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AUTHORS: Line Greve, **Sue Dyson**

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Body lean angle in sound dressage horses in-hand, on the lunge and ridden

Line Greve [a,b,]*, Sue Dyson [a]

[a] *Centre for Equine Studies, Animal Health Trust, Lanwades Park, Kentford, Newmarket, Suffolk CB8 7UU, UK*
[b] *Department of Clinical Science and Services, Royal Veterinary College, University of London, Hawkshead Lane, North Mymms, Hatfield AL9 7TA, UK*

* Corresponding author. Tel.: +44 163 8751908.
E-mail address: line.greve@aht.org.uk (L. Greve).

Highlights

- Animals can minimise the risk of falling by leaning into a curve.
- Horses ≤ 6 years of age leant more than predicted compared with horses ≥7 years of age.
- Ridden work-quality grade was significantly associated with leaning.
- There were no differences in lean between trot and canter, on the lunge or ridden.
- There were no differences in leaning between left and right reins.

Abstract

Animals can minimise the risk of falling by leaning into a curve. The aims of this study were: (1) to quantify the difference between observed (measured by an inertial measurement unit, IMU) and predicted body lean angle (calculated as a cyclist when turning) in horses; and (2) to compare circles versus straight lines ridden versus in-hand and trot with canter, and investigate the influence of age, rein and ridden work quality in trot (Fédération Equestre Internationale grading scale 1-10) in horses. Thirteen non-lame horses were assessed prospectively in a non-random, cross-sectional survey. The horses were trotted in straight lines, lunged and ridden on both reins. A global positioning system-aided IMU attached to the skin over the tuber sacrale quantified body lean and recorded the velocity and the radius, which were used to calculate predicted lean. Horses ≤ 6 years of age leant more than predicted (mean ± standard deviation 2.9 ± 2.6°) and more than horses ≥ 7 years' old (0.4 ± 3°) (*P* = 0.01). Horses that scored ≥ 7 in ridden work quality leant less than predicted (-1.1 ± 2.7°) and less than horses which scored ≤ 6 in ridden work quality (2.4 ± 1.5°) (*P* = 0.02). There were no significant differences between trot and canter, either on the lunge or ridden ($P = 0.3$), or between left and right reins ($P = 0.2$). Asymmetry of body lean between reins may be abnormal and may be helpful for recognition of lameness.

Keywords: Equine; Body lean; Inertial measurement units; Balance; Musculoskeletal coordination

Introduction

Horses are frequently worked in circles. Moving on a circle requires steady changes in direction. The resultant force is not aligned with gravity, but directed towards the centre of the circle, with a magnitude that depends on the velocity of the horse (v) and the radius (r) of the circle (transverse acceleration = v^2/r) (Pfau et al., 2012). The force (F_r) is perpendicular to the velocity and is the product of the mass (m) of the moving object multiplied by the acceleration.

Stability of turning is crucial in vehicle design (Ellis, 1994). If a vehicle turns with excessive transverse acceleration, it will roll over. Cyclists and animals can minimise the risk of falling by leaning into a curve. The degree of lean depends on the ratio of trackway width to the centre of mass height (the point on an object at which the weighted relative position of the distributed mass sums to zero, i.e. the point about which objects rotate). If a trackway width is effectively zero (the left and right feet are set down along a single line), the animal would have to lean in at an angle to the vertical corresponding to $\tan^{-1}$ (v^2/rg, where g is the gravitational acceleration, 9.8 m/s^2), similar to a turning cyclist (Alexander, 2002; Cain and Perkins, 2012). For the same velocity a turn of smaller radius requires increased lean. Previous studies in horses have indicated that this prediction is applicable to trotting horses when turning during lungeing (Pfau et al., 2012; Brocklehurst et al., 2014). However, whether this prediction can be used in canter and whether horses of different ages and quality of work will lean similarly or differently when turning, compared with what is predicted based on the radius and velocity, has not been investigated. It has been suggested that the ability of human runners to run on a circular path might be limited by the ability of the musculoskeletal system to generate the required forces (Greene, 1985).

