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Intersegmental strategies in frontal plane in moderately-skilled riders analyzed in ridden and un-mounted situations

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ABSTRACT

The symmetry of the rider is highly relevant, and in the equestrian community it is generally thought that a symmetrical rider has a better possibility to influence the horse in an optimal way. The aim of the study was to analyse and compare frontal plane kinematics of the core body segments in ten riders while riding and while rocking a balance chair from side-to-side. It was hypothesized that the riders were asymmetrical in relation to their intersegmental strategies when comparing between left and right directions and that individual riders would display the same postural strategies when riding and when rocking the balance chair. Ten moderately-skilled riders wore a full-body marker set that was tracked by a motion capture system as they rocked a balance chair from side to side. Inertial measurement units attached to the head, trunk and pelvis were used to measure the segmental movements while riding in left and right directions. Roll rotation data for head, trunk and pelvis were averaged over available strides/cycles. Results from mixed models showed that the riders were asymmetric when comparing riding in left vs right directions, for example the trunk was rotated 19° to the right on the right circle and 14° to the left on the left circle, on average. Riders adopted the same asymmetrical posture whether they were riding in the left or right direction on straight lines, circles or leg yielding. A significant relationship was found between postural asymmetries when riding and when rocking the balance chair, one degree of pelvis or head roll asymmetry on the chair predicted 2.4 (SE 0.9) degrees of asymmetry while riding. Future studies may investigate the value of seated, off-horse postural training for improving rider symmetry and thereby equestrian performance.

1. Introduction

Equestrianism is popular worldwide, with millions of horses and riders participating in competitive horse sports and non-competitive leisure riding. When riding a horse there is a complex interaction between the horse and the rider. A prerequisite for efficient horse-rider communication is the rider's ability to maintain a balanced position on the horse, that allows independent and controlled movements of the rider's limbs and axial body segments (pelvis, trunk and head) consistently while the horse is moving in different gaits. To guide the horse, riders are trained to apply and release pressure independently through the hands, legs, and seat to influence

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the movement of their horse.

To maintain balance on the moving horse, the rider needs to handle the movements that are generated by perturbations arising from the movements of the horse (Münz, Eckardt, & Witte, 2014; Wolframm, Bosga, & Meulenbroek, 2013). This means that the rider needs to move the head, trunk and pelvic segments in a coordinated manner in order to arrive at the same average (mean) position in each stride cycle, i.e. the rider needs to follow the horse's movement pattern. Otherwise, if the rider's centre of mass (COM) is displaced towards the periphery of the base of support (BOS) the rider is at risk of becoming unbalanced. The pelvis is considered central in the transfer of movements between the horse and the rider (Federation, 1997; von Dietze, 2011). During trot the rider's movement pattern relates to the stance and suspension phases of the horse. In the sagittal plane, the pelvis rotates posteriorly from late stance of one diagonal through the suspension phase and rotates anteriorly around the time of mid-stance. Thus the pelvis reaches its maximum posterior pitch in early diagonal stance phase and reaches maximal anterior pitch in late stance. The trunk follows the pelvic pattern with a delay about 13% of stride duration and the head follows with even longer delay (Byström, Roepstroff, Peinen, & Weishaupt, 2015; Engell, Clayton, Egenvall, Weishaupt, & Roepstorff, 2016). Biomechanical modelling suggests that these movements are driven by the horse and just modulated by the rider (de Cocq, Muller, Clayton, & van Leeuwen, 2013). In order to make the horse move in a certain gait or perform a particular movement at a specific location within the arena the rider must actively communicate with the horse. Active use of the seat requires the ability to initiate, control, and stop pelvic movements while the upper body segments (trunk and head) are stabilized. These two ways of using the seat, passively following the horse and actively influencing the horse, may be called the passive and active components of the seat (Engell et al., 2018). Although these concepts are widely accepted in the equestrian world, there is a substantial lack of scientifically based information defining the optimal seat, and a lack of scientific knowledge on how to develop technical riding skills (Münz et al., 2014).

In many equestrian disciplines, such as dressage and show-jumping, the aim is for the horse to be equally dynamic, balanced and flexible when being ridden to the left as it is when being ridden to the right (Blokhuis, Aronsson, Hartmann, Van Reenen, & Keeling, 2008; Münz et al., 2014). In the equestrian community it is generally thought that a symmetrical rider has a better possibility to influence the horse in an optimal way (Hobbs et al., 2014). Some studies have documented systematic asymmetries in the riders' movement pattern while riding. Experienced riders have been reported to sit in an asymmetrical posture with the pelvis rotated and twisted to the right (Alexander et al., 2015), the trunk twisted to the left (Symes & Ellis, 2009), and with greater external rotation of the right hip (Gandy, Bondi, Hogg, & Pigott, 2014). It is not evaluated in these studies if it is the riders themselves or the horses that are the main cause for these asymmetries. Postural asymmetries in riders have also been documented through various unmounted tests (Hobbs et al., 2014). Unmounted exercise programs focusing on posture, as well as physiotherapy, have been shown to improve the rider's balance and symmetry during riding (Nevison & Timmis, 2013; Hampson & Randle, 2015).

