EVALUATION OF TRI-AXIAL ACCELEROMETERS FOR Assessment of GAIT In Sound and ATAXIC HORSES

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Abstract

Introduction: Ataxia in horses is graded on a scale from 0 (normal) to 5 (recumbent). However, this scale is subjective and there is poor agreement between clinicians when evaluating an ataxic horse or when the same person re-evaluates the horse (1). This shows there is a need for an objective rating system for ataxia. The objectives of this study were: 1) to use accelerometers to evaluate the gait in sound horses while walking normally and while walking with the head elevated, 2) to compare accelerometer parameters from sound horses with those from ataxic horses and 3) to use accelerometers to evaluate the gait in sound experimental horses before and up to one week after experimental cervical stabilization surgery.

Materials and Method: For this study 7 adult horses were used. Three horses (2 – 10 years old) with clinically apparent ataxia (grade 2-3/5) and myelograms consistent with CVCM were used as a reference for ataxic hoses. Four healthy horses (1-2 years old) were used for experimental cervical stabilization surgery. Gait analysis consisted of a full neurological evaluation and analysis of accelerometer data. Accelerometers (Gulf Coast Data Concepts X16-4 and X16-1C 3-axis) were placed on the lateral metatarsus and metacarpus of all four limbs, the forehead and the sacrum. Data was collected while the horse was walked in a straight line at its own natural pace, and while walking with the head elevated. Raw data was then plotted using the XLR8R 2.1 application provided by Gulf Coast Data Concepts. A usable run was selected and exported to Microsoft Excel for further analysis. For analysis, five sequential strides were selected from the middle of a suitable run. In the leg-based accelerometer data it was possible to determine stride characteristics using all three axes. Acceleration in Ax represents vertical movement; Ay represents cranio-caudal movement while Az represents mediolateral movement. Single steps, the moment of lifting the heel and toe and the moment of touching the toe down were determined. For the sacrum-based accelerometer, the z-axis (vertical movement) and y-axis (mediolateral movement) could be used to determine steps with either the left or right leg. The acceleration in the y-axis could then be used as an indicator for truncal sway.

Results and discussion: The Ax, Ay and Az acceleration in healthy horses was significantly lower in the hind limbs when compared to the front limbs ($P<0,001$). When the head was elevated, the distal limb acceleration were also significantly higher ($P<0,0001$) when compared to a normal head position. Also, when the head was elevated the relative swing phase was significantly longer ($P=0,048$). In ataxic horses, the Ax and Az distal limb acceleration was significantly higher in both the front ($P=0,0451$ and $P=0,0005$) and hind ($P=0,0021$ and $P=0,0024$) limbs when compared to healthy horses. Mediolateral accelerations recorded from the sacrum in ataxic horses were significantly higher when compared to normal animals ($p<0.05$). The Ax value was lowered in the front limbs of the healthy horses at 24hr ($P>0,0001$), 48hr ($P=0,0038$) and 1 week ($P=0,0467$) post-surgery. Stride duration was significantly longer at one week after surgery ($P=0,0013$), as well as absolute swing phase ($P<0,0001$). Based on these results, we were able to differentiate between healthy and ataxic horses. The gait pattern changes significantly when the head is elevated in both healthy and ataxic horses. These tri-axial accelerometers are suitable to objectively measure differences between ataxic and healthy horses. The gait pattern did change after surgery, but the horses where not clinically ataxic. The changes in gait pattern can be explained by the general depression and slower walking rate after surgery. These data should be more extensively analyzed and more data from a larger group of animals should be collected in order to validate these results.

Conclusion: There is a significant change in gait pattern when both ataxic and healthy horses are walked with an elevated head. Accelerometers can be used to differentiate objectively between and within ataxic and clinically sound horses.

Abbreviations

CVCM	Cervical Vertebral Compressive Myelopathy
CS1 - 4	Cervical Vertebral Stabilization horse 1-4
CC 1-3	Clinical Case horse 1-3
UMN	upper motor neuron
PEEK	poly-ether-ether-ketone
LF	Left front
LH	Left hind
RF	Right front
RH	Right hind

Introduction and study background

Cervical vertebral compressive myelopathy (CVCM)

Cervical vertebral compressive myelopathy (CVCM) (also known as Wobblers' syndrome, equine spinal ataxia, cervical vertebral malformation, cervical stenotic myelopathy and cervical vertebral instability) is an equine disease characterized by clinical signs of cervical spinal ataxia. It is caused by narrowing of the cervical vertebral canal, which can be either intermittently or continuously present. Due to this narrowing of the cervical vertebral canal, the spinal cord is compressed and myelopathy and inflammation may occur.(2,3) In a study in France, it was found that CVCM was the second most common cause of neurological signs in horses, the first being trauma to the skull or vertebral column.(4) A higher incidence of CVCM has been reported in stallions and geldings than in mares.(4-7) It has been suggested that there is a higher incidence of CVCM in breeds including the Quarter Horse, Thoroughbred, Tennessee Walking Horse and European Warmblood breeds.(6) In two case-control studies by Levine et al. it was determined that there was a significantly higher incidence of CVCM in Thoroughbreds, Tennessee Walking Horses and Warmbloods, compared to Quarter Horses(5,8). Arabian Horses and Standardbreds were found to be less likely to develop CVCM. (5) The underlying cause of CVCM is not clear, however there are some factors that seem to increase the risk of CVCM. Recent studies suggest that the two underlying pathogeneses for this disease are 1) an underlying developmental disorder of bone and cartilage morphogenesis and maturation that ultimately leads to cervical vertebral malformations, and 2) an underlying biomechanical process whereby abnormal mechanical stresses and forces on the cervical column result in structural vertebral changes, leading to stenosis of the canal.(9) Based on the higher incidence of CVCM in certain breeds and families, a hereditary component is suspected; however, in a study investigating the hereditary component in Thoroughbred horses, no evidence of a genetic component could be found.(10) CVCM is likely to be a multifactorial disease, involving diet, growth rate, bony malformations, and abnormal biomechanical stresses (11). CVCM can be classified in two separate categories: dynamic vertebral compression and static vertebral compression. In the dynamic form, the spinal cord is compressed intermittently. The dynamic form is seen mostly in young horses between 8 to 18 months of age. On a myelogram, the compression is seen only during flexion or extension of the neck.(4,6) C3-C5 are most commonly affected. In the static form, the compression is continuously present. This form is seen most commonly in adult horses of all ages. Static compression may be associated with osteoarthritic lesions of the articular process. Here, C5-C6 and C6-C7 are most commonly affected. (4,6)