If a similar hypothesis is applied to horses, one would expect that older horses, which have been trained more, may have developed a better core stability and muscular strength to maintain a more vertical orientation of the body when turning, compared with young, untrained horses, which are less well-balanced and coordinated. However, our understanding of the stability and cornering of sound horses of different ages, and at different levels of training, is limited.

The aims of this study were to quantify the difference (diff.obs.pred) between observed (obs) body lean angles (measured by inertial measurement units, IMUs; Pfau et al., 2012; Brocklehurst et al., 2014) and predicted (pred) body lean angles (calculated as though horses behave as cyclists when turning, i.e. $\tan^{-1}$, equivalent to v^2/rg; Alexander, 2002) in sound horses when trotting in-hand in straight lines and on a circle on the lunge, and ridden, comparing left and right reins, in both trot and canter, on a soft surface. The objectives were: (1) to determine the difference in diff.obs.pred among horses in-hand in straight lines, on the lunge and ridden; (2) to investigate the influence of age, rein and the effect of ridden work quality on diff.obs.pred; (3) to determine the association between head/pelvic symmetry measures and diff.obs.pred; and (4) to compare diff.obs.pred in trot and canter.

It was hypothesised that: (1) younger horses lean more than predicted into a circle than older horses; (2) ridden horses lean more or less than predicted on circles, depending on the work quality (the higher score, the more vertical) compared with horses on the lunge; and (3) there would be no differences in diff.obs.pred between reins and between trot and canter.

Materials and methods

A cross-sectional study was performed comprising sports horses in regular work, presumed by the riders to be sound. This was a convenience sample, selected based on proximity to the authors and in order to obtain a uniform population of sports horses of different age groups. All horses were ridden by the normal rider in usual tack and had no recent history of lameness or thoracolumbosacral pain. Age, breed, sex and height (copied from the passport) were recorded. Body weight was estimated using a weight tape (Equimax, Virbac, Barneveld). Body condition score was assessed using a nine-point scale (Henneke et al. 1983), the repeatability of which has been verified (Greve and Dyson, 2013a, b). Work discipline and level of training or competition were recorded. The study was approved by the Ethical Review Committee of the Animal Health Trust (AHT 14.2014; 28 February 2014) and there was informed owner consent.

Comprehensive lameness examination

The horses underwent a comprehensive gait examination as described below and ‘sound’ horses were selected for inclusion in the study (Dyson and Greve, 2016). An overall grade of ‘sound’ was given if no lameness was detectable in-hand, on the lunge or ridden, and lameness of not more than 2/8 (n = 3) or 1/8 (n = 3) was detected in a single limb after flexion tests (Dyson, 2011).

The initial sample comprised a professional show jumping yard (*n* = 16), a dressage competition yard (*n* = 5), a dressage training centre (*n* = 27) and a private dressage yard (*n* = 7). All horses were examined moving in-hand, on a hard surface approximately 40-50 m long and the presence of lameness was graded on a 0-8 scale (Dyson, 2011). Horses were also examined on the lunge in a 15 m diameter circle on both soft and hard surfaces. All horses were assessed while being ridden around the perimeter of an arena in 'working trot rising' and in canter. Horses were also evaluated in 10-15 m diameter circles (depending on the level of training) in 'working trot rising'. Horses were ridden by the regular rider or trainer. The horses were assessed from two corners of the arena so that all were assessed from behind, in front and from the side. If, during ridden exercise, a stiff-stilted gait in canter or quadrupedally shortened cranial phase of the step were noted, affected horses were classified as lame (Greve and Dyson, 2014).

Distal limb flexion tests of the forelimbs and proximal limb flexion tests of the hind limbs were performed in a standard order (left forelimb, right forelimb, left hind limb, right hind limb) for 1 min each after the initial in-hand assessment. All flexion tests were performed by the same experienced clinician (SJD). A positive response was the presence of lameness for more than three strides. The grade of lameness was documented. The thoracolumbar region was palpated systematically (Girodroux et al., 2009) by the same clinician (SJD) after in-hand and lungeing exercise, and the presence of pain or abnormal muscle tension was recorded on a binary yes/no scale.

