Center-of-Pressure Movements During Equine-Assisted Activities

Hilary M. Clayton, LeeAnn J. Kaiser, Bonnie de Pue, Lana Kaiser

KEY WORDS
- cerebral palsy
- equine-assisted therapy
- motion
- postural balance
- pressure

We compared anteroposterior and mediolateral range of motion and velocity of the center of pressure (COP) on the horse's back between riders without disabilities and riders with cerebral palsy. An electronic pressure mat was used to track COP movements beneath the saddle in 4 riders without disabilities and 4 riders with cerebral palsy. Comparisons between rider groups were made using the Mann–Whitney test ($p < .05$). The two rider groups differed significantly in anteroposterior range of COP motion, mediolateral range of COP motion, and mediolateral COP velocity. Anteroposterior COP velocity did not differ between groups. The results suggest that measurements of COP range of motion and velocity are potentially useful for monitoring changes in balance as an indicator of core stability during equine-assisted activities.

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Hilary M. Clayton, PhD, DACVSMR, MRCVS, is Mary Anne McPhail Dressage Chair in Equine Sports Medicine and Professor of Large Animal Clinical Sciences, Mary Anne McPhail Equine Performance Center, Department of Large Animal Clinical Sciences, College of Veterinary Medicine, Michigan State University, East Lansing, MI 48824; claytonh@cvm.msu.edu

LeeAnn J. Kaiser, MS, is Laboratory Manager, Mary Anne McPhail Equine Performance Center, Department of Large Animal Clinical Sciences, College of Veterinary Medicine, Michigan State University, East Lansing.

Bonnie de Pue, OTR, is President, Children and Horses United in Movement (C.H.U.M.) Therapeutic Riding, Dansville, MI.

Lana Kaiser, MD, DVM, is Professor of Nursing and Medicine, Department of Medicine, College of Human Medicine, Michigan State University, East Lansing.

Equestrian sports require the ability to stabilize the rider's trunk in the face of perturbations provided by translations and rotations of the horse's body. Because the three-dimensional movements of the horse's back resemble those of human gait (Riede, 1988), riding provides people with cerebral palsy with a novel sensorimotor experience that simulates pelvic motion during ambulation.

The term *cerebral palsy* is used to describe a group of permanent disorders of the development of movement and posture that cause activity limitation and that are attributed to nonprogressive disturbances that occurred in the developing fetal or infant brain (Rosenbaum et al., 2007). The Gross Motor Function Classification System (GMFCS; Palisano et al., 1997) is a method of grading the severity of impairment of people with cerebral palsy. Grades I and II include people who are able to walk without assistance, whereas people in Grades III–V have increasingly limited self-mobility. People who are more severely affected may also lack strength in their core musculature and, consequently, have poor control of their trunk movements.

The rhythmic movements of the horse during equine-assisted activities are thought to improve co-contraction, joint stability, weight shift, and postural and equilibrium responses in people with cerebral palsy (Bertoti, 1988). The responses to therapeutic riding have been reported to include improvements in standing posture (Bertoti, 1988); in the walking, running, and jumping scores on the GMFCS Dimension E (McGibbon, Andrade, Widener & Cintas, 1998); and in dynamic postural stabilization, the ability to recover from perturbations, and anticipatory and feedback postural control (Sterba, 2007). Moreover, beneficial changes in trunk and head stability and reaching and targeting recorded after a 12-wk course of therapy were retained for at least 12 wk (Shurtleff, Standeven, & Engsberg, 2009).

