The Veterinary Journal 220 (2017) 95–104

Contents lists available at ScienceDirect

The Veterinary Journal

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

Thoracolumbar movement in sound horses trotting in straight lines in hand and on the lunge and the relationship with hind limb symmetry or asymmetry

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ARTICLE INFO

Article history:
Accepted 3 January 2017

Keywords:
Biomechanics
Back pain
Equine
Inertial measurement units
Lameness

ABSTRACT

Equine movement symmetry is changed when turning, which may induce alterations in thoracolumbosacral kinematics; however, this has not previously been investigated. Our objectives were to document thoracolumbar movement in subjectively sound horses comparing straight lines with circles on both reins and to relate these observations to the objectively determined symmetry/asymmetry of hindlimb gait. Fourteen non-lame horses were assessed prospectively in a non-random, cross-sectional survey. The horses were trotted in straight lines and lunged on both reins and inertial sensor data collected at landmarks: withers, T13 and T18, L3, tubera sacrale, and left and right tubera coxae. Data were processed using published methods; angular motion range of motion (ROM; flexion-extension, axial rotation, lateral bending) and translational ROM (dorsoventral and lateral) and symmetry within each stride were assessed.

The dorsoventral movement of the back exhibited a sinusoidal pattern with two oscillations per stride. Circles induced greater asymmetry in dorsoventral movement within each stride (mean ± standard deviation, up to 9 ± 6%) compared with straight lines (up to 6 ± 6%). The greatest amplitude of dorsoventral movement (119 ± 14 mm in straight lines vs. 126 ± 20 mm in circles) occurred at T13. Circles induced greater flexion-extension ROM (>1.3°; $P = 0.002$), lateral bending (>16°; $P < 0.001$), and lateral motion (>16 mm; $P = 0.002$) compared with straight lines. Circles induced a movement pattern similar to an inside hindlimb lameness, which was significantly associated with the circle-induced greater asymmetry of dorsoventral movement of the thoracolumbar region ($P = 0.03$). Moving in a circle induces measurable changes in thoracolumbar movement compared with moving in straight lines, associated with alterations in the hindlimb gait.

Introduction

Equine spinal motion has been assessed in great detail in vitro (Jeffcott and Dalin, 1980; Townsend et al., 1983) and to some extent in vivo (Faber et al., 2000, 2001a, 2001b; Licka et al., 2001a, 2001b). Movement symmetry is changed when turning (Pfau et al., 2012), which may induce alterations in thoracolumbosacral kinematics, however this has not been investigated.

Optical motion capture is the current reference standard to capture thoracolumbar kinematics with high repeatability (Faber et al., 2001a, 2001b, 2002) and has previously been used in asymptomatic riding horses (Johnson and Moore-Colyer, 2009) and in sports horses with epaxial muscle pain (Wennerstrand et al., 2004). However, the constriction of camera calibration makes it difficult and the high cost of multiple specialist cameras required to cover large areas (e.g. a whole riding arena) makes it economically unviable to be used outside gait laboratories. Preliminary work using inertial measurement units (IMUs) in non-ridden horses compared with optical motion capture concluded that IMUs are a reliable and accurate tool to measure thoracolumbar movement (Warner et al., 2010). More recently IMUs have been used to establish reference values for thoracolumbar movement in Franches-Montagnes horses in-hand and under saddle (Heim et al., 2016). Various methods have been developed to enable left/right asymmetry to be quantified numerically based on vertical displacement of upper body landmarks (Buchner et al., 1996; Peham et al., 1996; Uhlir et al., 1997; Keegan et al., 2001; Kramer et al., 2004). Symmetry indices can be calculated to quantify movement symmetry between the movement amplitudes of the two halves within each stride, while MinDiff and MaxDiff are used to quantify the differences in minimum and maximum displacements of the body landmark to which the sensor is attached, respectively, reached during and after the two stance phases.

HipHike difference (HHD) quantifies the difference in upward movement of each tuber coxae during contralateral hindlimb stance

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http://dx.doi.org/10.1016/j.tvjl.2017.01.003
1090-0233/

and this measure reflects one of the visual observations in horses with hindlimb lameness (May and Wyn-Jones, 1987). When measuring pelvic movement symmetry parameters (MinDiff, MaxDiff, HHD) quantifying the response to diagnostic analgesia in horses with hindlimb lameness, the most consistent changes were observed in MinDiff and HHD (Pfau et al., 2014).

There is evidence that saddle slip consistently to one side occurs in approximately 50% of horses with hindlimb lameness (Greve and Dyson, 2013, 2014) suggesting that the movement of the thoracolumbar region is altered by hindlimb lameness. However, we need to understand better the relationship between pelvic and thoracolumbar symmetries in sound horses and those with hindlimb lameness, and in particular to establish the interrelationship between the symmetry and amplitude of thoracolumbar movement and the hindlimb gait under a variety of movement conditions. Horses adapt to experimentally induced lameness by extending the thoracolumbar region and decreasing the range of motion (ROM) of the lumbosacral segment (Gómez Álvarez et al., 2008); induced epaxial muscle pain results in reduced movement of the thoracolumbar region (Wennerstrand et al., 2004, 2009). When measuring changes in thoracolumbar dimensions with a flexible curve ruler every two months over one year, it was demonstrated that the presence of pre-existing lameness had a negative influence on the development of the epaxial musculature (Greve and Dyson, 2015), presumably related to reduced use of the thoracolumbar epaxial muscles.

With sensitive measurement techniques one might expect to be able to measure asymmetry in pelvic and thoracolumbar movement in circles in sound horses, because in circles the inside and outside hindlimbs are each describing a path with a different radius. This alters the symmetry in loading and push off from each hindlimb during a stride compared with moving in straight lines and has been quantified in horses on the lunge (Pfau et al., 2012).

