait analysis are growing in popularity.

Systems such as AlogoTM, Seaver®, Equisense®, Equestic®, Arioneo iPulse® and Equisym® are aimed towards riders, whereas other devices have been developed specifically aimed at lameness workups by veterinarians, such as the Equinosis Q Lameness Locator®, Equigait® or EquiMoves®. Similar devices have also been developed for humans (Gaitsmart®).

Having a horse shod requires professional attention on a regular basis. The morphological principles behind a shod and a barefoot hoof are also drastically different (*De Klerk* 2021). *Lesniak* et al. suggested horses should be shod at least every six weeks (*Lesniak* et al. 2019), others acknowledge eight weeks to still be acceptable (*Moleman* et al. 2006). *Kummer* et al. determined that over an eight-week period, the dorsal hoof wall length will grow by approximately 1 cm (*Kummer* et al. 2006).

The aim of this study was to provide objective data on the changes in kinematic parameters over the course of an eight-week shoeing interval as the hoof changes in length and form. This was done by gathering data using a single sensor inertial measurement unit (IMU) fitted with a GPS receiver chip (ALOGO Move ProTM) and comparing it to radiographic measurements taken at the same points in time (the beginning and the end of the shoeing interval).

The hypothesis is that this IMU can pick up changes to several kinetic parameters in a horse's gait between two shoeing sessions.

Materials and methods

Device

The ALOGO Move ProTM is a single sensor consisting of an IMU (Inertial measurement unit) fitted with a GPS receiver chip (Figure 1). The proprietary algorithms allow for precise measurements of position and speed in a global reference frame and the device has been validated by the Travel and Mobility Department at the University of Geneva (*Guyard* et al. 2023). The GPS element measures the length of each individual stride, while a goniometer provides information about the horse's lateral or longitudinal balance at lift-off of all strides (*Leach* et al. 1984). The device is in this way able to pick up on gait abnormalities and inform the user of such events.

Animals

The study included 21 Swiss Warmblood horses belonging to the Swiss Armed Forces, 19 (90.5 %) geldings and two (9.5 %) mares. Ages ranged from four to 19 years (average 9.6 years, SD 5.0). The subjects had a body mass of 490 to 700 kg (average 620 kg, SD 50) and the height at the withers ranged from 159 cm – 177 cm (average 171 cm, SD 4.51).

For the duration of the study, the horses were used in dressage, show jumping and eventing. At the beginning of each round of testing they were each evaluated for lameness. Any horse showing lameness grading higher than 1/5 on the AAEP Lameness Scale was excluded from the study (*Gomez Alvarez & Oosterlinck* 2022).

Fig. 1 Example of an ALOGO Move ProTM sensor measuring device. | *Beispiel eines ALOGO Move ProTM Sensormessgerätes.*

Over the course of eight weeks, one horse was excluded due to a suspensory ligament injury from causes unrelated to the study. No other horses presented with any lameness or other issues nor did any need to have a shoe nailed back on.

Experimental Design

Two rounds of testing were conducted. The first round of testing consisted of horses being shod on day one of the study, radiography being performed on day three and dynamic testing on day four. For round two, these tests were repeated exactly eight weeks after shoeing. To accommodate third parties involved in the study, dynamic testing (day 57) was performed before radiography (day 58).

Definitions

Results were grouped into four categories. Radiographic values referred to all results from radiography (palmar/plantar angle and toe length). Dynamic values refer to all results from the sensor where movement was involved. The term stride is used as defined by *Leach*: "the full cycle of motion exhibited by the horse in locomotion, beginning at any point and completed when the legs have returned to the initial position" (*Leach* 1993). Stride length was defined as the distance covered in a horizontal plane during one stride (*Leach* et al. 1984). Stride height was defined as the difference between the highest and lowest point of the sensor within a single stride and strike power as the gravitational force measured by the accelerometer when the sensor abruptly changed vertical direction from downwards to upwards. Balance values refer to all results describing the horse's positioning in space – longitudinal balance as the sensor's tilt in the X-Y plane (*Leach* et al. 1984) and lateral balance as the sensor's tilt in the Y-Z plane (*Leach* et al. 1984). The fourth category refers to data belonging to the horse's height at the withers.

