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Postural changes and their effects in elite riders when actively influencing the horse versus sitting passively at trot

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Abstract

The objectives were to compare sagittal plane posture of the pelvis, trunk and head of elite dressage riders when they ride actively to train the horse versus sitting passively and following the horses' movements at trot, and to evaluate the effects of these changes in rider posture on load distribution on the horse's back. Synchronised motion capture and saddle mat data of seven elite dressage riders were used to measure minimal and maximal angles and range of motion (ROM) for the pelvic, trunk and head segments, the angle between pelvis and trunk segments, phase-shift between pitching motions of pelvis and trunk, and pelvic translation relative to the saddle. Non-parametric statistical tests compared variables between the two rider postures. In the passive rider posture the pelvis, trunk and head showed two pitching cycles per stride. Maximal posterior and anterior pelvic rotation occurred, respectively, early and late in the horse's diagonal stance phase. Compared with pelvic movements, trunk movements were slightly delayed and head movements were out-of-phase. In the active rider posture the pelvis and trunk pitched further posteriorly throughout the stride. Most of the riders showed similar sagittal plane movements of the axial body segments but with some notable individual variations.

Keywords: posture, riding technique, equestrian, saddle pressure, dressage

1. Introduction

During ridden exercise, the rider's weight applies substantial forces to the horse's back (Fruehwirth *et al.*, 2004) that play a role in the aetiology of equine back pain (Von Peinen *et al.*, 2010), which is common in athletic horses (Haussler, 1999; Jeffcott, 1980; Townsend *et al.*, 1986). Sport horse veterinarians are increasingly called upon to evaluate horses under saddle and to pass judgement on saddle fit and rider effects. In depth biomechanical studies of rider posture, movements and synchronisation with the horse are needed to identify potentially beneficial or damaging riding strategies.

The rider's ability to sit correctly in the face of perturbations from the horse requires good postural control (Brodal, 2004). Kinematic studies have described the rider's seat (Byström *et al.*, 2009) and the effect of experience on the rider's position and movements (Kang *et al.*, 2010; Schils *et al.*, 1993; Terada *et al.*, 2006). Riders must not only sit in a correct and balanced posture but must move the body parts independently and appropriately to follow the horse's motion. When training the horse, mounted posture must be sufficiently stable to support the application of aids that influence the horse's performance. Some information is available describing how the rider follows the horse's motion (Alexander *et al.*, 2014; Byström *et al.*, 2009; Münz *et al.*, 2014; Von Peinen *et al.*, 2009) and how pelvic pitch changes with collection (Byström *et al.*, 2015). However,

inter-segmental coordination patterns that allow elite riders to interface seamlessly with the horse's motion are largely uninvestigated.

The human spine has four distinct sagittal plane curvatures (cervical, thoracic, lumbar, lumbosacral) that facilitate absorption and transmission of perturbations and forces (Roussouly *et al.*, 2005). Experienced dressage riders flatten the lumbar curvature by a combination of posterior pelvic tilting and anterior trunk tilting (Alexander *et al.*, 2014). Some strategies employed to follow the horse's movement are generalised across riders as described for sitting trot (Byström *et al.*, 2009). Other movement patterns appear highly individualised to the rider (Terada *et al.*, 2006) or rider-horse combination (Schöllhorn *et al.*, 2006). The use of accelerometers to evaluate the phase relationship between horse and rider movements indicated a closer coupling and tighter synchronisation with the horse's movements in expert compared with novice riders (Lagarde *et al.*, 2005). Furthermore, good riders reduce the variability of the horse's movements (Peham *et al.*, 2004) and maintain a closer phase relationship with the horse (Peham *et al.*, 2001). Based on a phase shift between movements of the rider's pelvis and the horse's sternum Münz *et al.* (2014) showed the rider lagged behind the horse's movements, whereas Viry *et al.* (2013) demonstrated a relatively close synchronisation of dorsoventral movements of the rider's pelvis and the horse's sternum in endurance racing.

The present study addresses postural strategies used by elite dressage riders to actively train their horses as opposed to passively following the horse's movements. The experimental hypothesis is that pitch angulations of the pelvis, trunk and head segments change when the rider is actively influencing the horse versus sitting passively to follow the horse's movements.