All horses were handled by experienced people, familiar with the horses. The handlers were asked to allow the horses to trot at unrestrained speeds in-hand and on the lunge. All horses at each yard were assessed consecutively in-hand, after flexion tests and on the lunge. Ridden exercise of all horses was then performed in a randomised order.

Inertial measurement units

Thirteen horses had global positioning system (GPS) data obtained. Objective gait assessment was performed 4-14 days after the initial gait assessment. Three MTx (Xsens, Enschede) (18x gravity, 1200 °/s) and one modified MTi-G (Xsens, Enschede) (18x gravity, 1200 °/s) miniaturised IMUs were applied to each horse. The IMUs were attached to the head (the poll, using a custom-made Velcro attachment to the head piece of the bridle) and to the skin over the left (LTC) and right (RTC) tuber coxae (the sensors were in custom-made pouches and attached with double-sided tape (F ball Impact Tape, F. Ball Company). The MTi-G, which also contained a GPS and a pressure sensor, was attached over the tuber sacrale with a custom-made pouch with double-sided tape. The external GPS antenna was attached approximately 5 cm to the right of the GPS-enhanced IMU. An elasticated surcingle was used to fix the wireless transmitter unit (Xbusa, Xsens, Enschede) to the horse's body during lungeing and attached to the rider using a custom-made belt during ridden examination (See Appendix: Supplementary Fig. 1). Sensors were attached in two strings (1, head; 2, left tuber coxae, tuber sacrale, right tuber coxae) to the Xbusa transmitting IMU data at a sampling rate of 100 Hz per individual sensor channel.

Dynamic assessment with inertial measurement units

Horses were first lunged on the left rein followed by the right rein using a consistent lungeing technique, with a lunge line attached to the inside bit ring. The handlers (selected according to their familiarity with the horses) were asked to use the same lunge line with a fixed length of 5 m, resulting in a circle diameter of approximately 12 m. IMU and GPS data were collected for at least 30 strides. Notes and video recordings acquired during data collection described deviations from the expected movement condition, e.g. changes in gait, speed or gait quality. If a horse deviated from the required movement condition (e.g. broke into a different gait) data collection was repeated. Horses were lunged and ridden on the same soft surface without changing the position of the IMUs between recordings. One trot and one canter trial at the horse's preferred speed both on the lunge and ridden on 10-20 m diameter circles on both left and right reins in trot and canter were recorded. The video recordings of the horses were acquired from two corners of the arena, so that horses were assessed from in front, from behind and from the side.

Work quality

The work quality of the horses when ridden was graded using a 0-10 scale for trot as for Fédération Equestre Internationale dressage scoring[1] during the initial assessment and again during the video recordings (See Appendix: Supplementary material; Greve et al., 2015). Complete agreement was achieved. Grading was performed by one author (SJD, a British Horse Society Instructor) blinded to the other results. If horses had ≥ 1 grade difference between the left and right reins for trot, the lower grade was assigned. An inter-assessor and intra-assessor repeatability study on work quality has been performed previously (Greve et al., 2015). During riding the horses were assigned to two groups based on the trot grade: group 1 scored ≥ 7 and group 2 scored ≤ 6 (grades ≥ 7 are classified as ≥ fairly good).

Data analysis

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[1] See: https://www.fei.org/sites/default/files/DRE-Rules_2016_GA-approved_clean.pdf (accessed 11 June 2016).

Vertical displacement of the head, tuber sacrale and left and right tuber coxae was determined. Processing of IMU data followed published methods (Pfau et al., 2005) with custom-written software in MATLAB (Mathsworks).

