DIFFERENCES BETWEEN FORE- AND HIND LIMB LAMENESS COMPENSATION IN HORSES USING A CENTRE OF MASS MOVEMENT ANALYSIS

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Introduction:
The body centre of mass (BCM) might be a key factor in the analysis of equine gait, as its position and movement determines the distribution and magnitude of loads on the limbs. Changes in the BCM movement are proposed to be important factors in the lameness management of horses (Krüger, 1941; Leach, 1991). Especially a significant forward-backward movement during the stride might reduce the load on the lame limbs and increase the load on the contralateral sound limbs. On the other hand, Kastner (1989) discussed the significance of the asymmetric head movements for lameness management and described two different biomechanic aspects: a static quota due to a cranial to caudal shift of the BCM, and a dynamic quota due to a reduced vertical momentum of the head. Vorstenbosch et al. (1997) tested these two aspects of lameness compensation using kinematic data of lame horses as input for a model calculation of limb loading. They found only small effects of the different head and neck positions using the static analysis compared to considerable changes in limb loading when using the movements of head and neck in the dynamic analysis.

In this study the real changes in the position and the three-dimensional movement of the BCM in horses with fore and hind limb lameness were compared using a kinematic, segmental method.

Material and methods:

Horses

Twelve horses (age: 4-22 years, body weight: 450-670 kg), were used for the study. All horses belonged to the University of Veterinary Medicine Vienna and were clinically examined to be free of lameness. All horses were well trained to treadmill locomotion (Buchner et al. 1994) and accustomed to the recording environment. The experimental procedure was approved by the Austrian Ministry for Science and Research according to the national animal experiments law.

Segment model:

For the assessment of the BCM a 20 segment model was chosen. In accordance to the inertial segmental data of Buchner et al. (1997) the following segments were defined: head, neck, trunk, tail, digit, metacarpus, antebrachium and shoulder for each forelimb, and digit, metatarsus, crus and thigh for each hind limb. Relative segmental masses and position vectors for all segmental centres of mass were taken from Buchner et al. (1997).

Lameness model:

A transient lameness model, evoking pressure induced pain on the hoof sole (Merkens and Schamhardt 1988), was used to induce two degrees of lameness in two experiments: a forelimb lameness and a hind limb lameness, on two different days.

Kinematic recording:

Spherical passive markers with 4 cm diameter were attached to the skin of the horses at the reference points according to Buchner et al. (1997). Additionally, 5 back markers were used at the level of the dorsal spinal processes of the vertebrae Th5, Th10, Th16, L3 and the cranial edge of the sacral bone, to analyse the BCM position relative to trunk movement. After a warming up of at least two minutes, the locomotion pattern of the horses was recorded while trotting with constant speed (3.9 m s⁻¹) on a treadmill (Mustang 2200, Kagra AG, Fahrwangen, Switzerland). Three recordings were made: before lameness induction (control) and after lameness induction in one fore/hind limb with lameness degree 2 and 1. Kinematic data were collected using the ExpertVision® analysis high speed video system (Motion...
Analysis Corporation, Santa Rosa, California, USA) at a frame rate of 120 Hz during 10 seconds. Six cameras in total with a resolution of 240 x 833 points covering a field of view of 3 x 4 m were used on both sides of the treadmill. Following calibration of the cameras the markers were tracked automatically under manual control. The raw data were smoothed using a low-pass Butterworth filter with a cut-off frequency of 20 Hz for the limbs and 5 Hz for trunk and head markers.

**BCM calculation:**
The calculation of the BCM was a two step procedure. At first, for each frame and each segment, the 3D position of the segmental centres of mass within the global co-ordinate system were calculated from the reference marker positions and the inertial segmental data from Buchner et al. (1997). Using only two markers for each segment, no rotatorial movement along the longitudinal axis could be assessed, but this movement is assumed to be very small and negligible. In the second step, a weighted sum of all segmental centres of mass was calculated to give the x, y and z co-ordinates of the total body centre of mass for each frame.

