EQUINE VETERINARY JOURNAL
Equine vet. J. (2004) **36** (8) 758-763

Effects of girth, saddle and weight on movements of the horse

P. DE COCQ, P. R. VAN WEEREN and **W. BACK***

Department of Equine Sciences, Faculty of Veterinary Medicine, Utrecht University, Yalelaan 12, NL 3584 CM Utrecht, The Netherlands.

Keywords: horse; back; kinematics; kissing spine; load; tack

Summary

***Reasons for performing study*: Although the saddle is seen as one of the biggest causes of back pain, and weightbearing is seen as an important aetiological factor in 'kissing spine' syndrome (KSS), the effects of a saddle and weight on the back movements of the horse have never been studied.**

***Objective*: To determine the effects of pressure on the back, exerted by tack and weight, on movements of the horse.**

***Hypothesis*: Weight has an extending effect on the horse's back and, as a compensatory mechanism to this extension, an alteration in pro- and retraction angles was expected. A similar but smaller effect was expected from a saddle only and a lungeing girth.**

***Methods*: Data were captured during treadmill locomotion at walk, trot and canter under 4 conditions: unloaded; with lungeing girth; saddle only; and saddle with 75 kg of weight. Data were expressed as maximal extension, maximal flexion angles, range of motion of L3 and L5 and maximal pro- and retraction angles of the limbs.**

***Results*: At walk and trot, there was a significant influence on back kinematics in the 'saddle with weight' situation, but not in the other conditions. Overall extension of the back increased, but the range of movement remained the same. Limb kinematics changed in the sense that forelimb retraction increased. At canter, both the 'saddle with weight' and 'saddle only' conditions had a significant extending effect on the back, but there was no effect on limb kinematics.**

***Conclusions and potential relevance*: Weight and a saddle induce an overall extension of the back. This may contribute to soft tissue injuries and the KSS. The data from this study may help in understanding the reaction of the equine back to the challenges imposed by man when using the animal for riding.**

Introduction

Back pain is one of the most common and least understood clinical problems in horses. Causes are hard to identify but, as an important cause or aggregator, poorly fitting saddles are often mentioned (Harman 1999).

'Cold back', a syndrome of persistent hypersensitivity with temporary stiffness and dipping of the spine on being saddled, is seen as a sign of saddle-fitting problems (Harman 1999). Whether 'cold back' is actually painful, associated with some previous back pain or merely a matter of temperament is unclear (Jeffcott 1999). It is a fact that soft tissue injuries are important causes of back pain. Muscle damage and ligamentous strain are seen in about 25% of horses with back pain and are often related to accidents during ridden exercise (Jeffcott 1980). Chronic muscle or ligamentous pain could be caused or made worse by the pressure that a saddle with a rider puts on the muscles and ligaments.

Of the bony pathological conditions, crowding and overriding of the dorsal spinous processes or 'kissing spine' syndrome (KSS) is a common condition that may cause back problems. The lesions are detected most frequently in the saddle-bearing area, between the 12th and 18th vertebrae (Jeffcott 1980; Walmsley *et al.* 2002). It can be diagnosed in about 30% of the healthy horse population (Jeffcott 1980) and it also occurred in the extinct horse *Equus occidentalis* (Klide 1989). Clinically relevant KSS usually has a higher degree of severity in radiological findings (Jeffcott 1980). The incidence of KSS is related to the type of work, probably to the amount of extension of the back required (Jeffcott 1980). One of the causes of KSS is thought to be weightbearing and other stresses inflicted on horses by the rider.

The kinematics of the back have long been unexplored, because the subtle movements are difficult to capture with the human eye and the back is difficult to access with kinematic analysis techniques. The normal movement range of the equine back has been studied *in vitro* (Townsend *et al.* 1983; Townsend and Leach 1984; Denoix 1987). Recently, the normal back movements of the horse in stance and in motion have also been studied *in vivo* (Pourcelot *et al.* 1998; Licka and Peham 1998; Audigié *et al.* 1999; Faber *et al.* 2000, 2001a,b; Haussler *et al.* 2001; Licka *et al.* 2001). The effects of high-speed trotting (Robert *et al.* 2001) and of conformational aspects on back movements (Johnston *et al.* 2002) have been studied. The effect of manual therapy has been evaluated in a case study (Faber *et al.* 2003).

The effects of a saddle and weight on the back-movements of the horse have never ben studied, we therefore focused on the analysis of the influence of tack (lungeing girth, saddle) and weight (saddle with 75 kg of lead) on back-movements and locomotion in general.

*Author to whom correspondence should be addressed.
[Paper received for publication 10.05.04; Accepted 13.10.04]

Materials and methods

Horses

Nine Dutch Warmblood horses were used (8 mares and 1 gelding, mean age 9.4 years, mean weight 568 kg). The horses were clinically sound, had no apparent back problems, had comparable conformation and athletic ability and were in daily use by the Veterinary Students' Riding Association. Four horses were fully accustomed to the treadmill[1] as a result of earlier kinematic research. These horses underwent at least 5 training sessions with saddle or saddle with weight before the measurements started. Five horses had no prior experience on the treadmill. These horses underwent at least 15 training sessions beforehand, from which at least 5 sessions were with saddle or saddle and weight. None of the horses showed signs of 'cold back'.