2. Materials and methods

The Animal Health and Welfare Commission of the canton of Zurich (188/2005) approved the experimental protocol.

Horses and riders

Seven warmblood dressage horses (14±4.3 years) competing at intermediate level or above (height 1.70±0.07 m) were ridden by their own riders (3 male, 4 female; weight 78±17 kg). The riders used their own standard riding equipment consisting of a dressage saddle and a snaffle bridle, which were checked to fit correctly by one of the researchers.

Experimental design

Reflective markers attached to the rider's helmet (back, front, left, right); trunk (C6, left/right acromion processes); pelvis/hip (lumbosacral joint, left/right greater trochanters);

and over the horse's L3 were tracked by 12 infrared optical cameras (ProReflex; Qualisys AB, Göteborg, Sweden).

Data were recorded on a high-speed treadmill (Mustang 2200, Graber AG, Fahrwangen, Switzerland) with integrated force measuring system (Weishaupt *et al.*, 2002). After warming up a static file was recorded with the rider sitting in neutral spine and pelvic alignment. Horses were ridden at trot under two conditions: (1) passive riding posture with long reins (long reins were defined as hanging in a loop), the horse had an unrestrained head and neck position, and the rider was passively following the horse's movement; (2) active riding posture with the horse ridden in collected trot.

Kinematic and kinetic measurements

Kinematic data were collected for 15 s in each riding posture at 140 Hz (four horses) or 240 Hz (three horses). The laboratory coordinate system was right-handed with the X-axis horizontal, positive in the direction of motion and aligned with the treadmill; the Y-axis horizontal, positive to the left; and the Z-axis vertical, positive upwards. The vertical ground reaction force (GRFvert) was measured synchronously with the kinematic data at 420 Hz or 480 Hz, depending on the kinematic sampling rate. The start and end of stance were determined by the intersection of the linear approximation to the initial and terminal slope of the force curve with the zero-baseline.

Saddle mat measurements

Saddle pressure was measured with Pliance-X System (Novel GmbH, München, Germany) using integer sampling rates at 70 or 60 Hz and synchronised with the kinematic system. Prior to data collection the 256 sensors were equilibrated and calibrated for pressures ≤64 kPa. The mat was placed symmetrically on the horse's back, aligned with the dorsal midline and positioned to accommodate the entire saddle panels.

Data processing

GRFvert defined the diagonal stance phases and stride cycle. The 3D marker positions were reconstructed using a direct linear transformation algorithm (Qualisys Track Manager, Qualisys AB). The raw X-, Y- and Z-coordinates and raw pressure data were exported into MATLAB (The Math Works Inc., Natick, MA, USA) for further analysis.

The rider's head, trunk, and pelvis were subjected to rigid body analysis (Söderkvist and Wedin, 1993) using the neutral position in the static files to define the rigid body zero state. Segmental rotations around the Y (transverse) axis were defined as pitch with a positive rotation indicating forward (anterior) tilting of the head, trunk or pelvis. Anteroposterior translation of the rider's pelvis relative to

the saddle was positive when the pelvis moved anteriorly. Linear and angular measurements were expressed relative to zero as defined by the static file.

The longitudinal position of the centre of force (COF) was measured from the posterior edge of the saddle mat and its craniocaudal ROM was calculated. The loaded area was represented as the mean number of loaded cells per stride.

All data were split into strides based on left forelimb contacts. All strides were thereafter normalised to 101 points (0-100%). For each standardised stride discrete values were determined for the following variables: minimum (MIN), maximum (MAX) and range of motion (ROM) for pitch rotation of the rider's pelvis (P), trunk (T) and head (H) segments; difference in time of occurrence between P_{MAX} and T_{MAX} (PT-phase shift) expressed as % stride cycle with a delay in thoracic motion being positive; minimal and maximal anteroposterior translation of the rider's pelvis relative to the saddle; mean number of loaded saddle mat

cells per stride; longitudinal ROM of the COF on the saddle mat, and ROM for vertical excursion of the horse's L3.

