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The effect of loading on the equine spine - a preliminary study

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Summary

Although equine spinal motion has been analysed in vivo and in vitro, spinal pathophysiology and the mechanisms of injury are not well understood. Most horses are exercised mounted, yet the effect of a load on the spine is still unclear. The purpose of this study was to assess the effect of load placed on the spine on motion at the lumbosacral junction and the withers.

6 treadmill-trained Thoroughbreds were fitted with a saddle, hoof accelerometer and 2 MT9 inertial sensors (placed on the lumbosacral junction and withers), and spinal motion was analysed at walk (1.6 m/s) and trot (3.0 m/s) on a treadmill (condition 1). This was repeated whilst adding a load (2 sandbags, 30 kg, placed over the saddle) to the horse (condition 2). 3 of the 6 horses were re-tested a third time with the load removed again, this being identical to condition 1 (condition 3). The data were processed using Matlab™, and mean and standard deviation obtained and inferential statistics applied.

Spinal motion was significantly increased at the lumbosacral junction for mediolateral and pitch displacement at trot, and for roll displacement at the withers at trot when comparing condition 1 and 2. No significant changes were found when comparing all 3 test conditions.

Loading of the equine spine altered motion in some movement directions at the lumbosacral junction and withers at trot, but not in any movement direction at the lumbosacral junction or withers during walk. Further studies combining spinal motion analysis and muscle function are required to enhance knowledge of the effects of a rider on equine spinal biomechanics.

Abbreviations: C1,2,3 = condition 1,2,3; EMG = electromyography

Schlüsselwörter: Pferd, Wirbelsäule, Biomechanik, Trägheitssensoren.

Zusammenfassung

Die Auswirkungen von Belastungen auf die Wirbelsäule des Pferdes - eine Vorstudie

Obwohl die Bewegung der Pferdewirbelsäule in vivo und in vitro analysiert wurde, werden die spinale Pathophysiologie und die Verletzungsmechanismen nicht vollständig verstanden. Meistens werden Pferde unter dem Reiter gearbeitet, doch die Auswirkung der Wirbelsäulenbelastung ist weitgehend unklar. Ziel dieser Studie war es, den Einfluss der Wirbelsäulenbelastung am lumbosakralen Übergang und am Widerrist festzuhalten.

6 an das Laufband gewöhnte Vollblut-Galopper wurden, aufgesattelt und versehen mit einem Beschleunigungssensor am Huf und 2 MT9 Trägheitssensoren (am lumbosakralen Übergang und am Widerrrist), im Schritt (1,6 m/s) und im Trab (3,0 m/s), analysiert (Messung 1). Die Messung wurde mit 2 30 kg schweren Sandsäcken, die am Sattel befestigt waren, wiederholt (Messung 2). Zusätzlich wurden 3 der 6 Pferde danach erneut ohne Last, wie bei Messung 1, analysiert (Messung 3).

Die Daten wurden mit Hilfe von MATLAB verarbeitet. Mittelwert und Standardabweichung wurden bestimmt und einer statistischen Bewertung unterzogen.

Die mediolaterale, Wirbelsäulenbewegung und die Neigung (Drehung um die mediolaterale Achse) nahm im Trab am lumbosakralen Übergang signifikant zu. Von Messung 1 auf Messung 2 änderte sich die Torsion (Drehung um die Längsachse) am Widerrist im Trab. Beim Vergleich aller 3 Messungen konnten keine signifikanten Unterschiede gefunden werden.

Die Belastung der Wirbelsäule führte in manchen Bewegungsrichtungen zu Änderungen im Trab, aber nicht im Schritt. Weitere Studien in denen Bewegungsanalyse mit Muskelfunktionsmessungen kombiniert werden, sind notwendig, um das Wissen der reiterlichen Einflüsse auf die Biomechanik der Pferdewirbelsäule zu erweitern.

Introduction

Back pain has been reported as a common but not fully understood clinical condition in the horse (DE COCQ et al., 2004). This has lead to increased research efforts over the last few decades in the field of equine biomechanics, aimed at better understanding the pathophysiology of this clinical condition (GÓMEZ ALVAREZ et al., 2009). Equine spinal motion has been investigated in vitro (JEFFCOTT and DALIN, 1980; TOWNSEND et al., 1983) and in vivo (FABER et al., 2000, 2001; LICKA et al., 2001a,b), and differences in how the spine moves in these different states has been reported. This is likely due to the presence and action of many different soft tissue structures which can influence the

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flexibility and stability of the spine during in vivo testing, by creating movement or perhaps controlling stiffness (JEFFCOTT and DALIN, 1980).

