Influence of draw reins on the gate kinematics at the trot

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SAMMANFATTNING

Ett ofta angivet syfte vid olika former av träning inom både hoppning och dressyr är att påverka hästens rörelser och förmå hästen att bära mer vikt på bakdelen och avlasta frambenen. Om och hur detta sker har dock knappt alls utvärderats med objektiva metoder. Effekter av träning över längre tid har studerats med avseende på förändringar i gångartsmönstret men då har kraftmätningar har inte inkluderats. I andra studier har man konstaterat att tyngden av en ryttare ökar belastningen på hästens ben, och då särskilt frambenen. Endast en av dessa studier har dock givit indikation om att ryttaren har möjlighet att påverka belastningsförhållandena. En studie av gramantygelns inverkan på belastningsfördelningen mellan fram- och bakben kunde visa att gramantygel i kombination med vanlig tygel gav signifikant ökad såväl vertikal som propulsiv impuls i bakbenet (Roepstorff *et al.* 2002). Samtidigt gjordes även synkroniserade kinematiska registreringar. Från dessa har i följande arbete data från understödsfasen har valts ut och analyserats. Syftet är att utvärdera eventuella kinematiska effekter av gramantygeln samt att om möjligt upptäcka samband mellan kinetik och kinematik.

Analys av kinematiska data visade att gramantygeln förändrade hals- och nackvinklarna. Påverkan på halsvinkeln var mer än tre gånger så stor med graman som enda tygel jämfört med i kombination med vanlig tygel. Frambenet fördes snabbare med graman, både ensam och i kombination, men signifikant ökad retraktion sågs enbart med endast graman. Kombinationen av tyglar gav ökad sträckning av lårleden under andra hälften av understödet. Graman som enda tygel gav inte samma förändring. Lårledvinkeln kan därför antas vara kopplad till bakbenets propulsiva impuls, då denna förändrades på likartat sätt. Med gramantygel som komplement till vanlig tygel sågs även ökad flexion av has, knä och höft under första delen av understödet samt ökad flexion av hasen och minskad lutning av bäckenet i understödsfasens mitt. Motsvarande mönster kunde ej ses med endast graman. Det kan tyda på att gramantygeln, men endast i kombination med vanlig tygel, kan bidra till ökad upplagring av elastisk energi i bakdelen, vilket sedan kan utnyttjas för ökad propulsiv kraft i slutet av understödet. Förändringarna kan också ha samband med ökad vertikal belastning av bakdelen.

Fynden i denna studie är intressanta då det sedan tidigare saknas studier av samband mellan ändringar i kinetik och kinematik hos friska hästar. Resultaten måste dock tolkas med försiktighet. Materialet är litet och samtliga data som använts för den kinetiska analysen ej varit möjliga att analysera kinematiskt. Ytterligare undersökningar är därför nödvändigt för att validera föreslagna samband.

INTRODUCTION

One of the primary goals for many dressage and jumping training techniques is to gain influence on the gate kinematics in order to achieve a shift in weight-bearing distribution from fore to hind. Horses ability to do this has however been very little studied and few training methods have been evaluated in an objective way. In the author's knowledge it is still unknown which joint angulations and possibly other variables that might be important for a horse in order to increase the weight-bearing of the hind limbs. Basic relationship between limb kinematics and ground reaction force (GRF) patterns have been investigated (e.g. Merkens & Schamhardt 1994, Hodson *et al.* 2000, 2001, Khumsap *et al.* 2001, 2002). Studies have also been carried out on gate adaptations and related GRF changes in supporting fore limb lameness (e.g. Back *et al.* 1993, Buchner *et al.* 1996, Merkens & Schamhardt 1988, Morris & Seehrman 1987). Little is however known about how changes in limb kinematics may influence GRF patterns in the sound condition. There are also few studies evaluating the influence of particular training methods on gate kinematics during one particular training session. Kinetic effects of various types of reins have been evaluated at walk and trot in unmounted riding horses using accelerometer technique, but kinematic analysis was not included in this study (Biau *et al.* 2002). Some studies investigating the effects of training over time on the gate kinematics of the riding horse are also available (e.g. Back *et al.* 1995, Muñoz *et al.* 1997, Cano *et al.* 2000) but non of them include kinetic registrations.

It is previously known that the rider's mass influences the GRF patterns of the limbs, particularly so in the forehand (Schamhardt *et al.* 1991). Both vertical and horizontal impulses show greater increase in the fore limbs compared to the hind. Changes in GRF patterns cannot be considered equivalent to the effect of a plain increase in total mass, the presence of a rider produce a different effect than a proportionally heavier horse (Clayton *et al.* 1999). The effect of a rider also differs from carrying dead weight. Schamhardt and colleagues (1991) found that the unevenness in load increase was lower with a rider than with a sandbag of equivalent mass. Thus the rider must have some ability of influencing the weight-bearing distribution between the fore and hind limbs. There was however, perhaps surprisingly, little difference found in weight-bearing distribution whether the rider was a skilled professional or inexperienced.