Diagnosis

Clinical signs

As always, the first step in the diagnostic process should be a complete physical examination of the horse followed by a neurologic examination. The latter is used to determine the neuroanatomic localization of the suspected lesion. In CVCM, there will be signs of focal cervical spinal cord disease (C1-7). Therefore, no cranial nerve deficits will be found. During gait evaluation, signs of symmetric ataxia, paresis, dysmetria, and spasticity can be found involving all four limbs. The cervical part of the spinal cord white matter contains tracts influencing both the thoracic and pelvic limbs. The tracts influencing the pelvic limbs are located more peripherally. Due to this, the pelvic limbs are likely to be more severely affected compared to the thoracic limbs. Due to the neuroanatomic localization and spinal cord white matter involvement, signs of dysfunction of the upper motor neurons (UMN) are expected, resulting in upper motor neuron weakness and proprioceptive deficits. In UMN weakness, spasticity and exaggerated reflex responses occur, while muscle atrophy and fasciculations are absent. These horses tend to be strong for the standing tail pull test, while they are weaker during the walking tail pull test. In some cases, walking the horse in a straight line is not sufficient to distinguish the clinical signs. There are several tests that require fine-tuned coordination of the UNM and general proprioceptive tracts that can help distinguish the clinical signs. These tests include walking with the head elevated or walking down a slope, during which horses with CVCM will show worsening signs of ataxia. While turning in a tight circle, horses with CVCM will usually pivot on the inside limb, circumduct their outer hind limb and will sometimes step on themselves, stumble or strike their limbs. (12)

Diagnostic imaging

A presumptive clinical diagnosis is made based on the signalment, a detailed history and the clinical signs.(2,3) Analysis of CSF can be used to rule out other causes of symmetrical spinal ataxia, but is usually unremarkable in horses with CVCM. On cervical radiographs, there are five characteristic bony malformations that can be found in horses with CVCM. These are: Flare or enlargement of the caudal vertebral epiphysis, osteochondrosis of the articular processes, malalignment or subluxation between vertebrae, extension of the dorsal laminae and/ osteoarthritis and bony proliferations of the articular processes (2,13). Measurement of the intravertebral and intervertebral sagittal ratio can give an indication of the likelihood of CVCM. The intravertebral sagittal ratio is calculated by dividing the minimum sagittal diameter by the sagittal height of the cranial aspect of the vertebral body (see Figure 1) (14) However, assessment of cervical radiographs alone may lead to a false positive diagnosis of CVCM (13). In order to confirm a diagnosis of CVSM and to identify the affected site(s), a cervical myelogram has to be performed. In this procedure, a contrast medium is injected into the subarachnoid space and radiographs are taken with the neck in neutral, flexed and extended positions. Complete ventral myelographic column attenuation with 50% or greater reduction of the dorsal myelographic column at the junction of two vertebrae as compared to the width of the myelographic column midway the vertebrae is the currently used criterion to diagnose compression.(13) Advanced imaging techniques including CT and MRI are being investigated to assess the diameter of the vertebral canal. In a study where the cervical spine of 28 thoroughbred horses was evaluated post mortem, it was found that CVCM could be accurately diagnosed using MRI.(15) However, in an earlier study with mixed breeds, this was not possible.(16) Unfortunately this technique is not yet of clinical use, since current MRI units do not have large enough bore sizes to accommodate the entire equine cervical spine. It is also important to note that the vertebral canal should be evaluated during flexion and extension, which currently is not possible in an MRI unit. There are CT units available with large enough bore sizes to accommodate adult horse necks that are currently being investigated for the diagnostic utility in CVCM.

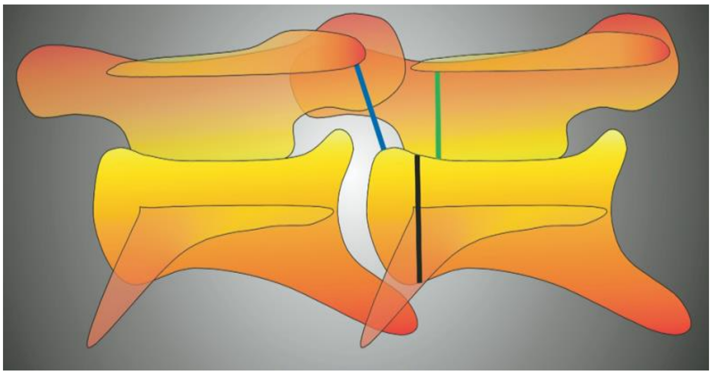


Figure 1: The intravertebral sagittal ratio can be calculated by measuring the minimum sagittal diameter (green line) and the maximal sagittal diameter at the cranial apect (left in this image) of the vertebra (black line). The intravertebral ratio is determined as green:black. The intervertebral sagittal ratio can be determined measuring the minimal distance between the most cranial aspect of the vertebral arch of the caudal vertebra (right in this image) and the most caudal part of the vertebral arch of the cranial vertebra (blue line) the ratio is determined as blue : black (Taken from van Biervliet et al [9])

Treatment

There are two possible treatment options for horses with CVCM. The first is a reduced caloric intake diet and reduced exercise program that can be pursued in young horses (< 2 years). The aim of this treatment is to slow down the growth of the horse, allowing the vertebral column to "catch up". This treatment should be closely supervised by a veterinarian, to ensure that all the nutritional requirements are met.(2) In a retrospective study, Hoffman et al found that 30% of Thoroughbred horses diagnosed with CVCM that underwent this treatment were able to start in at least one race (17). A second treatment option for horses with this disease is cervical vertebral stabilization surgery at the site(s) of stenosis. The aim of this surgery is to prevent further movement and subsequent trauma and compression of the spinal cord and allow inflammation around the compressed site to resolve. The most commonly used surgical implants are the modified Bagby basket and Kerf Cut cylinder. The Kerf Cut cylinder (see Figure 2) is a partially threaded titanium implant with several holes for bone graft and an open center where an isthmus of bone remains in place to encourage osseous fusion. The advantage is that this reduces postoperative fractions and implant migration.(18)

