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Effect of blindfolding on centre of pressure variables in healthy horses during quiet standing

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ABSTRACT

In a standing horse the centre of pressure (COP), measured as the resultant vertical ground reaction force (GRF) of all supporting limbs, is adjusted in response to visual, vestibular and proprioceptive information. Stabilographic analysis measures balance by tracking COP movements in the horizontal plane. Loss of visual input affects stability of balance in people and has clinical implications in that instability inherent in some neurological diseases increases with the eyes closed. The objectives of this study were to evaluate the visual contribution to postural stability in horses. The hypothesis was that the magnitude and variability of postural sway variables increases when visual input is removed. Vertical GRFs were measured using two synchronized force plates and COP movements were tracked in 20 horses as they stood without visible movements of the hooves, head or neck. Three trials of 60 s duration were recorded under sighted and blindfolded conditions. Stabilographic variables (craniocaudal and mediolateral COP amplitudes, velocities and mean power frequencies and their within-trial variabilities) were calculated and compared using univariate analysis of variance.

Compared with the sighted condition, blindfolding increased the magnitude and the within-trial variability of craniocaudal and mediolateral COP amplitudes and mediolateral COP velocity. The findings indicated that loss of visual input had more effect on the measured COP variables in the time domain (amplitudes, velocities) than in the frequency domain (mean power frequency). The effects of blindfolding on postural stability should be further investigated as part of a diagnostic approach to the evaluation of balance in horses with neurological impairment.

Introduction

The horse maintains balance during quiet standing by keeping the body's centre of mass (COM) vertically above the base of support (van Røgind et al., 2003). However, the COM is not absolutely stationary and shows small movements that are monitored by input from three sensory systems, namely, proprioceptive, visual and vestibular. Afferent information is processed by the nervous system which directs the neuromuscular response of the postural control system (Pavol, 2005). The response involves muscular contractions that change the forces beneath the feet causing movements of the COM that keep it safely within the base of support. The effects of these corrective muscular activations can be measured by changes in the vertical ground reaction forces (GRFvert) and their effects quantified by movements of the centre of pressure (COP), which is defined as the centroid of the GRFvert distribution projected onto the horizontal plane (Benda et al., 1994). Postural balance is mapped and quantified by tracking COP movements in the horizontal plane (Winter, 1990) in a procedure known as stabilography.

In the equine gait laboratory, COP position and movements can be determined from GRFvert data recorded synchronously from all weight-bearing limbs using one or more force plates. A number of stabilographic variables may be derived that quantify COP movements over time. Previous studies have validated the use of a force plate for measuring postural balance in horses (Clayton et al., 2003) and have shown that COP amplitudes, velocities and frequencies in the craniocaudal (CC) and mediolateral (ML) directions represent >91% of the variability in sway patterns (Clayton et al., 2013). Stabilography has been applied to determine the duration of balance disturbance following sedation with detomidine (Bialski et al., 2004) and in a preliminary study that measured differences in stabilographic variables between normal horses and those with neurological disorders (Clayton et al., 1999). It has also been used to compare the effects of land-based and underwater treadmills in rehabilitating horses with carpal osteoarthritis (King et al., 2013).

In veterinary medicine, the use of stabilography as a diagnostic tool has remained largely unexplored. In people, stabilogram amplitudes have been observed to increase with pathology (e.g.

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Roerdink et al., 2006), age (Melzer et al., 2001) and when attention is focused on a secondary task (Donker et al., 2007). Stabilography is applied in the diagnosis of several conditions that impair balance including cerebellar diseases (Diener et al., 1984), vestibular deficiencies (Norré and Forrez, 1986) and back pain (Byl and Sinnott, 1991). These findings raise the possibility of using force plate measurements and stabilographic analysis diagnostically to detect equine balance disorders and to differentiate horses with mild neurological disease from horses with mild lameness, which can pose a diagnostic dilemma (Bialski et al., 2004; Ishihara et al., 2009). Interestingly, people with borderline abnormal neurological examinations have been shown to lose their balance when the peripheral visual field is occluded (Manchester et al., 1989). It is not known whether blindfolding interferes with balance in normal horses or if visual loss exacerbates balance deficits associated with equine neurological diseases.

As a first step towards evaluating the effect of visual deprivation in horses with neurological diseases, the goal of this study was to test the effects of blindfolding on the postural balance of sound, healthy horses by measuring and comparing stabilographic variables when horses were sighted and blindfolded. We hypothesized that removal of visual input by blindfolding would increase the magnitude and variability of COP amplitudes, velocities and mean power frequencies in the CC and ML directions.

Materials and methods

The protocol used in this study was approved by the institutional animal care and use committee (approval number 11/08-170-00).

