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Multiplanar intersegmental angular velocity in the assessment of topline movement in horses

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Objective
To measure intersegmental movement in the sagittal, dorsal, and transverse planes of the cranial thoracic to caudal thoracic, caudal thoracic to lumbar, and lumbar to sacral segments using range of motion and angular velocity as measures of quality of movement.

Methods
6-degrees-of-freedom spinal motion was measured at the walk and trot in 3 sound Thoroughbred and Thoroughbred cross horses, and the data were pooled, giving a total of 54 gait cycles at walk and 33 at trot. These were compared against 8 cycles at walk and 13 at trot from 1 Thoroughbred horse that was confirmed as having moderate to severe impact and push-off lameness in the right hind limb.

Results
Both joint angles and angular velocities detected differences between the sound horses and the lame horse, with angular velocity showing notably greater differences in absolute values and percentages compared with joint angles.

Conclusions
The between-group differences indicated decreased quality of movement/control in the lame horse, and this was most apparent when trotting.

Clinical Relevance
Intersegmental angular velocity is measured noninvasively and may be used to assess the quality of intersegmental movement in horses as it does in humans. Further investigation to assess angular velocity throughout treatment of topline dysfunction of the horse and its association with different lameness patterns is warranted.

Keywords: topline dysfunction, spinal kinematics, quality of movement, lameness, equine back pain

Since the 1970s, equine "back pain" has been reported in the veterinary literature,[1,2] with an incidence up to 94% in some equine populations.[3] In 1979, Jeffcott[4] noted several limiting factors in the evaluation of back problems in horses, many of which still stand today. A recent survey of a large group of equine clinicians identified the need for more objective assessments of quality of movement.[5] Such measures could be useful in the assessment of clinical cases traditionally diagnosed with "back pain."

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One of the problems facing practitioners is the difficulty of establishing a specific diagnosis due to the lack of a consistent definition of what "back pain" encompasses.[4] Since pain is only 1 of the many presenting complaints, back pain may be better described as topline dysfunction, a term coined by the corresponding author to better describe the clinical presentation of many horses. This definition of topline dysfunction incorporates 3 main components: generalized pain, stiffness, and decreased mobility of the back during static and dynamic exercises. It is often characterized by weakness, identified by an inability to perform a certain exercise, and can be associated with muscle atrophy. Horses with clinical topline dysfunction may present with a multitude of complaints based on which of these components is affected and to what extent. Veterinarians report that generalized poor performance was the presenting complaint in 76% of horses diagnosed with back problems, closely followed by behavioral issues in 68% of horses and lameness in 50% of cases.[6] Horses with a large pain component may be more irritable under saddle, with evidence of tail swishing, bucking, or kicking out with the hind limbs.[7] If stiffness is a large contributor, clinicians note a poorer quality of movement using subjective functional assessments[5] while the horse performs specific tasks. Weakness is usually most evident in the horse's general inability to perform the work asked. This could manifest as a horse recording longer times in speed events, refusal or reluctance to perform certain exercises, or generally performing exercises poorly as assessed subjectively by the rider and or clinician.[5]

Regardless of the original presenting complaint, topline dysfunction can be a primary diagnosis in horses with poor performance but has also been clinically recognized by the authors in association with a variety of intrinsic and extrinsic factors, such as negative plantar angles of the hind feet, hind limb lameness, and poor rider technique. Previously, "back pain" was reported in 50% of horses that presented for lameness evaluation.[6] In addition, several studies[8–11] have shown altered spinal motion secondary to hind limb lameness, and it could be assumed that altered motion would eventually result in topline dysfunction; however, a direct causation of lameness with topline dysfunction or back pain has not been shown.

While all 3 components of topline dysfunction should ideally be assessed separately, there is a lack of standardized examination techniques. Currently, direct palpation and behavioral responses to back mobilization techniques have been reported to be the primary method of assessing topline function in horses.[5] In clinical practice, 97% of equine sports medicine and rehabilitation veterinarians and qualified equine paraprofessionals use digital pressure over paravertebral structures,[5] and 90% use mobilization assessment techniques.[6] However, these tests are based on subjective assessments and do not provide objective measures of the effect on quality of movement during functional movement tasks, which may be more sensitive when assessing interventions and outcomes. Recently, attempts have been made to develop a functional scoring system to assess overall quality of motion in horses performing a series of 30 different exercises.[12] However, despite extensive training on the score directives, there was poor agreement among the experienced veterinarians and physical therapists completing the scoring,[12] which highlights the variability in subjective motion assessments in horses.

Ideally, assessments to diagnose and track all 3 components of topline dysfunction would incorporate both subjective and objective measures at the time of diagnosis and while assessing the response to intervention. Pressure algometry can objectively and repeatedly measure withdrawal responses of the back of the horse,[13–15] and several objective tools are available for lameness detection in horses, including Equinosis Q (Equinosis), Sleip (Sleip AI), and others. However, there is no commercially available and validated system designed to assess quality of movement or motion control in quadrupeds.

To date, the majority of spinal motion analysis in horses has used single reflective markers applied to the dorsal midline.[10,16–18] Arguably, the use of single marker models in equine spinal tracking is insufficient to track motion in all 3 planes and are is suited to describe motion in the sagittal plane only. Two research groups have assessed spinal motion using bone pins implanted into the dorsal spinous processes,[19–21] but the invasive nature of the implanted pins makes use in clinical cases impossible. To more comprehensively track 3-D motion of joints and body segments with 6 degrees of freedom, human biomechanical studies[22–25] have transitioned to cluster-based marker models.

One of the challenges within clinical practice is the assessment of "quality of movement," which is often described subjectively when an assessment of function or movement of a patient is performed. Recall of quality-of-movement status before and after treatment and poor reliability between clinicians doing such assessments can make it difficult to determine if clinically important changes due to treatment have occurred.[26] Richards et al[27] presented how angular velocity, which assesses how body segments move from one position to another, could provide a new objective measure of quality of movement that clinicians could use to track recovery. Similarly, Schenkman et al[28] and Zhou et al[29] reported angular velocity to be a more sensitive indicator of quality of movement and body control in humans with chronic lower back pain, with angular velocity being recently reported to be a sensitive outcome measure to discriminate between back pain sufferers and healthy individuals.[30,31] Therefore, angular velocity between spinal segments is a noninvasive method to potentially assess intersegmental quality of movement in horses as it seems to be in humans.