Kinematic effects of collection at the trot have been studied previously (Clayton 1994, Holmström *et al.* 1995). Holmström and colleagues found that one of the most significant kinematic effects of collection on the trotting gaits in the hind limb was decreased backward movement of the limb with increased collection, corresponding to a decrease in femur inclination at lift off. The femur inclination did however remain unchanged at the moment of hoof contact. Pelvis inclination, as well as hock and stifle joint angular curves, differed significantly only when piaffe and passage were compared with less collected gates. From the results the authors concluded that horses do not step under themselves more with increased collection, despite the fact that this often is mentioned in riding literature as an important factor for the horse in order to increase the weight-bearing of the hind-quarters. Horses ability of stepping under themselves can however be influenced by training over time. Cano *et al.* (2000) found that a 10-month training program caused higher protraction and smaller retraction angles in the hind limbs in a group of young, previously untrained horses. Angular values at landing, midstance and lift off where found to be lower for pelvis inclination, hip joint, stifle and hock joints after training. This characteristic has been described as "engagement of the quarters" (Crossley, 1993) and is one of the primary goals in training young horses, highly desirable for increasing the load-bearing capacity of the hind limbs.

It has been shown in a previous study that the draw reins in the combination with normal reins can increase the weight-bearing of the hind limbs (Roepstorff *et al.* 2002), whereas riding with draw reins only failed to produce the same effect. The present work is based on analysis of the kinematic data recorded from the same experiment. The aim here is to analyse the influences of draw reins on the limb kinematics, and, if possible, implicate kinematic characteristics of important for the horse in order to increase the weight-bearing of the hindquarters.

MATERIAL AND METHODS

The experimental design has been described in detail elsewhere (Roepstorff *et al.* 2002). Experimental animals were eight sound Swedish Warmblood horses competing at different levels of showjumping (1.20-1.40). The horses were aged 5-11 years and of good conformation. The riders were all experienced graduate students or teachers from the Equine Studies programme at the Swedish University of Agricultural Sciences (SLU). The riders were instructed to ride at in near optimal manner and in a similar fashion regardless of the experimental condition. Riders were sitting at the trot, riding in a dressage seat.

Horses were ridden at collected trot, 3.0 m/s (Clayton 1994) over at 0.6 x 0.9 m 3-dimentional Bertec force plate. The experiment was carried out indoors on an asphalt surface, with both runway and force plate covered with a thin layer of sand. The draw reins were attached to the saddle girth and ran between the fore limbs to the bit and on to the rider's hand. The kinematics and speed were recoded by use of a 6-camera ProReflex motion capture system (Qualisys AB, Gothemburg, Sweden). Before recordings took place the horses were ridden over the force plate a number of times until they were judged to move without visible interference from the plate.

Three different experimental riding alternatives were evaluated: 1) draw reins only (DR), 2) the combination of draw reins and normal reins (DR+NR) and 3) normal reins only (NR). The recordings were repeated five times, including hits at the force plate from the two left fore- and hind limbs. The order of the riding alternatives was randomised.

Data were recorded simultaneously and synchronized from the force plate and the ProReflex system. Kinematic data was sampled at 240 Hz with an A/D-board. The reference marker positions on the horses were essentially the same as described by Holmström *et al.* (1990), with some modifications: Head and fore limb: 1) the bridge of the nose, approximately 10 cm above the nostrils; 2) the cranial end of the wing of atlas; 3) the proximal end of the spine of scapula; 4) the posterior part of the tuberculum majus of the humerus; 5) the dorsal edge of the coronary band.

Caudal back and hind limb: 6) the spinous process of L3; 7) the lumbosacral joint; 8) the spinous process of S3; 9) the proximal end of the tuber coxae; 10) the centre of the anterior part of the greater trochanter of femur; 11) the proximal attachment of the lateral collateral ligament of the stifle joint to the femur; 12) the distal epicondyl of tibia; 13) the head of the lateral splint bone; 14) the lateral collateral ligament of the fetlock joint at the level of the joint space and 15) the dorsal edge of the coronary band.

The reconstruction of the 3-dimesional position of each marker is based on direct linear transformation algorithm (Q Track, Qualisys AB, Gothemburg, Sweden). Subsequently the raw x-, y- and z-coordinat data were exported into Matlab for further processing. Kinematic data from fore- and hind stance phase, selected with reference to vertical force data, were then used for angular calculations. The following angels were calculated: 1) the angle between the head and neck, 2) the angle between the neck and the scapula, 3) the fore hoof position in reference to the horizontal plane, 4) the inclination of lumbar spine from the horizontal plane, 5) the inclination of sacrum from horizontal plane 6) the lumbosacral (LS) joint angle, 7) the hip joint angle, 8) the stifle joint angle, 9) the hock joint angle and 10) hind hoof position with reference to horizontal plane. All joint angles were measured on the flexor aspect of the joint (ventral side for LS). Fore and hind limb pendulation angles were measured on the cranial side of the limb, the angle is 90° then the hoof is just below the reference marker on the scapula and the tuber coxae, respectively.

For above described angles an average angular curve was calculated for each horse over available runs from the particular horse, 2-5 runs per horse and angle. Runs which produced aberrant angular patterns were excluded before averaging as well as runs where data for all x-, y- and z-coordinates were not available during the entire stance phase. Each stance phase data series were then normalised to 101 values (0-100 %). In order to search for significant changes between the different experimental conditions the angular curves were compared pairwise value per value for each horse, NR versus NR+DR, NR vs. DR and DR vs. NR+DR. Difference curves from available horses were then summarised as mean and s.d. curves for each comparison and angle. A Student's paired t test was used to compare the minimum and maximum angular values of the neck, fore and hind limb pendulation in the different experimental conditions.