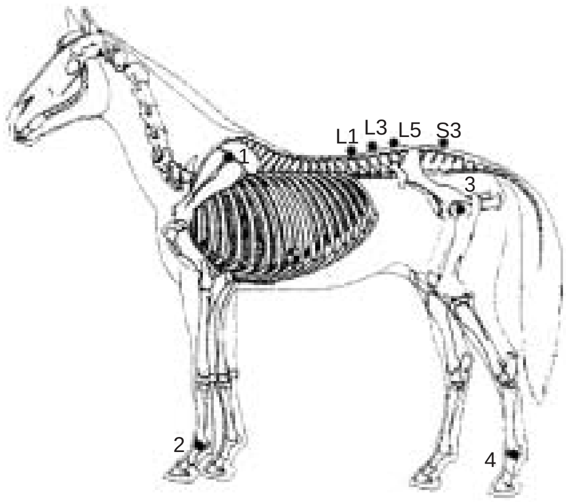

Fig 1: Marker placement on back and limbs. Lumbar vertebrae 1, 3 and 5 (L1, L3, L5); sacral vertebra 3 (S3). 1 = Proximal spina scapula; 2 = Lateral collateral ligament of the metacarpophalangeal joint; 3 = Cranial part of the trochanter major of the femur; 4 = Lateral collateral ligament of the metatarsophalangeal joint.

Tack

The same standard 17" (43 cm) dressage saddle (7 kg) and a standard lungeing girth were used on all horses. The same saddle was used in the situations with and without weight. In the latter condition, 2 bags each with 15 kg lead were attached to the stirrup bars of the saddle. Additionally, 2 lead flaps 22.5 kg were shaped similarly to the saddle and attached on top of it using safety belts and a lungeing girth (total additional weight 75 kg). To avoid any confounding effects of differences in tightening, the lungeing girth and saddle were always tightened by the same person and the saddle was tightened equally in both saddle only and saddle with weight situations.

Marker placement

The positions of the dorsal spinal processes of L1, L3, L5 and S3 were identified by palpation and used for marker placement (Faber 2001c, 2002; Fig 1). Identical marker position in all conditions was ensured by shaving small areas. At these positions, spherical, reflective markers (19 mm diameter) were placed. As marker positions for determination of pro- and retraction angles,

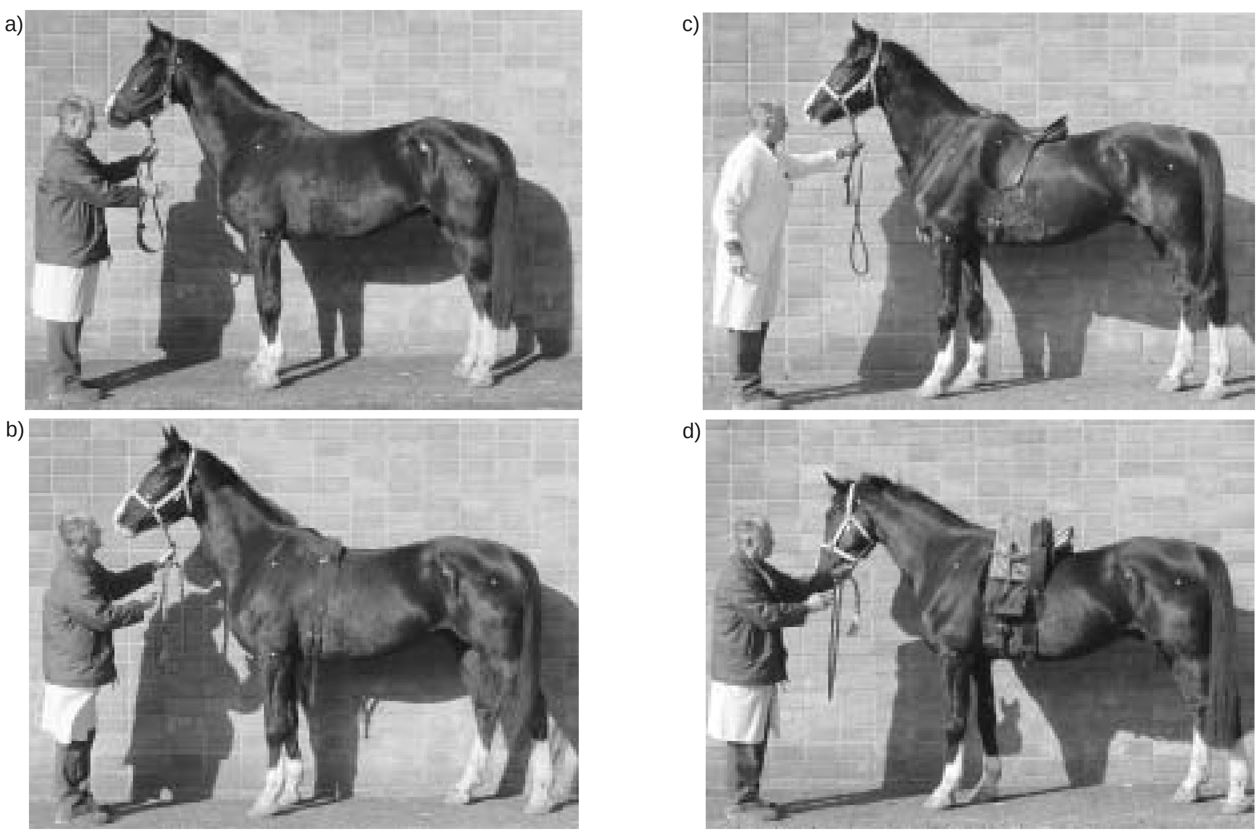

Fig 2: Pictures of all 4 situations: a) unloaded; b) with lungeing girth; c) with saddle; d) with saddle and 75 kg lead.