The aim of this study was to use marker clusters with moldable bases to document 3-D intersegmental angles and angular velocities between 4 separate spinal segments in horses using the calibrated anatomical system technique (CAST), first described by Cappozzo et al.[23] In addition, we explored the sensitivity of data describing angles and angular velocities to differentiate between a group of sound horses and a clinically lame horse.

Methods

Horses

Horses owned and maintained by the University of Tennessee Veterinary Research and Education Center were utilized with the approval of the IACUC of the University of Tennessee (protocol No. 2659). Immediately prior to data collection, the Equinosis Q (Equinosis) and visual lameness evaluation by a board-certified specialist were used to determine lameness. Horses that were determined to not have "no evidence of lameness" in any limb (± 6-mm difference in forelimbs, ± 3-mm difference in hind limbs) per the Equinosis Q were assigned to the nonlame group and will be further referred to as "sound."

Instrumentation and data collection

Horses were instrumented with 4 custom tracking marker clusters, each consisting of a 3-D–printed base with four 9-mm reflective markers (B&L Engineering) on rigid stems arranged in a noncolinear array **(Figure 1)**. The marker clusters were attached to a base of malleable struts that could be custom fit to each horse. Clusters were adhered to the skin of the horse over the dorsal spinous processes of the 7th thoracic, 15th thoracic, and 3rd vertebrae and between the tubera sacrale.

The tracking marker clusters defined 4 spinal motion segments: the cranial thoracic (CRT) segment at the 7th thoracic vertebra, the caudal thoracic (CDT) segment at the 15th thoracic vertebra, the lumbar segment (LUM) at the 3rd lumbar vertebra, and the sacral segment (SAC) at the tubera sacrale. These locations were selected to highlight relative motion patterns between the specific spinal segments, with the spaces between these segments being previously reported as the primary locations of overriding dorsal spinous processes,[3,32] spondylosis,[3] enthesophytes of the interspinous ligaments,[33] and lumbosacral disease.[34] Additionally, single anatomical reference markers were placed directly onto the skin at the poll; the 4th, 11th, 13th, and 18th thoracic dorsal spinous processes; the 1st and 6th lumbar dorsal spinous processes; the lumbosacral space; and the first coccygeal vertebra, which were used to define the segment coordinate systems within the CAST model,[35] which has been widely adopted in human motion analysis.

Marker data were collected at 100 Hz while horses performed 5 repetitions while traveling in hand at both a walk and trot from 12 cameras (Vantage 5; Vicon). At least 3 cameras tracked each marker at any time through a calibrated volume 8-m long, 4-m wide, and 2-m high over a flat asphalt surface with residual errors of less than 1 mm for all markers. The same handler was used throughout the data collection period, horses were allowed to travel at their own natural pace, and all data were collected on the same day. An inertial measurement unit (IMU; Delsys Inc) was placed on the right lateral metacarpal using a modified leg wrap. The IMU sampled data at 148 Hz and was synchronized with the motion-capture data, which were used to detect gait events using the vertical acceleration and sagittal plane gyroscopic data.

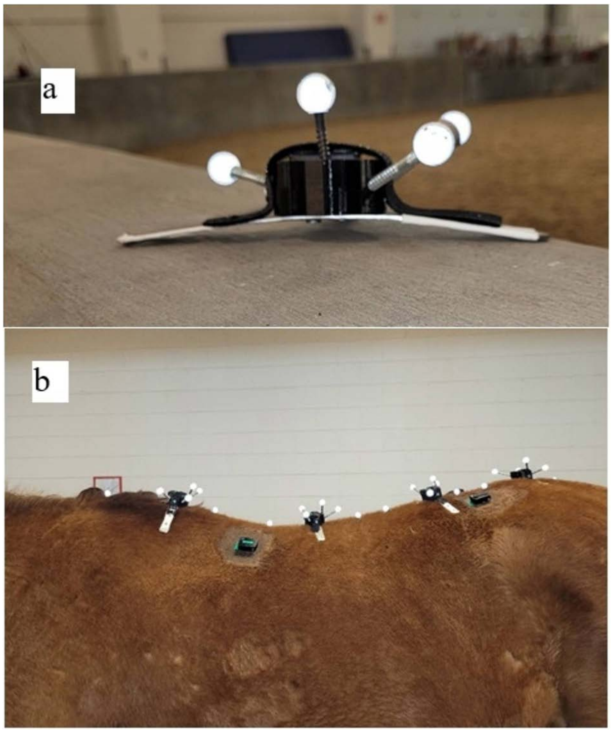

Figure 1—A—Marker cluster with moldable base and nonlinear cluster array using rigid stems inserted into a central base. B—Lateral view of marker cluster application to the topline of the horse.

Data processing

Marker data were filtered using a 15-Hz low-pass filter,[36] and the intersegmental spinal angles and angular velocities were calculated with Visual3D (HAS Motion) using a sagittal (flexion extension), dorsal (lateral bending), transverse (axial rotation) plane cardan sequence. A gait cycle was defined from right fore initial contact to the next right fore initial contact based on the IMU data and was normalized for time from frame 1 to 101 to therefore represent 100% of 1 gait cycle. The range of motion (ROM) for the intersegmental pairs was plotted and exported from each gait cycle.

Statistical analysis

The means and SDs for the CRT-CDT, CDT-LUM, and LUM-SAC angles and angular velocities in the 3 planes were extracted for the nonlame (sound) horse and lame horses. Furthermore, absolute and percentage differences were calculated to seek differences in intersegmental spinal angles and angular velocities between a lame horse and the sample of sound horses in the sagittal, dorsal, and transverse planes.

Differences in the range of angles and angular velocities and percentage differences between 1 lame horse and a group of sound horses in the sagittal, dorsal, and transverse planes are presented. A Shapiro-Wilk test determined that the data were normally distributed. The CRT-CDT, CDT-LUM, and LUM-SAC angles and angular velocities were reported using descriptive statistics, including means, SDs, and percentage differences, of all gait cycles from a lame horse, which were compared with all gait cycles from the sound horses. The method of using multiple gait cycles is supported by the National Centre for the Replacement, Refinement, and Reduction of Animals in Research[37] to maximize the number of observations/information that can be gathered per animal through noninvasive repeated measurements. All calculations were performed using SPSS, version 29 (IBM Corp).