RESULTS

The average speed of all horses and all strides were mean ± s.d. 3.0 ± 0.25 m/s and the average stance time durations were 87.27 ms in the fore limb and 79.28 ms in the hind limb (87.27 and 78.93 ms respectively, in the complete data material from Roepstorff *et al*. 2002). Speed and stance time did not differ significantly from the average in any single experimental set-up, either in total or in any single horse (neither in the present, nor in the complete material).

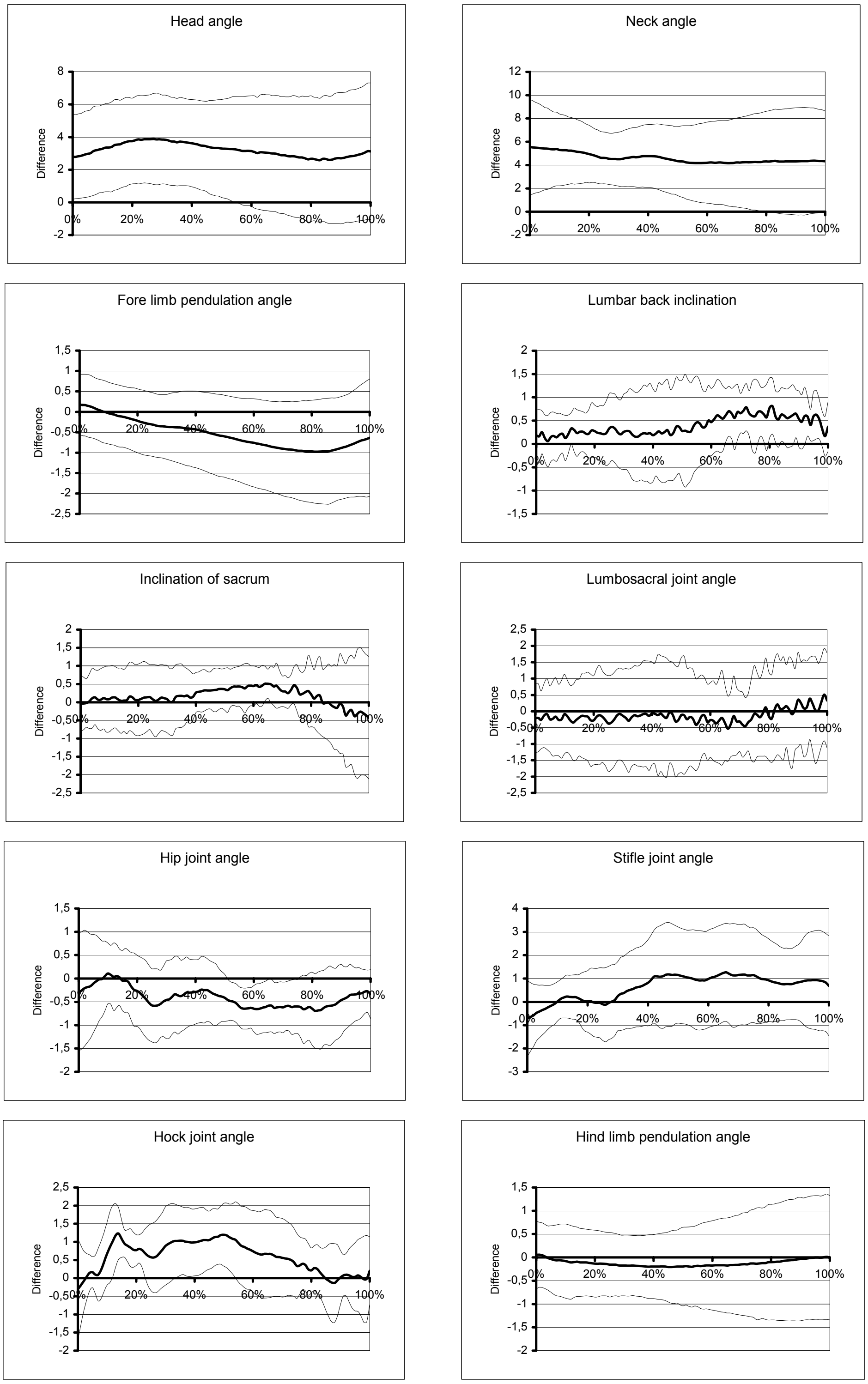


Fig 1: Angular difference from NR to NR+DR, presented as group mean (thick line) and s.d. (thin lines).

