

The effect of weighted boots on the movement of the back in the asymptomatic riding horse

Josefine Wennerstrand^{1,*}, Christopher Johnston^{1,2},
Marie Rhodin^{1,3}, Karin Roethlisberger-Holm⁴ and
Stig Drevemo¹

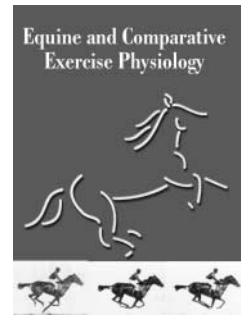
¹Department of Anatomy and Physiology, Swedish University of Agricultural Sciences, PO Box 7011, S-750 07 Uppsala, Sweden

²Equine Hospital Strömsholm, Kolbäck, Sweden

³Department of Equine Studies, Swedish University of Agricultural Sciences, Uppsala, Sweden

⁴Department of Large Animal Clinical Sciences, Swedish University of Agricultural Sciences, Uppsala, Sweden

*Corresponding author: josefine.wennerstrand@afys.slu.se



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Abstract

Back dysfunction is an important reason for impaired performance in sport horses. Limb movements influence the movements of the back and factors affecting the limbs may therefore affect the movement of the back. The aim of the study was to investigate the influence of weighted boots on the fore- and hind limbs on the movement of the back. The back kinematics of eight horses was studied at the walk and trot on a treadmill. The ranges of movement (ROM) of the back were compared intra-individually, using Wilcoxon matched pairs test, when the horses moved with and without weighted boots on the fore- and hind limbs, respectively. Differences were considered significant at $P < 0.05$. Weighted boots on the hind limbs increased the ROM for dorsoventral flexion and extension in the lumbar back at the walk and decreased the ROM for lateral bending at the thoracolumbar junction at the trot. Weighted boots on the forelimbs decreased the ROM for lateral bending at the withers at the trot. Knowledge of the effect of weighted boots on the back movement is useful in training and rehabilitation of sport horses. Weighted boots on the hind limbs at the walk may induce strengthening of the flexors of the lumbar back and increase the flexion–extension of the lumbar back under controlled conditions.

Keywords: equine; horse; back; kinematics; locomotion; limb movements; weighted boots

Introduction

Poor performance is not uncommonly related to back dysfunction¹. In order to mitigate a back-related problem and to reduce the risk of re-injury, it is important to understand how a normal, asymptomatic horse moves and how its movements can be affected.

At all gaits and in all movements, different parts of the body are synchronized^{2–4}, and one body segment may induce or inhibit the movement of another. The position of the neck and limbs influences the movement of the back⁵ and the protraction and retraction of the hind limb correlate directly with the flexion and extension of the lumbosacral joint^{6,7}.

Weights attached to the hooves affect the movement characteristics of the limbs. Willemen *et al.*⁸ found that the stride duration and the stride length were increased and the relative stance duration decreased after a horse was shod. Greater inertia of the distal limb improved the quality of the gait. Lanovaz *et al.*⁹ reported that changes in the segment mass of the forelimb segments affected the peak net joint moments and powers across the joints of the limb. A changed three-dimensional movement pattern of the limb may possibly result in altered movements of the back.

Recently, a Dutch group showed that a weighted saddle changed the movement of the lumbar spine¹⁰,

but at present there are no studies published that describe to what extent it is possible to change the movements of the vertebral column by adding weights to the limbs. The aim of the present study was to explore what effect weighting of the limbs might have on the movement of the back. To achieve this goal, back kinematics was evaluated before and after weighted boots were attached to the limbs.

The amplitude of the back movement is greater at the walk than at the trot^{2,4,11}. At the trot, the stabilizing muscle activity of the back is high, while the movement at the walk is more passive¹², and therefore probably more responsive to external influences. Based on these facts, our hypotheses were that the ranges of motion (ROM) of the back would increase at the walk and decrease at the trot when weighted boots were put on either the fore or the hind limbs.