Surgical technique

The patient is positioned in dorsal recumbency and a curved 30-cm block is placed under the affected area to ensure proper extension of the targeted vertebra and to provide a stable surface during drilling. Lateromedial radiographs are taken to identify the surgical site. A 20-cm skin incision is then made and after dissection of the cutaneous and sternothyroideus musculature, blunt dissection is continued at the right side of the trachea. The trachea is then reflected to the left and an incision in the longus colli musculature is made at the site of the ventral spinal process. The ventral spinal process is then removed and bone graft material can be prepared from it. The implant site is then drilled with a series of drills, leaving a shelf of bone 8-10 mm distant from the spinal canal. The implant is then inserted until firm resistance is encountered. After extensive flushing with sterile saline to prevent any contamination with debris, the wound is closed.(18) After surgery, an improvement of 1-2 (out of 5) grades of ataxia is expected. (2)

Prognosis

The ideal surgical candidate is a young horse (<2 years of age) with mild neurologic deficits with only one site affected (18). In a study with 12 horses with a triple level spinal cord compression, 92% of the patients survived the procedure and 75% improved more than 2 grades of ataxia. Two of the horses were able to enter (and win) a race, However, all horses experienced stiffness in the neck after surgery (19). Overall, it can be stated that the success rate of surgery is around 45-60% (18,20). The success rate is dependent on the number of sites of compression, the severity of the clinical signs, how long the signs have been apparent and the intended use of the animal. It is important to also acknowledge the age and temperament of the horse and the owner's motivation, since it may be up to a year after surgery before clinical signs improve. (18) Furthermore it should be noted that there are horses with grade 1 -2 out of 5 neurologic deficits that race successfully.(17)

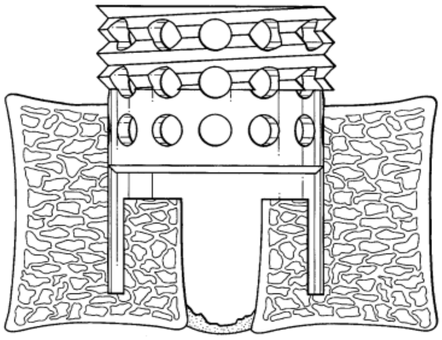


Figure 2: The Kerf Cut cylinder, placed in a prepared bone bed. (Taken from Walmsley et al)(18)

Accelerometric data collection

To diagnose ataxia in a clinical setting several clinical tests are used, including gait observation and limb placement tests.(3) However, the accuracy of rating of ataxia was found to vary between clinicians, especially when signs of ataxia were subtle. Furthermore, it was found that when a clinician re-evaluated a horse, there was not always a complete agreement with his/her previous assessment.(1) This shows that subtle ataxia is not always accurately diagnosed and that there is need for an objective measurement scale. Accelerometers are small devices that can measure the acceleration of the surface they are attached to. Each accelerometer measures acceleration in the direction it is attached, therefore two or three accelerometers are usually combined to obtain two- or three-dimensional data,(21) although there are currently triaxial devices available that can determine acceleration in three dimensions from one unit. Using accelerometric data, regularity, or stride-to-stride variance can be calculated in addition to other parameters including stride frequency, speed and energetic parameters such as propulsion. Leg-based inertial measurement units (combining accelerometry with gyroscopes and sometimes magnetometers) have been used in the past to objectively evaluate lameness in biomechanical research.(22-25) Accelerometers placed on the head, sternum and/or sacrum have recently been successfully used to detect ataxia induced by several different sedatives. (26-28)

Objectives and hypotheses

The objectives of this study were: (1) to use accelerometers to evaluate the gait in sound horses while walking normally and while walking with the head elevated, (2) to compare accelerometer parameters from sound horses with those from ataxic horses and (3) to use accelerometers to evaluate the gait in sound experimental horses before and up to one week after experimental cervical stabilization surgery.

We hypothesized that in sound horses, we would find a difference in distal limb acceleration between horses walked with their heads held normal vs. heads being elevated. Also, we hypothesized that the gait pattern would change when the head was elevated. It was expected that the placement of the foot would be more difficult which could result in a longer swing phase.(29)

We hypothesized that there would be no significant change in gait pattern, that there would be differences found in distal limb and pelvic accelerations between sound and ataxic horses and that there would be no differences found in distal limb or pelvic accelerations between horses before and after experimental cervical stabilization surgery.

Materials and Method

Animals

Four healthy horses that were sound on lameness and neurologic examinations, ranging 1-2 years of age (two mares, two stallions; CS1-4) were used for the experimental cervical vertebral stabilization surgery study. Three horses (2 – 10 years old) (one stallion, two geldings; CC1-3) with clinically apparent ataxia (grade 2-3/5) and myelograms consistent with CVCM were used as a reference for ataxic hoses. All horses were conditioned to the research location and the method of data collection (wearing the accelerometers) prior to data collection.

Experimental Design

Prospective observational. The experimental horses' (CS1-4) gait was analyzed before and after experimental cervical vertebral stabilization surgery, in which C3 and C4 were fused. Data collection took place at baseline (before surgery), 24 hours, 48 hours and 1 week after surgery. At each data collection point, a neurological exam was performed by an experienced veterinarian. At 24 and 48 hours after surgery, neck flexion tests were not performed to reduce the chance of complications (such as displacement of the implant). Gait of the ataxic horses (CC1-3) was recorded with accelerometers once.