the proximal spina scapula, lateral collateral ligaments of the metacarpo- or metatarsophalangeal joints over the centre of rotation of the joint, and the cranial part of the trochanter major of the femur were used (Back *et al.* 1995a,b; Fig 1). For these marker positions, round, flat, reflective markers (18 mm diameter) were used and left on the horses between measurements.

Data collection

A modern, commercially available analysing system (ProReflex)[2] was used. The system consists of 6 cameras and is based on passive infrared reflective markers and infrared cameras. Calibration of the system is performed dynamically, using a calibration frame that defines the orientation of the coordinate system and a wand with a defined length. The positive y-axis was orientated in the line of progression, parallel to the treadmill. The positive z-axis was orientated upward and the positive x-axis was orientated perpendicular to the y- and z-axes. The cameras were placed around the treadmill to obtain a field of view of 1.3 x 4.0 x 2.5 m. The system's inaccuracy in identifying the location of markers in this set-up was less than 1.4%.

All horses had a 15 min warm-up period just before the measurements, which were performed under 4 conditions: unloaded; with lungeing girth; with saddle only; with saddle and weight (Fig 2). The order of the conditions was assigned randomly. For each horse under each condition, movement was captured in steady state locomotion at walk (1.6 m/sec) for 10 secs, and at trot (4.0 m/sec) and canter (7.0 m/sec) for 5 secs at a sample rate of 240 Hz.

Data analysis

The reconstruction of the 3D position of each marker is based on a direct linear transformation algorithm (Q Track)[2]. The raw coordinates were exported into Excel[3] for further data analysis.

Individual stride cycles were determined,with the beginning of each stride cycle defined as the moment of hoof contact of the left hindlimb in walk and trot, or the trailing hindlimb in canter. Detection of the moment of hoof contact was based on the horizontal velocity profile of the marker on the metatarsophalangeal joint (Peham *et al.* 1999).

The back movements and pro- and retraction angles of the legs were calculated using the y and z marker coordinates. The back movements were calculated using a method that was developed and tested for validity and repeatability by Faber *et al.* (2001c, 2002); briefly, the flexion-extension angular movement pattern (AMP) of a given vertebra (V2) is calculated from the position of the adjacent cranial (V1) and caudal (V3) markers. The AMP of V2 is represented by the orientation of the line through V1 and V3. The maximal flexion, maximal extension and range of motion (ROM) (difference between maximal flexion and maximal extension) of L3 and L5 were used as variables for further analysis (Fig 3).

Pro- and retraction angles of the forelimbs were defined as the maximal angles between the line connecting the markers on the proximal spina scapula and on the metacarpophalangeal joint and a vertical line. Pro- and retraction angles of the hindlimbs were defined in a similar fashion using the markers on the cranial part of the trochanter major of the femur and on the metatarsophalangeal joint.