Comparison of NR with NR+DR

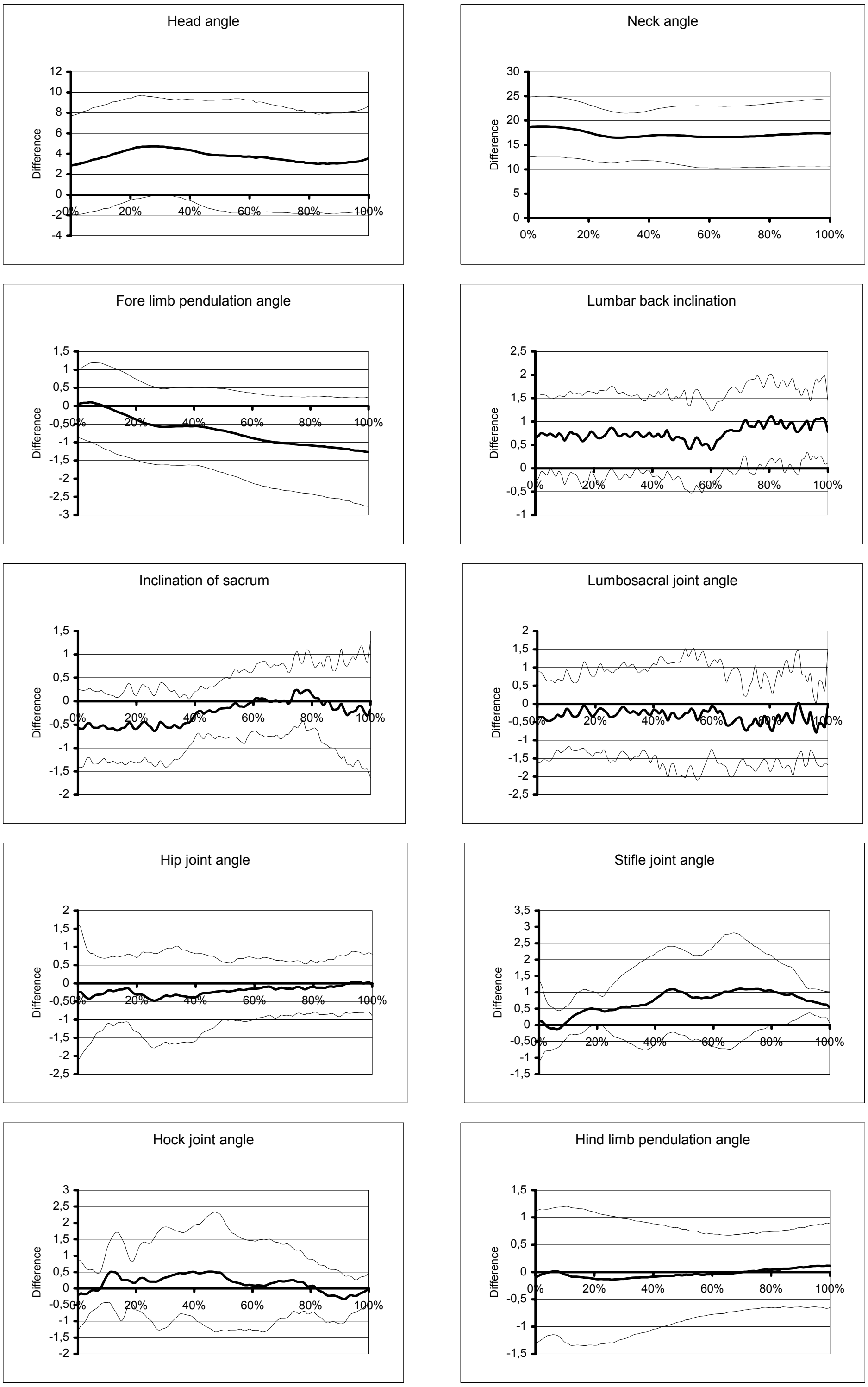
The differences in angular patterns from NR to NR+DR are plotted in Figure 1. Head and neck angles were lower during the entire stance phase in the NR+DR situation compared to NR, but the decrease was more pronounced during the first half of stance, especially in the head angle. Fore limb pendulation angle changed with NR+DR so that the angle was lager at any particular % stance, apart from during early stance and at the moment of lift off, with difference increasing to a maximum at 80 % stance. Minimum and maximum angular values were not significantly different (Table 1). The hock joint had increased flexion in the NR+DR case in early stance, during the initial loading of the hind limb, peaking at about 10-15 % stance. Similar changes, although of smaller magnitude, were also seen in the hip and stifle joint angular difference curves, however starting from increased extension and dropping to no difference between the experimental conditions. The hock joint was also more flexed during maximal vertical load of the hind limb, whereas the stifle joint angle was more flexed from 30 % stance onward in the NR+DR situation. The hip joint showed increased extension in the NR+DR case from about 20 % stance, but the difference decreased from 80 % stance onward to the end of stance. The inclination of sacrum decreased with NR+DR during the propulsive phase of the hind limb. A drop towards slightly increased inclination then followed the increase during the last 15-20 % of stance. Variation between horses however largely increased during this part. The lumbar back was slightly more horizontal in the NR+DR case during the second half of stance, whereas there were little if any differences in the lumbosacral angle. The pendulation angle of hind hoof showed no significant changes.