There are different instruments to test balance. The principle of balance chairs is to challenge the subject's ability to control the direction and amount of COM displacement when sitting, similar to standing balance tests (Olivier, Viseu, Vignais, & Vuillerme, 2019). Because of these properties, a balance chair can be used as a tool to evaluate a person's inter-segmental coordination of the head, trunk and pelvis, and movement symmetry during lateral left-right rocking movements. The use of an unmounted test situation, such as a balance chair, to evaluate riders' postural strategies offers an advantage over the mounted situation by isolating the rider's movements from the movements of the horse (Engell et al., 2018).

The primary objective of this study was to evaluate frontal-plane kinematics of the rider's core body segments (head, trunk and pelvis) on straight lines, circles and leg yields, and compare between riding to the left versus to the right. The second objective was to compare frontal plane kinematics of the core body segments while riding, to when rocking a balance chair from side to side (Engell et al., 2018). It was hypothesised that the riders' intersegmental strategies would deviate from perfect mirror symmetry, when comparing between left and right directions. It was also hypothesised that there would be a correlation between the riders' individual strategies when seated on a balance chair and when riding a horse.

2. Materials and methods

2.1. Experimental design

Ten female riders were included (age mean: 22 years, range: 21–25 years; weight mean 68 kg, range: 61–75 kg). Riders were students in equestrian science, and were competing in show jumping (115–130 cm) and/or dressage (Intermediate A or B) and were considered to be of moderate skill level. Subjects had no obvious foot abnormalities other than pronation (Engell et al., 2015). There were 13 riders with higher degree of pronation on the right foot and five riders with higher degree on the left (Engell et al., 2015). The horses were two Swedish warmblood school horses, ten and twelve years of age, from the National Equestrian Centre, Strömsholm, Sweden. The horses were considered sound based on clinical examination by an equine practitioner (LR) before the measurements, and were in regular work.

2.2. Study protocol

Nine riders rode one horse and one rider rode a different horse. Each rider had between 5 and 10 min of warm-up to familiarize themselves with the horse before the measurements were made. All riders were instructed to ride the same program; consisting of walk and trot on straight lines in both directions (i.e. turning left around the arena and turning right around the arena), trot on a 20 m diameter circle in both directions, and leg yield where the horse's inside limbs pass and cross in front of the outside limbs in trot to the left and right on a diagonal line.

Fig. 1. Subjects seated on a balance chair.

Within 2 days of the ridden test the riders performed an unmounted test, seated on a balance chair (Fig. 1), constructed with a stable base, and an adjustable height element with a seat on top. This chair had a metal rod that tilted around a pivot point located 0.3–0.7 m below the seat (Engell et al., 2018). The chair was moved and controlled by the rider. The riders were instructed to rock the chair by placing more weight alternately on their left and right seat bones (tubera ischii), as they would do during different exercises on horseback. When doing this, the chair would rock sideways from right to left and left to right.

2.3. Kinematic measurements

During the ridden data collection, the riders were equipped with inertial measurement units (x-IMU, X-io Technologies Limited, UK) recording at 256 Hz. The IMUs were attached using adhesive tape to the head (top of the helmet), trunk (between the shoulder blades) and pelvis (over the sacrum). The horse was equipped with an x-IMU-sensor between the two tubera sacrale. The IMU's were synchronized by use of a sync signal before and after the kinematic measurements. Two video cameras recorded the ridden tests from two corners of the arena.

During unmounted testing on the balance chair kinematic data were collected in 3D (250 Hz) using eight motion capture cameras (Qualisys Oqus, AB, Gothenburg). Riders were equipped with spherical, 8 mm diameter markers fixed to the skin according to a full body-marker set model (Serge van Sint, 2007). Markers were positioned on the following anatomical points: spinous processes of C7 and T10, and bilaterally on the acromial edge, anterior and posterior superior iliac spines, and greater trochanter.

In order to define neutral (zero) stance position for the core body segments, i.e. to provide a reference position for the kinematic recordings while ridden and while rocking the balance chair, the participants were positioned in a custom-designed reference position chair before each test, unmounted and mounted (Engell et al., 2018). In the reference position, each subject's acromial edges and iliac crests were aligned horizontally so that they were symmetrical in the frontal plane. In the sagittal plane, the head, trunk and pelvis were aligned vertically, in a neutral spine position. After adjusting the stance chair to each subject, thus "forcing" the subject into the aligned position (checked manually and visually), the reference measurements were obtained with both motion capture cameras and IMUs.