Results

Horses

Three sound Thoroughbred and Thoroughbred cross horses (2 geldings, 1 mare; 10 to 18 years of age; 160- to 168-cm height at withers; 470- to 565-kg body weight). Data for the sound horses were pooled, giving a total of 54 gait cycles at the walk and 33 at the trot. These were compared against 8 walk cycles and 13 trot cycles from 1 lame Thoroughbred mare (8 years of age; 163-cm height at withers; 468 kg). This horse had strong evidence of a moderate to severe right hind impact (12.9 ± 2.1 mm) and moderate to severe right hind push-off (12.7 ± 3.3 mm) lameness assessed using the Equinosis Q system and

Table 1—Comparative mean intersegmental angular and angular velocity range of motion between lame and sound horses during walk.

Walk	Lame mean (SD)	Sound mean (SD)	Mean difference	% difference
CRT to CDT angle (°)				
Sagittal plane	7.99 (1.27)	5.12 (0.77)	2.87	56.0
Dorsal plane	7.52 (1.41)	8.66 (1.91)	−1.14	−13.1
Transverse plane	9.64 (1.38)	6.39 (1.74)	3.26	50.8
CDT to LUM angle (°)				
Sagittal plane	3.87 (1.34)	3.89 (0.57)	−0.02	−0.5
Dorsal plane	8.18 (0.76)	6.67 (1.82)	1.51	22.7
Transverse plane	3.59 (0.49)	3.43 (0.93)	0.16	4.9
LUM to SAC angle (°)				
Sagittal plane	6.84 (0.37)	8.21 (1.28)	−1.37	−16.6
Dorsal plane	2.02 (0.19)	1.74 (0.32)	0.28	15.7
Transverse plane	4.68 (0.55)	4.35 (0.73)	0.33	7.7
CRT to CDT angular velocity (°/s)				
Sagittal plane	97.4 (17.4)	76.8 (24.2)	20.6	26.8
Dorsal plane	47.1 (6.2)	68.1 (6.2)	−21.0	−30.8
Transverse plane	164.8 (25.2)	107.0 (16.0)	57.8	54.0
CDT to LUM angular velocity (°/s)				
Sagittal plane	65.5 (10.4)	56.9 (14.6)	8.6	15.1
Dorsal plane	74.9 (74.9)	57.5 (7.8)	17.4	30.2
Transverse plane	52.2 (8.6)	64.5 (19.3)	−12.3	−19.0
LUM to SAC angular velocity (°/s)				
Sagittal plane	127.1 (17.5)	144.5 (48.3)	−17.4	−12.1
Dorsal plane	29.0 (2.6)	21.1 (4.7)	7.9	37.4
Transverse plane	103.1 (15.0)	75.5 (18.0)	27.6	36.7

CDT = Caudal Thoracic. CRT = Cranial thoracic. LUM = Lumbar. SAC = Sacral.

Table 2—Comparative mean intersegmental angular and angular velocity range of motion between lame and sound horses during trot.

Trot	Lame mean (SD)	Sound mean (SD)	Mean difference	% difference
CRT to CDT angle (°)				
Sagittal plane	8.87 (1.36)	5.71 (1.37)	3.2	55
Dorsal plane	5.63 (0.60)	5.23 (0.56)	0.4	8
Transverse plane	20.34 (1.24)	12.02 (1.77)	8.3	69
CDT to LUM angle (°)				
Sagittal plane	11.63 (4.39)	5.21 (1.15)	6.4	123
Dorsal plane	4.25 (0.84)	4.58 (1.14)	−0.3	−7
Transverse plane	7.34 (1.51)	5.00 (1.32)	2.3	47
LUM to SAC angle (°)				
Sagittal plane	9.93 (4.04)	7.54 (0.82)	2.4	32
Dorsal plane	2.90 (0.28)	3.09 (1.09)	−0.2	−6
Transverse plane	8.69 (2.45)	9.65 (2.23)	−1.0	−10
CRT to CDT angular velocity (°/s)				
Sagittal plane	353.0 (62.2)	139.4 (18.2)	213.6	153
Dorsal plane	174.0 (18.1)	76.7 (17.8)	97.3	127
Transverse plane	396.3 (23.4)	174.0 (24.3)	222.3	128
CDT to LUM angular velocity (°/s)				
Sagittal plane	385.5 (38.5)	135.9 (61.8)	249.6	184
Dorsal plane	87.6 (9.8)	51.7 (6.8)	35.9	70
Transverse plane	143.6 (8.9)	93.2 (16.7)	50.4	54
LUM to SAC angular velocity (°/s)				
Sagittal plane	326.0 (54.0)	148.9 (40.8)	177.1	119
Dorsal plane	86.6 (9.1)	48.2 (6.3)	38.4	80
Transverse plane	159.2 (11.1)	121.7 (10.0)	37.5	31

was confirmed to be consistently right hind lame at the trot and sound at the walk from a visual lameness assessment by an American College of Veterinary Sports Medicine and Rehabilitation specialist.

Normative data for walk and trot—The intersegmental angular ROM is defined as the range of angular motion measured between 2 segments over the course of 1 gait cycle. Similarly, the intersegmental range of angular velocity (RAV) is defined as the range of velocities at which a joint rotates, measured between 2 segments over the duration of 1 gait cycle.

Intersegmental angles in sound walking horses

In sound horses at the walk, the CRT-CDT ROM was largest in lateral bending (8.66°), followed by axial rotation (6.39°) and flexion-extension (5.12°). For the CDT-LUM angles, the greatest motion was in lateral bending (6.67°), with less motion in flexion extension (3.89°) and axial rotation (3.43°). For the LUM-SAC

