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Original Research

Trunk Kinematics of Experienced Riders and Novice Riders During Rising Trot on a Riding Simulator

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ABSTRACT

Asymmetry of horses and humans is widely acknowledged, but the influence of one upon the other during horse riding is poorly understood. Riding simulators are popular for education of beginners and analysis of rider biomechanics. This study compares trunk kinematics and saddle forces of 10 experienced riders (ER) and 10 novice riders (NR) performing rising trot on a simulator. Markers were placed on the 4th lumbar (L4) and 7th cervical (C7) spinous processes, and both acromion processes. Displacements in three axes of motion were tracked using 10 high-speed video cameras sampling at 240 Hz. Displacement trajectories at L4 and C7 were similar between both groups, displaying an asymmetrical butterfly pattern in the frontal plane, which reversed when changing diagonal. Comparison between groups, NR displayed greater vertical displacement and higher saddle impact forces at L4 ($P = .034$), greater amplitude of medio-lateral displacement on the right diagonal between C7 and L4, and on the right diagonal while seated they rotated left (acromion processes) while the ER rotated right. Within group comparison demonstrated that on the right diagonal both groups produced significantly greater medio-lateral displacement at L4, and NR displayed significantly greater medio-lateral displacement between C7 and L4. On the left diagonal NR produced significantly greater vertical displacement and higher saddle impact forces.

The findings of this study suggest that ER were more stable, symmetrical, and had lower impact force on the saddle. These issues could be addressed in beginners using a simulator to avoid unnecessary stresses on horses.

1. Introduction

Horse-rider interaction is a complex area, as both components have inherent functional and motor asymmetries which are influenced by each other. From a biological perspective, it is recognized that horses are asymmetrical in terms of anatomical structures, and motor and locomotor function [2,9,31], and studies have demonstrated the functional effect of asymmetry on the locomotor apparatus of the horse [4,16,40]. Asymmetry of the horse, along with the documented asymmetry of saddle movement [5,27] all influence the balance and dynamic stability of the rider.

Many over-ground ridden studies have quantified the kinematics of the horse and rider at trot due to its symmetrical gait pattern. Studies have quantified rider kinematics in sitting trot [10,12,18], and in rising trot [3,25,26]. The dynamics of rising trot are more varied than those of sitting trot due to the asymmetrical movement of the rider. Rising trot is the action of the rider lowering themselves into the saddle from standing in the stirrups during the second half of the stance phase of one diagonal pair of limbs (e.g., right hind-left fore), to then rise again at the end of that same stance phase and remain standing in the stirrups during the stance

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Animal welfare/ethical statement: This study was approved by the University of Sunderland Ethics committee (URN 008415). Participants were informed of the nature of the research and provided written consent for their inclusion. Participants were advised that they could withdraw from the study at any time and that their data would be removed from the study. All identifiable information was removed from the dataset prior to analysis.

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phase of the other diagonal pair of limbs (e.g., left hind-right fore).

Comparison of sitting trot, rising trot and the two-point seat position (as used by race jockeys), using inertial measurement units (IMU), indicates that rising trot induces significant changes in horse movement symmetry in the push off phase of the stride [39] compared to the symmetrical positions (sitting trot and two-point). More recently, rising trot has been reported to alter rotational movement and symmetry parameters of the horses back [28]. In sitting trot, the presence of the rider increases peak vertical forces of the forelimbs, and when performing rising trot, the alteration of the rider's center of mass (CoM) creates an uneven biphasic load, increasing the load on the limbs of the sitting diagonal and producing an asymmetry in the kinematics of the pelvis and limbs of the horse [41]. This additional asymmetry of the horse in rising trot will have a supplementary influence on the dynamics of the rider, and the interaction between the rider, saddle and horse, will be further compounded by rider skill.

Ridden over-ground studies have shown that experienced riders (ER) are more effective in synchronising their movement with the horses' motion pattern, moving with greater harmony than novice riders (NR), and display a greater ability to adapt to the horses' movement pattern [24,36]. In sitting trot, electromyography (EMG) studies have demonstrated that ER are more stable when compared to NR [30]. In addition to trunk stability, professional riders had greater stability of the pelvis with less medio-lateral deviation from the midline than NR. In ridden treadmill studies, ER had a stabilizing effect on the horse by reducing the forward acceleration and velocity variability [38]. However, a direct comparison quantifying the kinematics and forces between experienced and NR has yet to be conducted.

In an attempt to identify rider-specific asymmetries, studies have evaluated riders under various unmounted conditions, using a static balanced saddle (C. [32]), horizontal seating [17], standing platforms [20], and exercise balls [45]. Further attempts to evaluate dynamic rider-specific kinematics, while limiting the effect that the horse's locomotor asymmetries have on the rider, have been performed using a horse simulator [15,35,47]. A horse simulator provides a mechanism with which rider kinematics and asymmetries can be quantified without the influence of dynamic locomotor forces and asymmetries from the horse.

Simulators have been used to compare kinematics of jockeys whilst galloping horses over-ground compared to galloping on a simulator [48], rein tension in NR at different gaits [8], investigate saddle and stirrup forces [3] measure sympathetic responses of the rider [21], measure rider muscle activity [22], and to determine trunk kinematics and brain behaviour of a professional and a non-professional rider [6]. Whilst differences exist between the horse and simulators [7], simulators remain a useful tool when quantifying rider specific movement patterns.