2.4. Data analysis

IMU raw data were exported to Matlab (Matlab version 2016b, The MathWorks® Inc., Natick, MA, US). Roll, pitch and yaw angles, and vertical acceleration were extracted from each sensor. Vertical accelerations were double-integrated and high-pass filtered to yield vertical translations (Pfau, Witte, & Wilson, 2005). The data were segmented into specific exercises based on observation of the video footage and the corresponding clock times together with yaw (heading) rotational measurements of the horse's pelvis. The data for each exercise were then split into strides based on the vertical translation and roll rotation of the horse's pelvis (Starke, Witte, May, & Pfau, 2012). For analysis on the straight, all strides from corners were excluded. Rider angles were adjusted for the rider's reference position in the reference position chair, such that the segmental angles were expressed relative to that position. Positive roll rotation for all rider segments was defined as clockwise rotation when viewed from behind, i.e. positive rotation means that the right hip is lowered relative to the left. Stride mean roll was determined for each stride.

Motion capture data processing and model building were performed in Visual3D™ (C-Motion Inc., US). Marker data were gap-filled and signals were filtered with a 15 Hz, low-pass Butterworth filter. Roll rotation of the head, trunk and pelvis were exported to Matlab for further processing. The symmetry of rotation to the right and left sides was evaluated as the difference between positive and negative areas under the curve (AUC) over the available number of full left/right motion cycles, with zero defined by the reference position. Positive roll rotation was defined as for IMU-data. For more detailed information about data processing see Engell et al. (2018).

2.5. Statistical analysis

Descriptive statistics were calculated. Stride mean roll was averaged over the available strides for each horse and rider combination and exercise. An asymmetry measure was created for each body segment by summation of the values recorded when performing each exercise in the left and right directions. For example, if the mean rotation of the rider's pelvis was -2° to the left for the left direction and $+2^{\circ}$ to the right for the right direction, the rider summed to zero degrees. However, if the rider was rotated $+2^{\circ}$ to the right both for the right and left directions, this rider had a sum of 4° for the exercise.

Two categories of mixed models were constructed in SAS (Proc Mixed, SAS version 9.4, SAS Institute Inc., Cary, North Carolina, US). In the first category, systematic differences between left and right counterparts of each exercise were elucidated. Stride mean roll for each rider body segment and exercise were modelled as outcomes including exercise as a fixed effect. Random effects were rider and horse. Pair-wise comparisons were done between data for the same exercise when traveling in the left and right directions around the arena in straight lines, on left and right circles, and in left and right leg yield. In the second mixed model category the ridden asymmetries were modelled against chair asymmetries with exercise included as a fixed effect. Rider was included as random effect. The variables tested against each other were: ridden head vs chair head, ridden trunk vs chair trunk and ridden pelvis vs chair pelvis. Insignificant fixed effects were removed backwards, in the second category of models only models with significant asymmetry variables were kept. The p-value limit was set to < 0.05. To evaluate normal distributions of model residuals, these were plotted according to standard methods (SAS). Similarly, linearity for independent variables vs dependent variables was evaluated through plotting.

3. Results

The ridden data included 10 riders with 1888 strides. For straight trials there were between 12 and 32 strides, median 18 strides per rider and trial. For circle trials there were between 27 and 50 strides, median 39 strides per rider and trial. For leg yield trials there were between eight and 19 strides, median 11.5 strides per rider and trial. Two of the 10 riders had data failure for the trunk sensor and one rider had no data for pelvis and head (ridden data). For comparison with the chair only eight riders had data, and for the trunk comparison there were only six riders.

Fig. 2 shows stride-mean roll by exercise and rider. There were statistical differences between the left versus the right directions for pelvis roll ($p = 0.01$) and trunk roll ($p < 0.0001$) when traveling straight. There were differences between left and right circles for trunk roll ($p < 0.0001$) and between left and right leg yield for trunk roll ($p = 0.0002$) and head roll ($p < 0.0001$). Whenever an exercise was significant, the pelvis and the trunk were more roll rotated to the left (around the longitudinal-horizontal axis) in the left direction and more roll rotated to the right on the right direction. For the head the opposite was found (Fig. 2).

Many riders show asymmetrical core body segment position comparing exercises to the left and right, with uneven distribution around zero, as can be seen in Fig. 2. For example some riders maintained the same sign for pelvic roll when traveling in the left and right directions (Fig. 2). Fig. 3 shows stride-mean roll by rider and exercise. Comparing left and right circles, the majority of the riders changed their trunk angle more than the pelvic angle to adjust to the new direction.