The GMFCS has proven to be a valid and reliable method of classifying people with cerebral palsy on the basis of their mobility, but the grading criteria used are not related specifically to activities that would be expected to improve in response to therapeutic riding. Other methods of measuring the response to therapeutic riding in a manner that is both standardized and specific to the task should be developed (Pauw, 2000). In this study, we investigated the potential value of one such method that

Table 1. Rider Characteristics

Rider	Age (yr)	Height (cm)	Mass (kg)	Sex	Riding (yr)	Disability	GMFCS (level)
A1	22	161	69	F	19	None	N/A
A2	18	160	70	F	10	None	N/A
A3	18	137	58	F	10	None	N/A
A4	47	168	88	F	40	None	N/A
CP1	13	121	28	F	5	Spastic CP	IV
CP2	9	137	24	F	5	Athetoid CP	V
CP3	26	168	47	M	10	Spastic CP	IV
CP4	30	122	34	M	10	Spastic CP	V

Note. A = able bodied; CP = cerebral palsy; F = female; GMFCS = Gross Motor Function Classification System; M = male; N/A = not available.

uses a pressure mat to measure the forces acting on the horse's back and to track movements of the center of pressure (COP) during riding. The COP represents the point at which the total force transmitted through the saddle to the horse's back can be considered to act. The position of the COP is calculated from the magnitude and distribution of the forces applied to the pressure mat. Movements of the COP can be tracked, and variables describing the displacement and velocity of the COP can be calculated. These variables reflect movements of the rider's trunk. Comparison of COP variables between riders may reflect differences in core stability.

During horseback riding, COP variables are measured using a multisensor electronic pressure mat placed between the saddle and the horse's back to measure forces transmitted through the saddle. The forces exerted on the 256 sensors are used to locate and track movements of the COP dynamically (Freuhwirth, Peham, Scheidl, & Schobesberger, 2004). In experienced riders, the COP follows a characteristic path during a complete stride at each gait (Fruehwirth et al., 2004). One of the rider's goals is to control his or her body movements so that excursions of the COP are minimized, which facilitates the horse's balance and reduces energy expenditure by the horse (Sloet van Oldruitenborgh-Oosterbaan, Barneveld, & Schamhardt, 1996). The rider's ability to control COP motion depends on the rider's having sufficient strength in the core musculature to control trunk movements in the face of perturbations induced by the horse's motion, combined with a learning effect that allows the more experienced rider to further reduce COP motion by pretensioning the muscles in anticipation of the rhythmic movements of the horse (Pantall, Barton, & Collins, 2009; Terada, Mullineaux, Kiyotada, & Clayton, 2004).

Aim

The aim of the study was to record and compare COP motion in riders without disabilities and riders with cerebral palsy, all of whom participate regularly in a therapeutic riding program. The experimental hypotheses were that riders with cerebral palsy would have larger ranges of COP motion and faster COP velocities in the anteroposterior (AP) and mediolateral (ML) directions than riders without disabilities.

Table 2. Mean Values ± Standard Deviations for Range of Motion and Average Velocity of the Rider's Center of Pressure in Riders Without Disabilities and Riders With Cerebral Palsy During Horseback Riding at the Walk

Variable	Riders Without Disabilities (n = 4)	Riders With Cerebral Palsy (n = 4)
Anteroposterior range of motion (mm)	61.6* ± 20.6	111.5* ± 53.8
Mediolateral range of motion (mm)	35.5* ± 5.0	49.9* ± 5.4
Anteroposterior velocity (mm/s)	191.8 ± 59.1	320.1 ± 159.6
Mediolateral velocity (mm/s)	69.3* ± 7.4	103.5* ± 13.2

*Indicate values that differ significantly between groups ($p < .05$).

Method

The study was performed with exemption approval by the institutional animal care and use committee and the committee on research involving human participants.

Participants

All riders rode the same horse, a 15-yr-old Mustang gelding (height = 1.40 m, mass = 422 kg) that is used regularly in a therapeutic riding program. The horse was ridden in an English hunt seat saddle, which did not have any special supporting structures. Two groups of riders were evaluated: 4 riders without disabilities (A1–A4) and 4 riders with cerebral palsy (CP1–CP4). Participants with cerebral palsy were selected on the basis of being classified as GMFCS Level IV or V by an experienced occupational therapist (Table 1) and having at least 5 yr of equestrian experience through regular participation in a therapeutic riding program (Children and Horses United in Movement [C.H.U.M.] Therapeutic Riding, Dansville, MI). The control participants were people without disabilities who had several years experience in the same therapeutic riding program. All riders were familiar with the horse and equipment used in the study.