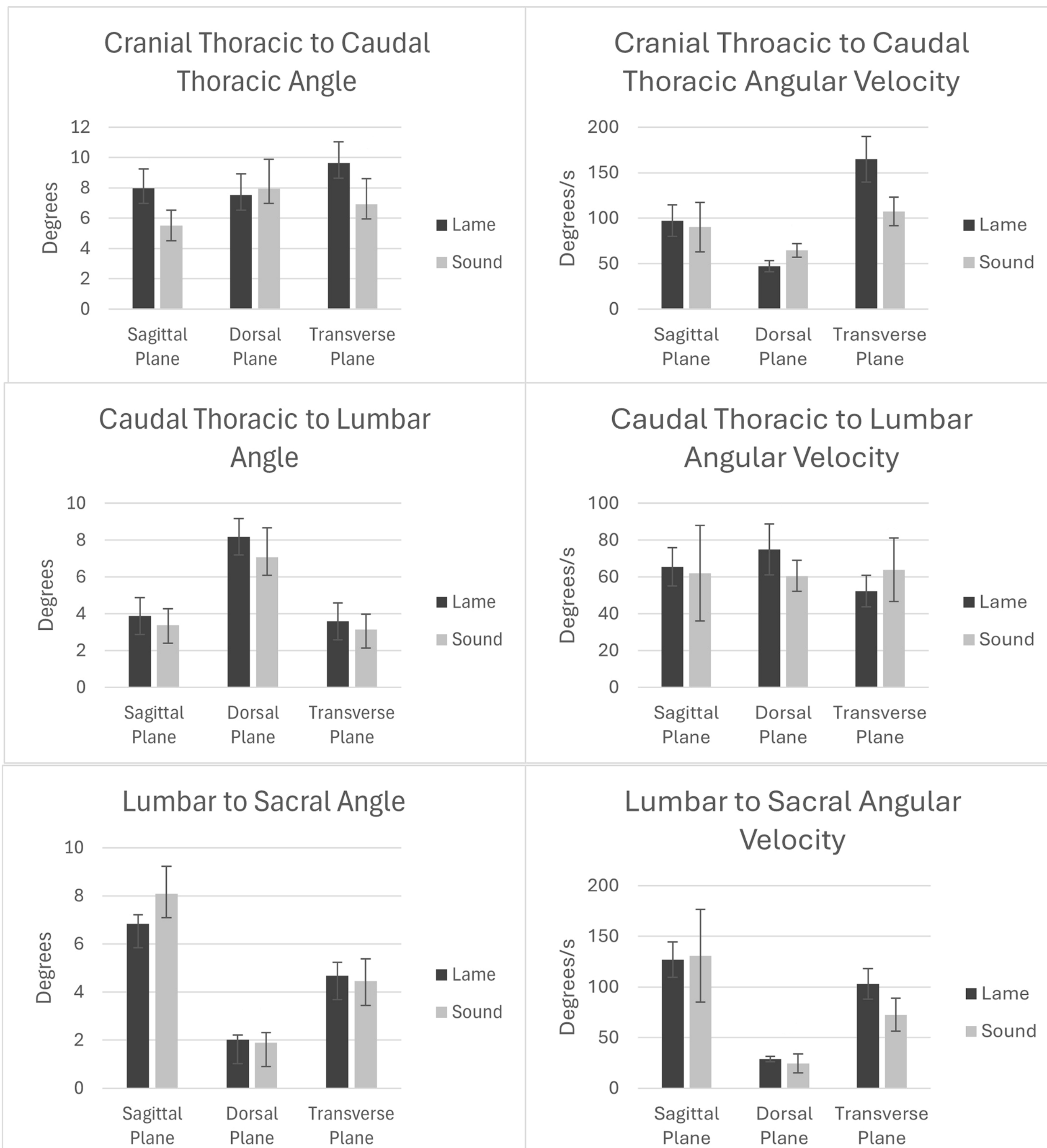

Figure 2—Comparison of intersegmental angle and angular velocity in all 3 planes of motion in lame and sound horses while walking.

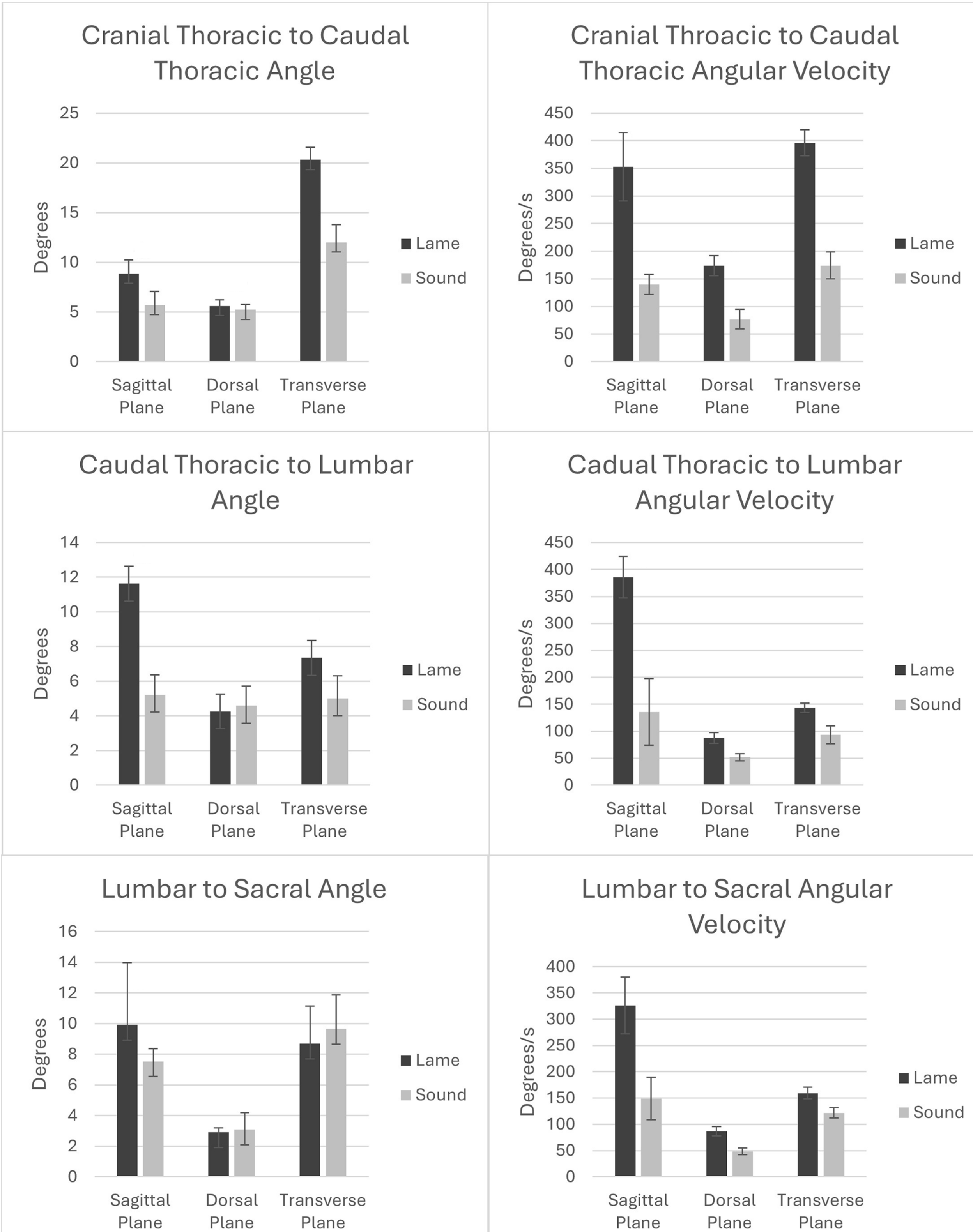

Figure 3—Comparison of intersegmental angle and angular velocity in all 3 planes of motion in lame and sound horses while trotting.