The aims of this study were to quantify differences between ER and NR when performing rising trot on a simulator in respect of (1) the movement pattern of the rider's trunk and pelvis; (2) the displacement trajectory of the spine and acromion processes (AcP); (3) the vertical forces at the point of impact with the saddle. The objectives of this study were to quantify differences between ER and NR in respect of: (1) the displacement trajectories of the 4th lumbar vertebrae (L4); (2) the vertical, longitudinal and transverse displacement at L4, the 7th cervical vertebrae (C7) and left & right AcP; (3) calculate and compare the three-dimensional symmetry of movement at these locations between groups; (4) calculate the vertical forces at L4 at the point of impact with the saddle; and (5) determine if participants display significant short-term changes in their movement with repeated use of the simulator. We hypothesize that NR will show a similar displacement trajectory to ER but will display greater amplitudes of displacement in all planes, a higher variance of movement, and higher forces at the point of impact with the saddle.

Table 1
Participant descriptive data (mean ± S.D.).

	Age (Years)	Height (cm)	Weight (kg)
Experienced riders	40.3 ± 11.4	162.4 ± 9.0	71.7 ± 16.1
Novice riders	37.4 ± 9.6	168.6 ± 5.9	63.4 ± 4.9
P value	.546	.089	.136

2. Methods

2.1. Participants

Ten ER who had ridden ≥ 10 years, and 10 NR who had not previously participated in any equestrian activities were recruited via social media. Participants were selected on a first response basis subject to fulfilling the study inclusion criteria. All participants were female, aged from 20 to 50, were right-handed and reported no physical disability or pain. Each participant completed a questionnaire to describe their riding experience and general physical activity. Participants in each group showed no significant differences in morphological characteristics of age, height and weight ($P > .05$) (Table 1).

2.2. Ethics

This study was approved by the University of Sunderland Ethics committee (URN 008415). Participants were informed of the nature of the research and provided written consent for their inclusion. Participants were advised that they could withdraw from the study at any time and that their data would be removed from the study, and that all identifiable information would be removed from the dataset prior to analysis.

2.3. Horse simulator

A dressage riding simulator (Racewood Ltd, Cheshire, UK) which had five speeds categorized as (1- slow walk, 2 - fast walk, 3 - slow trot, 4 - fast trot and 5 - canter) was used, each with distinct frequencies and amplitudes of displacement. Based on previous work [7] the cycle duration of "fast trot" (the speed used in this study) was 0.59 ± 0.01 seconds and produced displacement amplitudes of 51.2 ± 0.1 mm in the medio-lateral axis, 45.9 ± 0.4 mm in the cranio-caudal axis and 77.8 ± 0.3 mm in the dorso-ventral axis. A 17.5-inch general purpose saddle (Kent & Masters, West Midlands, UK) was positioned centrally on the simulator with a level pommel and cantle and was assessed each time by the same researcher (LC). The same saddle was used throughout the study to standardize rider position.

2.4. Instruments

To track the motion cycle of the simulator, a 14 mm spherical reflective marker was placed on the midline of the simulator, immediately behind the saddle corresponding to the level of the 18th spinous process (T18). To quantify rider kinematics, 10 mm spherical reflective markers were placed on bony landmarks of the spinous processes (SP) of C7 and L4, and bilaterally over the AcP of each shoulder. The L4 marker was chosen as the lower spinal marker rather than L5 due to the back of the saddle blocking this marker from the cameras in preliminary testing. All markers were applied by the same researcher (LC) who is an experienced Chartered Physiotherapist and Veterinary Physiotherapist.

A Vicon Nexus 2 three-dimensional motion capture system (Vicon Motion Systems Ltd, Oxford, UK) and 10 (Bonita 10) cameras were positioned around the simulator sampling at 240 Hz. Cameras were positioned and calibrated as per manufacturers recommendations. The displacement data from each of the transverse (x-axis), longitudinal (y-axis), and vertical (z-axis) axes were collated from each trial.

2.5. Procedure

A standardized demonstration was given by the same researcher (LC) demonstrating how to perform the action of rising trot. Each participant observed the process whilst being given verbal instructions. The instructions and dialogue were agreed upon in advance by five British Horse Society (BHSII) instructors. Each participant was allowed a practice session of three x 20 seconds, and for each 20 second session the rider was required to change their diagonal. Participants were permitted to adjust the stirrups to the most comfortable length during the practice session.

For the study data, all participants were instructed to perform rising trot for 20 seconds, with recordings taken during the last 10 seconds. They were then requested to "change their diagonal" which consisted of sitting into the saddle and remaining seated for one rise of the simulator, and then rising for a further 20 seconds. Recordings were again taken during the last 10 seconds. The change of diagonal was monitored to ensure it had been performed correctly. Participants then remained on the simulator and rested for 60 seconds before repeating the previously described procedure nine times. In total, each participant performed 10 trials of 40 seconds giving 10 × 10 seconds of data on each diagonal. Ten seconds of data provided 10 full motion cycles allowing for analysis of 100 cycles of rising trot per participant on each diagonal.