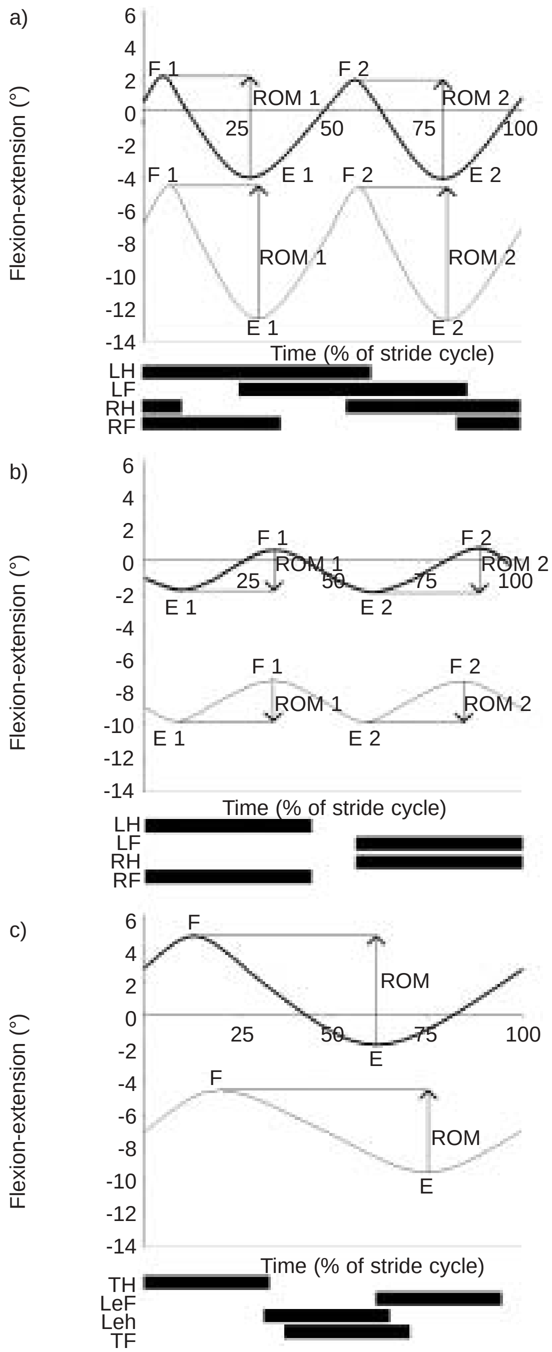

Fig 3: Process data analysis. Angular movement patterns of L3 (lower curves, thin line) and L5 (upper curves, thick line) in a) walk, b) trot and c) canter. L3 = lumbar vertebrae 3; L5 = lumbar vertebrae 5. E = maximal extension angle of the vertebrae; F = maximal flexion angle of the vertebrae; ROM = range of motion of the vertebrae. 1 = first half, 2 = second half of the stride cycle. LH = left hindlimb; LF = left forelimb; RH = right hindlimb; RF = right forelimb; TH = trailing hindlimb; LeF = leading forelimb; LeH = leading hindlimb; TF = trailing forelimb.

Stastistics

Means ± s.d. were calculated from the first 4 usable strides. A stride was unusable when marker losses occurred during this stride. Data were excluded from further analysis if not enough usable strides were available. Data were analysed statistically in an ANOVA-repeated measurement test followed by a *post hoc*

TABLE 1: Kinematic variables (mean ± s.d.) at the walk

Variables	Unloaded	Girth	Saddle	Saddle +	P value
L3 ME 1	--11.2 ± 0.6^{a}	-11.3 ± 0.7^{a}	-11.5 ± 0.6^{a}	-13.9 ± 0.6^{b}	<0.001
L3 MF 1	-4.0 ± 0.5^{a}	-4.1 ± 0.6^{a}	-4.2 ± 0.6^{a}	-6.5 ± 0.6^{b}	<0.001
L3 ROM 1	7.2 ± 0.3	7.1 ± 0.3	7.2 ± 0.3	7.4 ± 0.4	0.885†
L5 ME1	-4.5 ± 0.6^{a}	-4.4 ± 0.7^{a}	-4.6 ± 0.6^{a}	-6.3 ± 0.6^{b}	<0.001
L5 MF 1	1.2 ± 0.7^{a}	1.4 ± 0.6^{a}	1.1 ± 0.6^{a}	-0.9 ± 0.7^{b}	<0.001
L5 ROM 1	5.7 ± 0.4	5.7 ± 0.4	5.7 ± 0.5	5.5 ± 0.5	0.764†
Protraction F	24.7 ± 0.7	24.4 ± 0.4	24.3 ± 0.4	24.2 ± 0.6	0.171$^{\dagger\#}$
Retraction F	18.5 ± 0.5^{a}	18.1 ± 0.7^{a}	18.4 ± 0.5^{a}	19.4 ± 0.6^{b}	0.002
Protraction H	25.6 ± 0.6	25.1 ± 0.7	25.6 ± 0.5	26.2 ± 0.4	0.062†
Retraction H	21.6 ± 0.6	20.9 ± 0.8	21.3 ± 0.7	21.2 ± 0.7	0.773†

All variables are expressed in degrees; saddle + = saddle with 75 kg; L3 = lumbar vertebra 3; L5 = lumbar vertebra 5; ME = maximal extension angle of the vertebrae; MF = maximal flexion angle of the vertebrae; ROM = range of motion of the vertebrae; 1 = data of first half of the stride cycle, data of the second half of the stride cycle are similar; F = forelimb; H = hindlimb, data of the right-hand side of the horse, data of the left-hand side are similar. †No significant difference between groups (P≤0.05). ^{ab}Values with the same superscript are not significantly different (P≤0.05, Bonferroni correction). $^{\#}$Data of only 8 horses were used.

TABLE 2: Kinematic variables (mean ± s.d.) at the trot

Variables	Unloaded	Girth	Saddle	Saddle +	P value
L3 ME 1	-9.8 ± 0.6^{a}	-9.8 ± 0.6^{a}	-9.8 ± 0.7^{a}	-11.8 ± 0.9^{b}	0.050
L3 MF 1	-5.8 ± 0.6^{a}	-5.9 ± 0.6^{a}	-5.8 ± 0.6^{a}	-7.8 ± 0.7^{b}	0.002
L3 ROM 1	3.9 ± 0.5	4.0 ± 0.4	4.1 ± 0.6	4.0 ± 0.6	0.807$^{\dagger\#}$
L5 ME 1	-3.2 ± 0.8	-3.1 ± 0.9	-3.3 ± 0.8	-4.4 ± 0.9	0.080†
L5 MF 1	0.0 ± 0.8^{a}	0.1 ± 0.9^{a}	0.0 ± 0.8^{a}	-1.4 ± 0.8^{b}	0.008
L5 ROM 1	3.2 ± 0.4	3.3 ± 0.3	3.3 ± 0.5	3.1 ± 0.4	0.109†
Protraction F	20.4 ± 0.6^{a}	20.7 ± 0.6^{a}	21.0 ± 0.7^{a}	21.8 ± 0.6^{b}	0.005
Retraction F	18.4 ± 0.6^{a}	18.5 ± 0.6^{a}	18.6 ± 0.6^{a}	20.5 ± 0.6^{b}	0.002$^{\#}$
Protraction H	23.6 ± 0.4	23.7 ± 0.5	24.1 ± 0.5	24.6 ± 0.5	0.332†
Retraction H	18.6 ± 0.4^{a}	18.7 ± 0.4^{a}	18.8 ± 0.4^{ab}	19.3 ± 0.4^{b}	0.003

See Table 1 for explanation of abbreviations and symbols.