Protocol

Each rider rode at walk in a 20-m × 40-m indoor arena for 4 min, with the horse being led by an assistant. For the riders with cerebral palsy, side walkers walked beside the horse on the left and right sides. The side walkers were instructed to support the rider only when there was a loss of balance. Data were collected over 2 days to avoid fatiguing the horse.

An electronic pressure mat (Pliance Saddle System, Novel GmbH, Germany) was used to track movements of the rider's COP on the basis of the force distribution beneath the saddle. The pressure mat has 256 individual sensors, each measuring 9.375 cm^2, arranged in 8 columns and 16 rows on the left and right sides of the horse's back. Before the start of data collection each day, the pressure mat was calibrated according to the manufacturer's

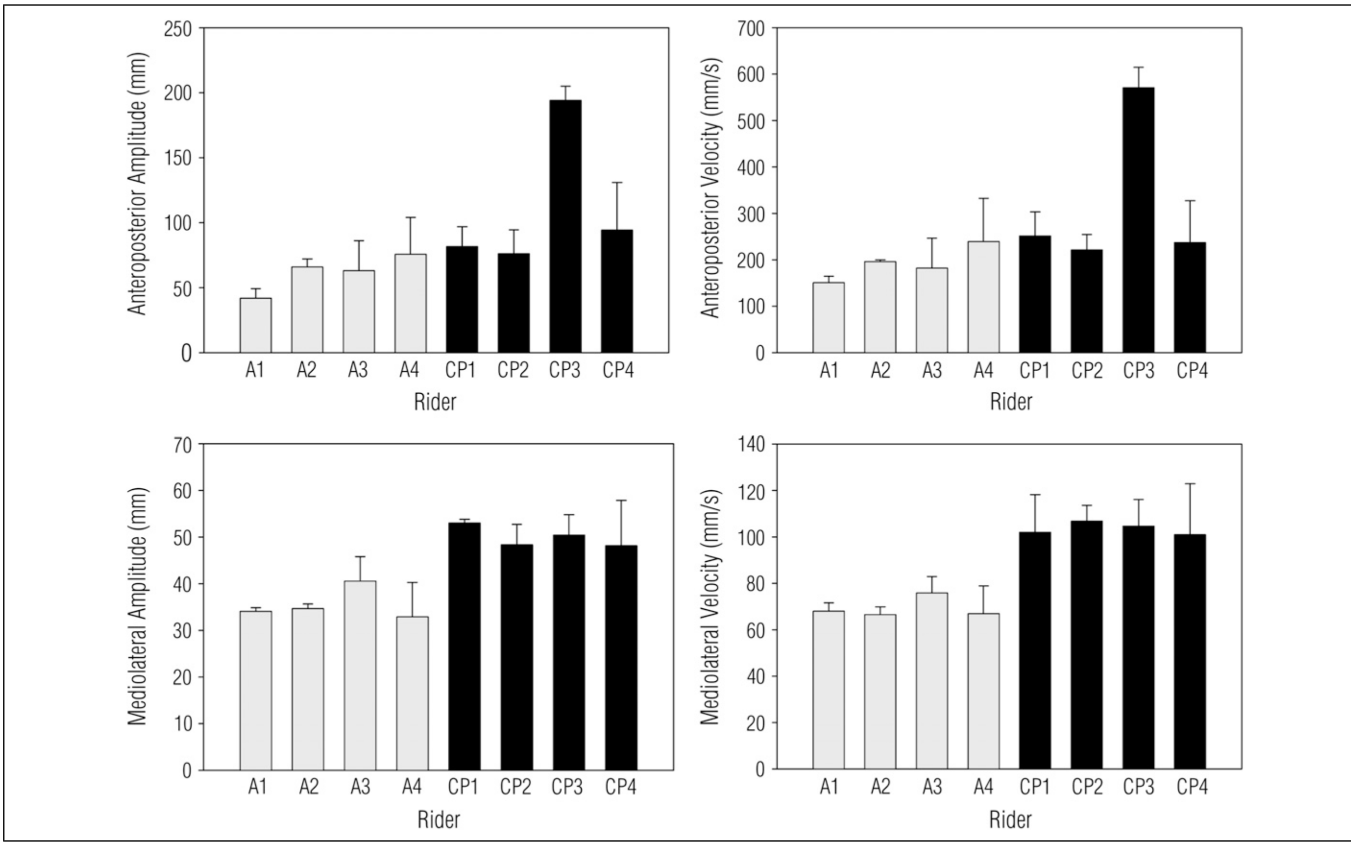

Figure 1. Range of motion (left panel) and velocity (right panel) of center of pressure in individual riders (A1–A4: riders without disabilities; CP1–CP4: riders with cerebral palsy) in the anteroposterior direction (above) and mediolateral direction (below). Values are the mean of three trials for each rider, and error bars show standard deviation.

instructions. The pressure mat was placed on the horse's back in the area beneath the saddle and initialized to 0. The saddle was placed on top of the pressure mat, and the girth was tightened gradually to a predetermined length. The rider was then assisted, as needed, to mount the horse, and any necessary adjustments to the tack were made.

For each rider, three 10-s pressure recordings were made at a sampling frequency of 60 Hz as the horse walked on a straight line. If a rider became obviously unbalanced or was assisted by a side walker, pressure recordings during that period were discarded. The rider's COP on the pressure mat was tracked, and the maximal and minimal coordinates of the data points in the AP and ML directions were used to measure the ranges of motion of the COP. The velocity of the COP was calculated by time integration of the COP displacement between each successive pair of data points in the AP and ML directions. The velocities between each pair of data points were then averaged to determine the mean values in the AP and ML directions for each trial.