Radiography

Positional radiographs of each hoof were taken (lateromedial and dorsopalmar/-plantar views) (Figures 3 and 4). For this, the horses were sedated with detomidine (Domosedan 10 mg/ml; Vetoquinol) (range 0.006 mg/kg – 0.019 mg/kg, ø 0.009 mg/kg, SD 0.017). The horses were positioned sym-

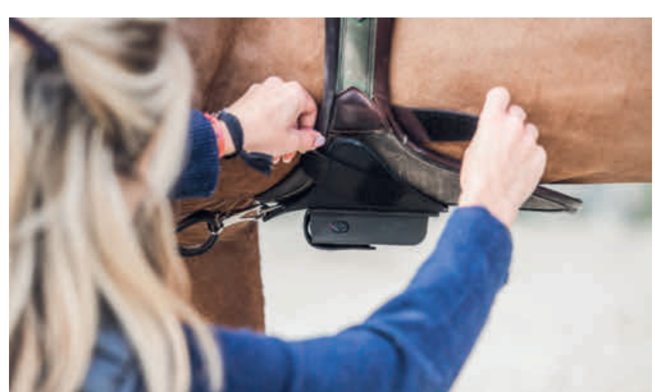

Fig. 2 The ALOGO Move Pro was attached to a jumping girth. *Befestigung des ALOGO Move Pro Geräts an einem Springgurt.*

metrically on two 8 cm thick wooden blocks and the generator was laid on two 1 cm thick planks of wood on an even surface, with a film-focal distance of 70 cm. This allowed for the central beam of the generator to be positioned 1 cm above the solar border of the hoof (*Staples* et al. 2021). For the lateromedial views, a deformable steel wire was attached to the coronary band of the hoof (Figure 3) to allow for measurements directly on the radiographic image (Figure 5). Analysis was performed using RadiAntTM software (RadiAntTM DICOM viewer, Medixant, Poznan, Poland).

The radiographs were analysed for the toe length of each hoof (T), and palmar/plantar angle (A).

Dynamic tests

The gait analysis system was attached to a jumping girth 135 cm in length (Figure 2) and the horse was saddled with a general-purpose saddle with the stirrups removed. For the hard surface tests at walk, horses were led in hand in a single, straight line of motion (*Leach* et al. 1984), on a left rein 10 m circle and then a right rein 10 m circle. They were trotted in hand in a single, straight line of motion on a hard surface and then lunged on soft ground first on a left rein 20 m circle at a trot and then at a canter before repeating on the right rein. The GPS fitted IMU returned values for stride height and length, strike force, as well as longitudinal and lateral balance. As the device is a single reference point in space, it is able to recognise movement patterns to determine what gait is being performed. It measures the amplitude of each movement pattern to determine stride height and strike power, uses GPS to determine stride length and the goniometer to describe longitudinal and lateral balance.

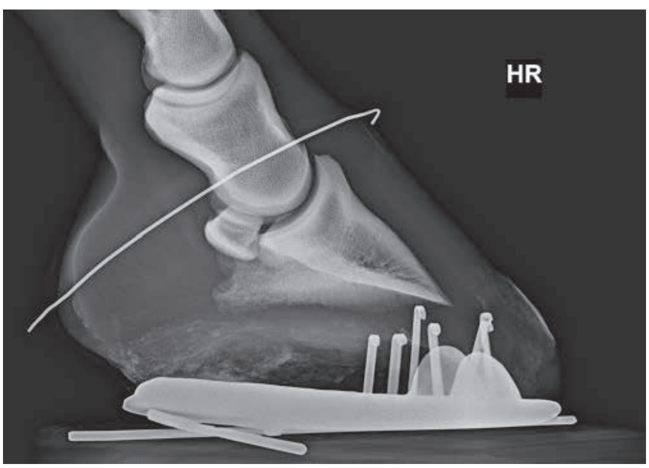

Fig. 3 Lateromedial radiograph of a right hind hoof with a deformable steel wire attached to the coronary border of the hoof. | *Lateromediale Röntgenaufnahme eines rechten Hinterhufs mit einem verformbaren Stahldraht, der am Kronsaum des Hufs befestigt ist.*