Accelerometer Data collection protocol

Accelerometric data were recorded using 6 accelerometers placed on the equine body. Gulf Coast Data Concepts X16-4 3-axis accelerometers (Gulf Coast Data Concepts LLC, Waveland, Mississippi) were placed on the lateral metacarpus and metatarsus of all four limbs, using splint boots on which the accelerometers were placed using self-adhesive Velcro. The accelerometers on the legs recorded the data at 200Hz. These accelerometers were placed in such as way that the Ax axis corresponded to the dorso-ventral direction, the Ay axis corresponded to the cranio-caudal direction , and the Az axis corresponded to the mediolateral direction. On the head and sacrum, Gulf Coast Data Concept X16-1C 3-axis accelerometers were used, recording at 25Hz. These accelerometers were placed such that the Ax axis corresponded to the cranio-caudal direction, the Ay axis corresponded to the medio-lateral direction , and the Az axis corresponded to the dorsoventral direction. The accelerometers on the head and sacrum were adhered by super-gluing Velcro to the coat of the horse, on which the accelerometer could be placed. Once all accelerometers were placed on the horse's body, they were turned on and were allowed to record until the end of the data collection. The data was collected while walking the horse in a straight line at its own natural pace, and while walking it in a straight line with its head elevated. At 24 and 48 hours after surgery, the head was not elevated. The horse was stopped at the end of the run before it was turned, in order to be able to identify separate runs. If a horse was reluctant to move while its head was elevated, the horse was encouraged by having a handler walk behind it. During data collection any abnormal events (e.g. sudden stop or spook) were recorded for each run, to ensure a suitable run was used for data analysis. In CC1-3, baseline data was recorded in a similar way.

Experimental cervical vertebral ventral stabilization surgery protocol

Surgery: The horses were positioned in dorsal recumbency with the neck extended. Using fluoroscopy, the articulation of C3-C4 (experimental horses) was determined and an incision of approximately 20-25 cm was made. (In clinical cases, the vertebral bodies at which spinal cord compression had been diagnosed were found using fluoroscopy). The trachea and adjacent musculature were reflected to the left and using both blunt and sharp dissection the ventral margin of the cervical vertebral column was identified. A threaded K-wire was placed in the most cranial part of the area of debridement, to act as guide for creating the defect (a bullet-shaped hole in the intervertebral disc and adjacent bone), the positioning was again confirmed using fluoroscopy. A modified 35mm×35mm×15mm tetrahedronal interbody spinal fusion cage (see below) was then inserted in the created defect, its correct placement and depth confirmed by fluoroscopy. After lavaging the wound, it was closed.

Implant

A poly-ether-ether-ketone (PEEK) cage combined with a pedicle screw and rod system was used. This system is an adaptation of similar implants used in human medicine(30). The advantage is that these implants require less disc space removal than the Bagby basket or Kerf Cut cylinder, and that this implant is expected to provide more rapid stability after surgery, reducing the recovery time.

Data analysis

Stride identification

For data analysis, five sequential strides from the midpoint of each run were used. The raw data was initially plotted using the XLR8R 2.1 application provided by Gulf Coast Data Concepts. A usable run was then identified based on the data collection notes and the regularity of the plotted data. A five-stride sequence was selected and exported to Microsoft Excel 2013 for further analysis. In the leg-based accelerometer data it was possible to determine stride characteristics using all three axes. Single steps, the moment of lifting the heel and toe and the moment of touching the toe down were determined (See Figure 3 and Figure 4). For the sacrum-based accelerometer, the z-axis (vertical movement) and y-axis (mediolateral movement) could be used to determine steps with either the left or right leg. Steps with the right leg corresponded to a positive peak in the y-axis while steps with the left leg corresponded to a negative peak (See Figure 5)

Calculations

Using Microsoft Excel 2013, raw data from both head and sacrum accelerometers were converted to g-forces using the relationship 1048 counts = 1g. Raw data from the leg-based accelerometers were converted to g-forces using the relationship 2048 counts = 1g.

Leg-based accelerometers

After determining five suitable steps as described boven, the acceleration in all three axes, stride duration and relative swing phase were calculated for each step, the mean of these values as then calculated. The acceleration was calculated as the difference between the highest and lowest acceleration value. The stride duration was defined as the time between point A and D in Figure 3 and Figure 4. The swing phase duration was defined as the time between point C and D in Figure 3 and Figure 4. The relative swing phase was then calculated as a percentage of the total stride duration.

Sacrum accelerometer

The Ay-axis from the sacrum accelerometer was used to obtain an indication of truncal sway. The difference in g-force was calculated for each peak corresponding to a step with the left or right leg (See Figure 5). This value, sacrum acceleration, was used as an indication for truncal sway.

Comparisons

To objectively evaluate the gait at baseline in CS1-4 the distal limb acceleration (for Ax, Ay and Az), stride duration, relative swing phase and absolute swing phase parameters were used, derived from the leg accelerometers. Using these parameters, thoracic and pelvic limbs were compared within the CS1-4 group. To evaluate the effect of head elevation, the parameters taken from the front leg accelerometer and the Ay-axis from the sacrum accelerometer were compared at a normal head position versus an elevated head position. In order to compare sound horses with ataxic horses the baseline data for CS1-4 were compared to the baseline data of CC1-3, using the parameters mentioned above. When evaluating the gait before and after surgery in CS1-4, baseline data were compared to data collected at 24hrs, 48hrs and 1 week after surgery. The head was not elevated after surgery.

Statistical analysis

The continuous data on Ax, Ay and Az were checked for normality using Shapiro-Wilk statistics. If normality was met, a linear regression analysis was used to compare the values across various categories of Front versus Hind limb, left versus right limb and different time points versus baseline. The analysis took into account the repeated measurements of same subjects over time. SAS v9.4 (SAS Institute Inc., Cary, NC, USA) was used to perform statistical analysis. A p-value of 0.05 was used to evaluate statistical significance.

