Is a single force plate adequate for stabilographic analysis in horses?

H. M. CLAYTON* and S. NAUWELAERTS

Department of Large Animal Clinical Sciences, Mary Anne McPhail Equine Performance Center, College of Veterinary Medicine, Michigan State University, East Lansing, USA.

*Correspondence email: claytonh@cvm.msu.edu; Received: 05.01.11; Accepted: 22.06.11

Summary

Reasons for performing study: Postural balance can be quantified using stabilographic variables derived from force plate data that describe movements of the horse’s centre of pressure (COP) in the horizontal plane. Most force plates are not large enough to accommodate all 4 limbs of a standing horse, so the study was designed to assess whether representative stabilographic data could be collected from the forelimbs or hindlimbs.

Objective: To determine whether stabilographic data from either the forelimbs or the hindlimbs were representative of data for the total body.

Methods: Stabilographic data (960 Hz) were collected from 17 sound horses standing with the forelimbs and the hindlimbs on separate force plates. To increase variability in the data, horses were of different sizes, the recording duration was varied (15–60 s) and data were collected under sighted and blindfolded conditions.

Results: Correlation matrices indicated that total body stabilographic variables were highly significantly correlated with both forelimb and hindlimb data but correlation coefficients were higher for forelimb data. Forward stepwise regression selected forelimb data for inclusion in the model for 15/16 variables, the exception being mean absolute mediolateral velocity.

Conclusions: Ground reaction force data from a pair of limbs, preferably the forelimbs, can be used to measure variables that represent total body postural balance in sound standing horses.

Potential relevance: Stabilographic data from either the forelimbs or hindlimbs may be useful for detecting and quantifying deficiencies in postural balance in ataxic horses.

Keywords: horse; force plate; ground reaction force; centre of pressure; stabilogram; stabilographic variables

Introduction

A standing horse maintains balance by keeping the centre of mass vertically above the base of support [1]. The position of the centre of mass is not stationary, however, as the body continually undergoes slight movements that are known as postural sway [2]. The destabilising forces responsible for postural sway are countered by the horse’s postural control system, which generates muscular activity to adjust the ground reaction forces. The summation of the ground reaction forces on all hooves acts at the centre of pressure (COP) and movements of the COP are indicative of postural control activity [3]. Movements of the COP can be displayed graphically as a stabilogram that shows the path of the COP in the horizontal plane and they can be quantified by stabilographic variables derived from motion of the COP [4].

Mechanical static equilibrium is the state in which the sum of the forces and torques on each particle of the body is zero. An animal’s ability to maintain its equilibrium or balance is critically important during standing and during locomotion. In man, ataxia has been shown to be associated with changes in the stabilographic variables and stabilography is used clinically in the diagnosis and monitoring of conditions such as vestibular deficiencies [5], Parkinson’s disease [6] and cerebral palsy [7]. Stabilographic measurements derived from horses standing with all 4 hooves on a single force plate have been shown to provide reliable data for quantifying movements of the COP in the standing horse [4] and this technique has been applied to measure balance disturbance following the administration of detomidine [8]. Stabilography has the potential to quantify disturbances of balance and preliminary data have shown increased amplitude of stabilographic variables in horses with cervical stenotic myelopathy [9]. Stabilography may have clinical applications since mild ataxia is notoriously difficult to diagnose and to differentiate from mild lameness [10].

One of the drawbacks to the further development of diagnostic stabilography in equine medicine is the large size of a horse’s base of support, which often exceeds the dimensions of force plates currently manufactured for equine use (60 × 60 cm; 60 × 90 cm; 60 × 120 cm). Even the largest of these force plates can only comfortably accommodate all 4 hooves of a small horse. One solution to this problem is to use synchronised data from multiple force plates to assess total body COP motion, but the availability of multiple force plates assembled in a suitable configuration for this type of analysis is confined to a small number of gait laboratories. However, many institutions have a single force plate that is large enough to accommodate a contralateral (fore or hind) pair of hooves during standing. The purpose of this study, therefore, was to investigate the possibility of obtaining representative values of total body COP variables using stabilographic data from a fore or hind pair of limbs. This is regarded as an important step toward developing stabilography as a practical tool for the detection of ataxia in horses.

Materials and methods

Since the purpose of the study was to test whether variation in stabilographic variables could be captured using data from one pair of limbs rather than all 4 limbs, it was important to collect data with high variability. This was achieved by using subjects of different sizes and by collecting data for different durations and under different visual conditions. The subjects were 17 nonlame horses and 82 trials were analysed. The horses were of a variety of breeds and they varied widely in height (range: 93–161 cm; mean ± s.d. 146 ± 17 cm), mass (range: 117–594 kg; mean ± s.d. 442 ± 109 kg) and age (range: 1–18 years; mean ± s.d. 9 ± 6 years).