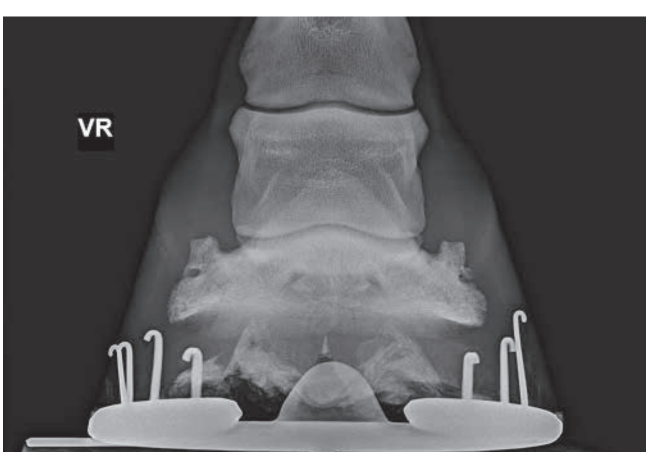

Fig. 4 Dorsopalmar radiograph of a right front hoof. | *Dorsopalmare Röntgenaufnahme eines rechten Vorderhufes.*

Negative values for longitudinal balance represent a horse leaning backwards, positive values the horse leaning forwards.

Statistical analysis

Statistical analysis was performed using RStudio (Posit®, PBC). First, the data was analysed for normality using a Shapiro Wilk normality test and, if it was normally distributed (p-value > 0.05), the data was subjected to a paired t-test to determine significance. If data was not normally distributed (p-value < 0.05), the difference between variables from both rounds was analysed for symmetry around the median. If symmetrical, the data was subjected to a paired two sample Wilcoxon test, if not symmetrical, a sign test was used. Significance was determined by a p-value < 0.05 with a 95 % confidence interval. It was not necessary to make corrections for multiple comparisons (*Rothman* 1990). Correlation analysis was performed by calculating a Spearman correlation coefficient for each comparative value. Subsequently, the data was submitted to a Spearman correlation test to assess if the Spearman correlation coefficient was significant.

Results

Lunging data from three horses had to be excluded from round one and one horse from round two due to unreliability: on the days of testing, these horses were unable to be lunged

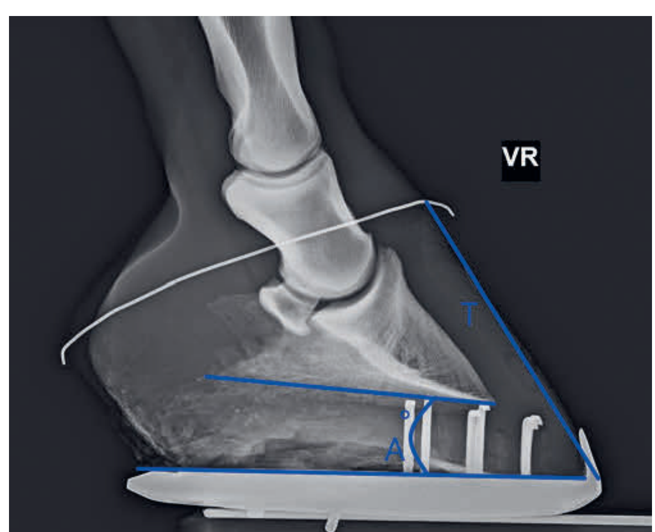

Fig. 5 Palmar angle (A) and toe length (T) on a right front hoof. *Palmarwinkel (A) und Zehenlänge (T) an einem rechten Vorderhuf.*

consistently at a trot or canter for the length of time required. The data acquired from these horses for the tests done in hand was used. Additionally, one horse with a suspensory ligament injury was excluded from round two as its rehabilitation program did not allow for its continued participation.