Kinematic symmetry measures - The following kinematic symmetry measurements for the head and pelvis (symmetry index, MinDiff and MaxDiff) and HipHike Difference (HHD) were based on vertical displacement of the upper body landmarks and calculated. The symmetry index was calculated based on the movement amplitudes between the two halves of a stride (Buchner et al., 1996; Uhlir et al., 1997). 'MinDiff' and 'MaxDiff' were defined as the difference between the two minima and maxima of the left and right diagonal stance phases (Kramer et al., 2004). HHD was defined as the difference between the two tuber coxae movement amplitudes, each quantified during contralateral stance (Starke et al., 2012). A horse moving perfectly symmetrically would have a symmetry index of 1 and a MinDiff, MaxDiff and HHD value of 0. Detailed description of the calculations can be found elsewhere (Pfau et al., 2012; Starke et al., 2012).

Predicted body lean angle - Predicted body lean angle was calculated based on GPS-obtained velocity and circle radius using the following equation $\tan^{-1}(v^2/rg)$, as used by Pfau et al. (2012).

Differences in observed and predicted body lean angles (diff.obs.pred) - When using IMUs, the observed body lean angle has been defined as the amount of rotation of the entire trunk determined from the GPS-enhanced IMU positioned over the tuber sacrale. Differences in observed and predicted body lean angles were calculated (diff.obs.pred) by subtracting the predicted value from the observed value measured by the GPS-enhanced IMU positioned over the tuber sacrale. Positive values of diff.obs.pred indicate that horses are leaning more into the circle than predicted and the inward lean was less than predicted if the values of diff.obs.pred were negative.

Statistical analysis - Sample size calculations are presented in the Supplementary material (see Appendix). Descriptive analysis was carried out for gait symmetry and diff.obs.pred. Mean ± SD and range of diff.obs.pred across horses for each condition were calculated. The data were assessed for normal data distribution via the Shapiro-Wilk test. A paired *t* test was used to determine the difference in diff.obs.pred between left and right reins and between trot and canter. A two-sample *t* test was used to determine the associations between diff.obs.pred and age groups ($\leq$ 6 years of age versus $\geq$ 7 years of age) and work quality groups (grade $\leq$ 6 for trot versus $\geq$ 7). A linear regression was used to test the association between head/pelvic symmetry measures and diff.obs.pred. A mixed-effect linear regression model was performed to assess the relationship between kinematic symmetry values for both head and pelvis, age groups, a combined variable of work quality group and exercise condition containing four categories (category 1 = all horses in-hand; category 2 = all horses on the lunge; categories 3 and 4 = all horses ridden, divided into two separate groups based on their work quality score: category 3 = all horses ridden that scored $\geq$ 7; category 4 = all horses ridden that scored $\leq$ 6) and outcome variable diff.obs.pred in trot using backward elimination. There was a linear relationship between outcome variable and each explanatory variable verified based on a large Pearson’s correlation (> 0.7). All analyses were adjusted for the clustering effect of the horse by including horse as random effect. Those variables that were statistically significant at $P < 0.20$ were put forward for inclusion in a multivariable, mixed-effects linear model. Two-way interaction terms for all variables retained in the final model were assessed. Final model results were reported as mean and *P* values. All statistical analyses were performed using SPSS Statistics 20 (IBM), with significance set at $P < 0.05$.

Results

Animals

Horse details are summarised in the Supplementary material (see Appendix). At the initial horse selection examination, 11 horses were sound under all circumstances. One horse had grade 2/8 left hind limb lameness and one horse had grade 1/8 right hind limb lameness, induced by flexion tests. None of the horses exhibited muscle hypertonicity or pain on palpation of the thoracolumbar region after the initial lameness examination. A mean of 32 strides/trial were acquired. Data acquisition was performed in an outdoor arena with sand and fibre on a firm base ($n = 2$) and in an indoor arena with a deep, non-uniform, sand surface, with a small amount of fibre ($n = 11$).

Gait symmetries

Gait symmetry data is summarised in Fig. 1 and the Supplementary material (see Appendix).