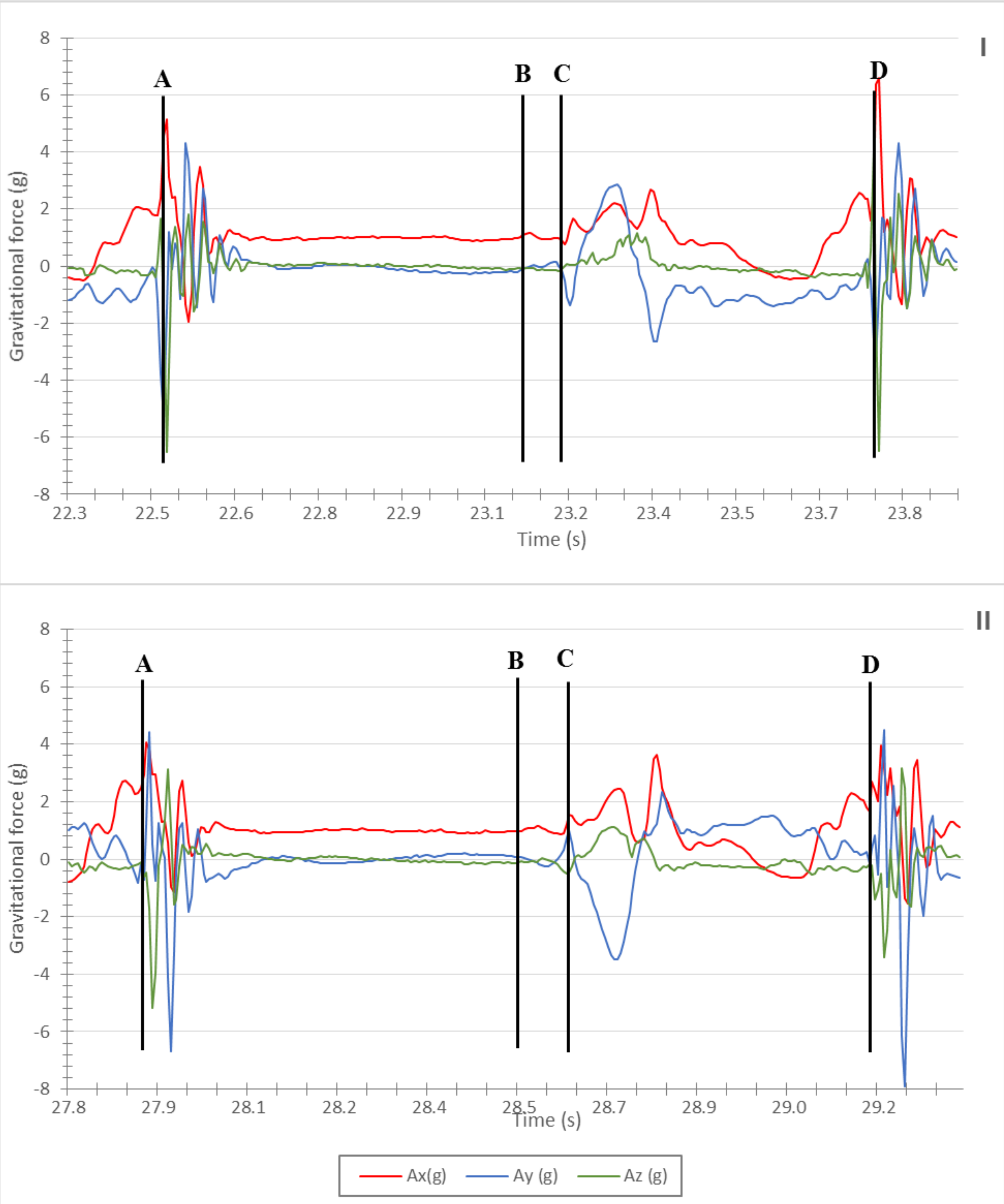


Figure 3: Example of a single step with the left (top) and right (bottom) front limbs in a sound horse. Ax represents acceleration in the vertical axis, Ay in the cranio-caudal axis and Az in the medio-lateral axis. A= toe on, B= heel off, C= toe off and D = heel down. A-D represents one step. A-C indicates the stance phase, C-D indicates the swing phase. I) Left front limb. II) Right front limb