Statistics

Standardised mean data for the passive and active rider postures were compared using the Wilcoxon matched-pair test.

3. Results

The full data set consisted of 224 strides; 113 for the passive rider posture and 111 for the active rider posture with 28 to 34 strides/rider. Speed did not differ significantly between the passive (range: 2.82-3.30 m/s) and active (range: 2.95-3.08 m/s) rider postures.

In the passive rider posture the pelvis, trunk and head angles followed a sinusoidal pattern with two oscillations/stride (Figure 1). Timing of pelvic oscillations in the passive posture were consistent across riders; the pelvis rotated

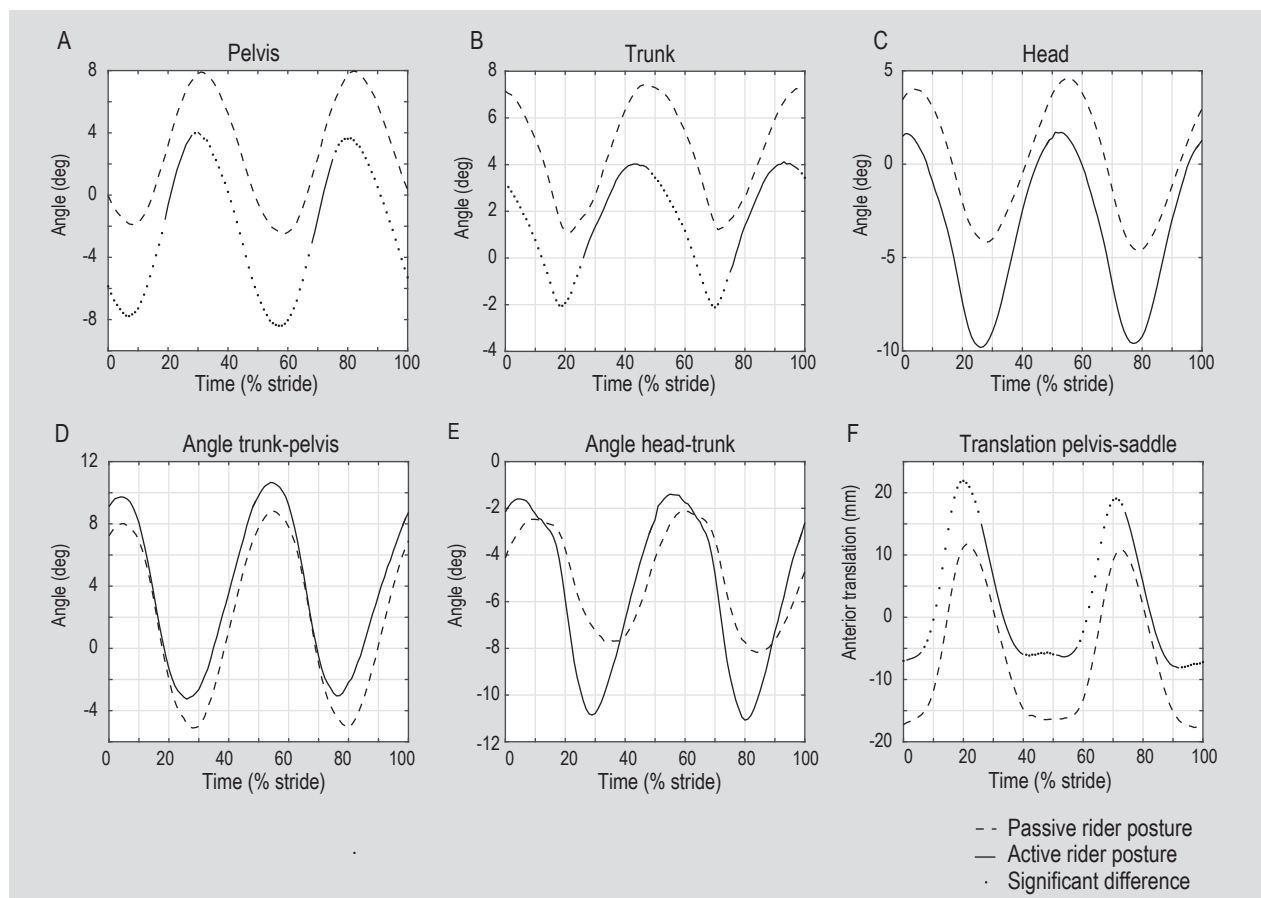


Figure 1. Sagittal plane kinematics of the rider during one stride of trot. Upper row, left to right: mean ($n=7$) angles of the pelvis, trunk and head segments. Lower row, left to right: angles between pelvis and trunk, trunk and head and anterior translation of the rider's trunk relative to the pelvis. Data represent one stride of sitting trot starting at contact of the left diagonal. Interrupted lines represent the passive rider posture and the whole-drawn lines represent the active rider posture. Where whole-drawn lines are dotted the passive and active postures differ significantly (analysed by each percentage in the stride).

posteriorly from late stance of one diagonal through suspension reaching maximal posterior pitch early in the next diagonal stance. The pelvis then rotated anteriorly through mid-stance reaching maximal anterior pitch in late stance. Trunk oscillations followed the pelvic pattern but were delayed by 13% of the stride cycle. Maximal posterior trunk pitching occurred just before midstance and maximal anterior trunk pitching occurred just before lift-off into suspension. Head pitching movements were out-of-phase with the pelvis; the head pitched maximally anteriorly at the start of stance and maximally posteriorly in midstance. Pelvic and trunk oscillations in the passive rider posture were predominantly positive indicating anterior pitching relative to the neutral position, whereas the head oscillated around its neutral position. Range of motion was largest for the pelvis and least for the trunk (Table 1, Figure 1). Individual segmental rotations exaggerated the lumbar lordosis (hollowed the back) in early stance and flattened the lumbar lordosis (rounded the back) in late stance (Figure 1). The COF on the saddle mat translated anteriorly as the pelvis pitched posteriorly.