Table 1: Minimum and maximum angles in degrees for fore and hind limb pendulation (different subscripts indicate significantly different values, p <0,05)

	Fore limb		Hind limb	
	Min	Max	Min	Max
DR	72.5	109.9^a	83.7	115.0
NR+DR	72.3	109.3	83.6	115.1
NR	72.5	108.7^b	83.6	115.1

Comparison of NR with DR

The differences in angular values from NR to DR only are plotted in Figure 2. The effect on the head angle with DR only compared with NR is largely similar to that of NR+DR. The neck angle however increased more with DR only, it became about 15-20° lower on average from the NR condition throughout the entire stance phase. The fore limb pendulation angle changed so that the angle was larger at any particular % stance in the DR case compared to NR, with increasing difference towards the end of stance. The increased difference also showed as a significantly (p <0,05) larger maximum angle in the DR case (Table 1). The hock and stifle joints showed slight increased flexion during various parts of midstance in the DR only condition, whereas the hip joint angular pattern remained largely unchanged. The sacrum showed increased inclination during the first half of the stance phase, but no difference was observed during the second half. The lumbar back was more horizontal during the entire stance, but the difference was more pronounced during the last third, from about 65 % onward. The lumbosacral angle as well as the hind hoof pendulation angle remained largely unchanged.


Head angle

Neck angle

Fore limb pendulation angle

Lumbar back inclination

Inclination of sacrum

Lumbosacral joint angle

Hip joint angle

Stifle joint angle

Hock joint angle

Hind limb pendulation angle

Fig 2: Mean (thick line) and s.d. (thin line) curves for angular difference from NR to DR.

Comparison of NR+DR with DR

Angular difference curves from NR+DR to DR only are plotted in Figure 3. The DR only caused a slight increase of the head angle compared to NR+DR, but the additional increase from NR+DR to DR only was smaller than the increase from NR to NR+DR. The neck angle on the other hand showed the opposite, the angle increased more from NR+DR to DR only than from NR to NR+DR, the increases being about 12-15° and 4-6°, respectively. Range of motion (ROM) for the neck angle during stance did not differ significantly (Table 2). The pendulation angular curves of the fore limb were much the same in both cases, apart from during the very last part of stance where DR only caused a somewhat larger angle. No significant differences were seen in the hock and stifle joint angular pattens, but the hip joint was less extended during the propulsive phase of the hind limb in the DR case. The sacrum had a larger inclination with DR only during most of stance, apart from the last 20 %. The lumbar back was more horizontal during the first half and during the terminal part of stance, with difference decreasing during the propulsive phase of the hind limb. The lumbosacral angle again showed little difference, possibly apart from last part of stance were there was a tendency towards decreased flexion in the DR case. The hind hoof pendulation angle seemed to decrease slightly with DR only at both hoof placement and lift off compared to the combination of reins, but significant differences in minimum and maximum angles were not found (Table 1).

Table 2: Range of motion in degrees for the angle between the neck and the scapula