Materials and methods

Horses

Warmblood riding horses that had previously been used in another study¹¹ participated in the present one. They were in regular training for dressage up to Intermediaire I or show jumping at levels up to 1.30 m, and were considered sound and fully functioning by their owners.

The horses underwent an examination in accordance with standardized routines at the University clinic. Body weights varied from 530 to 640 kg and height at the withers varied between 158 and 176 cm. No abnormalities of clinical importance were found in the extremities or the back in the conformation or on palpation. The horses were examined in hand at the walk and trot on a hard surface. They were also lunged at the walk and trot on both reins and a flexion test of the entire leg was performed on all four limbs. If lameness was detected in any of the above examinations or a response of more than 1 degree of lameness (on a scale of 0–5) on a flexion test was found, the horse was excluded. The back was thoroughly examined, including visual inspection of the muscle symmetry of the back, and palpation of the tips of the dorsal spinal processes of thoracic and lumbar vertebrae and the sacrum, as well as of the back muscles. Finally, a test of the back reflexes and the passive lateral flexibility was carried out. If a horse showed a significant reaction¹³ during palpation, it was excluded. Eight horses between 6 and 14 years of age (one stallion, three mares and four geldings) passed the clinical examination and were included in the study.

Experimental set-up and data collection

The horses were accustomed to and trained on a coir mat treadmill at the walk and trot on several occasions before they were measured^{14,15}. The horses were also accustomed to walking and trotting on the treadmill with

the weighted boots on the fore- and hind limbs, respectively. The boots, that were fastened around the metacarpal or metatarsal regions, were made of terylene and artificial leather and had vertical pockets side by side intended for weights (Fig. 1). Each boot weighed 700 g. The horses showed no signs of distraction related to the boots after becoming accustomed to them.

Spherical, reflective markers, 19 mm in diameter, were glued to the skin¹⁶ over the dorsal spinous processes of eight back vertebrae (T6, T10, T13, T17, L1, L3, L5 and S3). Markers were also placed on both left and right *tubera coxae*, on the lateral styloid process of the left radius, on the lateral malleolus of the left tibia and proximally on the lateral part of the left fore and hind hoof walls. The landmarks were all identified by palpation. The positions of the markers (inaccuracy less than 1.5 mm) were collected by six infrared cameras (ProReflex[®], Qualysis Medical AB, Gothenburg, Sweden). They were placed around the treadmill and positioned so that each marker was always seen by at least two cameras.

The measurement volume made up a laboratory coordinate system with the positive *y*-axis oriented in the line of progression, parallel to the direction of the treadmill, the positive *z*-axis oriented upward and the *x*-axis oriented perpendicular to the *y*- and *z*-axes. The calibration was done dynamically by use of a calibration frame, which defined the orientation of the right-handed orthogonal laboratory coordinate system and a wand with an exactly defined length. Data were captured for 10 s at a sampling rate of 240 Hz when the horses were walking (1.5 m s^{-1}) and trotting (3.5 m s^{-1}) at a steady state.

Each horse was measured three times at each gait: once with the weighted boots on the forelimbs, once with the boots on the hind limbs and once without boots. The measurement sequence of the different conditions was chosen randomly within each gait and for every horse. The repeatability for measurements like



Fig. 1 Weighted boots with separate weights in pockets

these has earlier been validated in a Dutch-Swedish cooperation project¹⁷.

Calculation of the back kinematics in two dimensions

The reconstruction of the three-dimensional position of each marker is based on a direct linear transformation algorithm (QTrack™, Qualysis Medical AB). Subsequently, the raw *x*-, *y*- and *z*-coordinates were exported into MatLab® (The Math Works Inc., Natick, MA, USA) and Backkin® (Qualysis Medical AB) for further data processing. The individual stride cycles were determined and the beginning of each stride cycle was defined as the moment for first ground contact of the left hind hoof. The moment of ground contact was determined from the velocity profile of the marker on the left hind hoof.

The *x*-, *y*-, and *z*-coordinates were used to calculate the back rotations in accordance with Faber *et al.*¹⁸. An explanation of the principles of the instantaneous orientation of a vertebra was presented by Johnston *et al.*¹⁹. The amount of protraction and retraction of the left hind limb was determined from the marker on S3 and the marker on the left hind hoof.