Comparing mean values between passive and active rider postures revealed significant differences for at least one variable per segment (Table 1, Figure 1). Overall, the active rider posture involved significantly greater

posterior (negative) pelvic rotation (-5.6° for PMIN; -4.1° for PMAX), so the entire cycle of pelvic rotation pitched more posteriorly, and PROM increased by 1.4° . When evaluated individually, 6/7 riders showed significantly increased posterior pelvic pitching in the active riding posture. The trunk also displayed a significant increase in posterior rotation with changes of -3.4° in TMIN and -2.8° in TMAX in the active rider posture but TROM did not change. Posterior trunk pitch increased in 5/7 riders. Neither HMIN nor HMAX differed between rider postures but HROM increased significantly by 1.6° when riding actively. Individually, 3/7 riders showed more posterior head rotation, 1/7 showed more anterior head rotation and 3/7 showed little difference between the two postures. The mean angle between pelvis and trunk did not change significantly between rider postures (Table 1, Figure 1).

Saddle mat variables (Table 1) indicated that in the active rider posture the pelvis translated significantly further anteriorly by 25.4 mm in the minimal position and 17.2 mm in the maximal position, indicating a more anterior position throughout the stride. The ROM of the COF on the saddle mat increased significantly in the active rider posture though only by 0.6 mm while the mean loaded area decreased by 29.2%. Vertical displacement of the horse's L3 decreased significantly while riding the horse at the collected trot (active rider posture).

Table 1. Data describing the body kinematics and saddle pressure distribution for a group of experienced riders (n=7) sitting passively at trot versus actively riding the horse in collected trot on a treadmill.