TABLE 3: Kinematic variables (mean ± s.d.) at the canter

Variables	Unloaded	Girth	Saddle	Saddle +	P value
L3 ME	-9.3 ± 0.8^{a}	-9.4 ± 0.7^{a}	-10.4 ± 0.9^{a}	-12.2 ± 0.7^{b}	0.022
L3 MF	-3.7 ± 0.5^{a}	-4.0 ± 0.5^{ab}	-4.4 ± 0.6^{b}	-5.0 ± 0.5^{b}	0.021
L3 ROM	5.6 ± 0.4	5.4 ± 0.4	6.0 ± 0.5	7.3 ± 0.6	0.065†
L5 ME	-3.5 ± 1.0^{a}	-3.5 ± 0.9^{a}	-4.0 ± 1.0^{a}	-5.8 ± 0.8^{b}	0.031
L5 MF	4.8 ± 0.7^{a}	4.4 ± 0.8^{ab}	4.2 ± 0.8^{b}	3.8 ± 0.7^{b}	0.033
L5 ROM	8.3 ± 0.5	8.0 ± 0.4	8.2 ± 0.5	9.6 ± 0.4	0.207†
Protraction LF	20.4 ± 0.9	19.8 ± 0.7	19.4 ± 1.0	21.7 ± 1.2	0.177$^{\dagger\#}$
Retraction LF	30.9 ± 1.1	31.2 ± 1.3	31.1 ± 1.3	31.8 ± 1.5	0.653†‡
Protraction TH	33.8 ± 1.0	33.9 ± 1.1	33.4 ± 1.3	33.2 ± 2.0	0.945†§
Retraction TH	21.0 ± 1.2	20.6 ± 1.0	21.1 ± 1.1	21.4 ± 1.2	0.750†

LF = leading forelimb; TH = trailing hindlimb; due to frequent marker losses, data of the trailing forelimb and leading hindlimb are not listed. $^{\#}$Data of only 8 horses were used; ‡data of only 7 horses were used; §data of only 5 horses were used. See Table 1 for further explanation of abbreviations and symbols.

Bonferroni test using SPSS[4] software. A P value of ≤0.05 was considered statistically significant.

Results

Data for maximal flexion, maximal extension and the resulting range of motion for L3 and L5 at walk, trot and canter are given in Tables 1, 2 and 3, along with pro- and retraction angles for front and hindlimbs. Significance of differences has been indicated.