Results from mixed models comparing asymmetries for the body segment while rocking the chair and while riding are shown in Table 1 and plots for the same variables are shown in Fig. 4. No significant association was found for trunk asymmetry ($p = 0.33$) and this model was discarded. Exercise was non-significant in head and pelvis models and was omitted (i.e. a correlation was present regardless of exercise). The data in Table 1 indicate that frontal plane positional asymmetries when rocking the chair and when riding, are positively associated with each other for the head and pelvis segments. This means that if the rider sat with for example the pelvis rotated predominantly to the right on the chair, the rider also sat with the pelvis predominantly rotated to the right while riding in trot (valid for chair asymmetries larger than 2°).

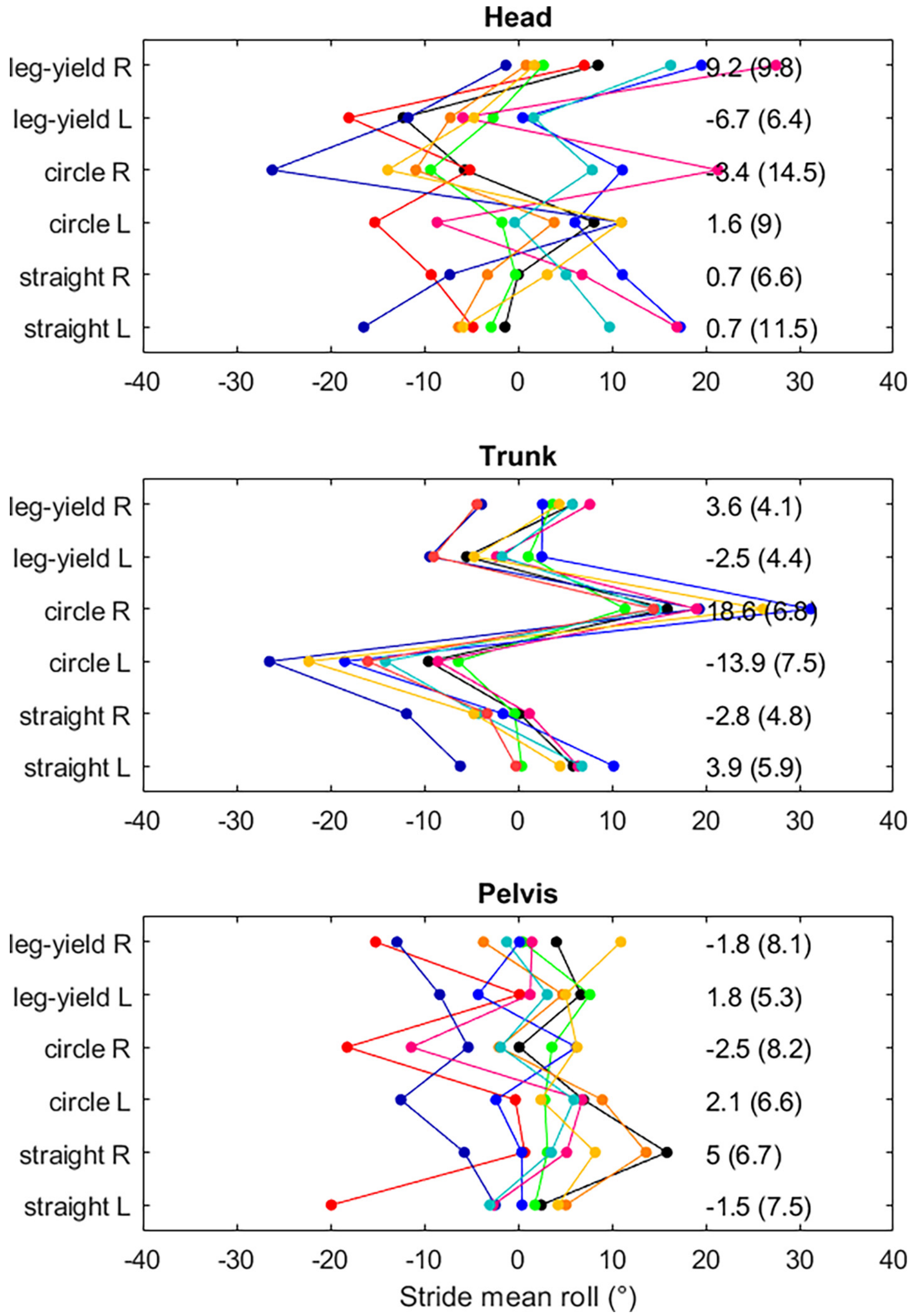

Fig. 2. Mean stride roll in degrees (x-axes) for each segment plotted against exercises (y-axes left (L)/right (R)) and by rider. Data from 10 riders are included (two riders lack trunk data, and one rider lack head and pelvic data). Values shown on the right of the plots are means and (standard deviations). Positive values indicate that the segment is lower on the right. Data for each rider are shown in a different colour.