	Mean	S.d.
DR	15,9	4,69
NR+DR	16,0	5,19
NR	14,4	2,35

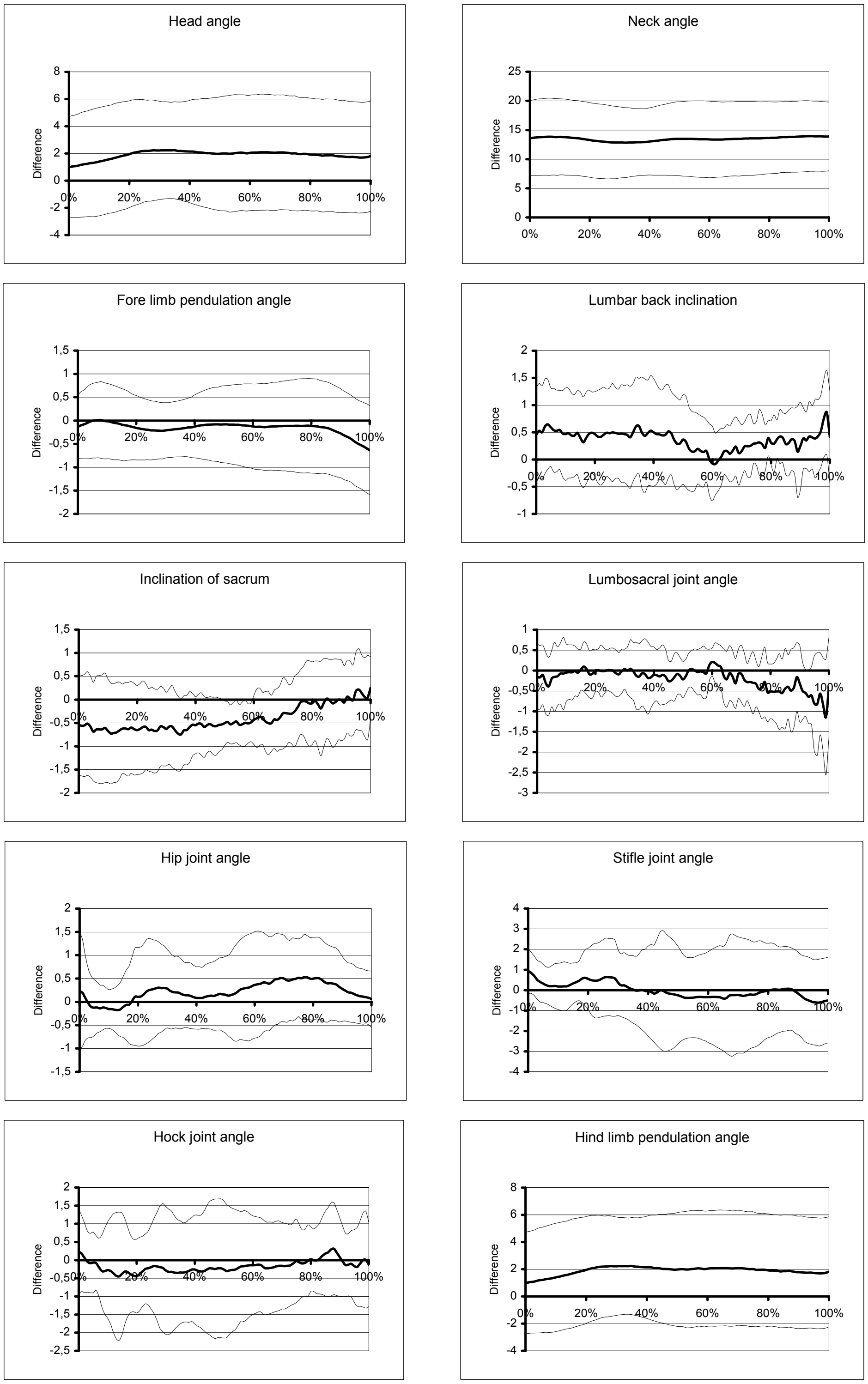


Fig 3: Curves of mean (thick line) and s.d. (thin line) angular difference from NR+DR to DR.

DISCUSSION

Roepstorff and colleagues (2002) found that when riders added a draw rein to the normal rein their horses showed significantly lower vertical GRF maximum in the fore limb as well as increased vertical and propulsive impulses in the hind limb. Also, the vertical impulse of the fore limb divided by hind decreased significantly. The DR used as single rein did however not cause the same effect. Both vertical and propulsive impulses where found to be significantly lower and the retarding impulse higher in the hind limb compared to the NR+DR registrations. When comparing NR with DR only significant changes were found mainly in the retardation phase in the hind limb, with the retarding impulse being increased and propulsive impulse divided with braking being lower in the hind limb in the later experimental condition.

The most obvious kinematic difference between the different experimental set-ups was changed head and neck angles, predominantly during the first half of stance. The effect being more pronounced during first 50 % of stance can be explained from the fact that horses moving freely tend to raise their head and neck during this part of stance, while lowering it during the later part. Although angular differences for the head and neck are numerically large, it seems however rather unlikely that these changes are the major cause for the differences observed in GRF patterns with the various combinations of reins. Thereby not suggesting that head and neck position and movement does not influences the loading of the fore limbs, this is a known fact well demonstrated by the lame horse decreasing its movement of the head and neck during the lame stance in order to decrease loading on the painful limb. But if the head and neck angles where crucial for GRF patterns, the DR only condition should then have caused a larger shift of weight towards the hindquarters than did the NR+DR combination, as the neck angle decreased 15-20° with DR only compared to only 4-6° with the combination of reins. This was however not found to be the case. Also, as stated by Buchner (2001), the effect of the static influences on the position of the body centre of mass due to different head positions are relatively small in comparison with the dynamic effects of head and neck movement. If the head is moved caudally by 10 cm, this will transfer only about 0.1 N/kg from fore to hind limb. And, the ROM for the neck angle during stance did not differ significantly between the different experimental conditions. Therefore, decreased ventral acceleration of the head during stance is not a probable explanation. Furthermore, changes in head and neck angles give no explanation for the observed differences in horizontal GRF patterns in the hind limb. Altering head and neck position by the use of various types of reins has previously been found to mainly effect the kinetics of the fore limb, whereas positive effects on the hind limb variables were few (Biau *et al.* 2002). All three types of reins tested (rubber bands, Chambons, Back lift) were found to significantly increase the fore limb propulsion at trot. In the hind limb however, increased dorsoventral activity was found only with Chambons type of rein, and none of the reins increased hind limb propulsion at trot.

The fore limb pendulation showed much the same changes when a draw rein was used, whether as single rein or together with the normal rein. In both cases the angle seems to have become progressively larger throughout stance compared to the NR values. The difference curves both start from little or no difference at hoof landing, then drop more or less linearly with stance time. However, during the last 10-20 % of the fore stance trends differ. During this part the angular difference from the NR condition decreases with NR+DR, whereas it increases for DR only. This is further illustrated by a sharp dip in the difference curve comparing NR+DR with DR only, and is also confirmed by the fact that the maximum angle of the fore limb pendulation increased significantly from the NR condition with DR as single rein but not with NR+DR. A numerical increase of average, though slight (0,64°), was however observed also in the later case. Reviewing kinetics it seems quite clear that the draw rein have altered the horizontal GRF parameters in opposite directions whether it was used as single rein or in conjunction with the normal rein. Compared to the NR situation, values representing braking force tend to decrease and those related to propulsion tend to increase with the combination of reins, whereas much the opposite was found with the draw rein alone. This is true for almost every value in both fore and hind limbs, although not all changes are in the magnitude of statistic significance. These findings indicates that a seemingly similar change in the fore limb pendulation may in fact represent two different conditions. A possible explanation is that in the NR+DR situation the increase in propulsive impulse, particularly in the hind limbs, causes the horse's body to move faster forward during the later part of stance and therefore the horse to pass more quickly over it's fore limb. Speed then decreases as the propulsive force declines, leaving the position of hoof lift-off more or less at the same as with NR only. In the NR+DR case the observed change in angular pattern would then represent an actively quicker fore limb movement. In the DR only condition increased propulsion is not seen, the propulsive impulse is in fact significantly decreased from the NR+DR situation in both fore and hind limbs. Faster caudal movement of the fore limb in this case may therefore be merely a passive effect of the horse being on the shoulders "falling forward" over the limb with the centre of gravity tilting downwards. Such an explanation is further supported by the fact that with DR only the difference curve increases its slope during the last 20 % of stance, when the centre of gravity is in its most forward position with respect to the fore hoof, and by the fact that the maximal angle of the fore limb during stance is significantly greater with DR only, compared to the NR. Altogether these facts truly give the impression of a passive backward sweep of the fore limb rather than the quicker, more powerful motion as assumed in the NR+DR case.

