Three-dimensional kinematic analysis of head and limb movements of lame and non-lame colts

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Abstract
Lameness manifests itself during the movement of the animal or at rest, indicating a structural or functional disturbance in one or more limbs. Videographic analyses allow the qualitative and quantitative investigation of the movement, reducing the subjectivity of evaluations. The objective was to record the alterations in the movement of the head and limbs of horses in a lame and non-lame condition. Video cameras (60 Hz) and computational methods were used. Six Purebred Arabian colts were filmed on a treadmill, at walk and at trot, before and after induction of lameness. Lameness was induced in the left forelimb utilizing a transient lameness model. Markers were placed on the zygomatic process of the temporal bone, spiny process of the sixth thoracic and first lumbar vertebrae and on the proximal phalange. Nine strides were analysed. At walk and at trot, the animals demonstrated two vertical head movements per stride, while after induction of lameness only one head movement was observed per stride, where this movement was of greater amplitude. The head was shown to be in a more elevated position when the lame limb made first contact with the treadmill belt, which was not observed in the case of the healthy limbs. Only with trotting did the lame animals manifest a prolonged duration of the stance phase for all limbs. The lame animals had a longer support time, lifted the non-lame limbs and showed a shorter stride. Videographic analyses offered details of the alterations in the movement of horses, which are important in the diagnosis of lameness.

Keywords: biomechanics; cinematography; lameness; treadmill; horses

Introduction
Morphologic studies and the determination of locomotor characteristics of horses are procedures utilized as indications of functionality, athletic condition and economic value of the animal. It is common to evaluate a horse adopting subjective scores in registration procedures, sale, analysis of performance or examinations of locomotor disorders. Cinematographic techniques offer a detailed and precise analysis of the movement of the body or parts of the body that are difficult to detail upon visual examination and in real time1. Three-dimensional kinematic analyses make it possible to get an objective comprehension of the movement based on diagrams and graphs2. Related to this technology, motion studies in horses have been advanced by the utilization of high-speed treadmills which, besides offering control of velocity and environmental conditions, guarantee greater uniformity and standardization of the motion3.

The horses that are normally involved in sport activities are accustomed to locomotor problems, and thus they have been the target of cinematographic studies. One of the objectives of clinical biomechanics is to help diagnostics4. Multiple analyses of kinematic characteristics and kinetics of movement offer specific signs that help in the elaboration of an objective and early
diagnosis of lameness, thereby optimizing therapeutic intervention before a pathologic condition worsens.

Lameness is one of the most common and complex locomotor disorders which compromises the athletic horse. It can be seen in motion and at rest, depending on the degree of lameness, which makes this a symptom indicative of a structural or functional disturbance in one or more limbs. The anatomic conformation, the type and intensity of the physical activity to which the animal is submitted, the conditions of the floor, trimming and/or shoeing and the presence of lesions are causal factors routinely involved in the diagnosis of the lame animal. The identification of the origin of lameness in horses is a difficult and laborious task, but indispensable for therapeutic success. Even specialists agree on the complexity of diagnosing lameness. During the traditional clinical examination, the veterinarian evaluates the horse’s pattern of locomotion, analysing the severity of the lameness for the purpose of identifying the lame limb and classifying the degree of lameness.

Movements of the head, trunk and limbs are taken into consideration during the analysis of the animal. The horse in the lame condition of the forelimb tries to reduce the force of the reaction of the limb with the ground by producing a greater vertical displacement of this limb induced asymmetry in the movement of the trunk and head. Various works have utilized kinematics data of these anatomic regions to quantify the severity of the lameness and to improve diagnosis. Cinematographic studies of lame horses have been carried out on a treadmill, recording the changes in the characteristics of movement during walking and trotting. The aim of the present study was to utilize three-dimensional kinematic analysis as a tool to investigate the variation in head movement and alterations in the dynamics of the limbs of lame and non-lame colts.

**Materials and methods**

Analysis of the variation in head and limb movement of lame and non-lame horses on a treadmill (Esteira Galloper® Sahinco LTDA, 5500, Palmital, SP, Brazil) was conducted in the Horse Exercise Physiology Laboratory of the Department of Animal Morphology and Physiology, Faculty of Agricultural and Veterinary Sciences, São Paulo State University (UNESP), Jaboticabal, SP. Six colts of the Purebred Arabian breed were used with a mean age of 3 years and a mean weight of 330 kg. The protocol used was adapted for the animals on a treadmill for 3 days. These animals participated in the control and experimental groups.