4. Discussion

Frontal plane positional asymmetries of pelvis, trunk and head segments in ten riders have been analysed while riding on straight lines, circles and in leg yields in trot in both left and right directions. Both hypotheses were accepted; in line with our first hypothesis we found that the rider's individual intersegmental strategies were asymmetrical when comparing between left and right directions, but the riders as a group showed some degree of left-right mirroring. Further, there was a correlation between the rider's individual strategies when seated on a balance chair and when riding, which supports our second hypothesis.

Horses lean their body toward the inside of the turn when ridden on circles or when being lunged. At the trot, the degree of

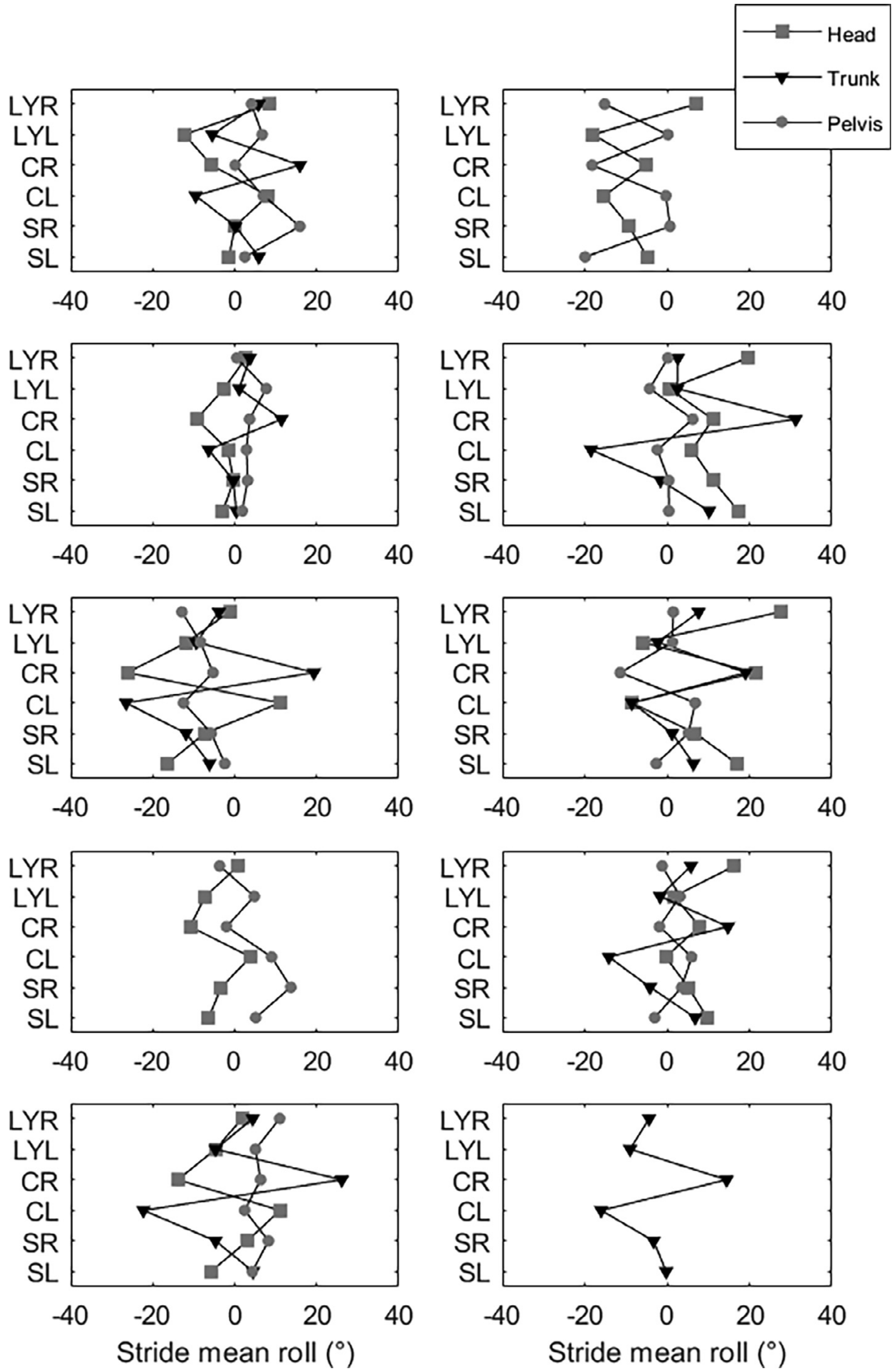

Fig. 3. Mean roll in degrees (x-axes) for 10 riders (panels 1–10) plotted against exercises (y-axes, SL = straight left, SR = straight right, CL = circle left, CR = circle right, LYL = leg yield left, LYR = leg yield right). Positive roll values correspond with lowering of the right side of the segment. Two riders lack trunk data, and one rider lack head and pelvic data.