Variable	Passive rider posture ²	Active rider posture ²
Pelvis minimal angle (deg)	-3.1 (0.6)*	-8.6 (0.8)*
Pelvis maximal angle (deg)	7.8 (0.3)*	3.7 (0.4)*
Pelvis angular ROM ¹ (deg)	10.8 (1.6)*	12.2 (1.5)*
Trunk minimal angle (deg)	1.4 (0.8)*	-2.0 (0.4)*
Trunk maximal angle (deg)	7.6 (0.7)	4.8 (0.5)
Trunk angular ROM (deg)	6.5 (4.5)	6.6 (4.3)
Head minimal angle (deg)	-5.4 (0.3)	-7.7 (0.5)
Head maximal angle (deg)	4.0 (0.5)	-0.3 (0.4)
Head angular ROM (deg)	9.40 (4.4)*	11.0 (4.3)*
Phase shift pelvis-trunk (%)	-13 (0.06)	-11 (0.05)
Max translation rider pelvis to saddle (mm)	43.3 (6.2)*	60.5 (5.7)*
Min translation rider pelvis to saddle (mm)	-46.2 (14.8)*	-20.8 (13.5)*
Mean number of loaded saddle mat cells (#)	31.2 (12.6)*	22.4 (4.3)*
Craniocaudal ROM of saddle mat centre of force (mm)	9.1 (0.4)*	9.7 (0.4)*
Vertical motion of the horse's L3 (mm)	10.1 (1.4)*	8.0 (7.1)*

¹ ROM = range of motion.
² Asterisks show values differ significantly ($P < 0.05$).

4. Discussion

The sagittal plane kinematics of the pelvis, trunk and head segments in seven elite dressage riders have been compared at the trot when sitting passively with loose reins versus riding actively and collecting the stride. The findings partially support the experimental hypothesis in that posture of the rider's pelvis and trunk, but not the head, changed when riding actively to influence the horse's performance compared with passively following the horse's movements. In sitting trot, sagittal plane angles of the pelvis, trunk and head undergo two rhythmic oscillations per stride with each segment reaching peak values at specific times in the stride. Relative to pelvic rotations, trunk rotations are slightly delayed and head rotations are out-of-phase. Changes in rider kinematics were associated with a small increase in ROM of the COF on the horse's back and a large decrease in the loaded area of the horse's back indicating higher pressures when ridden in collection thus increasing the risk of pressure-induced lesions of the withers or shoulders (Von Peinen *et al.*, 2010).

The axial skeleton, controlled by the core musculature, forms a stable base that allows the rider's legs and arms to move independently to follow the horse's motion and give riding aids. The position, stability and movements of the pelvis, trunk and head are pivotal in determining a rider's effectiveness; if they are not adequately stabilised

and controlled it will adversely affect the rider's balance and coordination (Roussouly *et al.*, 2005). The importance of head stabilisation is reinforced by the suggestion of Peham *et al.* (2001) that segmental-based kinematic evaluation of the rider's skills could be replaced by a single head-mounted sensor. Although neither HMIN nor HMAX changed between the two riding postures, HROM showed a small but significant increase, which was interpreted as being necessary to maintain a stable head position in the face of changes of pelvic and trunk orientation.

The rider's movements are driven by movements of the horse (Münz *et al.*, 2014; Von Peinen, 2009; Wolfram *et al.*, 2013). The rider's pelvis, which provides the point of contact with the saddle, transmits forces directly between horse and rider. Thus, the rider's pelvis acts as a coupling mechanism and its movements play a key role in the rider's ability to follow the horse's movements and influence the horse's performance (Blokhuis *et al.*, 2008; Panni and Tulli, 1994).

The horse's back movements involve gait-specific 3D translations (vertical, longitudinal, transverse) and rotations (yaw, roll, pitch) that affect the amount and type of pelvic motion required from the rider. During trotting the diagonal limb support pattern offers pitch and roll stability (Hobbs and Clayton, 2014) resulting in a small range of pitching motion of the horse's back (Buchner *et al.*, 2000). The rider's pelvis accommodates both pitching rotations and vertical displacements while the trunk compensates for longitudinal translational motion (Terada *et al.*, 2006). The magnitude and orientation of the velocity vector of the horse's trunk affect the rider's trunk and head position. Pelvic pitching motion in sitting trot is highly repeatable even in riders of moderate ability and riders with reduced pelvic pitching compensate by using increased pelvic roll (Münz *et al.*, 2013). Thus, riders may use individualised strategies to stabilise their upper body and accommodate perturbations from the horse.