The digital cameras (JVC, Gr-D70U, Victor Company of Japan, Ltd) were positioned for a left lateral view, oblique to the animal. One had a posterior view and the other had an anterior view, both at 1.8 m from the floor and at a distance of c. 5 m from the treadmill belt. The calibration system of the cameras and three-dimensional reconstruction of the points of interest, represented by markers fixed on the skin of the animals, were based on the direct linear transformation (DLT) method.

The animals were filmed at rest and in motion, at walk and at trot, at a speed of 1.7 and 3.0 m s⁻¹, respectively. Then, a metal sphere of 20 mm diameter was placed in the medial region, next to the apex of frog of the left forelimb (LF) to induce lameness, and the animals were filmed at walk and at trot according to the step described earlier. In this study, we opted for the forelimb to induce lameness due to the fact that the majority of case histories of lameness occur in these limbs, because they support 60-65% of the weight of the horse. The study was approved by the Commission of Ethics and Animal Well-being of FCAV/UNESP (protocol no. 006981).

Markers were fixed on the skin in the region of the temporal bone of the forehead, on the extremity of the spiny process of the sixth thoracic vertebra (T6), on the extremity of the spiny process of the first lumbar vertebra (L1) and on each proximal phalanx of the right and LFs and hindlimbs.

The images were transferred to a Pentium IV computer by means of a capture program (AMCap-capture application sample, v. 8000, Microsoft Corporation). The image analysis program Dvideow was used to cut the images and to identify and trace the markers. The motion images of nine strides were analysed. Utilizing the calibration system, together with the cutting of the images and tracing data, a three-dimensional reconstruction of the points of interest was made. This process allowed the acquisition of an archive of data with the three-dimensional coordinates of each marker traced. These coordinates for each marker were filtered using a fourth-order Butterworth digital filter. The videographic representation was obtained using the mathematical program Matlab® R12 (v. 6.0, 2000).

With the animal at rest, the heights of the withers and of the croup and the dorsolumbar length were measured for the purpose of verifying the homogeneity of the animals, since these measurements are directly related to the parameters utilized in the evaluation of the animal in motion. The height of withers was considered the distance between the contact of the hoof sole of the LF with the treadmill belt and the marker placed on the extremity of the spiny process of the T6. The height of the croup was measured in the same manner, based on the left hindlimb (LH) to the extremity of the spiny process of the L1. The dorsolumbar length was measured as the distance between the markers fixed on T6 and L1.
In the images of the animals in motion, alterations in the head and limb movements were recorded for lame and non-lame conditions, in the two gaits studied. The mean maximum and minimum heights for the head and limbs were obtained for each stride. The mean amplitude of the vertical displacement of head and limbs was determined as the difference of the maximum and minimum values for these variables. The time necessary for the animal to perform the stance phase of the limbs was calculated based on the number of frames in which the limb remained in contact with the treadmill belt, considering a frequency of 60 Hz at which the images were captured (1 s corresponds to 60 frames). To calculate the mean stance time, eight stance phases were determined for each limb.

The amplitude of horizontal displacement was determined for the limb in which lameness was induced (LF), considering its greater anterior and posterior projection, in the two gaits studied. The length of the stride was also calculated, considering two successive stances of LF. In this manner, the space travelled by the limb in the lame and non-lame conditions, while at walk and at trot, was determined based on velocity and time. A comparison of the variables obtained for the lame and non-lame animals for each gait was performed using Student’s \( t \)-test.

Results

Three-dimensional analyses of the measurements (mean ± SD) resulted in 1.40 m ± 0.02 for the height of the withers, 1.38 m ± 0.05 for the height the croup and 0.68 m ± 0.06 for the dorsolumbar length. These values characterized the group of animals used in these experiments, indicating their homogeneity in size.

In Figs 1a and 2a, alterations in the head movement are seen in healthy and lame horses, at walk and at trot, respectively. Both at walk and at trot, the animals demonstrated two vertical head movements per stride, while with the induction of lameness, there was an increase in the amplitude of this movement, with a single manifestation.