leaning in healthy horses increases with a smaller radius of the circle and with an increase in speed (Pfau, Stubbs, Kaiser, Brown, & Clayton, 2012), but decrease with horse educational level (Greve & Dyson, 2016). When riding a circle, the rider should lean with the horse, as the rider is typically expected to put more weight on the inside seat-bone while turning (FN, 1997). Our results showed that the riders indeed leaned to the inside in all exercises but to a varying degree. The riders mainly adapted to the left and right directions by leaning the trunk towards the inside on the circles, indicating a more static pelvis and a more moveable trunk in most riders

Table 1

Mixed models with chair roll asymmetries predicting riding roll asymmetries of pelvis and head in 8 subjects. The dependent riding variable consists of roll, riding to the left and right added (e.g. straight left plus straight right).

Variables	Estimate	SE	P-value	Perecnt variation	
				Rider	Horsc
Intercept	3.21	3.11		69	0
Pelvis roll asymmetry	2.37	0.85	0.01		
Intercept	−3.60	5.65		73	14
Head roll asymmetry	2.39	0.93	0.02		

(Fig. 2). Perhaps the strategy of rolling the trunk laterally is the simplest and most intuitive way of turning on circles since it takes advantage of the long lever arm of this segment, but riding theory often focus on pelvic interaction with the horse, not the trunk (Blokhuis et al., 2008; Münz et al., 2014). Further, the interaction between horse and rider body lean has yet not been studied.

The riders were given the task to rock a balance chair from side to side by alternately placing weight on the left and right seat bones. This task was intended to isolate the active part of the seat (Engell et al., 2018). To solve this task the riders used a similar strategy as when changing between left and right direction during riding. When moving the balance chair the riders displayed either a high degree of trunk roll rotation (in general more than 1.5 times the degree of pelvic rotation) or a large trunk translation combined with a very low degree of pelvic translation and roll rotation (Engell et al., 2018). This appears to be contradictory to the equestrian literature stating that the riders should guide the horse using the pelvis (Blokhuis et al., 2008; Münz et al., 2014). The fact that pelvic movements are small does not preclude the pelvis from transferring forces/pressure to the horse but large (exaggerated) movements of the upper body decrease the possibility for the rider to have a fine tuned control of the forces between the pelvis (seat) and the saddle/horse. The optimal interplay between trunk and pelvic motion when it comes to transmitting signaling force cues through the saddle to the horse is not yet known. The amplitude of the force cue can be one factor, the possibility of controlling the timing of it another. The latter factor could be better achieved by increased emphasis on pelvic motion. It would be interesting to evaluate whether riders trained on the balance chair, would become more symmetrical and display better pelvic controlled dynamics during riding.

We included leg yield in our evaluation as lateral exercises are a considerable part of riding (FN, 1997). Learning lateral exercises poses challenges to the horse and rider, of which how to sit and use the aids to move the horse forwards and sideways are key motor skills. Leg yield has hardly been addressed in the scientific literature. de Cocq et al. (2010) studied saddle and leg aid forces in lateral exercises (shoulder-in and travers/half pass, which have similarities to leg yield but also require lateral bending to the inside) (de Cocq et al., 2010). They found that mean total saddle force during the exercise, was lower when riding straight ahead than when riding shoulder-in or travers and that mean inside saddle force was higher when riding travers than when riding straight or shoulder-in. Maximum outside leg force was higher when riding travers than when riding straight or shoulder-in. In a study of rein tension during ordinary riding sessions it was found that that half-pass to the right was associated with higher minimal and median rein tension compared with half-pass to the left, perhaps due to asymmetry or inherent laterality (Eisersiö, Rhodin, Roepstorff, & Egenvall, 2015). In our data the majority of riders positioned their head and trunk to the respective inside in leg yield, while the pelvis segment had no such pattern (Fig. 2).