2.6. Data Processing and Analysis

All data were exported to Microsoft Excel (Microsoft Co, Redmond, WA). Data from the marker placed on the simulator at T18 were analyzed for each trial (n = 10) performed by each participant. The center point of displacement of this marker in the transverse axis (x-axis) was used as a reference point for the center of displacement for the simulator and rider. Data strings from the L4, C7 and AcP markers were cut and separated into 10 full cycles of displacement for each of the 10 runs on each diagonal using the midpoint of displacement of the marker on the simulator in the transverse axis as the start and finish point of each cycle. Using this midpoint of displacement for each participant the degree of displacement (left-right) at L4 and C7 was calculated and compared for symmetry of displacement in the transverse axis.

Data were separated into left and right diagonals and considered separately so any differences or rider side-preferences could be quantified. The mean displacement of each of the 10 trials (1 trial = 10 cycles) on each diagonal was calculated in the transverse, longitudinal and vertical axes. Data used to measure deviation of the spine in the sagittal plane and the frontal plane were derived from subtracting the positional data of the C7 marker from that of the L4 marker in the longitudinal and transverse axes respectively.

Data collected from markers placed on the AcP of all participants allowed analysis of shoulder displacement. Data in the vertical axis and in the longitudinal axis were analysed at two time points, 1) the point at which the values of the AcP markers were at their greatest in the vertical axis which coincided with the period at which the subjects were at the peak of the rising phase and 2), and the point at which the values of the AcP markers were at their lowest in the vertical axis which coincided with the period at which the subjects were in the seated position. Data used to determine positional rotational asymmetry of the AcP in the transverse plane and vertical asymmetry in the frontal plane were derived from subtracting the positional data of the left AcP from the right AcP in the longitudinal axis and vertical axis respectively.

Vertical acceleration (a) data from the L4 marker were collected at the point of impact of the riders with the saddle and using the known body mass (m) of each rider this data was converted into force (F) using the equation F = m x a.

Values of mean and standard deviation of displacement were calculated in three planes of motion and analyzed using SPSS Statistics v24 (IBM Co, Armonk, NY). Normal distribution of data and homogeneity of variance was tested using the Shapiro-Wilk test. Independent t-tests were used to test for differences between force of impact with the saddle, displacement amplitudes and symmetry of movement between groups (ER vs NR) Paired t-tests were used to test for differences in force of impact with the saddle, displacement amplitudes, and symmetry of movement between the right and left diagonals within each group. Repeated measures analysis of variance (ANOVA) with post hoc LSD adjustments was used to determine intra-participant differences in mean displacement amplitudes at L4 for each group over the 10 repeated trials to test for: (1) participant fatigue, and (2) participant accommodating to the movement and altering their movement throughout the process. A chi-squared goodness-of-fit test (Chi^2 test) was used to analyse preference of rider diagonal, and frequency of medio-lateral asymmetry at L4. The cut off for significance for all tests was $P \leq .05$.

3. Results

3.1. Lumbosacral Displacement Trajectory - L4

All participants from both groups, irrespective of their level of riding experience, demonstrated a similar displacement trajectory. In the frontal plane the trajectory can be best described as a butterfly with asymmetrical sized wings. The determination of which wing is longer (i.e., greater vertical displacement) is dependent on which diagonal the participant is riding on, with the left wing being longer while on the left diagonal and the right wing being longer while on the right diagonal (Fig.1). In the sagittal plane the movement trajectory is similar to that of the frontal plane with the smaller wing at the cranial portion of the displacement pattern (Fig. 2).

3.2. Magnitude of Displacement - L4

A significant difference in vertical displacement between groups was found with NR demonstrating greater vertical displacement during the rising phase on both diagonals (left, $t(18) = -4.82$, $P < .001$ (NR 158.49 ± 5.89 mm, ER 129.58 ± 5.13 mm), right $t(18) = -4.81$, $P < .001$ (NR 155.76 ± 6.54 mm, ER 125.61 ± 4.93 mm). (see Table 2).

Analysis of data within each rider group indicated that both groups had significantly greater overall medio-lateral displacement while on the right diagonal than when they were on the left diagonal. The experienced rider group demonstrated displacement amplitudes of 62.67 mm on the right diagonal compared to 53.91 mm on the left diagonal, $t(9) = 2.447$, $P = .035$, and the NR demonstrated displacement amplitudes of 69.48 mm on the right diagonal compared to 60.49mm on the left diagonal, $t(9) = 2.590$, $P = .018$. The novice group also demonstrated significantly greater vertical displacement while on the left diagonal (158.49 mm) than when they were on the right diagonal (155.76), $t(9) = 1.453$, $P = .017$.