Two 60 × 90 cm force plates (FP6090 Force Plate) with 900 kg load capacity were precisely aligned in a custom frame with their short sides separated by a distance of 0.046 m. Each force plate had a 16-bit digital internal amplifier, with embedded calibration information to reduce cross-talk between channels. Force data were recorded at 960 Hz and transmitted via an analogue amplifier (AM6800 Amplifier) into a DAQ board (SCB-100) [10].

Horses stood with the fore hooves on one force plate and the hind hooves on the other, with the sagittal plane of the horse’s body aligned along the longitudinal axes of the force plates. The fore and hind hoof pairs were offset by no more than 10 cm in a cranio-caudal direction since foot placement may affect the postural sway characteristics [11]. The behaviour and movements of the horse were observed throughout the trials. Force recordings started when the horses were standing without visible motion and continued until visible movement occurred or until 60 s had elapsed.
whichever occurred sooner. The handler had no physical contact with the horse during the recording period. Data were collected sighted and blindfolded but, for the purposes of this study, the 2 conditions were not distinguished.

The fore- and hindlimb COPs were represented by the total vertical force and its COP on the 2 force plates, which were aligned in the y direction and separated by a gap of 0.046 m in the x direction. The total body COP was determined from the coordinates of the fore- and hindlimb COPs, weighted according to the magnitude of the vertical force on each force plate. The x and y coordinates of the total body COP were calculated as follows:

\[ F_{z} = F_{z1} + F_{z2}; \]
\[ \text{COP}_x = \left( F_{z1} \times [0.046 - \text{COP}_x1] + F_{z2} \times [0.046 + \text{COP}_x2] \right) / F_{z} \]
\[ \text{COP}_y = \left( F_{z1} \times \text{COP}_y1 + F_{z2} \times \text{COP}_y2 \right) / F_{z} \]

where \( F_{z1} \) and \( F_{z2} \) are the vertical forces on force Plates 1 and 2 respectively; \( \text{COP}_x1, \text{COP}_y1 \) are the coordinates of the COP on force Plate 1; \( \text{COP}_x2, \text{COP}_y2 \) are the coordinates of the COP on force Plate 2.

The following stabilographic variables were calculated.

- Cranio-caudal COP amplitude: range of motion along the longitudinal axis calculated as the difference between the maximal and minimal coordinate values.
- Mediolateral COP amplitude: range of motion along the transverse axis calculated as the difference between the maximal and minimal coordinate values.
- Resultant COP absolute velocity: the magnitude and direction of the COP velocity were determined from the time derivative of the displacement between successive pairs of data points. The resultant COP absolute velocity was the mean of the absolute values of the velocities for each successive pair of data points throughout the trial.
- Mean absolute cranio-caudal COP velocity: mean of the longitudinal components of the absolute COP velocities between successive pairs of data points.
- Mean absolute mediolateral COP velocity: mean of the mediolateral components of the absolute COP velocities between successive pairs of data points.
- Planar deviation: square root of the sum of the variances of displacements in the mediolateral and cranio-caudal directions.
- Total path length: summation of COP displacements between successive data points throughout the trial.
- Radial distance: mean of the distances from the centroid of the stabilogram to each data point.
- Mean power frequency: determined by Fast Fourier transformation of the cranio-caudal and mediolateral displacement data.

Descriptive statistics (mean ± s.d.) were calculated for the stabilographic variables from the dual force plate system (total body) and for each force plate individually (forelimb, hindlimb). The Pearson correlation coefficient was used to seek correlations between stabilographic variables measured for the total body and the same variables measured concurrently for the forelimbs or for the hindlimbs. Significant correlations were detected using a probability of P<0.05. Forward stepwise regression with probability of entry 0.05 and probability of removal 0.1 was used to select whether forelimb data or hindlimb data were more representative of total body values for each variable.

### Results

Mean values and s.d. of the stabilographic variables for the total body, the forelimbs and the hindlimbs are shown in Table 1. Since the objective of this study was to seek correlations between the conditions rather than to compare their values, it is not relevant to make statistical comparisons of the mean values across the 3 conditions. Figure 1 is a graphic illustration of the cranio-caudal displacement of the COP, the mediolateral displacement of the COP, and stabilogram (below) for a single trial of 30 s duration.