On the individual level, many of the riders in our study demonstrated a consistent intersegmental strategy with regards to the usage of head, trunk and pelvis, irrespective of the direction of movement. Some riders were highly asymmetrical even though they had some degree of left-right mirroring. Also, the riders had individual strategies, despite that they were measured riding the same horse. In both directions, asymmetry while riding in trot displayed a significant relationship to the rider's postural asymmetries unmounted. The rider apparently uses the same pattern when sitting on a chair or riding a horse. This suggests that it is not the horse that causes the rider to be asymmetrical.

Development of a high level of postural control, balance and stability, which are necessary in almost all dynamic sports at high levels, is achieved through training with high precision, at different speeds and with frequent speed changes, and in different environments. The sensorimotor strategy of the rider has been developed through years of training and understanding the given sport (Perrin, Deviterne, Hugel, & Perrot, 2002). This concept is called deliberate training (Ericsson, Krampe, & Tesch-Römer, 1993). Training of riders specifically targeted towards these skills has not been common practice in equestrian sports.

We have previously reported that during walking the majority of riders had significantly greater contralateral pelvic drop when the foot with the higher degree of eversion was in early stance (Engell et al., 2015). For the task of rocking a balance chair from side to side, the data in Engell et al. (2018) demonstrated an association between eversion on one foot and a higher degree of rotation to the opposite side in the pelvis and/or trunk. The reason for this observation might be that over time walking with a postural asymmetry (e.g. contralateral pelvic drop due to a highly everted foot) eventually changes the organization of movement representations in the primary motor cortex (Jensen et al., 2005; Lakhani et al., 2016). In this paper we show that the same postural asymmetries that were present during sitting are also present during riding. This suggests that riders may benefit from unmounted training to define a more specific technical strategy for each exercise and to train that strategy at slow speed and with even higher precision than is possible when mounted on the horse. Since the same kinematic frontal-plane asymmetries are significantly correlated between the chair data and ridden data, riders could potentially benefit from balance control training, since asymmetry is recognised as a negative trait with regards to equestrian performance (Hobbs et al., 2014; Symes & Ellis, 2009). If a rider needs to