ROM, the predominant motion was in the sagittal plane (8.21°), with less motion in axial rotation (4.35°) and the least in lateral bending (1.74°; **Table 1**).

Angular velocity in sound walking horses

During walking, in the sound horses the CRT-CDT RAV showed the greatest values in the transverse plane (107°/s), followed by the sagittal (76.8°/s) and dorsal (68.1°/s) planes. The CDT-LUM showed similar RAV in all 3 planes (sagittal, 56.9°/s; dorsal, 57.5°/s; transverse, 64.5°/s). Similar to the intersegmental angles, the LUM-SAC RAVs were greatest in the sagittal plane (144.5°/s), less during axial rotation (75.5°/s), and least during lateral bending (64.5°/s; Table 1).

Intersegmental angles in sound trotting horses

For sound trotting horses, CRT-CDT ROM was highest in axial rotation (12.02°), followed by flexion extension (5.71°) and lateral bending (5.23°). For the CDT-LUM ROM, the values were similar in all 3 planes (sagittal, 5.21°; dorsal, 4.58°; transverse, 5.00°). The LUM-SAC ROM was highest in the transverse plane (9.65°), followed by the sagittal (7.54°) and dorsal planes (3.09°**; Table 2**).

Angular velocity in sound trotting horses

Similar to the walk, sound horses showed the greatest CRT-CDT RAV in the transverse plane (174°/s), followed by the sagittal (139.4°/s) and dorsal (76.7°/s) planes. The CDT-LUM RAV was highest in the sagittal plane (135.9°/s), followed by the transverse (93.2°/s) and dorsal (51.7°/s) planes. For the LUM-SAC RAV, the greatest values were in the sagittal (148.9°/s) and transverse (121.7°/s) planes, with the dorsal plane showing much lower values (48.2°/s), similar to those of CDT-LUM RAV (Table 2).

Comparative data between lame and sound horses during walk and trot

Comparative intersegmental angles at walk—The CRT-CDT ROMs were greater in the lame horse compared to the sound horses in the sagittal (56%) and transverse (50.8%) planes. Smaller differences were present in the CDT-LUM ROM in the dorsal plane (22.7%). The LUM-SAC ROM in the sound horses was greater in the sagittal plane (−16.6%) and lower in the dorsal plane (15.7%; **Figure 2**; Table 1).

Comparative intersegmental angular velocity at the walk—In the lame horse, CRT-CDT RAV was greater when compared with the sound horses in the sagittal (26.8%) and transverse (54.0%) planes but lower in the dorsal plane (30.8%). For CDT-LUM RAV, higher values were seen in the lame horse in the dorsal plane (30.2%) and lower values in the transverse plane (19.0%). The LUM-SAC RAV was higher in the lame horse for the dorsal (37.4%) and transverse (36.7%) planes (Figure 2; Table 1).

Comparative intersegmental angles at the trot—For the CRT-CDT ROM, the lame horse showed greater values in all 3 planes, specifically in the sagittal (55%) and transverse planes (69%), with the dorsal plane showing only a 0.4° difference (8%). Similarly, for the CDT-LUM ROM, differences were seen in the sagittal (123%) and transverse (47%) planes but not in the dorsal plane. However, the LUM-SAC RAV only showed a difference in the sagittal plane (32%), with a 2.4° greater value seen in the lame horse (**Figure 3**; Table 2).

Comparative intersegmental angular velocity at the trot—The CRT-CDT RAV, CDT-LUM RAV, and LUM-SAC RAV all showed notably greater differences between the lame horse and the sound horses in all 3 planes of motion. Specifically, CRT-CDT RAV showed greater values in the lame horse in the sagittal, dorsal, and transverse planes, with differences of 213.6°/s (153%), 97.3°/s (127%), and 222.3°/s (128%), respectively. Similarly, the CDT-LUM RAV showed differences of 249.6°/s (184%), 35.9°/s (70%), and 50.4°/s (54%), and the LUM-SAC RAV differed by 177.1°/s (119%), 38.4°/s (80%), and 37.5°/s (31%), with all values being greater in the lame horse and showing differences between the lame horse and the sound horses (Figure 3; Table 2).

An example of angle and angular velocity movement curves for CRT-CDT in the sagittal plane is provided in **Figure 4**.

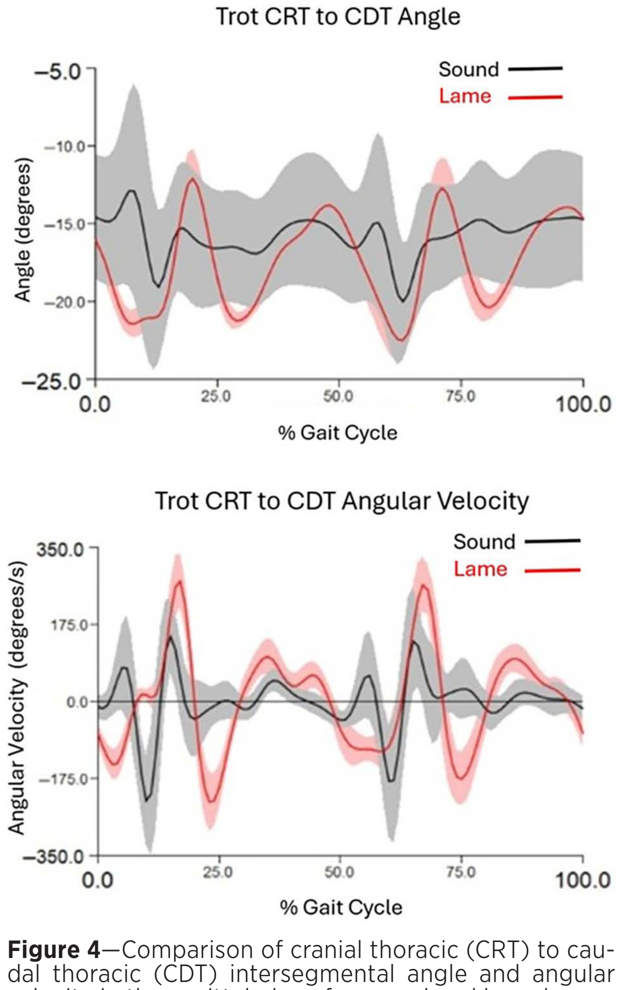

Figure 4—Comparison of cranial thoracic (CRT) to caudal thoracic (CDT) intersegmental angle and angular velocity in the sagittal plane for sound and lame horses while trotting.