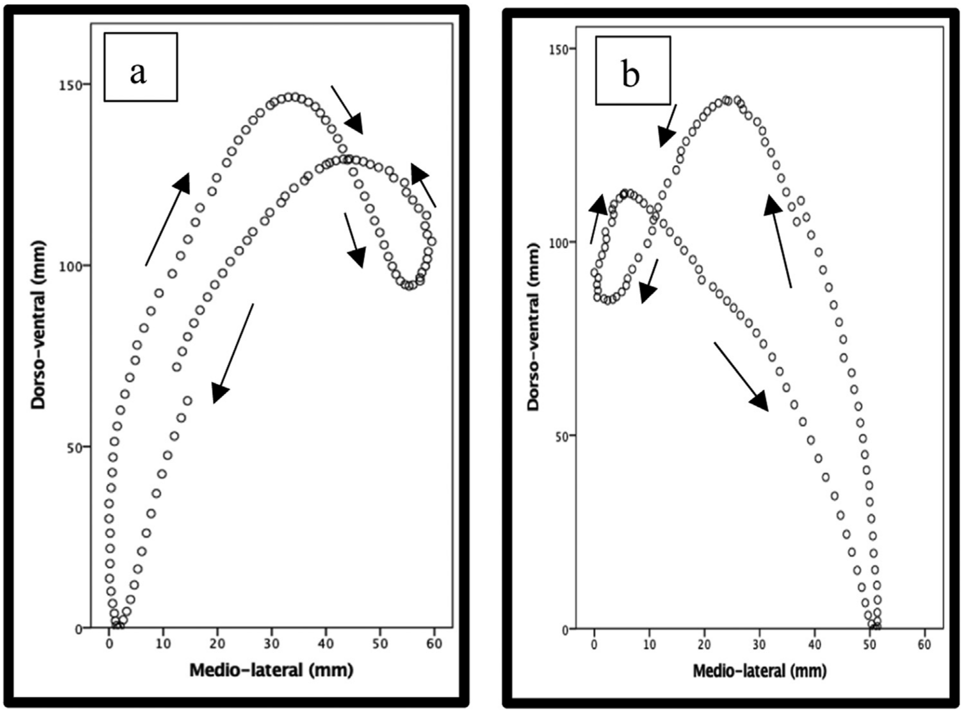

Fig. 1. Example of displacement trajectories of the L4 marker in the frontal plane (as if viewed from the posterior of the simulator) with the rider: (A) on the left diagonal (B) on the right diagonal. Arrows show direction of motion. Sample frequency = 240 Hz.

Table 2
Means and standard deviations (mm) for both groups in the transverse (x), longitudinal (y) and the vertical (z) axes on each diagonal at L4, and the results of independent t-tests of means between groups.

Axis	Diagonal	Experienced Riders	Novice Riders	F	df	*P* Value
X	Right	62.67 ± 5.97	67.05 ± 7.11	2.167	18	.324
	Left	53.91 ± 6.74	60.49 ± 7.23	0.444	18	.274
Y	Right	136.01 ± 9.67	119.60 ± 16.70	1.690	18	.297
	Left	139.58 ± 9.32	120.00 ± 16.76	1.798	18	.196
Z	Right diagonal long wing	125.61 ± 4.93	155.76 ± 6.54	2.590	18	.000*
	Right diagonal short wing	46.07 ± 3.58	70.97 ± 6.86	6.350	18	.045*
	Left diagonal long wing	129.58 ± 5.13	158.49 ± 5.89	8.618	18	.000*
	Left diagonal short wing	41.67 ± 3.63	67.38 ± 6.13	7.607	18	.021*

* Indicates significant difference ($P \leq .05$).

3.3. Medio-Lateral Symmetry of Movement – L4

The novice rider group exhibited greater displacement to the right in 65% of the trials, while the experienced rider group exhibited greater displacement to the right in 55% trials (Table 3). A Chi^2 test indicated that the frequency of this tendency to move more to the right was not significant. (ER X^2 *(1) = 0.20, P* = .66 and NR X^2 *(1) = 1.80, P* = .18). Neither group displayed any difference in the degree (amplitude) of asymmetry of movement from the midline at L4.

3.4. Displacement Changes With Repetition

Repeated measures ANOVAs showed no significant differences in displacement for either group with repeated trials (n = 10) indicating intra-participant consistency when riding on the simulator. *P*-values all > .109.

3.5. Force of Impact With the Saddle

The NR produced significantly higher impact forces on the saddle than the ER (Fig. 3). Combined diagonals *t(18) = -2.29, P* = .034*:* right diagonal *t(18) = -2.38, P* = .028*:* left diagonal *t(18) = -2.23, P* = .039. The novice group also produced significantly higher forces when on the left diagonal than when on the right diagonal, t(9) = 2.713, *P* = .024.

3.6. Displacement at C7

The trajectory of displacement at C7 is replicated at L4 but comparison of the amplitudes demonstrates a higher degree of movement at L4 in comparison to that at C7.

Amplitude of displacement in the transverse (x) and longitudinal (y) axes are in Table 4. No significant differences in the total amplitude of displacement or deviation from the midline at C7 between groups were found.

3.7. Spinal Displacement Between C7 and L4

3.7.1. Sagittal Plane Displacement of the Trunk

The ER showed smaller values of spinal displacement values which translated into mean angular values of 20° forward lean in the sitting position and 7° at the point of the rise. The NR demonstrated forward lean angles of 24° in the sitting position and 11° at

Table 3
Mean displacement (mm) at L4 from the center point of the mechanical horse in the transverse axis (x-axis) during rising trot on each diagonal for both groups.