Data Analysis

Mean values ± standard deviations of the COP range of motion and velocity in the AP and ML directions were calculated over the three trials of each rider. Because of the small sample size, nonparametric statistics were used. Mean values for riders without disabilities and riders with cerebral palsy were compared across groups using the Mann–Whitney test (Statistical Package for the Social Sciences v. 17; SPSS, Inc., Chicago) with a probability of $p < .05$.

Results

COP range of motion in the AP and ML directions and COP velocity in the ML direction were significantly larger in riders with cerebral palsy than in riders without disabilities (Table 2). Mean values for the individual riders (Figure 1) indicate that all riders with cerebral palsy had larger ML ranges of motion and velocities compared with riders without disabilities, whereas only 1 rider with cerebral palsy had an obviously larger COP range of motion and velocity in the AP direction. Pressure distribution patterns on the horse's back (Figure 2) show a more forward distribution for the rider with cerebral palsy in contrast to the rider without disabilities, who exerted more pressure on the back of the saddle as a consequence of sitting on the tuber ischii. The typical pattern of COP motion (Figure 2) was similar in shape for all riders but with larger excursions in the riders with cerebral palsy.

Discussion

The pressure mat used in this study has been shown to be a valid and reliable pressure measurement tool both in laboratory tests (Hochmann, Diesing, & Boenick, 2002) and in use with live horses (de Cocq, Clayton, Terada, Muller, & van Leeuwen, 2009). The Pearson correlation coefficient between rider weight and the measured total force was .936 ($p < .001$),