Quantification of diff.obs.pred body lean angle

The mean ± SD of diff.obs.pred was 3.2 ± 0.4˚ in-hand in straight lines (diff.obs.pred equals obs because pred = 0); 3.8 ± 1.5˚ on the lunge for group 2 ($n = 7$); 2.4 ± 1.5˚ ridden on 10-20 m circles for group 2; -0.1 ± 2.9˚ on the lunge for group 1 ($n = 6$) and -1.1 ± 2.7˚ ridden on 10-20 m circles for group 1. There was a significant difference in diff.obs.pred between age groups. Horses ≤ 6 years of age leant significantly ($P = 0.01$) more than expected (diff.obs.pred 2.9 ± 2.6°) compared with horses ≥ 7 years of age (0.4 ± 3°), with slightly greater variation among older horses. Error bars for diff.obs.pred body lean angle for the two age groups are shown in Fig. 2. Diff.obs.pred body lean angle was also influenced by work quality. Horses in group 1 ridden leant less than predicted (-1.1 ± 2.7°) and less than group 2 ridden (2.4 ± 1.5°; *P* = 0.02). On the lunge the apparent differences (group 2, 3.8 ± 1.5° versus group 1, -0.1 ± 2.9°) were non-significant (*P* = 0.1). There were no significant differences in diff.obs.pred between trot and canter either on the lunge or ridden (*P* = 0.3), or between left and right reins (*P* = 0.2). There was no association between the work quality grade and age (*P* = 0.6).

In the mixed effect model, comprising horse as a random effect, diff.obs.pred as outcome variable, age-groups, a combined variable of work quality group and exercise condition containing four categories (category 1 = all horses in-hand; category 2 = all horses on the lunge: categories 3 and 4 = all horses ridden, divided into two separate groups based on their work quality score; category 3 = all horses ridden that scored ≥ 7; category 4 = all horses ridden that scored ≤ 6) and head/pelvic kinematic symmetry measures as fixed effects, only the combined variable of work quality group and exercise condition retained significance as illustrated by the mean ± standard error (SE) in Fig. 3.

The parameter estimates ± SE, 95% CIs and post hoc comparisons among the categories are given in Table 1. There was no significant difference in diff.obs.pred among group 2 ridden compared with all horses in-hand in straight lines and all horses on the lunge. However, horses in group 1 ridden had significantly smaller diff.obs.pred (mean ± SE -1.1 ± 0.9°) compared with group 2 ridden (2.4 ± 1.1°) (*P* = 0.02). Horses in group 1 when ridden leant less than all horses in straight lines in-hand (3.2 ± 0.8°) (*P* = 0.001). All horses in-hand in straight lines leant consistently more than predicted (which should be zero because the radius is zero) towards the handler. Horses in group 2 when ridden leant on average more than predicted into the circle, whereas horses in group 1 when ridden on average leant less than predicted into the circle (Table 1; Fig. 3).

Discussion

This study showed differences in body lean between young and older horses and between horses with different work qualities. Horses ≤ 6 years of age leant significantly more than predicted compared with horses ≥ 7 years of age. Horses which scored ≤ 6 in trot ridden leant more into the circle during ridden exercise compared with horses which scored ≥7 in trot ridden. Both observations are in agreement with our hypotheses. A better understanding of the difference between observed and predicted body lean angle [diff.obs.pred] body lean angle in normal sound horses of different ages and level of training is important in order to distinguish normal ('sound') horses from horses with pain-related gait abnormalities.

We found a significant influence of age groups on body lean angle, presumably because young horses do not have the level of musculoskeletal strength, coordination and balance of older horses that have been in training for much longer (Dyson, 2013). There have been limited investigations into how riding skills are developed from novice to expert riders and how this may influence the quality of movement of the horse (Greve and Dyson, 2013b). However, the degree of lameness measured by the vertical movement of the head and pelvis can be altered by the skill level of the rider (Licka et al. 2004).

There is also evidence that expert riders sustain a movement pattern in synchronisation with the movement of the horse (Peham et al., 2001; Lagarde et al., 2005; Clayton et al., 2011) and that skilled riders maintain horses in balance, working in a correct frame on the bit

(Peham et al., 2004). It is possible that skilled riders are able to make continually subtle adjustments to the horse's balance going round the perimeter of a circle to maintain a more vertical orientation of the horse's body when turning. This may result in long-term development of muscular support and core strength of the horse, so that it is able to turn with less lean than young untrained horses, which would concur with the results of the current study.