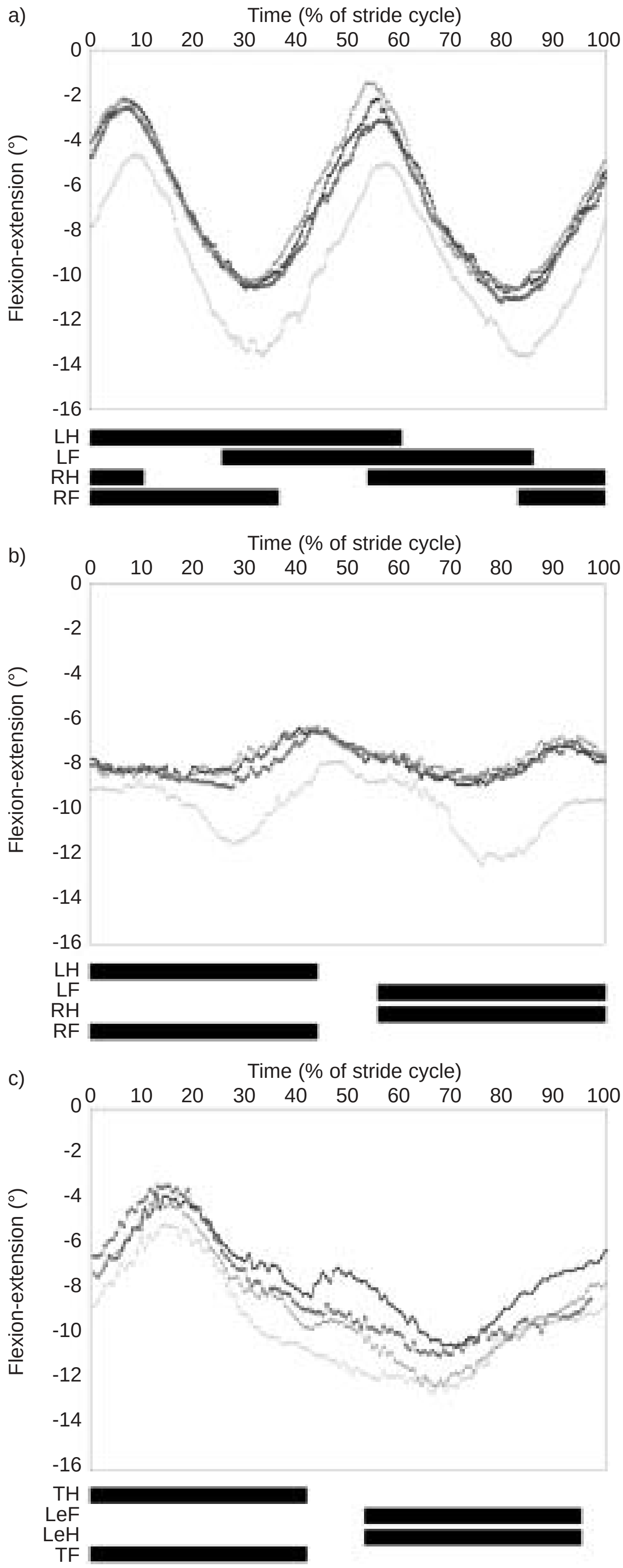

Fig 4: Typical example of the angular movement patterns of L3 in a) walk, b) trot and c) canter, during one stride of one horse in all 4 situations: ◆ = unloaded; ■ = lungeing girth; ▲ = saddle; x = extra weight. LH = left hindlimb; LF = left forelimb; RH = right hindlimb; RF = right forelimb. TH = trailing hindlimb; LeF = leading forelimb; LeH = leading hindlimb; TF = trailing forelimb.

While no influence on any of the variables measured at walk was seen in the situations with a lungeing girth or a saddle only, an overall extension of the back, represented by a decrease in the maximum flexion and extension angles of L3 and L5, was provoked by a saddle with weight, whereas the range of motion of the back appeared unaffected (Fig 4). An increase in the retraction angle of the forelimb was caused by the saddle with weight.

The situation was comparable at trot and canter, with an overall decrease in flexion and extension angles in the 'saddle with weight' condition and no effect on the range of motion. At trot, the increase in retraction angle of the forelimb was accompanied by (smaller) increases in retraction angle of the hindlimb and in protraction angle in the forelimb. At canter, a smaller decrease in maximal flexion angles of L3 and L5 could also be seen in the 'saddle only' situation, but there was no influence on pro- and retraction angles.

Discussion

No other studies on the changes in back movements caused by a saddle and weight exist, but there are models on back biomechanics. There is common agreement that the bow-and-string concept as proposed by Slijper (1946) is the best biomechanical model for the back of the horse (Jeffcott 1979). In this concept, the bow (thoracolumbar spine with adnexa) forms a functional entity with the string (abdominal muscles, *linea alba*). There are several factors that increase tension in the bow (i.e. flex the back), or decrease tension (i.e. extend the back), among which limb action is one of the most important. There is a tight connection between limb movements and excursions of the back, due to the continuity of soft tissue structures such as the common aponeurosis of the *longissimus dorsi* muscle (which is one of the most powerful muscles influencing back motion) and the middle gluteal muscle (which is instrumental for propulsion) (Dyce *et al.* 1996). Protraction of the forelimbs extends the back, as does retraction of the hindlimbs. Retraction of the forelimbs and protraction of the hindlimbs have the opposite effect (Jeffcott 1979).

Another important factor in the bow-and-string concept not included in this study is the position of the head. The head acts as an attached beam supported at one end only. This beam receives additional support from the cervical muscles and the nuchal ligament. The tail represents a similar beam, but is of much less biomechanical importance (Jeffcott 1979).

The weight used in this study (75 kg) is representative of the average rider. It may be argued that it is dead weight and not comparable to a rider. A study using a force-plate demonstrated that, compared with a sandbag, a rider was able to shift part of the weight towards the hindlimbs (Schamhardt *et al.* 1991). This may mean that, compared with a rider, the 'saddle with weight' situation will have more impact on the forelimbs. However, in kinematic studies on treadmill locomotion of horses with lead saddles and riders of the same weight, no significant differences could be demonstrated between the 2 conditions (Sloet van Oldruitenborgh-Oosterbaan *et al.* 1995, 1997). Therefore, we feel confident that the 'saddle with weight' condition sufficiently simulated a saddle with rider.

Saddling a horse influenced back movement at walk and trot only when at the same time the horse's back was challenged with a considerable weight. Although perhaps obvious at first sight, this observation means that tightening a girth around the horse's chest, thereby exerting pressure on the sternum and the withers, does not measurably influence back-movement. Girth tension has been related to reduced respiratory performance (Bowers and Slocombe 1999), but there seems to be no biomechanical restriction to locomotion.

The reduction in maximal flexion of the angles of L3 and L5 seen in the canter in the condition with a saddle only, may be explained by the bigger and faster vertical movement of the back of the horse causing a larger acceleration of the saddle resulting in a higher impact on the back due to inertial forces, compared to walk and trot.