Novice Riders	1	2	3	4	5	6	7	8	9	10	Mean
Right diagonal											
Left	**39.98**	**67.76**	17.73	31.71	20.16	31.22	24.12	**43.95**	18.20	20.35	31.52
Right	38.38	10.81	**43.58**	**48.55**	**44.74**	**41.93**	**37.75**	12.24	**26.83**	**51.20**	35.60
Left diagonal											
Left	**37.99**	**57.40**	16.35	32.00	17.12	38.60	4.38	**38.45**	**43.14**	8.92	29.43
Right	24.36	15.87	**37.75**	**47.60**	**35.31**	**40.34**	**34.22**	13.64	-4.09*	**44.39**	28.94
Experienced Riders	1	2	3	4	5	6	7	8	9	10	
Right diagonal											
Left	13.73	23.86	**51.78**	**43.40**	19.46	**54.69**	**37.64**	29.09	10.78	**30.53**	31.50
Right	**55.89**	**36.45**	21.43	20.33	**48.40**	12.99	13.23	**36.07**	**42.48**	24.88	31.26
Left diagonal											
Left	-1.60*	34.06	**47.74**	**33.19**	18.13	**40.85**	23.15	23.39	-0.89*	**37.51**	25.55
Right	**63.76**	**35.54**	15.82	4.89	**39.14**	5.79	**25.40**	**34.29**	**36.17**	23.67	28.45

Note: Bold text highlights which direction had the greatest amount of deviation. *A negative value means that the rider did not cross the midline during movement.

Table 4
Mean ± S.D (mm) of displacement at L4 and C7 for both groups in the transverse (x) and longitudinal (y) axes.

Axes	Diagonal	Experienced Riders		Novice Riders	
		C7	L4	C7	L4
Transverse	Right	45.21 ± 8.58	62.67 ± 5.97	43.17 ± 8.78	67.05 ± 7.11
	Left	46.03 ± 9.16	53.91 ± 6.74	40.26 ± 9.01	60.49 ± 7.23
Longitudinal	Right	63.53 ± 26.81	136.01 ± 9.67	48.84 ± 21.50	119.60 ± 16.70
	Left	63.98 ± 24.52	139.58 ± 9.32	48.87 ± 22.61	120.00 ± 16.76

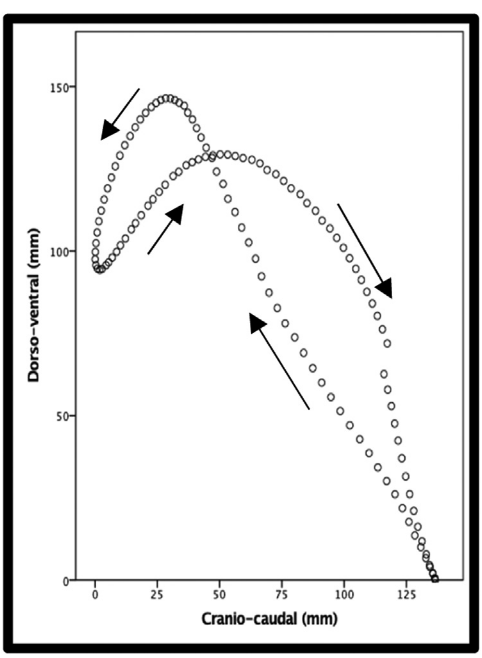

Fig. 2. Example of displacement trajectories of the L4 marker in the sagittal plane of the rider (as if viewed from the left side of simulator). Arrows show direction of motion. Sample frequency = 240 Hz.

the point of the rise. There were no significant differences between groups or within groups on either diagonal (all $P > 0.63$).

3.7.2. Frontal Plane Displacement of the Trunk

On the right diagonal differences in mean total spinal displacement between groups were found, with NR (59.93 mm) displaying greater deviation than ER (48.08 mm), $t(18) = 2.74$, $P = .014$. Angular translations across both groups showed mean lateral lean angles between 3.08° and 5.67° from the vertical. Analysis within groups showed that NR had significantly greater displacement on the right diagonal (59.93 mm) than on the left (51.56 mm) ($t(9) = 4.037$, $P = .003$).

3.8. Shoulders

3.8.1. Vertical Displacement (Shoulder Tilt)

Displacement of the AcP markers in the vertical axis is representative of shoulder tilt. Mean AcP height differences of each group was separated into diagonals. Individually, values ranged from almost symmetrical for one the ER on the left diagonal in the seated position (0.10 ± 19.26 mm) to the most asymmetrical for one of the NR on the left diagonal at the same point (14.10 ± 29.61 mm). Statistical evaluation showed no differences between groups or within groups (All $P > .09$).

3.8.2. Longitudinal Displacement (Shoulder Rotation)

Displacement of the AcP markers in the longitudinal axis is representative of shoulder rotation. Participants demonstrated four displacement patterns, (1) rotation to the right at the peak of the rise and in the seated position, (2) rotation to the left at the peak of the rise and in the seated position, (3) rotation to the left at the peak of the rise and right in the seated position, and (4) rotation right at the peak of the rise and left in the seated position. With 20 participants, all riding on both diagonals there were 40 trials. Overall, 29/40 (72.5%) trials demonstrated rotation to the same side at the peak of the rise and in the seated position, with 17/29 (11 NR and six ER) rotated right as in pattern 1, and 12/29 (five NR and seven ER) to the left as in pattern two. Only 11/40 demonstrated rotation to opposite sides at the peak of the rise and in the seated