Horses

The subjects were 20 privately owned horses of a variety of breeds and conformational types (mean ± SD: age 10.3 ± 0.7 years; height: 1.50 ± 0.02 m; mass: 470 ± 17 kg) that had received regular hoof trimming and dental care. None of the horses showed signs of lameness or neurological impairment and none had a history of neurological disease. Reflective 6 mm markers were attached to the mid-lateral wall of each hoof, the middle of the forehead, the highest point of the withers and the middle of the croup between the left and right sacral tuberosities. The horses stood in a comfortable position with the limbs vertical and contralateral hoof pairs offset by no more than 10 cm in the craniocaudal direction. The hoof marker coordinates were used to determine base of support (BOS) length as the average distance between the ipsilateral pairs of front and hind limbs and BOS width as the average distance between the contralateral pairs of right and left limbs.

Data collection

The location of the horse's COP was determined based on GRFvert recorded synchronously at a sampling rate of 960 Hz from two 60 × 90 cm force plates (FP6090 Force Plate, Bertec Corporation) each of which had 900 kg load capacity. The force plates were aligned precisely and mounted in a custom frame with their short sides separated by a distance of 4.6 cm (Fig. 1). Each force plate had a 16-bit digital internal amplifier, with embedded calibration information to reduce cross-talk between channels. The force plates were connected to an analog amplifier (AM6800 Amplifier, Bertec Corporation) that fed into a DAQ board (SCB-100, National Instruments Corporation).

The markers on the horse were tracked by an eight camera motion capture system (Motion Analysis System, Motion Analysis Corporation) recording at 60 Hz and synchronized with the analog data from the two force plates (Evart 5.0.4, Motion Analysis Corporation). The kinematic data were collected in the same coordinate system as the force plate by placing the calibration frame of the motion capture system in the corner of one of the force plates.

During data collection the horses stood with their CC axis aligned with the longitudinal axis of the force plate coordinate system, with the fore hooves and hind hooves on separate force plates. The handler led the horse onto the force plates and halted it in a straight and square position as described above. During data collection the handler stood close to (but not in physical contact with) the horse to discourage movement. Visual input was removed using a full blinder hood with plastic eye cups that was put on after the horse was already standing comfortably on the force plates. The sighted and blindfolded conditions were evaluated in random order with the horse standing in a similar position for all trials. Three trials of 60 s duration were recorded for the sighted and blindfolded conditions. Trials were discarded immediately if the limbs or the head and neck were observed to move during the trial. If the limbs moved, the horse was walked off the force plates then repositioned on the force plates as described above.

Fig. 1. Horse standing on the two force plate system with forelimbs and hind limbs on separate force plates. Note that the handler did not have physical contact with the horse during data collection.

Data analysis

Prior to analysis of the stabilographic data, the kinematic data were screened and trimmed to remove segments that showed movement of the hoof markers or if the head marker moved outside a 5 cm × 5 cm × 5 cm volume that was centred around the position of the head marker at the start of the trial. From segments of data that fulfilled these conditions, the first 15 s of each trial was analyzed.

Custom software (Matlab, Mathworks) was used to calculate movements of the COP of the resultant GRFvert of the two force plate combination. The results were displayed in a stabilogram with its origin defined as the mean value of all data points in CC and ML directions. Craniocaudal and ML amplitudes were determined as the differences between maximal and minimal values of COP position in the two directions. Craniocaudal and ML velocities were calculated as the magnitude of the time derivative of the displacement between successive pairs of data points in CC and ML directions averaged over the 15 s trial. In addition, the within trial SD of the mean was calculated for the amplitude and velocity variables. Mean CC and ML frequencies were determined by Fast Fourier transformation of the COP signal followed by mean power frequency analysis. The mean power frequency is an average of frequencies weighted by the power in each.

All statistical tests were performed in statistics software (SPSS v20) with a probability of $P < 0.05$. Mean values ± standard error (SE) were calculated for all variables under sighted and blindfolded conditions. Differences in stabilographic variables between the two visual conditions were sought using a mixed effects ANOVA with horse as a fixed factor and visual condition as a random effect.

Results

Compared with the sighted condition, CC amplitude, ML amplitude and ML velocity increased and showed greater within-trial variability when horses were blindfolded (Table 1). Fig. 2 shows typical stabilograms for the sighted and blindfolded conditions. Some horses were reluctant to stand still when wearing a blindfold which made it more difficult to obtain trials of a sufficient duration for the blindfolded condition. The graph of CC and ML power density against frequency (Fig. 3) shows that almost all of the power is contained in low frequencies <0.5 Hz for both sighted and blindfolded conditions.