![Graphical illustration of stabilogram and displacement](image)

**TABLE 1:** Mean value and s.d. of stabilographic variables recorded using data from all 4 limbs (total body), from the forelimbs only or from the hindlimbs only

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total body (Mean ± s.d.)</th>
<th>Forelimbs (Mean ± s.d.)</th>
<th>Hindlimbs (Mean ± s.d.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC amplitude (mm)*</td>
<td>1.5 ± 1.5</td>
<td>1.8 ± 2.3</td>
<td>1.7 ± 1.7</td>
</tr>
<tr>
<td>ML amplitude (mm)</td>
<td>2.9 ± 1.7</td>
<td>4.4 ± 2.8</td>
<td>2.6 ± 2.2</td>
</tr>
<tr>
<td>s.d. CC amplitude (mm)*</td>
<td>0.3 ± 0.2</td>
<td>0.4 ± 0.5</td>
<td>0.5 ± 0.2</td>
</tr>
<tr>
<td>s.d. ML amplitude (mm)</td>
<td>0.6 ± 0.3</td>
<td>0.9 ± 0.5</td>
<td>0.4 ± 0.3</td>
</tr>
<tr>
<td>Planar deviation (mm)*</td>
<td>0.3 ± 0.2</td>
<td>0.5 ± 0.3</td>
<td>0.3 ± 0.2</td>
</tr>
<tr>
<td>Total path length (mm)</td>
<td>27.5 ± 24.1</td>
<td>28.1 ± 18.8</td>
<td>27.8 ± 21.3</td>
</tr>
<tr>
<td>Mean CC velocity (mm/s)</td>
<td>0.3 ± 0.3</td>
<td>0.2 ± 0.2</td>
<td>0.3 ± 0.2</td>
</tr>
<tr>
<td>Mean ML velocity (mm/s)</td>
<td>0.4 ± 0.2</td>
<td>0.5 ± 0.2</td>
<td>0.4 ± 0.3</td>
</tr>
<tr>
<td>Mean resultant velocity (mm/s)</td>
<td>0.6 ± 0.4</td>
<td>0.6 ± 0.3</td>
<td>0.6 ± 0.3</td>
</tr>
<tr>
<td>s.d. CC velocity (mm/s)*</td>
<td>0.6 ± 0.8</td>
<td>0.4 ± 0.6</td>
<td>0.5 ± 0.4</td>
</tr>
<tr>
<td>s.d. ML velocity (mm/s)*</td>
<td>0.6 ± 0.4</td>
<td>0.8 ± 0.5</td>
<td>0.7 ± 0.6</td>
</tr>
<tr>
<td>s.d. resultant velocity (mm/s)*</td>
<td>0.7 ± 0.8</td>
<td>0.7 ± 0.7</td>
<td>0.6 ± 0.6</td>
</tr>
<tr>
<td>Mean radial distance (mm)</td>
<td>0.5 ± 0.3</td>
<td>0.8 ± 0.5</td>
<td>0.4 ± 0.2</td>
</tr>
<tr>
<td>s.d. radial distance (mm)</td>
<td>0.4 ± 0.2</td>
<td>0.6 ± 0.4</td>
<td>0.3 ± 0.3</td>
</tr>
<tr>
<td>Mean CC power frequency (Hz)*</td>
<td>0.39 ± 0.16</td>
<td>0.32 ± 0.12</td>
<td>0.27 ± 0.41</td>
</tr>
<tr>
<td>Mean ML power frequency (Hz)</td>
<td>0.18 ± 0.13</td>
<td>0.17 ± 0.15</td>
<td>0.26 ± 0.24</td>
</tr>
</tbody>
</table>

CC: cranio-caudal; ML: mediolateral. *Indicates variables that are not normally distributed.

the forelimbs as being more representative of total body COP for all variables except mean absolute mediolateral velocity for which the hindlimb data were more representative than the forelimb data. Figure 2 illustrates the higher correlation coefficient for the variable planar deviation between the values for total body and forelimb (r = 0.953) compared with total body and hindlimb (r = 0.513). Lines of perfect agreement are included on the graph to emphasise the greater scatter of the hindlimb points.

### Discussion

The findings of this study indicate that COP variables derived from the forelimbs or from the hindlimbs are representative of total body stabilograpy. However, the correlation coefficients were higher for the forelimbs and stepwise regression selected the forelimb data for the majority of variables, indicating that forelimb data capture more of the variability than hindlimb data. These findings suggest that bilateral limb stabilograpy should be investigated further as a tool to study postural balance and as a potential diagnostic test for ataxia in horses.