Pitching motion of the rider's trunk occurs in the same direction but lags slightly behind pelvic pitch. It is thought to accommodate changes in the horse's longitudinal motion (Terada *et al.*, 2006). The rider's trunk inclines posteriorly during the braking phase in early diagonal stance, reverses direction around the time of zero longitudinal GRF (Hobbs and Clayton, 2014), and inclines anteriorly during the propulsive phase in late diagonal stance. Maximal anterior pitch coincides with push off into the suspension. Experienced riders anticipate the horse's movements (feed forward mechanism) and compensate for perturbations from the horse (Terada *et al.*, 2006). Contraction of the rider's rectus abdominis muscles in the second half of diagonal stance (Terada *et al.*, 2004) may contribute to the synchronous posterior pelvic pitch and anterior trunk pitch reported here and in other studies (Byström *et al.*, 2015; Münz *et al.*, 2013). In the latter study the riders'

upper body became more anteriorly rotated relative to the pelvis as trotting speed increased, which may be a learned response to accommodate the effects of increasing speed. The combined pelvic and trunk rotations flatten the lumbar lordosis as observed in the present study and by Alexander *et al.* (2014). In the active rider posture the lumbar lordosis is exaggerated in mid-late stance and reduced during suspension and early stance.

When actively influencing the horse, the pelvis pitched further posteriorly which equestrians describe as a 'driving seat'. At the same time the rider's ischial tuberosities moved anteriorly on the saddle with an increased ROM of the COF being transmitted to the horse's back. In general, sitting trot has a larger longitudinal ROM of the COF than rising trot or two-point position (Peham *et al.*, 2010), because the rider's pelvis follows the horse's motion more closely.

Byström *et al.* (2015) found greater pelvic posterior pitch in collected trot and passage than when trotting freely with loose reins which was suggested to result from the intermittent application of aids for the half halt, which riders use to increase the degree of collection. In our study the findings show increased posterior pelvic pitching throughout each stride rather than an intermittently applied half halt.

Relative to the neutral position in the static file, the rider's trunk rotated anteriorly in the passive posture and oscillated around the neutral position in the active posture. Considering all riders together, both TMIN and TMAX indicated a more posterior trunk inclination in the active rider posture with this pattern being clearly evident in 5/7 riders. Terada *et al.* (2006) identified different strategies in pelvic-trunk movement and coordination among experienced dressage riders; 5/6 riders moved the pelvis while stabilising the trunk whereas the sixth rider stabilised the pelvis while rocking the trunk around the hip joint (Terada *et al.*, 2006).

A limitation of this study is the small number of participants. Since the goal was to use elite riders, we used a smaller number of subjects rather than diluting the quality by including riders of lesser ability. Marker displacement relative to underlying bony landmarks is a consideration in kinematic studies based on tracking external markers and markers placed on tightly fitted riding clothes may move more than skin-fixed markers. However, similar errors are expected for each individual in the different riding postures, so comparisons among conditions are thought to be valid, as in clinical evaluations of horses based on skin markers (Van Weeren *et al.*, 1992). Horses move slightly differently on a treadmill versus over-ground (Buchner *et al.*, 1994) but the advantages were in control of speed and the environment. Two sampling rates were used but this is

not regarded as a problem since even the lower sampling rate of 140 Hz is adequate for the purposes of this study.

It is recommended that additional markers be attached to the rider's trunk to define movements of the thoracolumbar spine in greater detail and facilitate studies of frontal plane asymmetries (Alexander *et al.*, 2014; Symes and Ellis, 2009). It is important to record a static trial with the rider sitting in a neutral spine and pelvis position as a reference for the motion data.

Future studies should characterise the most functional rider posture and further explore individual rider strategies. Common postural aberrations in riders should be identified and related to morphological characteristics and levels of experience. The effects of common postural aberrations on the dynamic qualities of the horse-rider interaction should be addressed with specific reference to their effects on health and performance.

5. Conclusions

This study adds to previous descriptions of rider kinematics by describing the magnitude and timing of pitching rotations of the rider's pelvis, trunk and head segments in sitting trot and shows that most riders increase posterior pitching of the pelvis and trunk when collecting the stride. The resulting anterior shift of the COF and the reduced weight-bearing area beneath the saddle indicate the need for vigilance in checking for signs of pressure-induced injuries around the withers and shoulders in horses that perform in collection for long periods.

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