Even though many horses are exercised mounted, little is known about how the equine spine responds to the application of a rider (PEHAM and SCHOBESBERGER, 2004). Previous studies have shown loading to have an effect on other aspects of locomotion in the horse, such as increased stance duration (SLOET et al., 1995; CLAYTON, 1997), peak ground reaction force (CLAYTON et al., 1999), fetlock motion (CLAYTON, 1997), and hoof wall strain (SUMMERLY et al., 1998). It has also been suggested that horses carrying excess weight may compromise their safety and performance, and be at greater risk of injuries (CLAYTON, 1997).

In addition to loading, a rider brings further variables which can affect equine locomotion. Reins have an affect on head placement and limb activity (BIAU et al., 2002; ROEPSTORFF et al., 2002; RHODIN et al., 2009), which may have a further impact on spinal motion and alignment. Saddle type and fit have also been shown to exert additional pressures on the equine spine and negatively influence motion of the spine (WINKELMAYR et al., 2006; PEINEN et al., 2009). Additionally, riding style has been shown to have an effect on spinal motion. For example, DE COCQ et al. (2009) showed that sitting trot had the overall effect of extending the spine and that rising trot increased total range of spinal motion.

Due to the complexity of the physical horse-rider interaction, it would be useful to investigate the effects of a static load, before considering the additional variables that come with a rider. One study which investigated the effect of loading (static, 75 kg) on equine spinal motion showed that the total range of motion undergone did not change, but the range had shifted to include more extension and less flexion, which the authors suggest may predispose the horse to soft tissue injury and impinging spinous processes (DE COCQ et al., 2004).

Studies into human and animal movement such as that described above (DE COCQ et al., 2004) commonly use camera-based systems to investigate motion in 3D. These systems can provide excellent detail on intricate linear and angular motions but data collection is restricted to a fixed calibrated area, equipment is expensive and data processing and analysis can be a complex and lengthy process.

Inertial sensors are now increasingly being used in equine locomotion studies to investigate motion in 3D, as they are small, light (portable) and relatively inexpensive - enabling analysis of motion beyond the confines of a laboratory setting (PFAU et al., 2008). An inertial sensing system has been validated to capture motion of the withers of the horse in walk, trot and canter (PFAU et al., 2005). Therefore, this technology provides a simple, cost-effective way of measuring displacements and rotations, and as such was chosen for use in the present study.

The purpose of this study was to assess the effects of the application of a load on motion at the lumbosacral junction and the withers in the horse.

Materials and methods

The study was approved by the Royal Veterinary College as part of an MSc Thesis in 2004 and ethical approval was granted by the Royal Veterinary College ethics committee.

Horses

6 Thoroughbred horses were used (same-subject design; 3 mares and 3 geldings), aged between 5 and 10 years. The horses were treadmill trained and were deemed sound by a veterinary surgeon immediately prior to testing. They were field-kept and not in regular ridden work.

Experimental set-up

An accelerometer (ADXL150, Analog Devices, Norwood, MA, USA) with battery and transceiver were attached to the left forelimb of the horse to analyse foot-fall sequence and to enable motion data to be split into individual strides. The signal was transmitted wirelessly to a nearby computer workstation for subsequent processing. A General Purpose saddle and standard girth were fitted to the horse. The saddle (total mass 10 kg) remained in place for all test conditions. The inertial sensors selected for this study were MT9s (XSens Ltd, Enschede, The Netherlands), an inertial sensor which contains a 3-axis accelerometer, a 3-axis gyroscope and a 3-axis magnetometer, to measure 3D linear acceleration, 3D angular velocity and 3D magnetic field data (dimensions 39 mm x 54 mm x 28 mm, mass 35 g) (FINDLOW et al., 2008). One MT9 was glued to a clipped section of skin over the lumbosacral junction, which was identified by palpation of the dorsal spinous processes of L6 and S1 and the marker placed at the midpoint of these palpable landmarks. This method of lumbosacral joint location is similar to that used in other studies (JOHNSTON and MOORE-COLYER, 2009). A second identical MT9 was placed into a withers-mount especially designed for the study and placed in front of the saddle over the withers at T4-5. The withers-mount was used due to difficulty in securing the inertial sensor directly onto the withers. This methodology has been reported in a previous study (PFAU et al., 2005). A small battery pack for the sensors was attached in front of the saddle using a surcingle.