The one angular curve in which changes most closely follow observed changes in propulsive force in the hind limb is the hip joint angle. The hip joint had increased extension with NR+DR compared to NR only during the propulsive phase of the hind limb, with the difference being greater than 1 s.d. from 50 to 70 % stance, the part of stance during which the horizontal GRF increases most rapidly. The difference then decreased towards the end of stance, from 80 % onward, the time at which the propulsive force of the hind limb normally starts to decline. This may indicate that the hip joint extended more quickly in the NR+DR case, rather than extended to a larger maximum. A quicker extension can be coupled to the significant increase in propulsive impulse seen in GRF data when comparing NR with NR+DR. In the DR only case there is very little difference the in hip joint angular pattern from the NR condition and, also, there were no significant changes in propulsive force in the hind limb. When comparing NR+DR with DR only, differences in angular pattern of the hip joint are again mainly observed during the propulsive phase of the hind limb, although being of smaller magnitude than with

NR+DR compared to NR. At the same time kinetic data showed a slightly larger difference in propulsive impulse with the former comparison, as well as significantly increased propulsive power in this case. These findings thus partly contradict a close coupling between hip joint angular pattern and hind limb propulsion. However, a smaller difference in angular pattern between NR+DR and DR only, despite the differences in horizontal GRF being somewhat larger, may be due to the slightly larger difference in the vertical GRF observed as NR+DR is compared with DR rather than NR. The femur being the most important factor for the hind limb propulsion has been suggested previously (Holmström *et al.* 1994). Holmström and colleges (1995) found that the femur inclination decreased with more collection, a finding that was interpreted as implicating that propulsion emanates mainly from the femur. The inclination of femur in the square standing horse also turned out to be the one conformational detail that showed the highest correlation to gate scores (Holmström and Philipsson 1993).

The hock and stifle joint angles may be important for the horse in order to carry more weight on the hind limbs. Holmström and colleagues (1995) found that in piaffe the hock and stifle joint angles were significantly more flexed at the beginning of stance phase and that the hock joint had a smaller minimum angle at the middle of stance compared to trot in hand, working and collected trot, respectively. These changes correspond quite well with changes observed in the angular patterns of the hock and stifle joints when adding a draw rein to the normal rein. Kinetic data also implies that these changes may be coupled to an increase in the vertical load of the hind limb. The increased hock and stifle joint angles could represent effects of increased vertical loading of the hind limb, or may possibly be the very cause for a shift of weight from fore to hind by lowering the hindquarters. Slightly increased flexion of the hock joint during initial stance, as well at lower angular values for the hock and particularly the stifle throughout the middle part of stance, was however observed also in the DR only condition. Increased flexion in this case may perhaps be explained from significantly higher braking impulse in the hind limb compared with NR, as increased vertical load was not observed with DR only, whereas the combination of reins rather tended to decrease the braking impulse compared to the NR. The hock angular difference curve also showed an apparent increase in between horse variation during early stance in comparing DR and NR. This was not seen with NR compared to the combination of reins and may indicate that the horses somewhat differed in their reaction to the draw rein used as single rein, whereas the reaction to the combination of reins was more uniform with respect to the hock joint angular pattern.

The pelvis inclination, the hock joint angle, the hind fetlock joint angle, and possibly also the stifle joint angle have been suggested as the most important contributors for storage of elastic energy in the hind limb (Holmström *et al.* 1993, 1994). When adding a draw rein to the normal rein the sacrum was found to decrease its inclination during maximal vertical load of the hind limb, from 40 to 70 % stance. Then during the later part of stance, when off-loading of the hind limb begins, the difference decreased with tendency towards increased inclination in the NR+DR case at the very end of stance. Interpreted in conjunction with the fact that the hock joint increased its flexion at the beginning of stance and at midstance followed by difference decreasing to zero during the last 20-25 % of stance, this may indicate improved absorption and release of elastic energy in the hind limb in the NR+DR case. Increased storage of elastic energy may contribute to more efficient propulsion, as seen in the GRF data as significantly increased propulsive impulse. At the beginning of stance, corresponding flexion peaks are also seen in the hip and stifle joint angular difference curves. The stifle joint, which was slightly more extended in the NR+DR situation at the beginning of stance, flexed more rapidly during the first 10 % and then slowed its flexion reaching no difference compared to NR at 25 % stance. This may indicate a slight contribution from the stifle region as well in storage and release of elastic energy during the initial part of stance. Similar patterns are not seen in a consistent way with DR only. There are some changes in above mentioned angles in this case as well, but these are better explained by decreased vertical load and decreased activity of the hip extensors, indicated in GRF data as significantly lower vertical and propulsive impulse and lower propulsive power with DR only compared to NR+DR. Increased storage of elastic energy may be positive for the performance in the riding horse. Previous studies have found that horses with good gates seem to have a higher level of compression (increased flexion of the hind limb joints during stance) compared with poor movers, resulting in greater storage of elastic energy. A higher level of compression was also pointed towards in Grand Prix dressage horses performing passage, when this gate was compared to trot in hand. Greater compression was therefore stated probably contributing to the larger springiness of horses with superior gates and as well as Grand Prix dressage horses (Holmström *et al*. 1994, 1995, 1997).