Our objectives were to document movement of the thoracolumbar region in subjectively sound horses in straight lines in hand and on the lunge, comparing left and right reins, and relate these observations to the objectively determined symmetry or asymmetry of hindlimb gait. We hypothesised that trotting in circles will induce asymmetry in the thoracolumbar movement which is symmetrical between the left and right reins and that these changes will be associated with alterations in the hindlimb gait.

Materials and methods

A prospective 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. All horses were ridden by the normal rider in usual tack and had no recent history of lameness or epaxial muscle pain. Age, breed, gender, height (copied from the passport), work discipline and level of training or competition were recorded. The current 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.

Horse inclusion criteria

Fourteen selected horses were sound in hand, no more than grade 1/8 lame (Dyson, 2011) after flexion of a single limb, and sound on the lunge on soft and firm surfaces and ridden (Dyson and Greve, 2016).

Inertial measurement units (IMUs)

Objective gait assessment was performed 4–14 days after the initial gait assessment. Each horse was instrumented with seven MTx ($18 \times g$, 1200 degree/s) miniaturised IMUs (Xsens Technologies) and one MTi-G IMU with integrated global positioning system receiver. 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 left and right tubera coxae, over the midline of the horse at the level of the tubera sacrale (MTi-G), the withers, T13, T18 and L3; the sensors were in custom-made pouches and attached with double-sided tape (F ball Impact Tape, F. Ball). An elasticated surcingle was used to fix the wireless transmitter unit (Xbus, Xsens Technologies) to the horse's body. Sensors were attached in three strings (1, head; 2, left and right tubera coxae, tubera sacrale, L3; 3, withers, T13, T18) to the Xbus transmitting IMU data at a sampling rate of 100 Hz per individual sensor channel.

Dynamic assessment with IMUs

Fourteen horses selected as sound were trotted in hand on a soft surface (an indoor arena approximately 25 m × 60 m, with sand and fibre on a very firm base, $n = 2$; or with a very soft base, $n = 10$; or an outdoor arena approximately 30 m × 70 m with sand and fibre on a firm base, $n = 2$) and then lunged on the left rein followed by the right rein using a consistent lunging 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 10 m. The handlers were asked to allow the horses to trot in hand and on the lunge at each horse's preferred speed. IMU data were collected for at least 40 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. One trot trial at the horse's preferred speed on the lunge on both left and right reins in trot was recorded for each circumstance. Two trials were performed in four horses trotting in straight lines and up to ± 5 mm difference of the median of any outcome variable between trials was achieved. The video recordings of the horses were acquired from outside of the circle. Video recordings of the horses were acquired during objective data acquisition for subsequent assessment by SJD. Intra-assessor repeatability of the 14 horses videoed was performed three times at intervals of 2 months and 100% agreement was achieved with regard to the presence of lameness (yes/no). Previous intra-assessor repeatability has been documented in 50 horses that were randomly selected and assessed twice in a random order at an interval of 1–4 months; 98% correlation was achieved for lameness group (Greve and Dyson, 2014).

Data processing

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

Quantification of kinematic symmetry measures

The following kinematic symmetry measurements were determined: symmetry index, MinDiff and MaxDiff for pelvis and HHD. A horse moving perfectly symmetrically would have a symmetry index of 1 and MinDiff, MaxDiff and HHD values of 0. Detailed description of the calculations can be found elsewhere (Pfau et al., 2012). MinDiff > 0 mm means greater downward movement during right hindlimb (RH) stance compared with left hindlimb (LH) stance, whereas MinDiff < 0 mm means greater downward movement during the LH stance compared with RH stance. MaxDiff < 0 mm means greater upward movement after RH stance compared with LH stance, whereas MaxDiff > 0 mm means greater upward movement after LH stance compared with RH stance.

Three-dimensional kinematics of the vertebral column

A standard right-handed orthogonal Cartesian coordinate system was used (craniocaudal or x positive axis directed along the line of progression; dorsoventral or z axis vertical [aligned with gravitational field] and positive in the upward direction; lateral–lateral or y, axis perpendicular to the first two axes positive to the left of the line of progression). The craniocaudal (x), lateral–lateral (y) and dorsoventral (z) displacement data in the horse based reference system were calculated following published methods (Pfau et al., 2005; Warner et al., 2010) with modified highpass filter frequencies chosen as 1.5 Hz for dorsoventral and 0.75 Hz for lateral–lateral movement.

Outcome variables

Angular movement (a change in orientation) of the withers, T13, T18 and L3 was assessed in three planes measured in degrees as ROM: flexion-extension ROM, which is the body rotation about the transverse (lateral-lateral); axial rotation ROM, which is the body rotation about the longitudinal (craniocaudal) axis; and lateral bending, which is the body rotation about the vertical (dorsoventral) axis. Translational movement in two directions was measured in millimetres. Displacements in the vertical direction (up and down movement of the whole horse) and lateral–lateral direction (side to the side movement of the whole horse) at the withers, T13, T18 and L3 and the asymmetry of the two oscillations of the thoracolumbar movement during a stride (asymmetry) based on the symmetry index (SI) were considered. SI is always calculated as the movement amplitude of the first half of the stride (LH right forelimb, RF; diagonal stance phase) minus the movement amplitude of the second half of the stride (RH and left forelimb, LF; diagonal stance phase) and then normalised by dividing by the range of motion and 1 is added.

$$SI = ([\text{Amplitude up1} - \text{Amplitude up2}]/\text{maximum}[\text{amplitude up1; up2}] + 1,$$