Discussion

After an extensive literature review, this appears to be the first study to use the CAST to measure the intersegmental spinal motion in all 3 planes in horses using noninvasive 3-D marker clusters. Cappozzo et al[23] first presented the idea of a CAST procedure in order to standardize experimental protocols to allow for direct comparison of data sets. Specifically, Cappozzo et al[23] proposed the use of rigid frames of marker clusters in addition to the traditional single anatomic markers. The coordinate systems and segment orientations of the marker clusters are calibrated using the anatomical markers from a static trial, after which the movement during complex exercises is tracked by the marker clusters.[23] The fixed alignment of the markers within the rigid cluster allows for 6-degrees-of-freedom tracking, whereas single markers are restricted to tracking motion predominantly in 2 planes.

Publications to date have explored spinal motion in horses by tracking motion from single markers along the spine, which do not have the capacity to measure all 3 planes of motion.[8,10,16,17,38–43] The closest method to the one explored here implanted bone pins with attached marker clusters into the dorsal spinous processes[20,21,44] and then assessed the movement relative to a global coordinate system.[45] The methods described in this study focus on relative motion between segments rather than relative to a global coordinate system, which arguably provides more clinically relevant information on joint and intersegmental movement patterns.

Due to improvements in processing methodology and advancing technology, it is impossible to directly compare the results presented here to previous publications; however, overall motion patterns can be compared. In their study using sound horses at the walk, Faber et al[20] reported that lateral bending was the predominant motion in the thoracolumbar region but that flexion and extension predominated at the lumbosacral junction. During trotting, we found that flexion and extension had the largest ROM at the lumbosacral junction in sound trotting horses, which agrees with Audigié et al.[17] These findings also reinforce the greatest lateral bending to occur within the mid-thoracic region.[21] Also similar to Faber et al,[21] we reported the greatest motion between the cranial and CDT region to be during axial rotation in the transverse plane. With noninvasive methods, the angle ranges found were to be 3° to 5° throughout the spine in lateral bending, which are nearly identical to those previously reported by Faber et al[21] when using bone pins. Interestingly, we detected more axial rotation ROM in the CRT region; however, the overall trends of highest and lowest ROM are comparable with Faber et al.[21]

Based on the agreement to the previously reported literature using implanted bone pins,[20,21] the small numerical differences are likely related to previous methods using a global coordinate system[45] rather than the intersegmental method defined in this study. Therefore, the noninvasive marker clusters appear to give a robust representation of 3-D spinal motion and provide more information than using single markers placed along the spine, which may enhance our clinical understanding of movements during functional tasks.

It is well reported that both experimentally induced[8,10] and naturally occurring hind limb lameness[11] alters the ROM of the spine in horses at both the walk and the trot. The methods from all of these studies used single markers placed on the dorsal spinous processes but still calculated changes in spinal motion. Similar to Gomez Alvarez et al,[8] we detected an overall increased ROM when walking after lameness was induced. However, the only significant findings while walking from Gomez Alvarez et al[8] were an increased ROM at the mid- to CDT region in the sagittal plane and lumbosacral junction in the dorsal plane, whereas using intersegmental comparisons we noted greater movement in lateral bending during the walk at CDT-LUM and LUM-SAC junctions, greater movement into flexion and extension at CRT-CDT and LUM-SAC, and greater axial rotation at CRT-CDT in the lame horse. At the trot, Gomez Alvarez et al[8] again appreciated general increased motion in lame horses; however, the only significant finding was actually decreased flexion extension at the caudal lumbar and decreased pelvic axial rotation. We also appreciated a 10% lower motion in axial rotation at the lumbosacral junction that was not notably different. However, we noted large and clinically important differences between the sound horses and lame horse in sagittal plane ROM at every intersegmental interface (55%, 123%, and 32% cranial to caudal, respectively). Interestingly, we also noted greater and potentially clinically important differences, with greater values of axial rotation noted between the CRT-CDT segment in the lame horse when compared to sound. Gomez Alvarez et al[8] also used horses that were reportedly inconsistently lame (grade 2/5 on American Association of Equine Practitioners lameness scale), whereas our horse was consistently lame (grade 3/5 on American Association of Equine Practitioners lameness scale).

This is the first study reporting intersegmental spinal angular velocity in sound and lame horses. Angular velocity has been recently expanded upon in human literature as an indication of postural stability at stance and quality of motion.[30,46–48] In this work, the angular velocities in the lame horse while trotting, at every intersegmental position and in every plane of motion, were notably higher in the lame horse compared to the sound horse. Of note, angular velocities detected differences in all 3 planes, whereas the angle data only detected differences in the sagittal plane. Similarly at the walk, the angular velocities were all different between the lame and sound horses with the exception of the sagittal plane at the CDT-LUM and LUM-SAC junctions. It is important to note that the lame horse included in this study was visually sound at the walk, yet differences were still observed. This work is of particular clinical importance since there were notably greater percentage differences in angular velocities than in the angle data, indicating a greater sensitivity to detect differences even at the walk. This sensitivity is similar to what has previously been shown in stroke survivors that experienced an excellent recovery, with angular velocity being able to distinguish between stroke survivors and healthy controls and between the paretic and nonparetic sides, whereas joint angles were not.[27] Greater angular velocities could be indicating a decreased quality of movement and poorer core body control in the lame horse as is noted in human literature.[31,46–48] While more research is required, this altered body control could be investigated to determine the link between clinical topline dysfunction and lameness. Developing a sensitive objective method to analyze topline function in horses is crucial to explore the management of this complicated syndrome.

When considering limitations, it should be noted that the use of marker clusters does not provide direct data on boney movements; however, such methods have been shown to be sensitive to measure differences between patient groups and changes due to intervention in human studies. As this work included a small sample size in both lame and sound horses, we used descriptive statistics and percentage differences to identify if potentially clinically important and noteworthy differences were being observed between all gait cycles from the sound horses and a single lame horse. However, even with only 3 sound horses, the SDs calculated from both angle and angular velocity data were relatively small and comparable to the lame horse, indicating a similar degree of variation. Similarly, using a single lame horse limited the number of gait cycles for comparison; however, this horse also showed low variability between gait cycles. While we discuss normative data from the group of sound horses, we make no claims that all lame horses will have similar recordings to the horse included in this study. Further work is necessary to record angles and angular velocities from the intersegmental spine in larger cohorts of both sound and lame horses as well as to record changes due to treatment in those with clinical topline dysfunction.