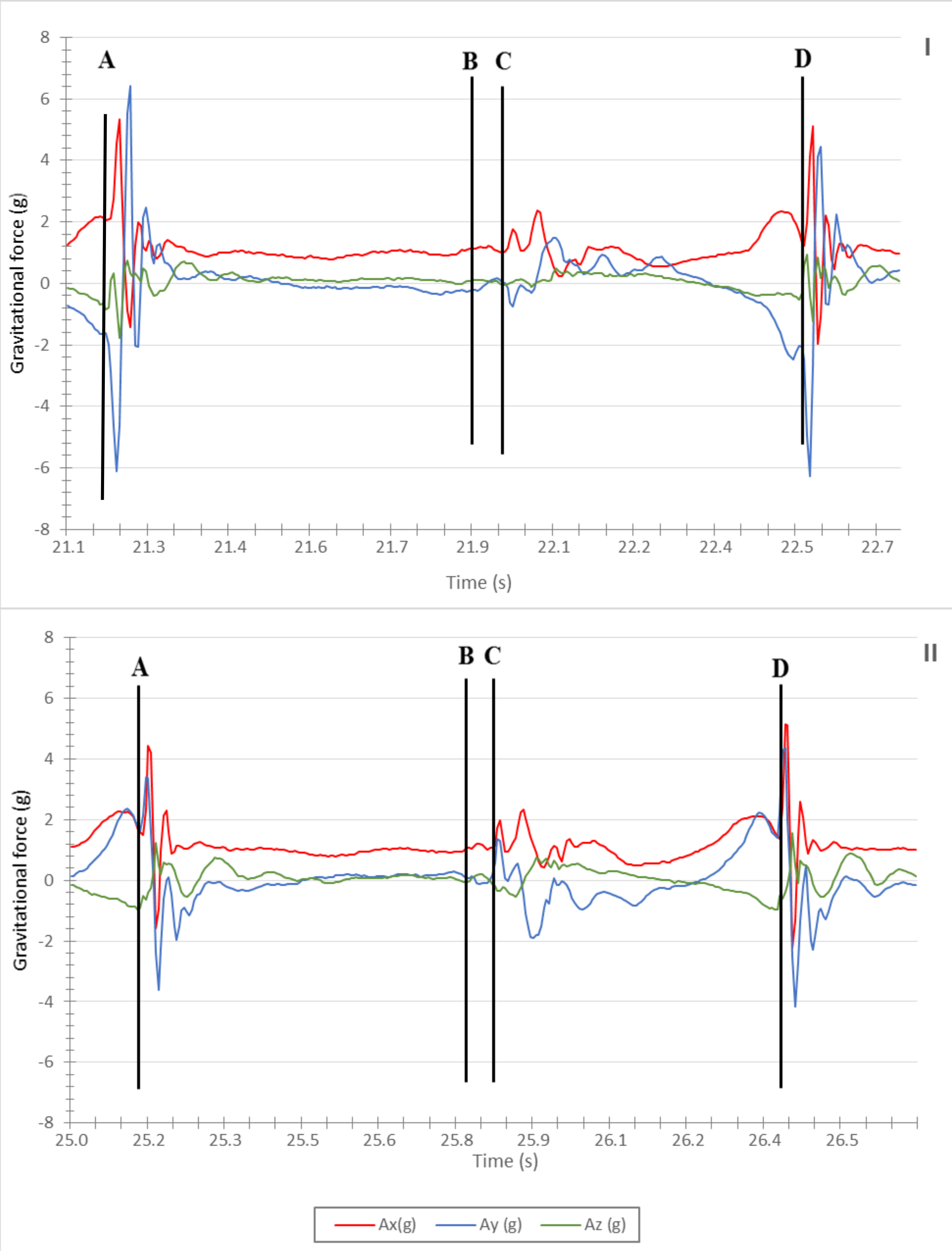


Figure 4: Example of a single step with the left (top) and right (bottom) hind limbs in a sound horse. Ax represents acceleration in the vertical axis, Ay in the cranio-caudal axis and Az in the medio-lateral axis. A= toe on, B= heel off, C= toe off and D = heel down. A-D represents one step. A-C indicates the stance phase, C-D indicates the swing phase. I) Left hind limb. II) Right hind limb

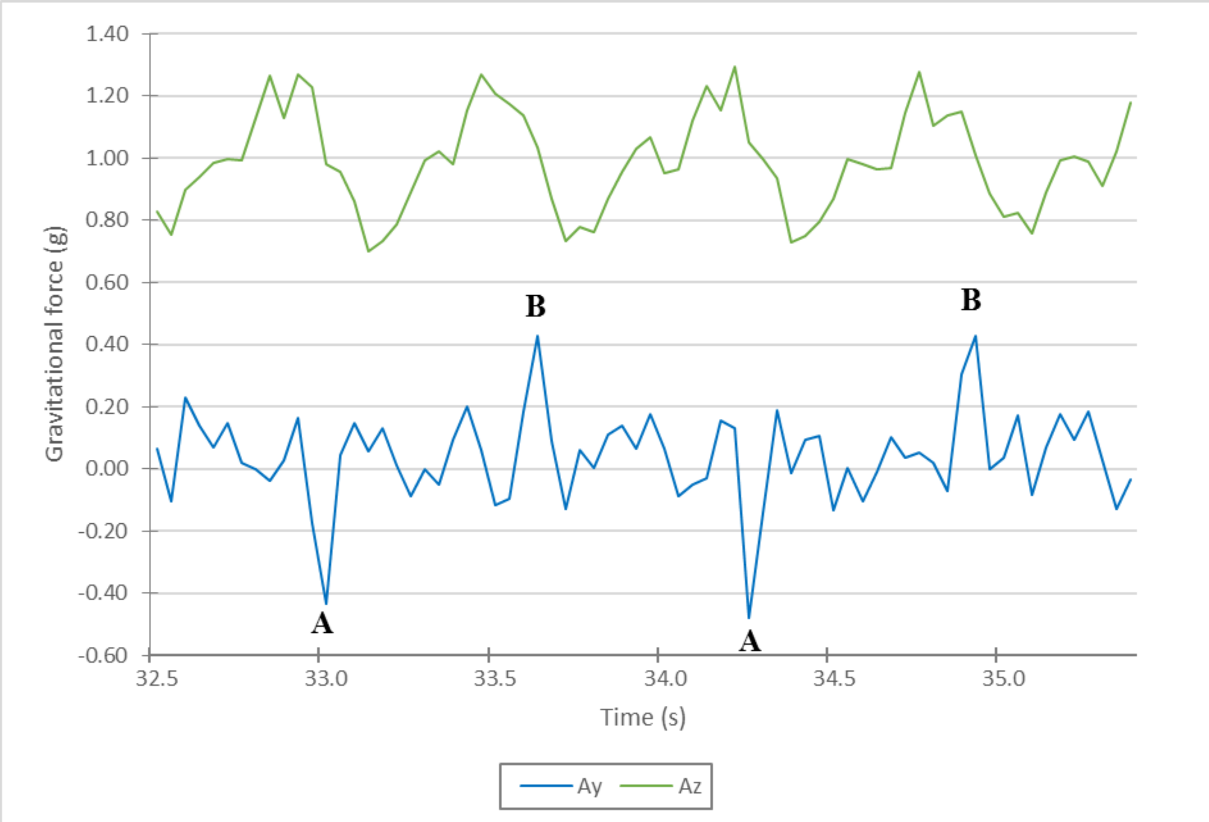


Figure 5: Example of typical movement from the sacrum-based accelerometer. Ay describes the movement in the Lateromedial axis, with positive values being movement to the right and negative values being movement to the left. The difference between a negative and positive peak (point A and B) is used as an indication for truncal sway.

Results

CS1-4 at baseline

In CS1-4, significantly higher distal limb acceleration for Ax, Ay and Az was found in the front limbs when compared to the hind limbs (P<0,0001), see Figure 6. When the head was elevated the distal limb acceleration for Ax, Ay and Az was significantly higher in the front limbs (P<0,0001 in all comparisons, see Figure 6). There were no significant changes in stride duration and absolute swing phase. However, the relative swing phase was significantly longer (P=0,048).