The position within the trunk, the movements of the BCM in all three planes as well as selected variables were analysed and statistically compared: Cranial to caudal movement (x): the difference between the x-position during midstance of the lame forelimb and midstance of the sound forelimb (“stancesdifference”). Transversal movement (y): difference between mean position of BCM and the position of Th16 (“y rel. Th16”) and the difference between the mean position of the BCM and the mean position of both fore/hind hooves (“y rel. hooves”). “Y rel” values are positive for positions nearer to the sound limb. Vertical movement (z): the displacement amplitudes (“displacement”) of the BCM during the lame and sound stance phase.

**Statistical analysis**
All variables were tested for the influence of lameness using an ANOVA test for repeated measurements and a following paired t test to compare the different lameness degrees. A significance level of p<0.05 was chosen. Data are presented as mean values and standard deviations of all horses.

**Results and Discussion:**
Displacement of the BCM in all three dimensions was generally smaller than trunk displacement and changes due to hind limb lameness smaller than these due to forelimb lameness. The displacement pattern of the BCM shows in each movement plane a typical shape. In the xz plane as seen from the right side (Fig. 1) the BCM of the sound horse follows a nearly symmetrical double loop, with its lowest point at midstance and its maximum during suspension. With increasing lameness the loop during the stance phase of the lame forelimb deforms to be less high and pointed slightly more caudally. The vertical displacement reduced during the stance phase of the lame limb with 34% in forelimb lameness while hind limb lameness caused a reduction of only 15% (Tab. 1). In the sound limb a compensatory increase of 9% in forelimb lameness and 7% in hind limb lameness was found. The position of the BCM in the sagittal, fore-after direction did show a slight shift of 9mm backwards during forelimb lameness, while during hind limb lameness a remarkable stability without any change was found. This shift, assuming a distance of 1.20 m between supporting fore and hind limb, would change the loading of the

**Fig 1:** Displacement of the body centre of mass (BCM) of a horse when sound (———) and with moderate forelimb lameness (--------) in the xz-plane. The arrow indicates the start at the suspension phase before landing of the lame forelimb and direction of the movement during the stride.
lame forelimb only by 0.75%. This change is interpreted as negligible compared to an unloading of the lame limb of 10% as measured by Morris and Seeherman (1987), or 28% as measured by Clayton et al. (2000). These results disprove the interpretations of Krüger (1941) and Leach (1991) and support the results of Vorstenbosch et al. (1997), which describe the static component of the cranial to caudal shift of the BCM due to head movements to be of minor significance for the lameness compensation. Transversal movements changed in the forelimb lameness to a mean position 17 mm nearer to the sound forelimb, while hind limb lameness did not affect transversal mean position.

The results show a similar pattern of BCM movement and trunk movement with only minor adaptations of BCM position due to forelimb lameness and even smaller due to hind limb lameness. The influence of the static position of the BCM has therefore to be seen as a minor factor in lameness management compared to dynamic influences such as the changed vertical acceleration of head and trunk in lame horses.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Stance phase</th>
<th>Lameness degree</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td><strong>BCM</strong></td>
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<tr>
<td>X</td>
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<td>-0.001&lt;sup&gt;a&lt;/sup&gt; (0.006)</td>
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<tr>
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<td>-0.007 (0.013)</td>
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<tr>
<td>Z</td>
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<td>0.046&lt;sup&gt;b&lt;/sup&gt; (0.007)</td>
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<td><strong>Hind limb lameness</strong></td>
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<tr>
<td>X</td>
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<td>-0.000 (0.004)</td>
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<tr>
<td>Y</td>
<td>-0.001 (0.013)</td>
<td>0.005 (0.013)</td>
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<tr>
<td>Z</td>
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<td>0.048&lt;sup&gt;b&lt;/sup&gt; (0.011)</td>
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**Table 1.:** Kinematic variables of BCM and head/neck segment in 12 horses evaluated when sound and with two degrees of induced fore or hind limb lameness at the trot (3.9 m/s). X Stancedifference: difference between x-position during midstance of the lame and the sound forelimb. Y Rel. Th 16: mean position relative to trunk position at Th16. Y Rel. hooves: mean position relative to middle position of both fore hooves. Different superscripts indicate significantly different values (p<0.05). l: value during the stance phase of the lame forelimb. s: value during the stance phase of the sound forelimb.

**References:**

Krüger W. Tierärztl. Rundschau 47, 147-151, 162-166, 1941.