Data was therefore gathered from 18 horses in round one and 19 horses in round two that had usable data from lunging sessions. 16 horses had usable data from both rounds.

The eight dynamic tests provided 144 independent sets of data for round one and 152 sets of data for round two. In 25/144 tests performed in round one (17.4 %) and 3/152 tests performed in round two (2 %), the GPS malfunctioned and returned unreliable data for stride length. This malfunction was only detected at the time of data analysis. The affected tests could not be repeated, as the timing of these tests was a key factor in the experimental design of the study.

Table 1 Palmar/plantar angles got smaller over the 8-week period but only on the hind feet were these changes significant. | *Die Palmar- bzw. Plantarwinkel wurden über den Zeitraum von 8 Wochen kleiner, aber nur an den Hintergliedmassen waren diese Veränderungen signifikant.*

	Test	P-value	Mean of the differences
Front right	Paired t-test	<0.132	0.59°
Front left	Paired t-test	<0.093	0.74°
Hind right	Paired t-test	<0.00028	1.67°
Hind left	Paired t-test	<0.000078	2.06°

Table 2 Length of stride was significantly greater in round 2 in all measurements done at trot or canter. | *Die Schrittlänge war in Runde 2 bei allen Messungen, die im Trab oder Galopp durchgeführt wurden, signifikant größer.*

	Test	P-value	Mean of the differences
Trot in straight line	Paired t-test	<0.035	6.38cm
Trot on left rein	Paired t-test	<0.000023	22.00cm
Trot on right rein	Paired t-test	<0.000023	22.25cm
Canter on left rein	Paired t-test	<0.000016	37.33cm
Canter on right rein	Paired t-test	<0.00012	38.67cm

Table 3 Height of stride was also significantly greater at canter in round 2. | *Auch die Schritthöhe war im Galopp in Runde 2 signifikant größer.*

	Test	P-value	Mean of the differences
Trot in straight line	Paired 2 sample Wilcoxon test	<0.539	0.15cm
Trot on left rein	Paired 2 sample Wilcoxon test	<0.608	0.13cm
Trot on right rein	Sign test	<0.0064	0.56cm
Canter on left rein	Paired t-test	<0.00076	1.00cm
Canter on right rein	Paired 2 sample Wilcoxon test	<0.0034	1.06cm

Radiographic values

Palmar/plantar angles were reduced over the eight-week period (Δ front feet 0.41°, Δ hind feet 1.81°) but these changes were only significant in the hind feet were (Table 1). Measured toe length reflected the expected increase in all four hooves.

Dynamic values

The only significant difference observed at the walk was the stride length on the right rein where the mean difference in stride length between rounds one and two was 6.06 cm. The increase in stride length at the walk on the left rein was 4.53 cm but according to a paired t-test, but this was not significant. Stride length was significantly greater in round two for all measurements done at a trot or canter (Table 2). Stride height was also significantly greater in round two in both tests performed at the canter and one test performed at the trot (Table 3).

Balance values

Longitudinal balance values showed a significant shift in balance towards the forelimbs in five of the eight tests conducted (mean difference 1.61°) (Table 4).

Analytical results

Stride dynamics vs equilibrium

At round one, correlation between stride height and inclination to the inside of the lunging circle was absent at a trot (correlation coefficient mean -0.061) and not significant but negative at a canter (mean -0.475). The negative correlation at a canter was significant on the left rein (p-value 0.017) but not on the right. This negative correlation coefficient at the canter means that, just after being shod, horses with a low stride will lean towards the inside of a lunging circle more than horses with a higher stride. The correlation developed in the same direction in all tests: at round two, values at the trot showed significant positive correlation (mean 0.547, trot left rein p-value < 0.05, trot right rein p-value < 0.005), and at the canter, correlation became mildly positive (mean 0.134) but was not significant.

On the lunge, correlation between stride length and longitudinal balance shows a development towards becoming positive in round two (Average correlation coefficient at round one-0.019, average correlation coefficient at round two 0.322), meaning, as the horse advances further into the shoeing period and its strides lengthen (Table 2), it carries more weight on the forelimbs. However, according to the data, this correlation was not significant.