Angular velocity appears to yield new information on the quality of movement in the 3 rotational planes and may provide more detail in the assessment of topline dysfunction and the efficacy of its management in horses. These data support previous literature but with improved methods, allowing assessment of intersegmental motion with 6 degrees of freedom noninvasively.

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References

1. Crowhurst RC. Symposium on back problems in the horse. *Equine Vet J.* 1975;7(2):66–68. doi:10.1111/j.2042-3306.1975.tb03232.x
2. Jeffcott LB. Symposium on back problems in the horse: (2) the diagnosis of diseases of the horse's back. *Equine Vet J.* 1975;7(2):69–78. doi:10.1111/j.2042-3306.1975.tb03234.x
3. Jeffcott LB. Disorders of the thoracolumbar spin of the horse—a survey of 443 cases. *Equine Vet J.* 1980;12(4):197–210. doi:10.1111/j.2042-3306.1980.tb03427.x
4. Jeffcott LB. Back problems in the horse—look at past, present and future progress. *Equine Vet J.* 1979;11(3):129–136. doi:10.1111/j.2042-3306.1979.tb01324.x
5. Bowen AG, Tabor G, Labens R, Randle H. Visually assessing equine quality of movement: a survey to identify key movements and patient-specific measures. *Animals (Basel).* 2023;13(18):2822. doi:10.3390/ani13182822
6. Riccio B, Fraschetto C, Villanueva J, Cantatore F, Bertuglia A. Two multicenter surveys on equine back-pain 10 years a part. *Front Vet Sci.* 2018;5:195. doi:10.3389/fvets.2018.00195
7. Dyson S. The ridden horse pain ethogram. *Equine Vet Educ.* 2022;34(7):372–380. doi:10.1111/eve.13468
8. Gomez Alvarez CB, Bobbert MF, Lamers L, Johnston C, Back W, van Weeren PR. The effect of induced hindlimb lameness on thoracolumbar kinematics during treadmill locomotion. *Equine Vet J.* 2008;40(2):147–152. doi:10.2746/042516408X250184
9. Buchner HHF, Savelberg HHCM, Schamhardt HC, Barneveld A. Head and trunk movement adaptations in horses with experimentally induced fore- or hindlimb lameness. *Equine Vet J.* 1996;28(1):71–76. doi:10.1111/j.2042-3306.1996.tb01592.x
10. Spoormakers TJP, St. George L, Smit IH, et al. Adaptations in equine axial movement and muscle activity occur during induced fore- and hindlimb lameness: a kinematic and electromyographic evaluation during in-hand trot. *Equine Vet J.* 2023;55(6):1112–1127. doi:10.1111/evj.13906
11. Greve L, Dyson S, Pfau T. Alterations in thoracolumbosacral movement when pain causing lameness has been improved by diagnostic analgesia. *Vet J.* 2017;224:55–63. doi:10.1016/j.tvjl.2017.03.009
12. Bowen AG, Tabor G, Labens R, Douglas M, Randle H. The equine quality of movement score: how reliable is it? *J Equine Rehabil.* 2025;3:100023. doi:10.1016/j.eqre.2025.100023
13. Haussler KK, Manchon PT, Donnell JR, Frisbie DD. Effects of low-level laser therapy and chiropractic care on back pain in quarter horses. *J Equine Vet Sci.* 2020;86:102891–102891. doi:10.1016/j.jevs.2019.102891
14. De Heus P, Van Oossanen G, Van Dierendonck MC, Back W. A pressure algometer is a useful tool to objectively monitor the effect of diagnostic palpation by a physiotherapist in warmblood horses. *J Equine Vet Sci.* 2010;30(6):310–321. doi:10.1016/j.jevs.2010.04.010
15. Menke ES, Blom G, van Loon JPAM, Back W. Pressure algometry in Icelandic horses: interexaminer and intraexaminer reliability. *J Equine Vet Sci.* 2016;36:26–31. doi:10.1016/j.jevs.2015.10.007
16. Wennerstrand J, Alvarez CBG, Meulenbelt R, et al. Spinal kinematics in horses with induced back pain. *Vet Comp Orthop Traumatol.* 2009;22(6):448–454. doi:10.3415/VCOT-08-09-0088
17. Audigié F, Pourcelot P, Degueurce C, Denoix JM, Geiger D. Kinematics of the equine back: flexion-extension movements in sound trotting horses. *Equine Vet J Suppl.* 1999;(30):210–213. doi:10.1111/j.2042-3306.1999.tb05219.x