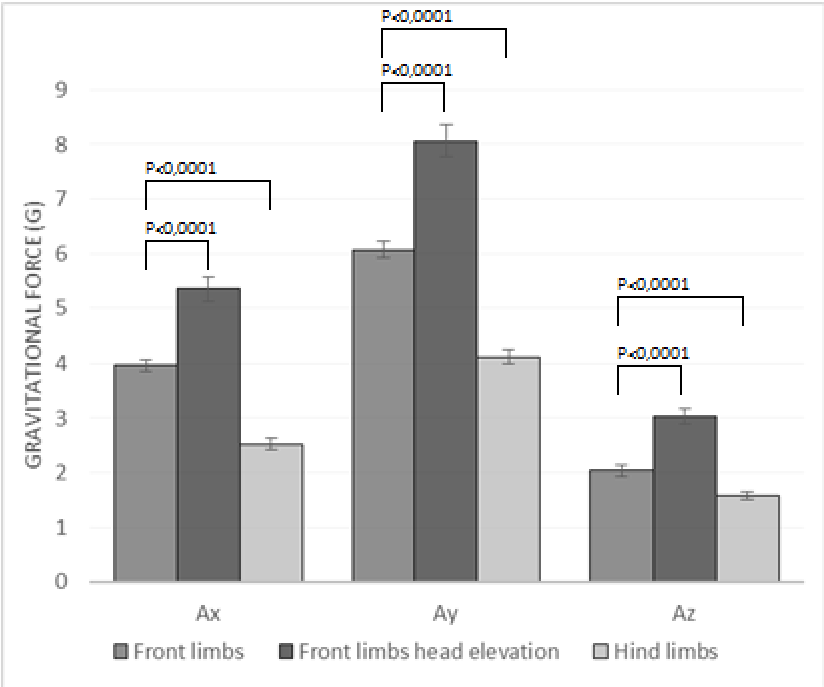
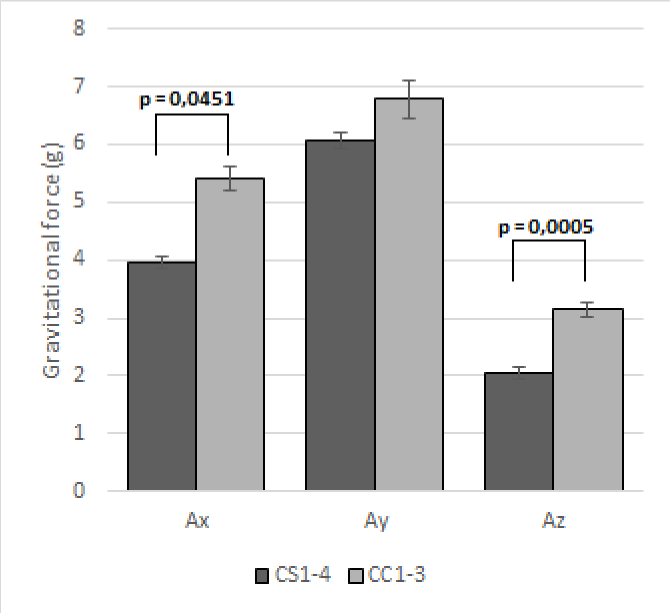


Figure 6: Mean distal limb acceleration (in g-force) for Ax, Ay and Az in CS1-4, comparison between front and hind limbs at a normal walk and changes in front limbs with head elevation.

CS1-4 compared to CC1-3

In both the front and hind limbs, the Ax and Az distal limb accelerations were significantly higher in CC1-3 when compared to CS1-4 see Figure 7 and Figure 8. There were no significant differences in stride duration or absolute swing phase when CC1-3 was compared to CS1-4. However, the relative duration of the swing phase was significantly higher in CC1-3 in both front and hind limbs (P>0,0001). The acceleration in the sacrum was significantly higher in CC1-3 when compared to CS1-4 (P=0,0235). In the CC1-3 the stride duration and absolute swing phase were significantly longer P<0,0001 and P=0,0004) during head elevation, while the relative swing phase did not change. In CS1-4, the relative swing phase did change when the head was elevated, as mentioned above. In both sound and ataxic horses, the Ay acceleration from the sacrum accelerometer did not change significantly following head elevation.



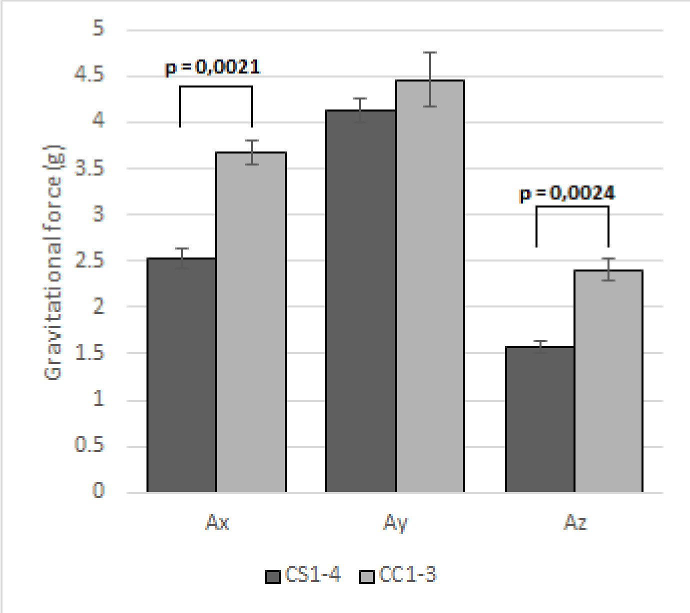


Figure 9: distal limb acceleration in front limbs (g-force), CS1-4 compared to CC1-3, significance shown

Figure 7: Figure 8: distal limb acceleration in hind limbs (g-force), CS1-4 compared to CC1-3, significance shown

The ventral stabilization surgery was successful in all four horses in group CS1-4. There were no complications that affected horse health or data collection. In CS1-4, no neurological signs were observed before or after surgery. However, it was found that all horses exhibited a reduced range of motion and increased stiffness in the neck post operatively. Occasionally data were not collected due to either malfunctioning of the accelerometers or failing to turn them on properly. When possible, the data collection was then repeated. The sacrum data for CS1 at 24 and 48 hours after surgery were not collected. For CS4, the baseline data for LF and LH was not collected. The baseline data for this horse was collected on the day of surgery, and the missing data were not noted until after surgery. The RH data for CS4 at one week after surgery is also missing. The LF distal limb acceleration data for CS3 was excluded, since a vibration rendered the range value not useable for analysis.