Coordinate and angular motion pattern (AMP) data were extracted at the walk and trot from c. 7 and 12 representative strides, respectively. Each stride was normalized to 101 data points to make averaging of the AMPs possible over strides.

Statistical analysis

All results are presented as means ± SD. The ROM of the vertebral column when wearing weighted boots on the forelimbs or on the hind limbs was compared intra-individually to the ROM without weights and to each other. Comparisons of stride data were performed in a similar way. The results are not normally distributed. For the statistical calculations, Wilcoxon matched pairs test was used. Differences were considered significant at $P < 0.05$.

Ethical review

The local ethical committee for the Swedish National Board for Laboratory Animals approved the study.

Results

At the walk, the ROM for the dorsoventral flexion and extension was greater at L3 and L5 with weighted boots on the hind limbs compared to that without boots (Table 1). Hind limb boots also resulted in a greater flexion-extension at L5 compared to the forelimb boots. The ROM for the lateral bending was greater at L5 with the weighted boots on the hind limbs compared to that on the forelimbs at the walk.

At the trot, weighting of the hind limbs resulted in a significantly smaller ROM for the flexion-extension at L5 than weighting of the forelimbs, and a significantly smaller lateral bending at the thoracolumbar junction (L1) compared to the movement without boots (Table 1). Boots on the forelimbs led to a smaller ROM for the lateral bending at the withers (T10 and T13) and a greater ROM for the same parameter at L3 (Table 1) compared to that without boots. At T10, weighted forelimbs also gave a smaller ROM for the lateral bending compared to that for weighted hind limbs. The lateral bending of the back at the trot was greater at L3 with forelimb boots than with hind limb boots.

The weighted boots did not change the ROM for the axial rotation of the pelvis at either the walk or the trot

Table 1 The mean ROM in degrees with SD for the flexion-extension and lateral bending movements of the back at the walk and trot

			Flexion-extension		Lateral bending	
Back segment			Mean	SD	Mean	SD
Walk	Normal	T10	6.1	1.6	11.2	1.5
		T13	8.3	1.4	7.4	1.5
		T17	8.8	1.2	5.5	1.6
		L1	8.3	0.9	4.3	0.9
		L3	8.0	1.1	5.0	1.7
	Hind limb	L5	7.1	1.3	6.4	1.6
		T10	6.0	1.4	11.4	1.7
		T13	8.5	1.3	7.1	1.2
		T17	9.0	1.1	5.0	0.9
		L1	8.8	1.0	4.1	1.1
	Forelimb	L3	8.6 ^a	1.1	5.0	1.4
		L5	7.8 ^{a,b}	1.5	6.5 ^b	1.4
		T10	6.2	1.4	11.1	1.9
		T13	8.8	1.5	7.3	1.5
		T17	9.2	1.4	5.5	1.1
Trot	Normal	L1	8.5	1.3	4.5	0.8
		L3	8.2	1.3	4.9	1.2
		L5	7.1	1.4	5.9	1.2
		T10	5.1	0.8	8.3	1.8
		T13	3.7	0.6	6.6	1.2
	Hind limb	T17	3.0	0.7	5.5	1.7
		L1	3.5	0.9	4.1	1.0
		L3	4.7	1.3	4.9	1.4
		L5	4.0	1.1	5.9	1.2
		T10	5.0	0.8	8.1 ^b	1.6
	Forelimb	T13	3.9	0.7	6.2	1.2
		T17	3.2	0.9	5.3	1.6
		L1	3.4	0.9	3.7 ^a	0.7
		L3	4.5	1.3	4.7 ^b	1.5
		L5	3.8 ^b	1.1	5.9	1.3
Forelimb	T10	5.2	0.8	7.8 ^c	1.4	
	T13	3.6	0.5	6.2 ^c	1.2	
	T17	2.9	0.7	5.3	1.8	
	L1	3.6	1.1	4.1	1.4	
	L3	4.8	1.4	5.5 ^c	2.1	
L5	4.2	1.1	6.0	1.2		

Normal, no boots on the limbs; hind limb, weighted boots on the hind limbs; forelimb, weighted boots on the forelimbs.