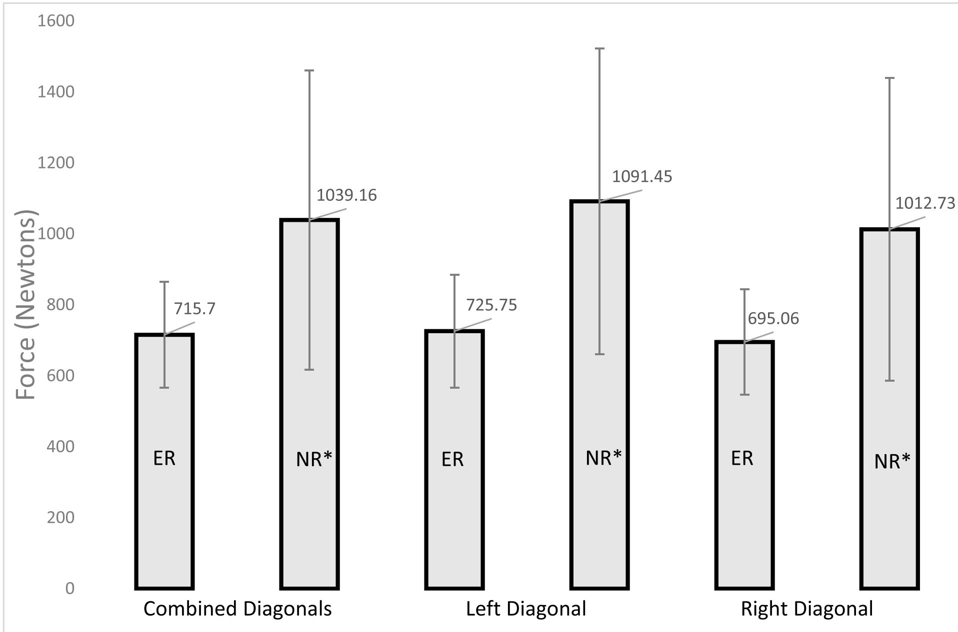

Fig. 3. Mean ± S.D Mean of force (Newtons) at the point of impact of experienced riders (ER) and novice riders (NR) on the saddle. * Indicates significance between groups at $P \leq .05$

position with 7/11 (1 NR and six ER) rotating right at the peak of the rise and left in the seated position as in pattern three, and 4/11 (three NR and one ER) rotating left at the peak of the rise and right in the seated position as in pattern four. Also, 14/20 participants at the peak of the rise and 17/20 in the seated position demonstrated rotation to the same side irrelevant to which diagonal they were on. Statistical evaluation within groups showed that ER had significantly greater total range of rotation than NR (15.84 mm vs 7.61 mm) when on the right diagonal ($t(9) = -2.95$, $P = .016$). Analysis between groups revealed a significance between ER and NR on the right diagonal in the seated position $t(18) = -2.61$, $P = .018$, with the NR demonstrating shoulder rotation to the left (10.64 ± 16.55 mm) and the ER to the right (7.91 ± 15.15 mm).

4. Discussion

The dynamics of rising trot have been studied in relation to the kinematics of the horse [26,39,41] and the forces applied to the horse [37], but not in relation to the motion of the rider and comparisons of diagonals. To our knowledge, this is the first study to describe the displacement trajectory of the riders' pelvis and trunk in rising trot, and to document the displacement amplitudes in the longitudinal, transverse and vertical axes when comparing diagonals. The aim of this study was to quantify displacement trajectories, quantify trunk and pelvic kinematics, and calculate the magnitude of mean forces applied to the saddle during impact, between experienced and novice horse rider's during rising trot. This was performed utilizing a riding simulator with the aim of reducing possible effect that asymmetrical locomotor forces (generated by the horse), and incorrectly fitting saddles may have on the rider's pelvic and trunk kinematics.

Recommendations have been made that an equal amount of time should be allocated to riding on each diagonal to prevent the horse developing musculoskeletal asymmetries [23]. This advice is also transferrable to the rider to prevent the rider from acquiring similar horse-induced and rider-induced asymmetries. Although technically it is challenging to ride a horse simulator on a designated diagonal as it has no limbs to determine which diagonal the rider would be on, the movement of rising and remaining elevated for one cycle of motion is still possible. The allocation of which diagonal riders are on is determined by the phase of the cycle the simulator is in at the point at which the rider sits into the saddle. The riders can choose to sit as the simulator moves the right (right diagonal) or the left (left diagonal). Anecdotally, when performing rising trot, riders may prefer a particular diagonal which may be influenced by the riders' preferences and or in response to the horse's locomotor patterning. In the current study, although not significant, a trend was observed in both groups, with riders opting to start on the left diagonal (54% ER, 57% NR).

4.1. Lumbosacral Displacement – L4

4.1.1. Trajectory

The trajectory of the L4 marker describes a butterfly pattern displayed in the frontal and sagittal planes (see Figs. 1 and 2) of the riders' lumbosacral spine is novel. In the frontal plane this pattern is a mirror image when comparing the displacement of the pelvis on one diagonal to the other, and all patterns were duplicated, regardless of previous riding experience.

4.1.2. Magnitude

Less-ER have increased range of motion of their limbs while performing sitting trot [11], however, no studies have specifically investigated limb or spinal kinematics when performing rising trot.