The maximum and minimum values and the vertical amplitude of the head movement of the animals, in the lame and non-lame conditions, while at walk and at trot, are shown in Figs 1b and 2b, respectively. In the two gaits studied, there was a significant difference (\( P < 0.05 \)) only for the mean value of the minimum head height of the lame animals compared with the non-lame animals. This finding was reflected in a significant increase in the mean vertical amplitude of the head movement at walk and at trot.

All the animals manifested maximum head height coinciding with the moment of first contact of the lame limb with the ground (Fig. 3). On the contrary, the moment at which the head was in the lowest position coincided with the support phase of the contralateral limb.

Table 1 presents the values for vertical displacement and amplitude of the vertical displacement of the LF, LH, right forelimb and right hindlimb of lame and non-lame animals at walk and at trot. At walk, the only significant difference (\( P < 0.05 \)) was seen in the amplitude of the vertical displacement of the LH and right forelimb of the lame group in relation to the control. Meanwhile, at trot, there was a significant increase (\( P < 0.05 \)) in the amplitude of the vertical displacement of all the limbs in the lame group in relation to the non-lame group, except for the amplitude of the movement of LF, i.e., the limb in which lameness was induced.

The mean values for support time of the limbs are shown in Table 2. It was seen that the animals at trot, in the lame condition, had a significantly increased support time (\( P < 0.05 \)), but this was not observed at walk. The mean horizontal amplitude and mean length of stride of the LF, at walk and at trot, in the lame and non-lame conditions are presented in Table 3. There was a significant reduction
in the mean length of stride at walk and at trot in the animals in the lame condition. However, no significant difference was observed in the mean amplitude of the LF in the two gaits.

To compose the three-dimensional kinematic analysis of the motion of lame horses on a treadmill, important variables for the study locomotion were combined.

It can be concluded that the data obtained allow the qualitative and quantitative evaluation of the movement of the head and limbs of lame horses, facilitating a more precise diagnosis. The animals manifested more evident alterations at trot, demonstrating that this gait is the most indicated for the evaluation of lameness.

**Discussion**

Cinematography is a tool that can contribute greatly to the evaluation of specific training programmes.

**Table 1** Mean amplitude of vertical displacement of the forelimbs and hindlimbs of lame and non-lame horses at walk and at trot

<table>
<thead>
<tr>
<th>Limb</th>
<th>At walk</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-lame</td>
<td>Lame</td>
<td>Non-lame</td>
<td>Lame</td>
</tr>
<tr>
<td>LF</td>
<td>8.0 ± 0.004</td>
<td>8.3 ± 0.006</td>
<td>8.0 ± 0.001</td>
<td>9.0 ± 0.01</td>
</tr>
<tr>
<td>LH</td>
<td>9.0 ± 0.007</td>
<td>13.0 ± 0.01*</td>
<td>9.0 ± 0.006</td>
<td>13.0 ± 0.01*</td>
</tr>
<tr>
<td>Right forelimb</td>
<td>10.0 ± 0.005</td>
<td>12.0 ± 0.01*</td>
<td>11.0 ± 0.004</td>
<td>15.0 ± 0.009*</td>
</tr>
<tr>
<td>Right hindlimb</td>
<td>9.0 ± 0.004</td>
<td>11.0 ± 0.009</td>
<td>10.0 ± 0.004</td>
<td>13.0 ± 0.008*</td>
</tr>
</tbody>
</table>

*Significant difference for lame animals, *P < 0.01.
The diagnosis of locomotor afflictions and determination of the outcome of a clinical treatment. This technique allows the extraction of data from various segments of the body at the same time, allowing the study of the movement in real time and permitting a detailed assessment of short-duration events. In this study, the method utilized for the induction of lameness in the different gaits had the advantage of being transitory and not invasive and not resulting in sequelae in the animals.

It is very common during the clinical examination of a lame animal to take into consideration the moment at which the head is in the highest position to identify the lame limb, regardless of whether lameness is in a forelimb or hind limb. Concordantly, the video-graphic analyses obtained in this study also demonstrated that the highest positioning of head was coincident with the moment the lame limb first contacts the ground.