^aHind limb statistically significant ($P < 0.05$) compared to normal.

^bHind limb statistically significant ($P < 0.05$) compared to forelimb.

^cForelimb statistically significant ($P < 0.05$) compared to normal.

Table 2 The mean ROM in degrees with SD for the axial rotation movement of the pelvis and pro- and retraction of the hind limb at the walk and trot

	Axial rotation	Pro- and retraction
<i>Walk</i>		
Normal	12.6 ± 2.0	43.4 ± 2.1
Hind limb	12.8 ± 2.7	43.9 ± 2.1
Forelimb	12.9 ± 2.1	43.8 ± 1.6
<i>Trot</i>		
Normal	5.7 ± 1.1	39.5 ± 2.6
Hind limb	5.3 ± 0.9	38.9 ± 2.5 ^{a,b}
Forelimb	6.0 ± 1.1	39.4 ± 2.4

Normal, no boots on the limbs; hind limb, weighted boots on the hind limbs; forelimb, weighted boots on the forelimbs.

^aHind limb statistically significant ($P < 0.05$) compared to normal.

^bHind limb statistically significant ($P < 0.05$) compared to forelimb.

(Table 2). The protraction and retraction of the hind limb decreased significantly at the trot when the weighted boots were on the hind limbs compared to that without boots or when the boots were on the forelimbs (Table 2).

The means and SD for the stride duration and stride velocity were calculated for the three conditions at the walk and trot (Table 3). No significant difference was found for any of these parameters.

Discussion

This study describes how weighted boots on the fore- or hind limbs affect the movement of individual segments of the thoracolumbar region. A validated, repeatable, standardized protocol and asymptomatic, fully functioning riding horses were used in order to minimize biases. The flexion–extension of the lumbar spine increased with boots on the hind limbs at the walk and the lateral bending of the thoracic spine decreased with boots on the forelimbs at the trot. This was in accordance with the hypotheses and it also supports previous work¹².

Earlier studies have shown that the movement of the back is greater at the walk than at the trot^{2,4,11}. This was also the case in the present study. For all three

types of back movement, the overall total ROM was greater at the walk than at the trot, most likely caused by the greater muscle activity at the trot as earlier shown by Robert¹².

Several studies indicate that important roles of the muscles associated with the vertebral column is to stabilize the back and to moderate movements that may arise^{6,7,20–22}. Back muscle activity does contribute to the movement of the back³ but this influence seems to be secondary rather than primary^{2,4}, which indicates an external influence on the movement of the back. There are indications that the dorsoventral flexion–extension of the back is generated by the hind limbs^{2,4}. At the walk, both flexion and extension movements start in the caudal part and are then transmitted cranially with a time-shift². This has also been observed in humans²³.

The flexion–extension of the back, especially in the caudal part, has been found to be directly correlated to the protraction and retraction of the hind limb². In the present study, weighted boots on the hind limbs increased the ROM for the flexion–extension at the lumbar back at the walk. However, there was no change in the protraction and retraction of the hind limbs at the walk. At the trot, the protraction and retraction of the hind limbs decreased significantly when the boots were fastened around the hind limbs, while the flexion–extension did not change significantly at any back segment.

It seems that the movement of the back is less susceptible to external influences at the trot compared to that at the walk. A possible contributing factor could be the difference in muscle activity between the two gaits. A horse at the trot has only a diagonal support during the support phase. To maintain the horse in balance, a muscle activity reasonably greater compared to at the walk is required¹². The muscle activity stabilizes the back more at the trot than at the walk.

