The Veterinary Journal 217 (2016) 52–57

Contents lists available at ScienceDirect

The Veterinary Journal

journal homepage: www.elsevier.com/locate/tvjl

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

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A R T I C L E I N F O

Article history:
Accepted 11 June 2016

Keywords:
Equine
Body lean
Inertial measurement units
Balance
Musculoskeletal coordination

A B S T R A C T

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.

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 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

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http://dx.doi.org/10.1016/j.tvjl.2016.06.004
1090-0233/

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, 2013b). 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) (18× gravity, 1200°/s) and one modified MTi-G (Xsens, Enschede) (18× 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. S1). 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

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 data (see Appendix S2). 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

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