With respect to NR, compared with ER they displayed greater displacement of L4 in the transverse axis on both diagonals suggesting that NR are less stable medio-laterally and that ER have a greater ability to remain stable during locomotion, which could be a sign of greater dynamic control of their axial segments. These findings are in accordance of those observed in sitting-trot studies [24,36,44] and canter [34]. Both groups also displayed significantly greater displacement amplitudes in the transverse axis on the right diagonal compared to the left diagonal suggesting that participants may all have a more stable or balanced diagonal irrelevant of their experience of riding horses.

In the current study, the magnitude of L4 displacement in the vertical axis was significantly higher (mean increase of 24% across both diagonals) in the novice rider group, and in respect to longitudinal displacement, although not significant, there was greater displacement at L4 for the experienced rider group on both diagonals (Table 2), which may be explained by rider experience and education. ER may be more skilled at translating their CoM forward during the standing phase of rising trot in order follow the horse's movement. In the absence of training and education, NR adopt a different movement strategy and replace the longitudinal (forward/backwards) displacement with greater vertical (up/down) displacement. This strategy may explain the increased impact forces seen in this study for the NR. This is further supported in the current study, with NR demonstrating significantly greater amplitudes of vertical displacement in conjunction with higher impact forces on the left diagonal than when on the right diagonal. The mean impact forces produced by the experienced rider group are similar to those reported by Peham et al. [37]. We speculate that this increase in impact force may be transmitted through the saddle, and subsequently to the horse. Increased impact force during the sitting phase of the rising trot may affect the kinematics of the thoracolumbar spine [26,29], asymmetries of gait [4], back pain [19] and saddle pressure distribution [42]. During locomotion, forces from the horse's limbs are transmitted to the saddle and rider [46] and when trotting the addition of the rider increases the forces acting on the horse's back [14]. Further work is needed to quantify the effect that the impact forces being described here have on saddle pressure distributions, however, it seems reasonable to expect that riders who have a greater vertical displacement and increased impact force will influence the locomotor apparatus of the horse [38].

Similarities exist between experienced and NR. Both groups displayed greater range of vertical displacement and less mediolateral displacement on the left diagonal than on the right diagonal (i.e., a movement pattern which is higher and narrower on the left diagonal and lower and wider on the right diagonal). All participants were right-handed which may pre-dispose them to be more stable on left diagonal when taking weight up and across to the right side and eccentrically lowering themselves down to the saddle. Although NR demonstrated greater medio-lateral displacement from the midline (Table 3), there was no significant difference within groups or between groups which differs from studies analyzing sitting trot, that demonstrated greater displacement in less ER [30]. Comparing deviation left on the left diagonal to right on the right diagonal (i.e., displacement amplitudes in the seated phase on each diagonal) both groups displayed greater deviation to the right on the right diagonal. Comparing deviation left on the right diagonal and right on the left diagonal (i.e., displacement amplitudes in the standing phase on each diagonal), both groups displayed greater deviation to the left on the left diagonal, although none of these reached statistical significance (Table 3). This consistent observation displayed across both groups could be related to the functional and motor asymmetries inherent in all individuals and may be expected in this group of right-handed participants. It is generally accepted that individuals will demonstrate some postural or locomotor asymmetries, and riders as a group have been shown to demonstrate a pattern of displacing their center of mass to the right while sitting on a stationary horse [33], and while sitting on a static surface [17]. Clarifying whether this is the result of naturally-occurring laterality requires further investigation and the inclusion of left-handed participants in future studies. Such laterality of riders may have subsequent effects including the asymmetrical displacement of the saddle and thereafter asymmetrical pressures on the horse.

4.1.3. Variation of displacement – L4

The NR demonstrated a greater variation of displacement in all planes on both diagonals (Table 2). In accordance with previous studies investigating sitting-trot [24,30,36], these results suggest that ER have a higher degree of motor control, being able to remain dynamically stable whilst altering their CoM in a repeatable manner when performing rising trot. NR demonstrated a smaller magnitude, yet higher variation of displacement in the longitudinal axis which could be an indication that the NR experience some degree of difficulty in stabilizing and controlling the transfer of their CoM forward during the standing phase of rising trot.

4.2. Displacement at C7

There are no previous studies describing the displacement trajectory or amplitude of riders at C7. The significant asymmetries highlighted from analysis of the marker at C7 suggests that NR did not shift their upper body to the right while on the left diagonal, or they have excessive upper body movement to the left while on the right diagonal. Such actions could produce an asymmetrical displacement of the rider's center of mass and uneven vertical forces through the stirrups and therefore the saddle.

4.3. Spinal Displacement Between C7 and L4

4.3.1. Sagittal Plane Displacement of the Trunk

During the seated portion of the movement, the C7 marker was more anteriorly positioned relative to the L4 marker in all participants, and in the more spinally flexed, or slumped individual the difference between these points is greater. When performing rising trot, as the rider rises and the pelvis moves anteriorly in relation to the thoracic spine, the degree of relative spinal displacement reduces (i.e., the spine moves into more extension). Although there were no statistical differences between groups the ER demonstrated a more upright posture during both components of the rising trot sequence (sitting and standing phases) by 4°.

From a small sample of riders performing sitting trot on real horses overground, Terada [44] reported NR having unstable movements of the upper body in the sagittal plane. Olivier et al. [34] also concluded that less ER have less stability of the upper trunk in the sagittal plane while cantering on a riding simulator.