Since the objective of this study was to determine whether data from the fore- and/or hindlimbs could capture the variability inherent in total body COP data, it was important to collect data that showed high variability between horses. It should be noted, however, that within each horse, data for the total body, forelimbs and hindlimbs were collected under identical conditions. To achieve high interhorse variability, this study used horses of different sizes, collected data under different conditions (sighted and blindfolded) and used trials of different durations. The variability in the resulting data is apparent from the high standard deviations (Table 1). On the contrary, if stabilograpy is to be used as a clinical tool, variability in the data should be reduced to facilitate comparisons with normative values. This can be achieved by standardising the data collection time and by analysing sighted and blindfolded conditions separately. It is recommended that a standard procedure should be established with the goals of making data collection quick and easy and to facilitate evaluation of the results. In the present study, analysis was limited to segments of data in which the head and neck did not move visibly. For the further development...
Single force plate stabilography

H. M. Clayton and S. Nauwelaerts

horses in the previous study (height: 1.43 m; mass: 337 kg; laboratory) suggest that horses with other neurological diseases also have relatively quickly and easily.

Stabilography represents a simple method of analysing postural balance that may be useful for detecting balance disturbances in ataxic horses. It has advantages over locomotor techniques in that, since horses are required to stand still during collection of stabilographic data since movement of the limbs, head or neck may affect the values of the COP variables. In previous studies \[4,8\], kinematic analysis was used to screen the trials and select segments of data that were suitable for COP analysis based on absence of visible movement of markers on the hoof, head or neck. In the study reported here, careful visual observation during data collection was adequate to screen out times when the horse was moving, thus dispensing with the need for kinematic analysis. If necessary, real-time visualisation could be augmented by a video recording for review during post processing.

Trial duration should be standardised in a clinical setting to reduce variability between trials. Longer recording times tend to capture a larger range of COP motion with consequent increases in amplitudes of COP motion. The recording time represents a compromise between the need for a sufficiently long collection time to gather representative data vs. the challenge of having horses stand still for a prolonged period. In the present study, the minimal data recording period was 15 s, indicating that all horses were willing to stand in a stationary position for at least this length of time. Further studies are needed to establish the minimal and ideal recording times for each variable.

Even though stabilography is widely used in human medicine as an aid in the diagnosis of a variety of neurological diseases \[5–7\], the potential diagnostic value in veterinary medicine remains largely unexplored. In horses, it is often difficult to distinguish mild ataxia from mild lameness \[8,10\]. Previous studies indicate that it is possible to detect and quantify balance disturbances using modern techniques in gait analysis. Kinematic data for the walk can distinguish horses with spinal ataxia \[12\] and mediolateral ground reaction forces at trot can detect horses with hindlimb ataxia \[10\]. Stabilography represents a simple method of analysing postural balance that may be useful for detecting balance disturbances in ataxic horses. It has advantages over locomotor techniques in that, since horses are evaluated while standing still, there is no need to control speed or path of motion during data collection and the analysis can be completed relatively quickly and easily.

Preliminary stabilographic studies showed that horses with cervical stenotic myelopathy had significant increases in craniocaudal COP range of motion, mediolateral COP range of motion, absolute COP velocity and COP radius, compared with normal horses \[9\]. Unpublished data from our laboratory suggest that horses with other neurological diseases also have

A previous study \[4\] confirmed the reliability of COP variables measured with 4 limbs on the force plate within and across days and showed small agreement boundaries for absolute COP velocity (±3.0 mm/s), craniocaudal range of COP motion (±4.0 mm), mediolateral range of COP motion (±8.0 mm) and COP radius (±2.0 mm). The values presented here are larger for all variables than those reported previously, which is probably due to the longer duration of data collection, which was up to 60 s in this study compared with only 10 s in the previous study. The smaller size of the horses in the previous study (height: 1.43 ± 0.05 m; mass: 337 ± 16 kg) is unlikely to be the source of the difference since COP variables do not appear to be affected by the horse’s height, mass or dimensions of the base of support \[4,8\].

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increased values of stabilographic variables and that lame horses may have a different pattern and frequency of COP movements than horses with ataxia. Before stabilography can be adopted as a diagnostic technique, more research is needed to determine the optimal conditions under which to record stabilographic data. However, the results reported here indicate that further investigations are warranted.

In conclusion, this study has shown that valid and representative stabilographic data can be obtained from horses standing with both forelimbs or both hindlimbs on a single force plate. Forelimb COP data are more highly correlated with total body COP data and so may be more suitable for diagnostic testing. Stabilography may be a useful technique for detecting ataxia and for differentiating ataxia from lameness. Future research should focus on standardising the testing protocol and determining which COP variables are the best indicators of ataxia or lameness.

**Authors’ declaration of interests**

No conflicts of interests have been declared.

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**Manufacturers’ addresses**

* Bertec Corporation, Columbus, Ohio, USA.
* National Instruments Corporation, Austin, Texas, USA.

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