Both MT9 inertial sensors were hard-wired to a laptop, and synchronised with the accelerometers so that both data sets could be processed and analysed together in MATLAB (The Mathworks, Natick, MA, USA) using custom written processing software. 2 hessian sandbags (Travis Perkins Plc, Hatfield, UK) with a combined mass of 30 kg were placed over the saddle, one bag hanging over either side of the saddle. The bags were firmly secured with electrical tape to the saddle to minimise their movement.

Data collection

Each horse was given an initial warm-up of 5 minutes of walking exercise in hand outdoors and 5 minutes on the treadmill at 1.6 m/s prior to testing. For the first phase of data collection, each horse walked on the treadmill at a speed of 1.6 m/s without the sandbags in place. 3 sets of data (10 s each) were collected from each MT9 inertial sensor and accelerometer synchronously. The same data collection setup was used at trot at 3.0 m/s. This test sequence was termed Condition 1 (C1). An identical protocol was repeated with the sandbags in place (30 kg). This was termed Condition 2 (C2).

For the first 3 of the 6 horses, the sandbags were removed and the protocol repeated identical to C1, to determine potential carry-over effects of C2. This was termed Condition 3 (C3). Unfortunately, C3 could only be performed in 3 out of the 6 horses due to time constraints.

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After testing, each horse was given a cool down period of 5 minutes of walking on the treadmill at 1.6 m/s followed by a 5 minute walk outdoors in-hand with the saddle and sandbags removed.

The MT9 and accelerometer data were processed and linear (craniocaudal, dorsoventral and mediolateral) and angular (roll, pitch and yaw) displacements were calculated in mm and degrees respectively. This approach has been reported in a previous study (PFAU et al., 2005).

Statistics

Descriptive statistics including means and standard deviations of total range of movement in each movement direction were described for C1 and C2, which included data for all 6 horses. Paired t-tests were performed between C1 and C2 to assess statistical significance of the findings. Subsequent analysis was performed on the 3 horses which completed all 3 conditions, including means and standard deviations, and within subject one way ANOVA (with Bonferroni correction). Pair-wise comparisons were planned for significant findings within the 3 test conditions, to identify the relationships between the individual groups. SPSS Statistics version 17.0 was used for all statistical testing.

Results

There was no significant difference in mean total linear or angular motion during walk at the lumbosacral junction between C1 and C2 (see Tab. 1 for p-values). At trot, mediolateral linear displacement (p=0.024) and pitch angular displacement (p=0.028) significantly increased in C2 (Tab. 1). Mediolateral displacement is shown in Fig. 1 and pitch displacement in Fig. 2.

There were no significant differences in mean total linear or angular displacements during walk at the withers between C1 and C2 (see Tab. 2 for p-values). At trot, roll displacement was significantly increased in C2 (p=0.042) (Tab. 2). This is shown in Fig. 3.

There was no statistical significance when comparing all 3 conditions for walk or trot at either the withers or lumbosacral junction for any movement direction (see Tab. 3 and 4).

Discussion

The purpose of this study was to investigate the effect of a load placed on the spine on motion at the lumbosacral junction and the withers in the horse. A load of 30 kg was found to significantly increase mediolateral linear displacement and pitch angular displacement at the lumbosacral junction and roll angular displacement at the withers during trot. No significant change in linear or angular displacement was observed during walking at either the lumbosacral junction or the withers when loaded. Comparison of all 3 test conditions for 3 of the 6 horses showed no statistical significance in any movement direction at walk or trot at the lumbosacral junction or withers. No other studies with similar methodologies have been identified to which the results of the present study could be directly compared. However, a study by DE COCQ et al. (2004) analysed the effects of a load on equine spinal motion at L1, L3, L5, and S3 using a 3D marker position system and infrared cameras. Although this study differed in methodology from the present study, the authors showed that total range of motion undergone was unchanged with the application of a load. However, motion was found to occur within greater ranges of extension and lesser ranges of flexion. It is possible that this finding may also be occurring in the present study, but there were restrictions to analysis of total range of motion alone, with inertial sensing techniques.