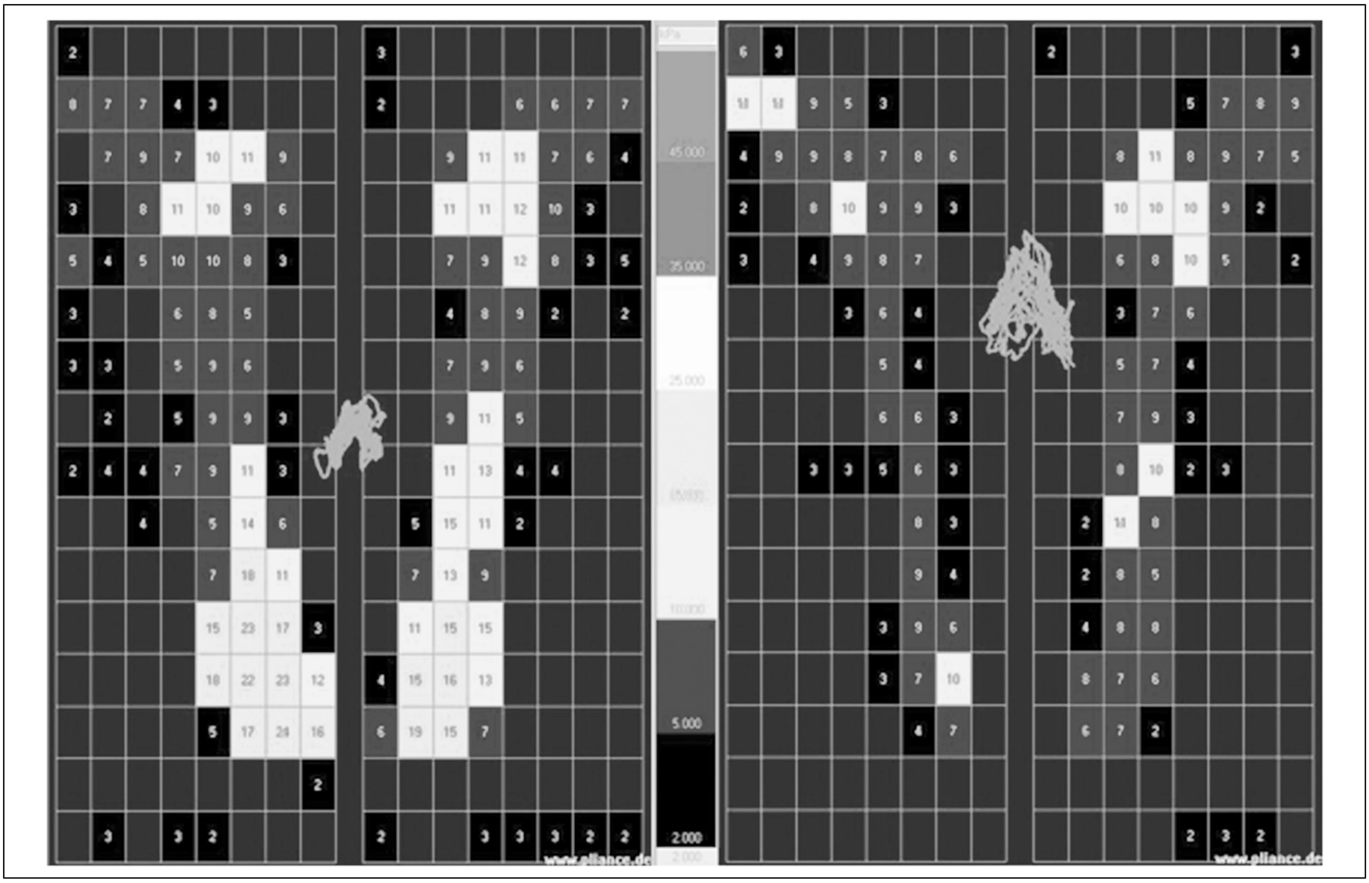

Figure 2. Pressure profile on the horse's back during walking for a rider without disabilities (left) and a rider with cerebral palsy (right). Each small rectangle represents one pressure sensor. The front of the saddle is toward the top. The color-coded pressure scale is shown in the center with the lowest pressure at the bottom of the scale. There is more pressure at the back of the saddle for the rider without disabilities (left diagram). The lower overall pressure values for the rider with cerebral palsy (right diagram) are caused by the smaller body mass of this rider. The path of the center of pressure during the 10-s trial is shown by the gray line in the central part of each figure.