Height at the withers vs equilibrium

Correlation between height at the withers and inclination to the inside of the lunging circle was initially absent immediately after shoeing (range -0.198–0.131, mean 0.048). The correlation coefficients changed to become positive eight weeks later (range 0.223–0.388, mean 0.296). Neither correlation, at round one nor at round two, carried significance.

Correlation between height at the withers and longitudinal balance is initially absent (range -0.197–0.167, mean -0.006) but eight weeks later was calculated to be moderately negative (range -0.461 – -0.117, mean -0.276). The only correlation that was significant was the negative correlation at the trot in a straight line (p-value 0.041). The other 15 tests were not.

Hoof conformation vs longitudinal balance

Correlation between the palmar/plantar angle and longitudinal balance is positive (range -0.034–0.483, mean 0.286) in round one. This correlation is significant only at a canter on the left rein (p-value 0.042). The other tests showed no significance. The positive correlation decreases (range -0.083–0.417, mean 0.179) eight weeks after shoeing, although was not significant.

Correlation between toe length and longitudinal balance is negative (range -0.440 – -0.241, mean -0.326) in the first round and tended to become less relevant (range -0.344 – -0.103, mean -0.232) in round two although still present. These findings were not significant.

Discussion

This study was performed to illustrate the difference in a horse's gait immediately after shoeing and at the end of a standardised shoeing period. Based on the results, the most notable differences were observed in stride length, longitudinal balance and the palmar/plantar angle. Although these changes appear gradual when occurring over a period of eight weeks, the inverse changes occur instantly when the horse is trimmed and shod.

As shown in Table 2, stride length increased as the shoeing period progressed. Another relevant finding regarding stride length is that, relatively speaking, the change measured over the shoeing period is most prominent at a trot. At a canter the change is 13–15%, whereas at a trot the stride lengthens by 20–22%.

The absence of any difference in the horse's strike force between the first and second rounds shows that, despite the gait changing in multiple aspects, the way an individual horse hits the ground tends not to change. Results show that all horses tend to lean further forward towards the end of their shoeing period. The shift to a negative correlation between longitudinal balance and height at the withers would imply that bigger horses are less affected by this. Degrees of correlation between longitudinal balance and various other parameters such as the palmar/plantar angle and toe length were also present. The positive correlation with the palmar/plantar angle in round one suggests that horses with more positive palmar/plantar angles tend to shift more weight to the front. The fact that this correlation is less present in round two is expected given the previously found results that palmar/plantar angles tend to flatten out (Table 1) and that horses generally lean further forward in round two (Table 4). This would suggest that although there is an initial correlation between the two parameters, there is no causal relationship. The same reasoning can be applied to the negative correlation between longitudinal balance and toe length, which is predominantly present in round one and loses importance at round two.

Weishaupt et al. previously described that when horses increase their speed, they naturally carry more weight on their forelimbs (*Weishaupt* et al. 2010). The results of this study complement the findings of *Weishaupt* et al. by suggesting that horses with a longer stride tend to redistribute more weight onto their forelimbs than horses with short strides when nearing the end of a shoeing period. Stride length was shown to have no influence on longitudinal balance at the start of a shoeing period. Equally, there is no initial correlation between a horse's height at the withers and longitudinal balance; but after eight weeks, smaller horses show more inclination to the front than bigger horses. Correlation between stride length and height at the withers was mainly positive but too inconsistent to draw significant conclusions, leading the authors to conclude that stride length remains specific to the individual horse and is not necessarily primarily the result of size.