The horses included in the present study were not in regular ridden work, which may explain why some movement directions showed significant increases in contrast to the studies by DE COCQ et al. (2004, 2009). The muscular system plays an important role in controlling joint motion and providing support, and the horses included in the present study may have lacked adequate muscular strength to control spinal motion. Previous studies have investigated the role of trunk muscles during locomotion in the horse. ROBERT et al. (2002) showed that the activity of rectus abdominis and longissimus dorsi increased with increasing speed using electromyography (EMG), even though spinal joint movement reduced with increasing speed. It was suggested that greater activity in these muscles is required at faster speeds to oppose the inertial forces on the abdomen, and that the muscles are likely to have a stabilising role in a sagittal plane. The authors also note that due to the data being collected on a treadmill, direct application of the findings should not be made to the horse exercised over-ground. Differences between treadmill and overground locomotion have been reported in previous studies, where reduced vertical displacement of the trunk has been shown during treadmill locomotion (BUCHNER et al., 1994). In contrast to the study by ROBERT et al. (2002), another study reported a linear relationship of increased motion at the lumbosacral junction with increasing speeds at canter, although EMG data were not collected in that study (JOHNSON and MOORE-COLYER, 2009). Therefore, motion of the spine and integration of muscle function during varying speeds is still unclear and requires further investigation.

Further studies have investigated the role of longissimus dorsi during equine locomotion. It has been proposed that longissimus dorsi activity may be responsible for stabilization of the vertebral column against dynamic forces (LICKA et al., 2004), and that this muscle may counteract the propulsive forces generated by the ipsilateral hindlimb (LICKA et al., 2009). These authors also found that maximal output occurred during the early phase of the maximal lateral excursion of the spine, perhaps as a pre-emptive tension which is put in place to control the range of movement. The study by LICKA et al. (2009) found maximal activity in longissimus dorsi to occur at T16 and lesser activity occurring at L3, and this data was collected during walk only (LICKA et al., 2009). Therefore, consideration of the role of longissimus dorsi in providing stability around the lumbosacral junction or at the trot for the purpose of the present study would require caution. The longissimus dorsi muscle has also been shown to increase activity 2 to 3-fold on EMG on the inside longissimus dorsi muscle compared to the outside longissimus dorsi muscle when the horse is walking and trotting on a circle (COTTRIAL et al., 2009). Similar to the study by LICKA et al. (2009), these

Tab. 1: Mean and standard deviation of total lumbosacral junction linear and angular displacement at walk and trot for C1 and C2

Condition	CC (SD) (mm)	DV (SD) (mm)	ML (SD) (mm)	roll (SD) (deg.)	pitch (SD) (deg.)	yaw (SD) (deg.)
Walk						
C 1	94.5 (24.27)	30.37 (8.59)	36.60 (7.38)	12.63 (2.97)	6.27 (1.78)	12.22 (2.8)
C 2	89.17 (23.43)	32.73 (5.16)	36.35 (7.54)	12.31 (2.59)	5.82 (2.26)	11.36 (2.4)
p-value	0.28	0.24	0.93	0.77	0.39	0.19
Trot						
C 1	66.37 (31.02)	77.98 (27.47)	21.55 (4.37)	9.03 (3.74)	2.74 (1.10)	10.47 (3.1)
C 2	80.37 (43.32)	76.83 (16.91)	40.92 (12.97)	8.41 (4.16)	4.35 (1.71)	9.09 (2.6)
p-value	0.15	0.931	0.024	0.638	0.028	0.425

CC = craniocaudal; deg. = degrees; DV = dorsoventral; ML = mediolateral; SD = standard deviation; abbreviations also valid for Tab. 2-4.

Tab. 2: Mean and standard deviation of total linear and angular displacements at the withers at walk and trot for C1 and C2

Condition	CC (SD) (mm)	DV (SD) (mm)	ML (SD) (mm)	roll (SD) (deg.)	pitch (SD) (deg.)	yaw (deg.)
Walk						
C1	61.43 (23.23)	62.15 (19.35)	77.28 (29.48)	18.11 (4.32)	8.08 (2.40)	12.86 (4.04)
C2	55.82 (21.99)	59.67 (15.454)	77.27 (30.48)	18.09 (5.22)	8.73 (2.70)	12.87 (4.62)
p-value	0.081	0.644	0.973	0.987	0.078	0.976
Trot						
C1	84.93 (60.16)	98.20 (29.89)	89.15 (38.56)	12.06 (4.67)	3.43 (0.87)	5.52 (2.64)
C2	98.88 (52.30)	113.52 (19.04)	121.08 (48.93)	18.35 (6.74)	4.29 (1.26)	10.76 (4.14)
p-value	0.324	0.277	0.165	0.042	0.278	0.061