Movement symmetry differed between straight lines and circles, which has been previously described both subjectively (Dyson, 2013) and objectively (Walker et al., 2010; Starke et al., 2012; Rhodin et al., 2016). In the current study, there was no association between head and pelvic symmetry measures and the difference between observed and predicted body lean angle. However, the observed body lean angle and pelvic symmetry measures were associated, as previously documented (Pfau et al., 2012). However, if the radius and velocity were taken into account in order to calculate the difference between observed and predicted body lean angle, there was no longer an association with pelvic/head symmetry measures.

In the current study, there was no significant difference in kinematic symmetry measures between lungeing and riding in circles. However, in a previous study, there was more pelvic asymmetry when horses were ridden on circles in rising trot compared with lungeing (Robartes et al., 2013). This may reflect both an effect of the weight of the rider on hind limb gait and the diagonal on which the rider was sitting, both of which may be influential in horses with subclinical lameness (Dyson, 2013). From a clinical perspective some hind limb lameness are more easily seen ridden than on the lunge; on the lunge, a horse can reduce the apparent degree of lameness by other adaptations (e.g. leaning, looking out, alterations of limb flight), which may be controlled to some extent when ridden. With increasing body lean subjective assessment of movement of the tuber coxae and tuber sacrale is more challenging than when the body is held more upright. Hind limb lameness may be worse with the lame limb on the outside when lunged and on the inside when ridden, or vice versa; the rein on which lameness is most apparent may also vary depending on circle diameter (Dyson, 2013). This emphasises how important it is to assess horses both on the lunge and ridden (Dyson, 2016).

Body lean may be influenced by lameness. Some horses adapt to lameness by increasing body lean angle on one rein compared with the other during lungeing (L. Greve and S. Dyson, unpublished data). Following improvement in lameness using diagnostic analgesia, body lean on the left and right reins becomes more symmetrical. We have demonstrated previously that the work quality score is significantly higher in sound horses than lame horses (Greve and Dyson, 2015). It is well-documented in the human literature that pain may be detrimental to the motor (movement, strength, activation) and sensory (proprioception, balance) components of muscle function (Hassan et al., 2002; Hirata et al., 2011; Zhang et al., 2015). It is possible that different trunk leaning patterns, limb inclinations and limb flexion patterns alter limb forces and reduce pain.

If there had been a good match between observed and predicted body lean angle, as described in previous studies (Pfau et al., 2012; Brocklehurst et al., 2014), it would be expected that CIs would include zero, which was not the case for group 2 ridden and horses ≤ 6-years of age. Predicted lean takes into account both radius and velocity, which therefore allows comparison between different conditions, e.g. lungeing and ridden. In the current study, horses leant less than predicted in ridden trot if they scored ≥ 7 in work quality and leant less compared with lungeing. This may be because the riders kept the horses in a better balance compared with on the lunge and the horses are trained to maintain a vertical orientation of the body. There were no significant differences between observed and predicted body lean angles at trot and canter when comparing similar conditions both on the lunge and ridden, suggesting that the individual horse-specific work quality and thus level of training, strength and muscular support are good predictors of body lean in both trot and canter.

The lack of constraint of horses on the lunge probably accounts for the greater variability of body lean angles on the lunge compared with ridden work. Different results may have been obtained if the horses had been lunged in side reins, a chambon, a Pessoa Training Aid or other devices. During ridden work, horses with a trot quality grade of ≤ 6 leaned significantly more than predicted compared with horses which scored ≥ 7. Thus, there is evidence that the rider has a potential influence on body lean angle and with better work quality there is less body lean angle. It appears that dressage horses are undergoing training that enables the horses to maintain a more vertical body orientation in circles compared with untrained horses with poor quality of work.