4.3.2. Frontal Plane Displacement (Trunk Lateral Shift)

As the total displacement values of C7 are always smaller than L4 (i.e., the lower portion of the spine/pelvis has a higher degree of movement than the upper spine), this action is better described as a lateral pelvic shift. The greatest difference in C7–L4 in a mediolateral direction occurred at two points throughout the stride cycle, once during the maximum point reached during the first rise and a second one during the lowest point when the rider was seated. Interestingly the NR displayed significantly greater pelvic shift on the right diagonal compared to the left diagonal and also displayed greater pelvic shift compared to the ER on the right diagonal. This suggests that the NR have excessive upper body movement on the right diagonal rather than reduced movement while on the left diagonal. As previously discussed, both groups demonstrated more lateral pelvic displacement (less stability) on the right diagonal, which may be influenced by all of the participants being right-handed, and the NR displayed greater variation of movement in all displacement magnitudes (less control). It would therefore seem logical that the greatest level of instability would be demonstrated by the NR on the right diagonal.

4.4. Shoulders (AcP Displacement)

4.4.1. Vertical Displacement (Shoulder Tilt)

On the left diagonal, both groups demonstrated the same displacement pattern of a higher right shoulder at the peak of the rise and higher left shoulder in the seated position. On the right diagonal the experienced rider group displayed the opposite pattern of higher left shoulder at the peak of the rise and higher right shoulder in the seated position which would be expected, however the novice rider group demonstrated a pattern of higher left shoulder at both time periods, again, perhaps due to lack of stability and control on this diagonal.

4.4.2. Longitudinal Displacement (Shoulder Rotation)

In this study there were no significant asymmetries displayed by the ER, however Symes & Ellis [43] analyzed 17 advanced dressage riders performing sitting trot on horses trotting over-ground, concluding all riders demonstrated thoracic girdle rotation to the left. Although data was collected while trotting along the straight sides of a menage, data were only collected on the left rein which may have influenced rider position. Alternatively, it may be possible that this asymmetry was due to influences from the horses. In this study NR demonstrated the opposite direction of shoulder rotation (left) in the seated position on the right diagonal compared to the ER (right) and they displayed significantly less total range of rotation throughout the rising trot action on this diagonal. This has not been described previously and warrants further investigation, it is cautiously speculated that this may be related to the novice rider's dynamic stability.

5. Limitations

In this study to standardize the balance and positioning of the participants the same saddle was used for everyone. Although there were no differences in morphological characteristics between groups, there may have been individual variations which could have influenced the motion of different sized participants in the same size saddle. Participants were also allowed to select their own stirrup length based on comfort and stability (as there is no published evidence of the ideal length), which are two of the main criteria riders use to select stirrup length [13]. However, Andrews-Rudd et al. [1] found that NR selected significantly shorter stirrup length compared to ER, and NR selected shorter stirrup length on real horses compared to when on a simulator. Forces of impact on the saddle were calculated using body weight and acceleration data rather than direct measurement which may lead to an overestimation in the magnitude of calculated forces, however, for the purpose of comparison between these two groups we feel that the proportional differences between groups will be the same. We acknowledge that horse simulators do not recreate the dynamics of a real horse. The displacement vectors of the simulator utilised in this study have been compared with that of real horses [7] and differences were found. Further research is therefore required to determine if results of any dynamic motion analysis of riders on simulators is transferable to that of riders on real horses.

6. Conclusion

ER and NR produce similar three-dimensional patterns of trunk displacement while performing rising trot on a riding simulator. NR have a greater range of displacement at L4 in the vertical axis (greater on the left diagonal than on the right diagonal) and display a higher variation of displacement in all planes of movement suggesting a lack of motor control. NR also demonstrated a non-significant but consistently lower values in the longitudinal axis suggesting that they do not displace their pelvis forwards/backwards but instead replace this with excessive vertical movement. The NR also produced higher forces at the point of contact with the saddle, which were also significantly greater on the left diagonal.

ER did not display any significant asymmetry of movement in any measured variable, they did however display greater transverse displacement on the right diagonal than the left. The NR did not display any significant asymmetries at the lumbosacral region (L4), but they did display numerous asymmetries through the thoracolumbar (C7–L4) region and shoulders (AcP). On the right diagonal NR demonstrated a greater shift between C7 and L4 and compared to the ER, in the sitting phase, they demonstrated the opposite shoulder position of rotation to the left (ER - rotated right) with the right shoulder lower (ER – left shoulder lower). Neither group showed any evidence of fatigue or accommodation after a short period of practice (10 × 60 sec). It is important for any professional using riding simulators to be aware of 'normal' movement patterns to be able to recognize abnormal movement patterns. This study describes the expected pattern, irrelevant of riding experience, and highlights some aspects of this movement that may need addressing in NR. In particular, the training of NR should focus on encouraging the transference of their CoM forwards instead of upwards, and to achieve symmetry of motion particularly in the upper trunk region, which may be less stable on the right diagonal. Focus should also be placed on the ability to control the lowering of the body into the saddle reducing the impact on the saddle. Improvement of these variable will potentially reduce the asymmetrical loading and impact on the horses back once these riders progress to riding real horses, therefore protecting these horses from unnecessary pain or injury.

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