Tab. 3: Mean and standard deviation of total lumbosacral junction linear and angular displacement at walk and trot for C1, C2 and C3

Condition	CC (SD) (mm)	DV (SD) (mm)	ML (SD) (mm)	roll (SD) (deg.)	pitch (SD) (deg.)	yaw (SD) (deg.)
Walk						
1	83.10 (14.64)	26.60 (10.36)	34.07 (8.71)	10.69 (1.75)	6.49 (1.20)	11.79 (3.22)
2	78.43 (7.56)	30.37 (5.50)	30.50 (4.12)	10.55 (2.27)	5.68 (2.79)	10.28 (2.73)
3	93.40 (6.08)	31.30 (3.17)	37.67 (9.16)	11.48 (0.15)	6.90 (1.18)	11.92 (4.27)
p-value	0.291	0.407	0.374	0.673	0.375	0.207
Trot						
1	59.33 (36.25)	67.47 (30.35)	19.43 (3.40)	10.84 (3.24)	2.29 (1.36)	9.38 (3.05)
2	61.60 (41.11)	67.27 (20.67)	41.17 (19.85)	9.91 (5.23)	3.52 (1.65)	8.90 (2.96)
3	75.60 (27.65)	84.40 (12.21)	27.20 (8.14)	10.45 (4.24)	3.30 (1.50)	10.16 (1.68)
p-value	0.192	0.524	0.250	0.844	0.322	0.754

Tab. 4: Mean and standard deviation of total withers linear and angular displacement at walk and trot for C1, C2 and C3

Condition	CC (SD) (mm)	DV (SD) (mm)	ML (SD) (mm)	roll (SD) (deg.)	pitch (SD) (deg.)	yaw (SD) (deg.)
Walk						
1	54.23 (9.72)	53.97 (25.76)	79.53 (22.53)	15.48 (3.61)	6.79 (2.06)	9.68 (0.95)
2	48.60 (9.38)	51.60 (19.08)	80.00 (20.27)	14.77 (4.76)	7.77 (2.48)	9.08 (2.20)
3	59.13 (8.73)	56.60 (22.03)	85.97 (16.00)	17.61 (2.71)	7.72 (1.96)	10.94 (0.45)
p-value	0.298	0.466	0.329	0.312	0.462	0.284
Trot						
1	58.80 (27.67)	86.10 (37.15)	67.10 (29.18)	10.49 (2.70)	2.94 (0.98)	4.95 (1.88)
2	86.47 (9.40)	105.93 (20.99)	113.00 (40.51)	16.57 (6.21)	4.26 (1.88)	9.21 (3.34)
3	60.13 (7.47)	111.07 (23.63)	89.90 (20.69)	13.89 (3.40)	3.89 (0.71)	7.87 (1.41)
p-value	0.187	0.715	0.586	0.321	0.338	0.241

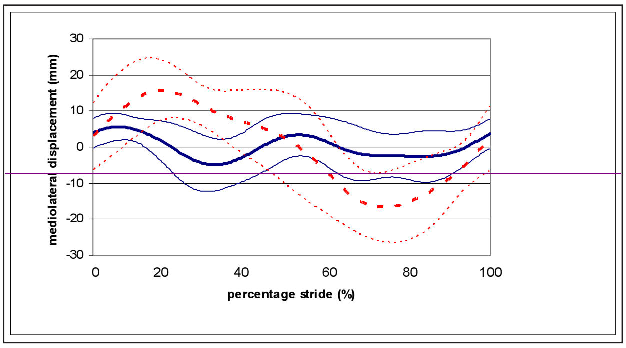

Fig. 1: Mean (thick lines) and standard deviations (thin lines) of total mediolateral displacement at the lumbosacral junction at trot shown for one stride for C1 (closed lines) and C2 (broken lines)