18. de Cocq P, van Weeren PR, Back W. Effects of girth, saddle and weight on movements of the horse. *Equine Vet J.* 2004;36(8):758–763. doi:10.2746/0425164044848000
19. Haussler KK, Bertram JE, Gellman K, Hermanson JW. Segmental in vivo vertebral kinematics at the walk, trot and canter: a preliminary study. *Equine Vet J Suppl.* 2001;(33):160–164. doi:10.1111/j.2042-3306.2001.tb05381.x
20. Faber M, Schamhardt H, van Weeren R, Johnston C, Roepstorff L, Barneveld A. Basic three-dimensional kinematics of the vertebral column of horses walking on a treadmill. *Am J Vet Res.* 2000;61(4):399–406. doi:10.2460/ajvr.2000.61.399
21. Faber M, Johnston C, Schamhardt H, van Weeren R, Roepstorff L, Barneveld A. Basic three-dimensional kinematics of the vertebral column of horses trotting on a treadmill. *Am J Vet Res.* 2001;62(5):757–764. doi:10.2460/ajvr.2001.62.757
22. Boser QA, Valevicius AM, Lavoie EB, et al. Cluster-based upper body marker models for three-dimensional kinematic analysis: comparison with an anatomical model and reliability analysis. *J Biomech.* 2018;72:228–234. doi:10.1016/j.jbiomech.2018.02.028
23. Cappozzo A, Catani F, Croce UD, Leardini A. Position and orientation in space of bones during movement: anatomical frame definition and determination. *Clin Biomech (Bristol).* 1995;10(4):171–178. doi:10.1016/0268-0033(95)91394-t
24. Collins TD, Ghoussayni SN, Ewins DJ, Kent JA. A six degrees-of-freedom marker set for gait analysis: repeatability and comparison with a modified Helen Hayes set. *Gait Posture.* 2009;30(2):173–180. doi:10.1016/j.gaitpost.2009.04.004
25. Evans NR, Hooper G, Edwards R, et al. A 3D motion analysis study comparing the effectiveness of cervical spine orthoses at restricting spinal motion through physiological ranges. *Eur Spine J.* 2013;22(suppl 1):10–15. doi:10.1007/s00586-012-2641-0
26. Pomeroy VM, Pramanik A, Sykes L, Richards J, Hill E. Agreement between physiotherapists on quality of movement rated via videotape. *Clin Rehabil.* 2003;17(3):264–272. doi:10.1191/0269215503cr607oa
27. Richards JD, Pramanik A, Sykes L, Pomeroy VM. A comparison of knee kinematic characteristics of stroke patients and age-matched healthy volunteers. *Clin Rehabil.* 2003;17(5):565–571. doi:10.1191/0269215503cr651oa
28. Schenkman M, Riley PO, Pieper C. Sit to stand from progressively lower seat heights – alterations in angular velocity. *Clinical Biomech (Bristol).* 1996;11(3):153–158. doi:10.1016/0268-0033(95)00060-7
29. Zhou H, Yang D, Li ZY, Zhou D, Guan J. Gait analysis based on angular velocity during human walking on five terrains. Abstract in: *2019 12th International Symposium on Computational Intelligence and Design (ISCID)*. IEEE; 2019:39–44.
30. Christe G, Aussems C, Jolles BM, Favre J. Patients with chronic low back pain have an individual movement signature: a comparison of angular amplitude, angular velocity and muscle activity across multiple functional tasks. *Front Bioeng Biotechnol.* 2021;9:767974. doi:10.3389/fbioe.2021.767974
31. Kongoun S, Klahan K, Rujirek N, Vachalathiti R, Richards J, Wattananon P. Association between movement speed and instability catch kinematics and the differences between individuals with and without chronic low back pain. *Sci Rep.* 2024;14(1):20850. doi:10.1038/s41598-024-72128-1
32. Kerbert MP, le Jeune SS, Philips KL, Shaw KL, Erickson CA, Espinosa-Mur P. Mild radiographic abnormalities of thoracolumbar spinous processes are not associated with decreased performance in 100 warmblood jumping horses in active competition. *J Equine Vet Sci.* 2025;147:105366. doi:10.1016/j.jevs.2025.105366
33. Clayton HM, Stubbs NC. Enthesophytosis and impingement of the dorsal spinous processes in the equine thoracolumbar spine. *J Equine Vet Sci.* 2016;47:9–15. doi:10.1016/j.jevs.2016.07.015
34. Boado A, Nagy A, Dyson S. Ultrasonographic features associated with the lumbosacral or lumbar 5–6 symphyses in 64 horses with lumbosacral-sacroiliac joint region pain (2012–2018). *Equine Vet Educ.* 2020;32(S10):136–143. doi:10.1111/eve.13236
35. Donati M, Camomilla V, Vannozzi G, Cappozzo A. Enhanced anatomical calibration in human movement analysis. *Gait Posture.* 2007;26(2):179–185. doi:10.1016/j.gaitpost.2007.04.009
36. Hanzlíková I, Richards J, Athens J, Hébert-Losier K. Which jump-landing task best represents lower extremity and trunk kinematics of unanticipated cutting maneuver? *Gait Posture.* 2021;85:171–177. doi:10.1016/j.gaitpost.2021.02.003
37. Burden N, Chapman K, Sewell F, Robinson V. Pioneering better science through the 3Rs: an introduction to the National Centre for the Replacement, Refinement, and Reduction of Animals in Research (NC3Rs). *J Am Assoc Lab Anim Sci.* 2015;54(2):198–208.
38. Wennerstrand J, Johnston C, Roethlisberger-Holm K, Erichsen C, Eksell P, Drevemo S. Kinematic evaluation of the back in the sport horse with back pain. *Equine Vet J.* 2004;36(8):707–711. doi:10.2746/0425164044848226
39. Alvarez CBG, Wennerstrand J, Bobbert MF, et al. The effect of induced forelimb lameness on thoracolumbar kinematics during treadmill locomotion. *Equine Vet J.* 2007;39(3):197–201. doi:10.2746/042516407x173668
40. Holm KR, Wennerstrand J, Lagerquist U, Eksell R, Johnston C. Effect of local analgesia on movement of the equine back. *Equine Vet J.* 2006;38(1):65–69. doi:10.2746/042516406775374351
41. Nankervis KJ, Finney P, Launder L. Water depth modifies back kinematics of horses during water treadmill exercise. *Equine Vet J.* 2016;48(6):732–736. doi:10.1111/evj.12519
42. Robert C, Valette JP, Denoix JM. The effects of treadmill inclination and speed on the activity of two hindlimb muscles in the trotting horse. *Equine Vet J.* 2000;32(4):312–317. doi:10.2746/042516400777032246
43. Robert C, Valette JP, Pourcelot P, Audigié F, Denoix JM. Effects of trotting speed on muscle activity and kinematics in saddlehorses. *Equine Vet J Suppl.* 2002;(34):295–301. doi:10.1111/j.2042-3306.2002.tb05436.x
44. Faber M, Johnston C, Schamhardt HC, van Weeren PR, Roepstorff L, Barneveld A. Three-dimensional kinematics of the equine spine during canter. *Equine Vet J Suppl.* 2001;(33):145–149. doi:10.1111/j.2042-3306.2001.tb05378.x
45. Faber MJ, Schamhardt HC, van Weeren PR. Determination of 3D spinal kinematics without defining a local vertebral coordinate system. *J Biomech.* 1999;32(12):1355–1358. doi:10.1016/s0021-9290(99)00131-1
46. Khobkhun F, Srivanitchapoom P, Richards J. Can a targeted home-based exercise programme improve turning characteristics in individuals with Parkinson's disease? *Clin Biomech (Bristol).* 2021;89:105469–105469. doi:10.1016/j.clinbiomech.2021.105469
47. Sinsurin K, Kiratisin P, Irawan DS, Vachalathiti R, Richards J. Residual deficits of knee and hip joint coordination and clinical performance after return to sports in athletes with anterior cruciate ligament reconstruction. *Knee Surg Relat Res.* 2024;36(1):22. doi:10.1186/s43019-024-00213-w
48. Wattananon P, Kongoun S, Chohan A, et al. The use of statistical parametric mapping to determine altered movement patterns in people with chronic low back pain. *J Biomech.* 2023;153:111601. doi:10.1016/j.jbiomech.2023.111601