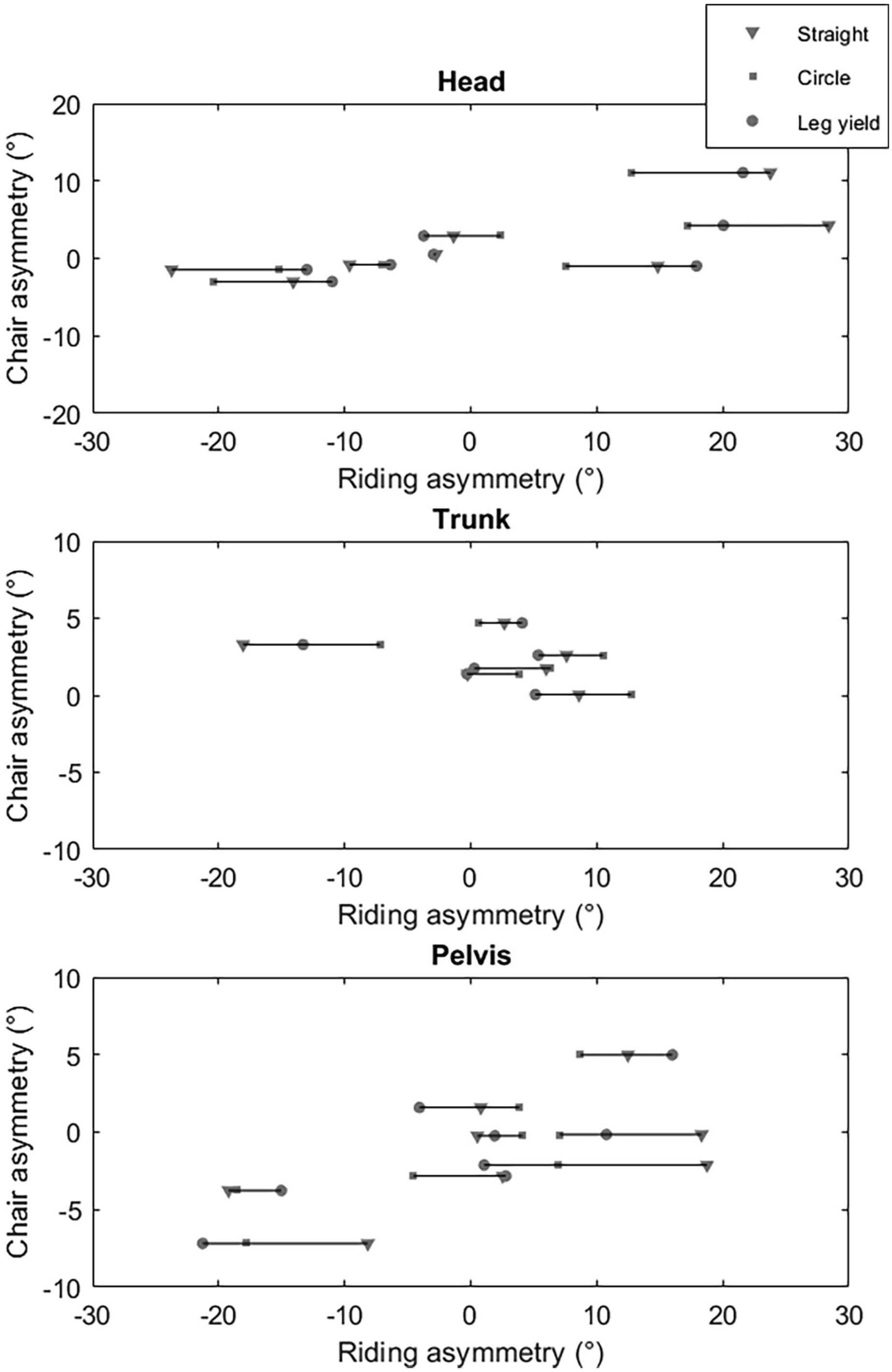

Fig. 4. Chair roll asymmetries in degrees (y-axes) plotted against left/right stride mean roll asymmetries on straight, circle and leg yield (on x-axes). Each series of horizontally connected data points represents one rider. Head and pelvis data include 8 riders, trunk data includes 6 riders. Positive values indicate the segment rotates down on the right. Eight riders have head and pelvis data and 6 riders have trunk data due to sensor failure in 2 riders. The symmetry of rotation to the right and left sides was evaluated as the difference between positive and negative areas under the curve (AUC) over the available number of full left/right motion cycles. An asymmetry measure was created for each body segment by summation of the roll values recorded when performing each exercise in the left and right directions.

develop better balance and posture, it might prove overly complex for the human brain to do that when they are riding. It might be easier to break down the motor skills into smaller and more precise pieces like athletes have done in other sports for decades (Bläsing et al., 2012; Perrin et al., 2002; Schmit, Regis, & Riley, 2005; Yarrow, Brown, & Krakauer, 2009). It would be interesting to evaluate whether riders trained to be more symmetrical on the balance chair and to actively drive the chair from side-to-side using pelvic roll instead of moving the trunk, would become more symmetrical and display better pelvic dynamics during riding.

The results of our study suggest that to evaluate rider asymmetry it is important to measure movements on both hands. Previous studies of rider asymmetry have been performed on straight lines and in different gaits (Alexander et al., 2015; Gandy et al., 2014; Symes & Ellis, 2009), but have not included analyses on circles or when riding to the left versus to the right nor compared to unmounted analysis. When riding on straight lines we might expect that the rider should sit in a symmetrical position. Symes and Ellis (2009) measured 17 riders and found that the riders sat on the horse not with the thoracic girdle evenly bisecting the horse's craniocaudal line, but with the thoracic girdle turned to the left. This was apparent in trot and left lead canter but not right-lead canter. In our study, the riders' pelvis was significantly more (roll) rotated to the inside of the arena or circle. Even on straight lines, the rider orients the body segments according to the direction of movement around the arena. This was significant on group level, which emphasizes the importance of taking both directions into consideration to avoid erroneous conclusions.

Benefits of the study include that a stance chair was used to determine an 'exact' reference position. The stance chair made it possible to zero the rider's seat at straight position, making it possible to determine mean position. Previous authors have, to the best of our knowledge, solved the stance position by placing the test person in quiet stance, without correcting precise details of the segmental position. Use of IMUs allowed the collection of many strides per rider and exercise. Limitations include the fact that IMU measurements may be subjected to skin displacement error, IMUs are not ideal for measuring absolute minima and maxima in horizontal translational movements, and leg position when sitting on the stance chair is somewhat different from that while riding with the leg supported by a stirrup. Mild asymmetries are common in sound horses and horse asymmetries might have influenced the results to some degree.

5. Conclusions

Our findings support the experimental hypothesis that riders were highly asymmetrical. Movements of the pelvis were not mirrored when comparing data for the left and right directions; instead the riders positioned the pelvis to the same side throughout. The riders also showed asymmetrical trunk positions, but with mirroring between left and right directions. The majority of riders changed their trunk angle rather than the pelvic angle to adjust to the new direction on the circle. A significant correlation was found between ridden asymmetry and performance on a balance chair. These findings suggest there may be value in performing specific unmounted training programs individually tailored to the asymmetry pattern of each rider, addressing technical riding skills necessary for a higher level of riding. If the riders' postural awareness and control can be improved, it would likely have a positive effect on sport performance.

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