A recent study has shown that loading of the distal hind limbs results in a changed movement pattern of the limbs²⁴. Distal hind limb loading increased the total ROM of the stifle, hock and hind fetlock, and decreased the ROM of the distal inter-phalangeal joint. The weighting did not affect the movement of the hip joint. In another study, it was observed that the increased

Table 3 Stride data for the left hind limb expressed as mean ± SD

	Normal	Hind limb	Forelimb
<i>Walk</i>			
Stride duration (s)	1.14 ± 0.053	1.15 ± 0.038	1.14 ± 0.055
Stride velocity (m s ⁻¹)	1.5 ± 0.06	1.5 ± 0.10	1.5 ± 0.08
<i>Trot</i>			
Stride duration (s)	0.75 ± 0.033	0.75 ± 0.020	0.76 ± 0.022
Stride velocity (m s ⁻¹)	3.5 ± 0.13	3.5 ± 0.24	3.5 ± 0.22

Normal, no boots on the limbs; hind limb, weighted boots on the hind limbs; forelimb, weighted boots on the forelimbs.

flexion of the joints, seen at increased trotting speed, was accompanied by higher excentric muscle activity during the stance phase, and during the swing phase shortened limbs because of higher concentric activity of the muscles²⁵. It seems reasonable to believe that distal weighting results in similar muscular activity and that this may be the reason for the increased flexion-extension of the lumbar back at the walk with the boots on the hind limbs. *M. longissimus dorsi* acts during the intermediate stance phase of the hind limbs to facilitate propulsion³. Weights on the hind limbs may increase the activity of this muscle. It is possible that non-weighted boots could also affect the three-dimensional movement pattern of the limbs²⁶, and perhaps in turn result in altered movements of the back.

If the flexion-extension of the back is affected by the hind limbs to a greater extent than by the forelimbs, it could explain why this parameter was not significantly affected when the weighted boots were applied to the forelimbs.

Just as for the flexion-extension, the lateral bending of the back is linked to the protraction and retraction of the hind limbs⁴. Since the lateral bending shows a mono-sinusoidal movement pattern during the stride cycle, the inter relationship becomes somewhat different, however. With the boots on the hind limbs at the trot, the lateral bending decreased significantly at the thoracolumbar junction (L1). This change may correspond to the significantly decreased protraction and retraction of the hind limbs caused by the hind limb boots.

It has been stated that the lateral bending of the thoracic back is influenced by the movement of the forelimbs. Boots on the forelimbs at the trot resulted in a smaller lateral bending at the cranial part of the back (T10 and T13). In humans, it has been shown that additional loading results in a greater muscular output²⁷. In the horse, it is possible that added extra weight on the forelimbs results in increased muscle activity, which may lead to more stable and balanced movements. In addition to the decreased lateral bending of the thoracic back with boots on the forelimbs, there was also a significant increase of the lateral bending at L3. This change was unexpected, especially as the protraction and retraction of the hind limbs did not change, and we do currently not have an explanation for this specific change.

Since the limb movements can change due to training^{28,29}, fatigue, pain or other factors, knowledge of their inter relationship with the movement of the back improves our understanding for which movements and situations may be beneficial or potential risk factors to the health of the back.

In the training and rehabilitation of sport horses, exercises to increase the flexion and extension flexibility of the lumbar back in a controlled way can sometimes be

desirable. The weighted boots used in the present study may be a good alternative for this purpose, especially when considering that the risk of overstraining and of injuries is supposedly low at the walk. Earlier studies have shown that confidence intervals are large between individuals, although very small within individuals². This study is an intra-individual study and the intervals only slightly overlap, if they do at all. Thus, we are confident that this study is significant¹⁷. The clinical relevance might be of great importance. Anecdotal observations indicate that the weights are sometimes successfully used to rehabilitate horses with caudal back problems in Sweden. Weights on the hind limbs are likely to, at the walk, induce strengthening of the flexor muscles of the caudal lumbar back and increase the mobility of the lumbar back in a controlled way. The boots we used were not very heavy. Increased weighting will probably affect the movements further, but excessively heavy boots may also increase the risk of overstraining. Walking over ground is likely to bring about the same results as in the study, although there might be minor differences in the movement pattern compared to on the treadmill. Before the full effects of the weighted boots can be evaluated, further studies, over a longer period of time and perhaps with the use of electromyography, are required.

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