Regardless of lameness being in the forelimb or hind limb, the examiner should pay attention to head movements, alterations in the height of the suspension arch of the limbs, flexion angles of articulations and the symmetry of gluteals. In the two gaits studied, there was an increased amplitude in the vertical displacement of the head in lame animals. However, this increase in amplitude was not due to an increase in mean maximum height in lame animals, but rather to a decrease in mean minimum height of the head in these animals. When an animal is being examined, this more accentuated manifestation in the lowering of the head is difficult to verify with the naked eye. It is possible that the variation seen in the head movement of lame animals is a way of mitigating the weight to which the affected limb is subjected and at the same time helps to maintain the equilibrium of the animal during its displacement.

Regarding the members, studies indicate that lameness of a forelimb, both lame and non-lame, show a prolonged stance time. There are reports of a shortening of the suspension phase and prolonging of the support phase in lame horses limbs. On the other hand, there are studies demonstrating a decrease in the duration of support in the lame limb.

Although lameness is often evaluated with the animal at trot, our study showed that the alterations observed at walk are similar to those found at trot in the majority of variables studied. A greater vertical displacement can be observed in the painful limb as a response to the reduced force of the ground reaction, although this condition was not observed in this study, in which, especially at trot, the increase in amplitude of vertical displacement was evident for all the limbs except the lame one.

In a lame animal, the time that the hoof contacts the ground can be altered in relation to the normal condition. This fact is influenced by a painful process where the pain in a limb can cause unequal distribution of the weight among the limbs, which alters the support time of healthy limbs. In the present study, the lame animals increased the support time, raised the non-lame limbs and showed a shorter stride.

To compose the three-dimensional kinematic analysis of the motion of lame horses on a treadmill, important variables for the study of locomotion were combined. It can be concluded that the data obtained allow the qualitative and quantitative evaluation of the movement of the head and limbs of lame horses.

### Table 2

<table>
<thead>
<tr>
<th>Limb</th>
<th>At walk</th>
<th>At trot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-lame</td>
<td>Lame</td>
</tr>
<tr>
<td>LF</td>
<td>0.61 ± 0.03</td>
<td>0.60 ± 0.03</td>
</tr>
<tr>
<td>LH</td>
<td>0.62 ± 0.04</td>
<td>0.59 ± 0.02</td>
</tr>
<tr>
<td>Right forelimb</td>
<td>0.61 ± 0.04</td>
<td>0.59 ± 0.03</td>
</tr>
<tr>
<td>Right hindlimb</td>
<td>0.61 ± 0.04</td>
<td>0.58 ± 0.04</td>
</tr>
</tbody>
</table>

*Significant difference for lame animals, P < 0.01.

### Table 3

<table>
<thead>
<tr>
<th>Variables</th>
<th>At walk</th>
<th>At trot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-lame</td>
<td>Lame</td>
</tr>
<tr>
<td>Mean horizontal amplitude (m)</td>
<td>1.04 ± 0.04</td>
<td>0.95 ± 0.07</td>
</tr>
<tr>
<td>Mean length of stride (m)</td>
<td>1.77 ± 0.4</td>
<td>1.81 ± 1.0*</td>
</tr>
</tbody>
</table>

*Significant difference for lame animals, P < 0.01.
The animals manifested more evident alterations at trot, demonstrating that this gait is the most indicated for the evaluation of lameness.

Three-dimensional kinematic analyses of body segments have broadened our understanding of normal patterns of movement. The precision obtained in three-dimensional measurements, guaranteed by a rigorously calibrated system, allows the investigator to obtain highly reliable data. However, techniques in kinematic studies combined with computational models and the use of a treadmill for studying gait in horses are still restricted to universities and research laboratories.

Of course, this technique is not a substitute for traditional methods of diagnosing lameness, because information on the same animal before displaying lameness would not be available. However, this technique can be of value in following recovery and determining the effectiveness of the treatment instituted.

Another possible contribution of this technique would be in determining the localization of the lesion responsible for lameness. In such case, studies would be necessary using animals that are ‘naturally’ lame due to afflictions of different regions of the limbs or of some other part of the body, so that gait could be examined to see if it shows different characteristic behaviour patterns.

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References