indicating that the pressure mat is a valid tool for measuring the force from the rider that passes through the saddle to the horse's back. Intraclass correlation coefficients showed good to excellent repeatability both within and between measurements when the pressure mat and saddle remain in place on the horse (de Cocq et al., 2009). When the mat is removed and replaced, care must be taken to ensure consistency of placement of the pressure mat relative to the horse's back and to the saddle when the objective is to evaluate distribution of forces relative to the horse's anatomy. Changes in placement of the mat or the saddle, however, do not affect the COP variables that were measured in this study, because these values are calculated relative to the imprint of the saddle on the pressure mat, regardless of position. Measurements from riders sitting upright and leaning forward, backward, or sideways have clearly demonstrated that, although the total force beneath the saddle does not change with rider position, the force is redistributed in the direction toward which the rider is leaning (de Cocq et al., 2009), so the COP moves in that direction. The larger COP range of motion and velocity in the ML direction for riders with cerebral palsy, which reflects lateral shifts of the rider's trunk, supports the experimental hypotheses for the ML direction but not for the AP direction.

The pattern of movements of the COP beneath the saddle is indicative of sway of the rider's trunk in response to the rhythmic movements of the horse's back during each stride. When the horse's trunk accelerates, the rider tends to be "left behind," causing the COP to move in the direction opposite from the horse's acceleration. The movements of the horse's back follow a consistent pattern within each gait (Galloux et al., 1994). In the walk, a pitching motion around the transverse axis occurs twice during each stride and is combined with a twisting motion around the vertical axis (Galloux et al., 1994). In response to these movements of the horse's back, the rider's COP typically has a loop on the left side and a loop on the right side of the horse's midline in each stride (Fruehwirth et al., 2004).

In both groups of riders in this study, COP motion followed the typical pattern, but the shape was less consistent and showed larger excursions in both the AP and the ML directions for the riders with cerebral palsy. Riders use their core stabilizing muscles, including muscles of the abdominal wall and paraspinal muscles, to control movements of the trunk relative to their base of support on the surface of the saddle (Pantall et al., 2009; Terada et al., 2004). People with cerebral palsy may lack control of posture and voluntary movements, resulting in an inability to stabilize the trunk in the face of perturbations arising from the horse's locomotion. MacPhail and colleagues (1998) reported that, when riding at a walk, lateral trunk displacement was greater in riders with cerebral palsy than in riders without disabilities. This finding is consistent with the larger range of COP motion in the ML direction in our study. These findings are also supported by the fact that children with cerebral palsy have larger postural sway than typically developing children when standing on a force plate (Donker, Ledebt, Roerdink, Savelsbergh, & Beek, 2008).

Weaknesses in the design of this study include the small sample size and the inability to match the morphological characteristics of the participants in the two groups. One of the difficulties was in matching body mass. The participants with cerebral palsy had considerably smaller body mass relative to height than the participants without disabilities. The rider showing the largest COP range of motion and COP velocity in the AP direction (CP3) was taller than the other riders with cerebral palsy. Taller participants have a higher center of mass, which may increase the effect of upper body motion on COP location, although the participant's relatively small mass would tend to reduce this effect. In the group without disabilities, Rider A4 was the same height as Rider CP3, but her body mass was almost double. Values of the COP variables were similar in Rider A4 to the other riders without disabilities who were shorter in stature. Thus, the large amount of AP motion in Rider CP3 is likely to be an individual characteristic indicative of poor trunk control in the sagittal plane, which was easily detected using COP analysis.

Equine-assisted activities have been shown to improve balance, coordination, and sitting posture off the horse (Fox, Lawlor, & Luttges, 1984), which is indicative of improved ability to control trunk movements. Impaired trunk control is consistent with finding a reduced range of COP motion beneath the saddle in response to equine-assisted therapy. Measurement of COP excursions is a highly task-specific method of assessing the effects of horseback riding on muscular control and posture.

Conclusion

Riders with cerebral palsy showed significantly larger COP range of motion in the AP and ML directions and higher COP velocity in the ML direction than riders without disabilities. This finding was attributed to poor control of trunk stability. COP analysis during horseback riding is a simple technique and may be a useful tool for monitoring improvements in postural stability during equine-assisted therapy. ▲

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