In this study, the horses were ridden by skilled professional riders; the same results may not have been achieved with less talented riders. An unskilled rider, who lacks balance, may accentuate body lean angle, whereas a highly skilled rider may be able to maintain a horse in balance going around the perimeter of an arena and on small circles. One could speculate that some confounding may occur between age and work quality, and the level of training. However, in the current study, we were not able to show any association between the work quality grade and age. Future longitudinal studies of more horses should be performed.

Our study showed that horses consistently leant towards the handler trotting in-hand in straight lines, which differed from previous studies (Pfau et al., 2012; Brocklehurst et al., 2014), in which there was random variation in direction of lean among horses. This may reflect that the study comprised 'exuberant, extravagantly moving' Warmblood dressage horses ranging from 3-13 (mean 7.8) years of age; previous studies used mixed disciplines (no dressage horses) 2-19 (mean 9.7) years of age (Brocklehurst et al., 2014) or 'mature, advanced level' dressage horses (Pfau et al., 2012). This merits further investigation by comparing horses led from both the left and right sides, however this may be difficult to achieve in Warmbloods that are only accustomed to being led from the left.

When using IMUs, the observed body lean angle has been defined as the amount of rotation of the entire trunk determined from the GPS-enhanced IMU positioned over the tuber sacrale. Sensor orientation accuracy was reported by the manufacturer to be 1° under general conditions and 2.6° in Pfau et al. (2005). To account for body lean angle deviating from zero during straight-line trotting, Pfau et al. (2012) subtracted the mean value of sensor roll observed during straight-line trotting from the values observed during lungeing. It was proposed that, in straight lines, deviation of the mean value from zero was caused by imperfect sensor attachment or skeletal asymmetries of the sacral region and the value should therefore be subtracted. This could be determined by standing the horse squarely on a horizontal surface and acquiring measurements with the horse static. Based on measuring sensor orientation in lame horses with subjectively assessed pelvic symmetry (n = 5), static and standing squarely on a level surface, imperfect sensor attachment or skeletal asymmetries of the sacral region did not vary more than ± 1° (L. Greve and S. Dyson, unpublished data). It therefore seems likely that, presuming the pelvis is symmetrical, the deviation from zero in straight lines is because horses genuinely lean towards or away from the handler.

This study had some limitations. The measurements were obtained on a soft arena surface and therefore do not represent the body lean angle and movement symmetry data on a hard surface or on a different type of arena surface. Data collection was limited to four upper body landmarks. Detailed quantification of spatiotemporal limb movement parameters or limb angles have been reported (Clayton et al., 2006; Hobbs et al., 2011), but were not acquired. More detailed studies with simultaneous measurement of limb forces would complement the understanding of circular movement mechanics. We have not discussed how the horse effectuated this leaning when meeting the ground, because this was outside the scope of the current study. The results relate to dressage horses and further studies are required to determine if similar results would be obtained with horses from other work disciplines, such as eventing and show jumping. In upper level show jumping, marked body lean is observed in horses turning between fences. Two animals were ponies; because they were lunged on the same diameter as the horses, it is possible that the 'circle diameter effect' would be smaller. However, these ponies were ‘upper level’ dressage ponies.

Speed was not standardised among horses, but we were simulating a clinical situation when speed cannot be controlled. The handlers were asked to allow the horses to trot at their preferred speeds, which were subjectively very similar on the left and right reins. There were two different surfaces which could have influenced the results, but the two animals assessed outside were not in the same groups for statistical analyses; thus, the outcomes are unlikely to be related to surface type. We believe that the internal validity of work quality assessment was good, but this could not necessarily be extrapolated to other assessors.

Conclusions

This study has quantified body lean angle in sound dressage horses, showing the differences between observed body lean angle in horses exercised in-hand while moving in straight lines and horses being lunged or ridden. It has demonstrated the influence of age and the effect of the quality of work when ridden. Dressage horses moving in-hand in straight lines on average lean towards the handler. Horses ≤ 6 years of age leant more than predicted into a circle during lungeing than older horses. Horses which scored ≥ 7 in ridden work quality leant less than predicted compared with horses that scored ≤ 6. Development and determination of objective body lean angle parameters for sound horses is important to be able to distinguish normal from abnormal and to be able to use the parameters in future lameness examinations.

Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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Appendix. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi: ...

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Figure legends

Fig. 1. Mean and 95% confidence intervals (CIs) of the vertical head and pelvis movement symmetry for 13 subjectively sound horses, assessed in-hand, on the lunge and ridden. The y-axis represents the 95% CI of the vertical head and pelvis movement symmetry, and the x-axis represents the different conditions. The symmetry index was calculated based on the movement amplitudes between the two halves of a stride. The line of perfect symmetry is given as 1. Based on this line, the conditions which cause the most prominent change in movement symmetry can be seen. Values below 1 would represent patterns with right forelimb or left hind limb asymmetry. Values above 1 would represent horses with left forelimb or right hind limb asymmetry. The black bars indicate the pelvic movement symmetry and the blue bars the head symmetry index. The numbers represent the mean value. Circles, means; bars, 95% confidence intervals.

Fig. 2. Error bars showing the differences between observed and predicted body lean angles (diff.obs.pred) acquired from 13 dressage horses free from lameness. The error bars depict the mean and standard error (SE) of diff.obs.pred in degrees for horses ≤ 6 years of age (*n* = 7) compared with horses ≥ 7 years of age (*n* = 6) for all conditions, i.e. in-hand, on the lunge and ridden in trot. A mixed effect linear regression revealed a significant difference between the two groups ($P = 0.01$). Positive values of diff.obs.pred indicate that horses leant more into the circle than predicted. The inward lean was less than predicted if the diff.obs.pred values were negative. Circles, means; bars, 95% confidence intervals.

Fig. 3. Error bars illustrating the differences between observed and predicted body lean angles (diff.obs.pred) acquired from 13 horses free from lameness which were examined in-hand in

straight lines, on the lunge and ridden. The bars depict the mean and standard error of the mean (SE) of diff.obs.pred in degrees for horses led in-hand compared with lungeing and ridden exercise. The figure illustrates the results of the final mixed effect linear regression model, comprising horse as a random effect, diff.obs.pred as outcome variable, age groups, a combined variable of work quality group and exercise condition containing four categories (category 1 = all horses in-hand; category 2 = all horses on the lunge; categories 3 and 4 = all horses ridden, divided into two separate groups based on their work quality score: category 3 = all horses ridden that scored ≥ 7; category 4 = all horses ridden that scored ≤ 6) and head/pelvic kinematic symmetry measures as fixed effects, where only the combined variable retained significance. There was substantially more variation among horses being lunged compared with horses in-hand and ridden. Horses which scored ≥ 7 in trot ridden (group 1) leant significantly less than predicted when ridden compared with all the horses in-hand and compared with ridden horses which scored ≤ 6 in trot (group 2). Positive values of diff.obs.pred indicated that horses leant more into the circle than predicted or towards the handler (which was zero since radius is zero) and the inward lean was less than predicted if the diff.obs.pred values were negative. Circles, mean; bars, 95% confidence intervals.

Table 1. Results of multivariable mixed effect linear regression of the differences between observed and predicted body lean angles acquired from 13 dressage horses free from lameness, assessed in-hand, on the lunge and ridden.

			95% Confidence interval	
	Mean	SE	Lower	Upper
In-hand	3.2	0.8	1.6	4.9
Lungeing	1.2	0.8	-0.3	2.8
Ridden group 1	-1.1	0.9	-2.9	0.7
Ridden group 2	2.4	1.1	0.1	4.6
Post hoc comparisons [a]	Mean difference		Standard error	*P* value
Ridden group 2 versus ridden group 1	3.5		1.4	0.02
In-hand versus ridden group 1	4.3		1.2	0.001

Ridden work quality was graded 1-10: Group 1, horses which scored ≥ 7 in trot ridden; group 2, horse which scored ≤ 6 in trot ridden.

[a] Only significant comparisons are presented in the table.