The influence of a saddle with weight can best be described as an overall extension or 'hollowing' of the back. Both maximal flexion and maximal extension angles decreased and ranges of motion remained unchanged. This suggests that loading a horse's back to the degree used in this study does not restrict the mobility of the back and hence will probably not significantly affect athletic potential. However, it should be understood that it slightly affects the conformation of the vertebral column and therefore the internal forces in this and adjacent anatomical structures. A slightly more extended back leads to a closer position of the spinous processes of the thoracolumbar vertebrae. This effect can be expected to be largest in the area where ventrodorsal flexion/extension excursions are largest, i.e. the last part of the thoracic vertebral column (Faber *et al.* 2000), which is the region where lesions associated with dorsal spinous processes of vertebral bodies are most frequently encountered (Jeffcott 1980; Walmsley *et al.* 2002). Further, the altered anatomical situation when loaded with a saddle with weight also leads to other stresses and tensions in the many ligaments and muscles that make up the equine back. It is clear that these alterations will not invariably lead to clinical problems, but they may represent a predisposing factor, just as in the case of kissing spines.

For evaluation of the effect of a saddle with weight on locomotion (pro- and retraction), the back should be considered in the context of the entire animal. In order to counteract the extension of the back seen in the saddle with weight situation, an increased retraction of the forelimbs and protraction of the hindlimbs can be expected. In the present study, it seemed that the horses sought to counteract this influence by adapting the gait such that the retraction angle of the forelimbs increased. Apparently the forelimbs take the lead in this compensatory mechanism, which may be unsurprising as it is known that in the horse the forelimbs support 60% of bodyweight (Merkens *et al.* 1985). At trot there is also an increase in retraction angle of the forelimbs, but accompanied by lesser increases in retraction angle of the hindlimbs and protraction angle of the forelimbs. These latter changes seem contradictory, but become logical when considering that the trot is a gait where, unlike the situation at walk, there is a tight coupling between front and hindlimb movement and between the movements of the contralateral limb pairs. A significant increase in retraction angle of the forelimb at trot will lead to some increase of retraction angle of the contralateral hindlimb if the limbs are to remain in phase. Similarly, an increase in retraction angle of a forelimb, which results in a slight increase in retraction time if speed remains the same, may influence the simultaneous protraction of the contralateral forelimb. At canter, no effects on locomotion were noted. There may be methodological explanations for this. Data variation was larger here, because both right and left canter lead were used. In this asymmetrical gait, asymmetries in marker placement may have more effect and shifting of horses from the y-axis occurs earlier (Audigié *et al.* 1998). Further, because of frequent marker losses at this gait, not all horses could be used in the data analysis.

In conclusion, it seems intuitive that increased weight on the back might cause extension of the spine. This study confirms that loading of the dorsal back region with weights of the order experienced in competition does influence posture during exercise. An overall extending effect on the back, but no effect on mobility, was observed. Although no causal relationship can be concluded from this study, these changes in back motion are consistent with those allegedly implicated in the pathogenesis of kissing spines. It seems that the horse tries to compensate for the extending effect of the saddle by increasing retraction of the forelimbs.

Manufacturers' addresses

[1]Kagra AG, Fahrwangen, Switzerland.
[2]Qualysis AB, Sävedalen, Sweden.
[3]Microsoft Corporation, Redmond, Washington, USA.
[4]SPSS Inc., Chicago, Illinois, USA.

References

Audigié, F., Pourcelot, P., Degueurce, C., Denoix, J.-M. and Geiger, D. (1999) Kinematics of the equine back: flexion-extension movements in sound trotting horses. *Equine vet. J., Suppl*. **30**, 210-213.

Audigié, F., Pourcelot, P., Degueurce, C., Denoix, J.-M., Geiger, D. and Bortolussi, C. (1998) Asymmetry in placement of bilateral skin markers on horses and effects of asymmetric skin marker placement on kinematic variables. *Am. J. vet. Res*. **59**, 938-944.

Back, W., Schamhardt, H.C., Savelberg, H.H., van den Bogert, A.J., Bruin, G., Hartman, W. and Barneveld, A. (1995a) How the horse moves: 1. Significance of graphical representation of the equine forelimb kinematics. *Equine vet. J*. **27**, 31-38.

Back, W., Schamhardt, H.C., Savelberg, H.H., van den Bogert, A.J., Bruin, G., Hartman, W. and Barneveld, A. (1995b) How the horse moves: 2. Significance of graphical representation of the equine hindlimb kinematics. *Equine vet. J*. **27**, 39-45.

Bowers, J.R. and Slocombe, R.F. (1999) Influence of girth strap tensions on athletic performance of racehorses. *Equine vet. J., Suppl*. **30**, 52-56.

Denoix, J.-M. (1987) Kinematics of the thoracolumbar spine of the horse during dorsoventral movements: a preliminary study. In: *Equine Exercise Physiology 2*, Eds: J.R. Gillespie and N.E. Robinson, ICEEP Publications, Davis, California. pp 607-614.

Dyce, K.M., Sack, W.O. and Wensing, C.J.G. (1996) The hindlimb of the horse. In: *Textbook of Veterinary Anatomy*, 2nd edn., W.B. Saunders Co., Philadelphia. p 613.

Faber, M., Johnston, C., van Weeren, R. and Barneveld, A. (2002) Repeatability of back kinematics of horses during treadmill locomotion. *Equine vet. J*. **34**, 235-241.

Faber, M.J., van Weeren, P.R., Schepers, M. and Barneveld, A. (2003) Long-term follow-up of manipulative treatment in a horse with back problems. *Am. J. vet. med. Ass*. **50**, 241-245.