Cano and co-workers (2000) investigated the influence of a 10-month training program on the kinematics in the trot of sixteen young, male, previously untrained Andalusian horses. They found that after training the horses were significantly more flexed in their hind limb joints (hip, stifle, hock and hind fetlock) at the moment of ground contact and presented a greater hind limb protraction. Training also produced increased flexion of the proximal joints (hip and stifle) at midstance and at lift off. The inclination of the pelvis became lower at midstance. The hip and stifle joints being more flexed after training was interpreted as possibly suggesting improved storage of elastic energy and thus, a contribution to greater impulsion. Much the same changes were found in the present study when comparing NR to NR+DR. However, we found an increased extension of the hip joint rather than a smaller angle and the hind limb protraction did not change significantly with any combination of reins. This may be due to the different training methods used, differences in conformation between horse breeds, or differences in the effects of training during one session and over longer time. It is possible that with long time training, increased muscular power of the hip extensors may allow for the horse to generate the same propulsive impulse with lesser extension of the hip joint, performing a shorter but quicker movement. This seems likely, as training tends to lower the hind limb stance percentage (Back *et al*. 1995, Cano *et al*. 2000).

A study comparing the kinematics of the trotting gate in two groups of horses judged as having good and poor gate quality at the trot (Holmström *et al*. 1994) found that the pelvis inclination decreased, the femur inclination increased and the hind fetlock joint angle flexed more during the stance phase in the good horses than in the horses with inferior gates, whereas the hock joint angle was somewhat more flexed in the horses with good trot at the middle of stance and more extended at the beginning of the swing phase. In a later study of angular velocities in the same horses (Holmström *et al*. 1997) it was found that in the group of horses judged as poor, the angular velocity of the pelvis was almost zero during the second half of the stance phase. During the same period, the good horses had first a negative angular velocity and then shifting to a positive velocity at approximately 80 % of stance. The findings by Holmström *et al*. are thus much the same as the differences found in this study when comparing NR with NR+DR, although not all of them being statistically significant. This may suggest that supplementing a draw rein to the normal rein improved the gate quality in the hind limb of the horses in this study.

The material presented here is in our knowledge the first attempt to evaluate horse and rider interaction using simultaneous and synchronized kinetic and kinematic registrations. The results show interesting implications. Although well corresponding with previous studies, the findings should however be interpreted with some care. Unfortunately not all runs used for calculation of average GRF curves have been available for kinematic analysis. In several cases one or more runs had to be excluded in the process due to some horses having lost a particular marker or problems where the cameras have not been able to film all markers during the entire stance phase. A minimum of two runs per horse was used for averaging, if two runs were not available that particular horse was excluded in the overall average for that particular angle. However, in sound horses both kinematic and ground reaction force (GRF) variables are quite stable as long as the horses are trotting at constant speed. Analysis of a relatively small number of strides can therefore be considered representative for the gait pattern. It has been suggested that 3-5 strides are sufficient for kinematic (Drevemo *et al*. 1980) as well as GRF (Schamhardt 1996) analysis. Low variations is also strongly pointed towards in the present material as there is very little difference in average stance duration from the original data used for GRF evaluations (Roepstorff *et al*. 2002) to the reduced data in the present work, practically no difference in the fore limb (87,27 ms in both data series) and only 0,35 ms in the hind limb. This should ensure a fairly good accuracy, at least for joint angle data, despite the limited number of runs per horse. In the head and neck angles there were a somewhat larger within, as well as between, horse variation. However, the differences between the experimental set-ups were larger for head and neck angles compared to joint angular data and the results found are in line with the subjective impression of the effects on a horse ridden with draw reins, giving reassurance that these data as well are valid. And since the recorded data is fairly unique, low static power of the results should not preclude interest in the findings. Due to the fact that considering significant changes only in some parts appear insufficient to explain observed differences in GRF patterns it seems reasonable include kinematic tendencies as well in the discussion, especially when several angles show a common trend. The changes observed in joint angular patterns are quite subtle and a larger number of horses is therefore likely to be required in order to find them statistically significant. It is also possible that there are significant effects on the sum of the hind limb angles, while not significant for any particular joint. Further studies are however needed to validate and confirm suggested relations between kinetics and kinematics.

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