Post-surgery evaluation

In CS1-4, post-surgery data was compared to baseline. In the front limbs the mean distal limb acceleration for Ax was significantly different at 24hr (P >0,0001), 48hr (P=0,0038) and 1 week (P=0,0467) after surgery. For Ay, distal limb acceleration was significantly lower at 1 week after surgery (P<0,0001) and there were no significant changes in Az. In the hind limbs, no significant changes in distal limb acceleration was found, see **Fout! Verwijzingsbron niet gevonden.** . The distal limb acceleration for Ay from the sacrum accelerometer did not change significantly after surgery. In front and hind limbs combined, stride duration was significantly higher at one week after surgery (P=0,0013), as well as the absolute swing phase (P <0,0001). There was no significant difference in relative swing phase duration.

	Baseline	24 hours	48 hours	1 week
Front				
Ax	3,96	3,74*	3,65*	4,06*
Ay	6,07	6,29	6,14	5,87*
Az	2,04	2,48	2,00	2,66
Hind				
Ax	2,52	2,73	2,75	2,23
Ay	4,12	4,30	4,61	3,64
Az	1,57	1,80	1,95	1,31
Sacrum				
Ay	1,16	0,75	1,00	0,76

Table 1: Changes in mean distal limb and sacrum acceleration (in g-force), 24 hours, 48 hours and 1 week after surgery, compared to baseline. *=significant difference compared to baseline

Discussion

The objectives of this study were: (1) to objectively evaluate the gait in sound horses while walking normally and while walking with the head elevated with tria-axial accelerometers, (2) to compare distal limb and pelvic accelerations in sound and ataxic horses and (3) to objectively evaluate the gait in sound experimental horses before and up to one week after experimental cervical stabilization surgery. Our data suggests it is possible to differentiate between sound and ataxic horses using accelerometers placed on the sacrum, metacarpi and metatarsi. Also, we have discovered that there are quantifiable changes that occur in gait in both sound and ataxic horses when the head is elevated. Furthermore we found that some gait parameters changed within the first week of sound horses that underwent experimental ventral stabilization surgery.

When evaluating the sound horses at baseline, the distal limb acceleration for the front limb accelerometers were significantly higher when compared to the hind limbs. This shows that there is a difference in gait pattern between the front and hind limbs. In a previous kinematic study by Pourcelot et. al, it was found that there is a greater degree of symmetry in the front legs when compared to the hind legs when trotting. This was explained by the propulsive role of the hind legs as compared to the supportive role of the front limbs (31). In a pressure plate study a slightly lower symmetry was also found at walk in ponies (32). This difference in function of the thoracic vs. pelvic limbs may also explain the differences in distal limb accelerations that were found while walking the horses normally.

When the head was elevated, distal limb acceleration for Ax, Ay and Az increased significantly in both sound and ataxic horses at baseline in the front limbs This indicates a shorter or faster step. In a previous study by Nout-Lomas et al. it was shown that head elevation resulted in shorter, faster steps with a decreased stance phase in both sedated and control horses. (28) In a study by Waldern et. al, horses were walked and trotted on a treadmill with different head-neck positions. The head was positioned similar to our “head elevated” position, described as: “extreme high position and bridge of the nose considerably in front of the vertical”. In this position, walking speed and stride length decreased significantly. Using force plate data, it was also seen that the weight of the horse was shifted more to the back in this position. (33) When performing a neurological examination, lifting the head is often used to evaluate horses that are only mildly ataxic. When the head is elevated, visual input is altered making it more difficult for an ataxic horse to correct its gait. Clinically, the foot is held in the air longer and the steps are shorter. This phenomenon could explain the higher distal limb acceleration in ataxic and healthy horses at baseline.

Ataxic horses had higher distal limb acceleration for Ax and Az, which suggests more movement in the vertical and mediolateral plane. This is consistent with what we see clinically and is likely secondary to decreased proprioception. Ataxic horses also had a longer relative swing phase when compared to sound horses, which was also found in a previous study by Strobach et al (29). The acceleration for the sacrum accelerometer (Ay, which indicates lateral movement) was significantly higher in CC1-3 when compared to CS1-4. This indicates more lateral movement (truncal sway) in clinical cases, which is a common sign of spinal ataxia in horses (12). In clinical cases the stride duration increased, as well as the swing phase. The relative swing phase did not increase. This means that the steps were taken more slowly which could indicate that it is more difficult for the ataxic horse to place its limb while the head is elevated. In the sound horses, the stride duration did not increase. However, the relative swing phase did increase which was also found in the study by Nout-Lomas et al, where a shorter stance phase was found.(28) However, the study group was small and it would be interesting to further investigate this difference. The study group should then be expanded to include larger control and ataxic group sizes. These groups should be similar in age, breed and height to eliminate these influences.

After surgery the Ax distal limb acceleration decreased significantly at all time points. It is expected that the horses experienced some degree of neck pain due to the surgery, which likely affected gait. Neck pain may result in lifting the limbs less and walking slower than at baseline, which explains the lower values in vertical acceleration. Also, at 48hrs and 1 week after surgery, lateral movement (Ay distal limb acceleration) was significantly decreased, as well as absolute swing phase duration at one week after surgery. Again, generally slower movement due to mild discomfort on stiffness may account for this. It would be interesting to determine at what time point post operatively these changes would disappear and gait would be similar as at baseline using objective accelerometer measures.

For further research, it would be interesting to analyze the accelerometer data from this study more extensively. For example, using more advanced mathematical software such as “MATLAB” the symmetry and regularity can be calculated, as was previously done by López-Sanromán et al. These are more specific parameters that can be used as a measure of coordination. Future studies could be performed in which repeatability could be increased by standardizing the walking speed. Also, further work using more horses should be performed to confirm findings of this study that was conducting using a relatively low sample size.

Conclusion

Using tri-axial accelerometers we could effectively differentiate between sound and ataxic horses. Ataxic horses had a shorter stance phase when compared to sound horses, as well as higher distal limb acceleration in the mediolateral and vertical planes. When both sound and ataxic horses were walked with an elevated head, their gait pattern changed significantly. One week after surgery, the experimental horses had lower distal limb acceleration; this could likely be explained by mild postoperative pain or stiffness in this immediate postoperative period.

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