The multifactorial change in longitudinal balance over eight weeks is expected given that horses are trimmed and reshod in regular intervals. It was found that smaller horses have more issues adapting to longer hooves from a longitudinal point of view, as they carry progressively more weight on their front limbs compared to bigger horses. On the other hand, bigger horses struggle to maintain equilibrium on the circle and will lean into the curve more towards the end of their shoeing period in order to compensate for their lack of lateral balance. The changes in lateral balance over the course of the shoeing period are correlated to variables such as stride height or more importantly, height at the withers. These observations indicate that the variable "height at the withers" plays a central role in the results of this study. To fully understand

Table 4 Longitudinal balance values showed a significant shift towards the front in 5 of our 8 tests conducted. | *Die Längsbalancewerte zeigten bei 5 unserer 8 durchgeführten Tests eine deutliche Verschiebung nach vorne.*

	Test	P-value	Mean of the differences
Walk in straight line	Paired t-test	<0.00029	1.102°
Walk on right rein	Paired t-test	<0.0269	0.678°
Trot on right rein	Paired t-test	<0.000016	2.164°
Canter on left rein	Paired t-test	<0.0026	1.642°
Canter on right rein	Paired 2 sample Wilcoxon	<0.00039	2.450°
Trot on left rein	Paired t-test	<0.057	0.888°

the implications of this, it would be necessary to know which balance axis carries more importance to the horse's equilibrium, a question that this study is unable to answer. If it was shown that, hypothetically, a horse's lateromedial balance is more important than its longitudinal balance, it could be concluded that bigger horses would benefit more from a shorter shoeing interval than smaller ones.

As all study participants were provided by the Swiss Armed Forces, the horses used were all shod by the same farrier and were all used in the same manner by the same people for the entire duration of the study. Despite this, the sample population in this study was composed of a wide range of ages and sizes, providing a desired degree of randomisation. As mentioned previously, some difficulties with the GPS tracking system were encountered. This meant that values for stride length were not usable in 27/296 tests and therefore reduced the sample size for this value by 9.1%. However, given that changes in stride length over the eight-week period were significant (Table 3), the authors do not believe that this reduction in sample size influenced the data and would have expected similar results if this malfunction had not occurred.

To better illustrate the data, the same tests could have been performed at a mid-way point through the study, which could have provided an idea as to whether the changes happen in a linear, exponential, or logarithmical fashion. Another way to test this would have been to randomly separate the population to be retested and subsequently reshod at six, eight and 10 weeks respectively. However, this would have significantly reduced the sample size of comparable data.

Unfortunately, the sensor was not able to measure the speed of the horses. When a horse's velocity increases, the stride length generally increases as well (*Ratzlaff* et al. 1995). It therefore cannot be ruled out that the observed increase in stride length between rounds one and two could have at least partially been due to an increase in speed. The authors acknowledge this weakness in the study.

A disparity in consistency was observed between lunging to the left and to the right across all subjects. The absolute values obtained for lateral balance when lunging on the right rein were greater by an average of 2° in round one and by 5° in round two, both at the trot and at the canter, than when lunging on the left rein. *Keegan* suggests this can be caused by an individual variation for each horse and could therefore be considered coincidental (*Keegan* 2022) (unpublished). Another explanation could be imprecise positioning of the device. However, this observation was highly consistent, and the authors suggest that this consistency makes the above explanations very unlikely, instead hypothesising that the device itself was the cause of the disparity due to mild inaccuracy.

This study has also raised further questions, notably how to best determine when an individual horse should be reshod? Which of the measured values play an important role in a horse's comfort and/or performance and should have a greater influence on the length of the shoeing interval? To better answer these questions, competition horses would need to be studied over multiple shoeing periods, varying in length, in order to calculate whether there is a correlation between shoeing interval, analysed values and competition results. Another important factor would be rider feedback on the horse's performance at a given point in time. Standardising such a study would prove difficult, as bias unrelated to the nature of the tests, such as injury, poor performance, rider changes, and weather conditions would play an important role.

Conclusion

The ALOGO Move ProTM can track gait changes throughout the course of a shoeing period and could be used as a tool to aid in determining when an individual horse needs reshoeing.

Conflict of interest statement

The authors have no conflict of interest to declare.

Animal welfare statement

This study was conducted during the regular shoeing period of the Swiss Armed Forces horses. It fully complies with the Swiss legislation concerning the codes of ethical behaviour and animal protection.

Statement of informed consent

All horses belonged to the Swiss Armed Forces. The Swiss Armed Forces consented to inclusion of all gathered data in a scientific publication.

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