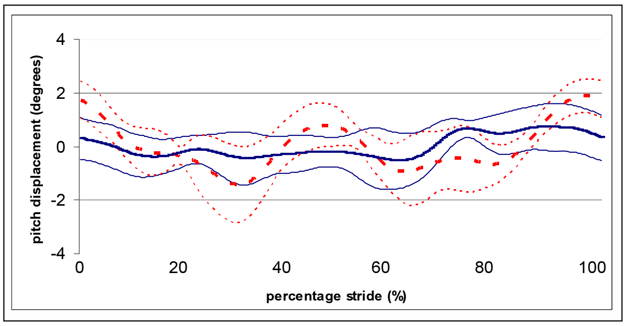

Fig. 2: Mean (thick lines) and standard deviations (thin lines) of total pitch displacement at the lumbosacral junction at trot shown for one stride for C1 (closed lines) and C2 (broken lines)

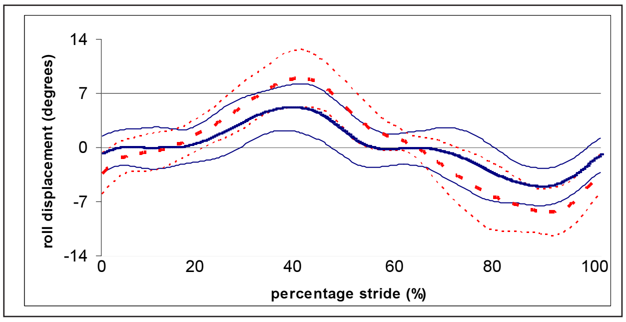

Fig. 3: Mean (thick lines) and standard deviations (thin lines) of total roll displacement at the withers at trot shown for one stride for C1 (closed lines) and C2 (broken lines)

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measurements were taken at T16 and cannot be directly extrapolated to the lumbosacral junction.

Limitations to the present study were restrictions in the load being applied, thus future research should apply a load greater than 30 kg as a more accurate representation of a rider. The application of greater loads was piloted for the present study. A load greater than 30 kg created excessive saddle displacement, thus disrupting sensor placement and potentially causing discomfort to the horse. A load of 30 kg did not have this effect, which was why this load application was chosen for the study. A more dense substance could have been used instead of sand for load application, but such materials were not soft enough to shape to the contours of the horse and may have caused discomfort. The small sample size of horses included in the present study was adequate for the provision of data as a preliminary study. Future studies should include a larger number of horses to provide a greater understanding of the effects of load on the motion of the lumbosacral junction and other areas of the spine. Additionally, future research should investigate spinal motion using inertial sensors alongside trunk muscle activity measurement using EMG, to assess these muscles' role in creating or limiting spinal motion. This information could serve as baseline data when investigating spinal motion and muscle function in horses with back pain. Understanding the differences in motion and muscle function in horses with and without back pain may lead to enhanced treatment approaches for back pain and assist in prevention strategies for this condition.

Treadmill studies can provide highly repeatable data (FABER et al., 2002) and this approach is very useful when controlling variables such as speed and incline, which was why the treadmill was chosen for the purpose of the present study. However, horses are generally exercised over ground. Therefore future studies should investigate the influences of the rider on equine spinal motion during over ground locomotion, as demonstrated in the study by DE COCQ et al. (2009). Data from the MT9 can be received remotely via telemetry, therefore the use of such motion sensors to assess locomotion overground would be highly valuable, as it eliminates the requirement to remain in the laboratory environment for more "traditional" motion analysis, such as marker positioning and infrared cameras. The use of the inertial sensors for the purpose of this study was found to be a useful tool, although future studies should aim to place inertial sensors along different points of the spine, as there is a variation between spinal segments and their mobility (TOWNSEND et al., 1984). Additionally, anatomical variations have been reported in the thoracolumbar and lumbosacral area of the spine, with 40 % of Thoroughbreds showing this variation (STUBBS et al., 2006). Future studies should investigate the effect of loading on spinal motion within different breeds or conformational variations which could help clinicians understand breed-specific aspects of back pain and dysfunction.

Conclusion

In the present study, loading the equine spine with a mass of 30 kg did not significantly affect motion at the lumbosacral junction and withers for the majority of movement directions at walk and trot. However, inertial sensors were found to be a valuable measurement tool for the provision of quantitative kinematic data at the withers and lumbosacral junction. Future studies investigating the effects of a load on spinal motion with inertial sensors are recommended, alongside trunk muscle EMG analysis.

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