Faber, M., Schamhardt, H., van Weeren, R., Johnston, C., Roepstorff, L. and Barneveld, A. (2000) Basic three-dimensional kinematics of the vertebral column of horses walking on a treadmill. *Am. J. vet. Res*. **61**, 399-406.

Faber, M., Johnston, C., Schamhardt, H., van Weeren, R., Roepstorff, L. and Barneveld, A. (2001a) Basic three-dimensional kinematics of the vertebral column of horses trotting on a treadmill. *Am. J. vet. Res.* **62**, 757-764.

Faber, M., Johnston, C., Schamhardt, H., van Weeren, R., Roepstorff, L. and Barneveld, A. (2001b) Basic three-dimensional kinematics of the equine spine during canter. *Equine vet. J., Suppl.* **33**, 145-149.

Faber, M.J., Schamhardt, H.C., van Weeren, P.R. and Barneveld, A. (2001c) Methodology and validity of assessing kinematics of the thorocolumbar vertebral column in horses on the basis of skin-fixated markers. *Am. J. vet. Res*. **62**, 301-306.

Harman, J.C. (1999) Tack and saddle fit. *Vet. Clin. N. Am.: Equine Pract.* **15**, 247-261.

Haussler, K.K., Bertram, J.E.A., Gellman, K. and Hermanson, J.W. (2001) Segmental *in vivo* vertebral kinematics at the walk, trot and canter: a preliminary study. *Equine vet. J., Suppl*. **33**, 160-164.

Jeffcott, L.B. (1979) Back problems in the horse - a look at past present and future progress. *Equine vet. J*. **11**, 129-136.

Jeffcott, L.B. (1980) Disorders of the thoracolumbar spine of the horse - a survey of 443 cases. *Equine vet. J*. **12**, 197-210.

Jeffcott, L.B. (1999) Historical perspective and clinical indications. *Vet. Clin. N. Am.: Equine Pract.* **15**, 1-11.

Johnston, C., Holm, K., Faber, M., Erichsen, C., Eksell, P. and Drevemo, S. (2002) Effects of conformational aspects on the movement of the equine back. *Equine vet. J., Suppl*. **34**, 314-318.

Klide, A.M. (1989) Overriding vertebral spinous processes in the extinct horse, *Equus occidentalis*. *Am. J. vet. Res*. **50**, 592-593.

Licka, T. and Peham, C. (1998) An objective method for evaluating the flexibility of the back of standing horses. *Equine vet. J*. **30**, 412-415.

Licka, T.F., Peham, C. and Zohmann, E. (2001) Treadmill study of the range of back movement in horses without back pain. *Am. J. vet. Res.* **62**, 1173-1179.

Merkens, H.W., Schamhardt, H.C., Hartman, W. and Kersjes, A.W. (1985) Ground reaction force patterns of Dutch Warmblood horses at normal walk. *Equine vet. J.* **18**, 207-214.

Peham, C., Scheidl, M. and Licka, T. (1999) Limb locomotion - speed distribution analysis as a new method for stance phase detection. *J. Biomech*. **32**, 1119-1124.

Pourcelot, P., Audigié, F., Degueurce, C., Denoix, J.-M. and Geiger, D. (1998) Kinematics of the equine back: a method to study the thoracolumbar flexion-extension movement at the trot. *Vet. Res*. **29**, 519-525.

Robert, C., Audigié, F., Valette, J.P., Pourcelot, P. and Denoix, J.-M. (2001) Effects of treadmill speed on the mechanics of the back in the trotting saddlehorse. *Equine vet. J., Suppl*., **33**, 154-159.

Schamhardt, H.C., Merkens, H.W. and van Osch, G.J.V.M. (1991) Ground reaction force analysis of horses ridden at the walk and the trot. In: *Equine Exercise Physiology*, Eds: S.G.B. Persson, A. Lindholm and L.B. Jeffcott, ICEEP Publications, Davis, California. pp 120-127.

Slijper, E.J. (1946) Comparative biologic-anatomical investigations on the vertebral column and spinal musculature of mammals. *Proc. K. Ned. Acad. Wetensch*. **42**, 1-128.

Sloet van Oldruitenborgh-Oosterbaan, M.M., Barneveld, A. and Schamhardt, H.C. (1995) Effects of weight and riding on workload and locomotion during treadmill exercise. *Equine vet. J., Suppl*. **18**, 413-417.

Sloet van Oldruitenborgh-Oosterbaan, M.M., Barneveld, A. and Schamhardt, H.C. (1997) Effects of treadmill inclination on kinematics of the trot in Dutch Warmblood horses. *Equine vet. J., Suppl*. **23**, 71-75.

Townsend, H.G. and Leach, D.H. (1984) Relationship between intervertebral joint morphology and mobility in the equine thoracolumbar spine. *Equine vet. J*. **16**, 461-465.

Townsend, H.G., Leach, D.H. and Fretz, P.B. (1983) Kinematics of the equine thoracolumbar spine. *Equine vet. J*. **15**, 117-122.

Walmsley, J.P., Petterson, H., Winberg, F. and McEvoy, F. (2002) Impingement of dorsal spinous processes in two hundred and fifteen horses: case selection, surgical technique and results. *Equine vet. J*. **34**, 23-28.