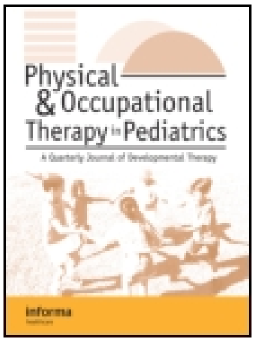

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Changes in Trunk and Head Stability in Children with Cerebral Palsy after Hippotherapy: A Pilot Study

Tim L. Shurtleff
Jack R. Engsberg

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ABSTRACT. Hippotherapy (HPOT) is a therapy that uses horse movement. This pilot investigation objectively evaluated the efficacy of HPOT in improving head/trunk stability in children with cerebral palsy (CP). The participants were six children with spastic diplegia and six children without disability. Head and trunk stability was challenged by using a motorized barrel and measured by a video motion capture system before and after a 12-week intervention of 45 min of HPOT a week. The variables measured were anterior–posterior (AP) translation of the head, and spine at five points and average AP head angles. At pre-testing, children with CP demonstrated significant differences in AP translation and AP head rotation compared with children without disability. Following HPOT, children with CP demonstrated significant reductions in head rotation and AP translation at C7, eye, and vertex. At post-testing, translation at C7 did not differ significantly between children with CP and children without disability. After HPOT intervention, children with CP reduced their AP head rotation and translation, suggesting that they had increased stability of the head and trunk in response to perturbations at the pelvis. The findings suggest that HPOT might improve head and trunk stability in children with CP.

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KEYWORDS. Cerebral palsy, children, hippotherapy, motion analysis, postural control, trunk stability

"Hippos" is the Greek word for horse. Hippotherapy (HPOT) is a physical, occupational, and speech–language therapy treatment strategy that utilizes equine movement as part of an integrated intervention program to achieve functional outcomes. The therapist uses the horse and its movement to challenge balance, posture, and strength and to integrate sensory input (vestibular, tactile, visual, and proprioception) with a motor response, stabilizing the trunk and head. Components of a HPOT session are designed to accomplish specific therapeutic goals based upon pre-intervention assessments (Benjamin, 2000).

HPOT involves a series of activities based upon the movement of the horse and the position and movement of the rider while mounted. The client sits on the horse in various positions including forward astride (typical horse riding position), side sit, and astride facing rearward. The mounted client may also perform a quadruped position, kneel, stand, or variations of these positions depending on their capability and goals. Each position change or school figure targets sensorimotor integration differently.

The rationale for HPOT is based on principles of motor learning and control, specifically the intense practice experience of learning to respond to a rhythmically moving horse (Benjamin, 2000; Casady & Nichols-Larsen, 2004; Sterba, Rogers, France, & Vokes, 2002). Riding a horse represents massed practice of trunk postural control and righting reactions under variable conditions. Horses average 55 strides per minute in a medium walk. Each stride cycle includes a left and right hind leg pushing the rider's pelvis forward with some vertical and horizontal translation and with rotation on each of three axes in a rhythmic pattern. (Clayton, 2002). When mounted for 30–45 min, a rider experiences 3000–5000 repetitions of a trunk challenge and recovery exercise. HPOT is further characterized by changes in speed and direction (weave cones or do circles), speed and gait changes (e.g., from walk to trot or half-halt), and challenging terrain. Position changes further vary the effect of the inherent rhythm of the AP thrust of each stride on different motor units of the head and trunk.

Recent studies support the effectiveness of HPOT. Casady & Nichols-Larsen (2004) used a pre-intervention baseline design ($n = 10$) and showed significant improvements in gross motor and functional performance after HPOT using the GMFM (gross motor function measure) and the PEDI (pediatric evaluation of disability inventory). In a double baseline design, energy expenditure was shown to decrease significantly while walking efficiency increased ($p < .05$) after HPOT ($n = 5$) by using GMFM and the EEI (energy expenditure index) after 8 weeks of twice weekly HPOT (McGibbon, Andrade, Widener, & Cintas, 1998). Children with CP ($n = 15$) have also demonstrated significant ($p = .05$) improvements in muscle symmetry using electromyography (Benda, McGibbon, & Grant, 2003). Therapeutic riding (TR) is adapted sport riding for people with disabilities and does not have the one-on-one therapist to client relationship; however, children with disabilities in TR sessions still experience horse movement. Winchester ($n = 7$) found significantly improved GMFM scores ($p = .01$) after 7 weeks of TR, which persisted after riding ceased and showed a trend of improved average gait speed (Winchester, Kendall, Peters, Sears, & Winkley, 2002). Sterba ($n = 17$) showed improvements on dimension E (walking, running, and jumping) of the GMFM, which persisted 6 weeks after TR ceased, but the total GMFM score returned to pre-intervention levels (Sterba, Rogers, France, & Vokes, 2002). No randomized controlled trials of HPOT are

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reported in the medical literature. One RCT of TR is reported by using three dimensions of the GMFM, but results were inconclusive (MacKinnon, Noh, Lariviere, MacPhail, Allan, & Laliberte, 1995).

Three investigations have addressed the effects of HPOT or TR specifically on trunk stability of children with CP. Bertoti developed a 3-point scale (posture assessment scale) to assess the effect of TR on five body areas: (1) head and neck, (2) shoulder and scapula, (3) trunk, (4) spine, and (5) pelvis using clinical observation and reported significant improvements in trunk control and voluntary strength of the abdominal, trunk extensor, hip extensor, and shoulder musculature after HPOT. She also noted significant improvements in sitting balance, including the ability to right the trunk in all directions after displacement following 10 weeks of biweekly 1 hour TR sessions (Bertoti, 1988). Haehl used kinematic measures to compare movement of two children who were experienced riders without disabilities with two children with CP. She used three markers on each of the rider's and horse's spines with a video motion capture (VMC) system to record movement data. She measured improvement in upper and lower trunk coordination of biphasic movement patterns while mounted in response to horse movement in the sagittal plane. After 12 weeks of HPOT, these movement patterns became closer to those of children without disabilities. However, small sample size precluded use of statistical comparisons (Haehl, Giuliani, & Lewis, 1999). MacPhail and colleagues also used VMC to measure postural responses to horse movement in the coronal plane of six riders without disabilities and six with CP in a single riding session. Significant differences in postural responses and movement patterns ($p < .01$) were found between riders with no disabilities, those with diplegic CP, and those with quadriplegic CP. The authors concluded that kinematic VMC measurements might be a sensitive measure of change in children with CP receiving HPOT (MacPhail, Edwards, Golding, Miller, Mosier, & Zwiers, 1998). None of these studies objectively quantified changes in both head and trunk stability following a HPOT intervention. The purpose of this investigation was to conduct a pilot study to quantify the effect of a HPOT intervention on head and trunk control in the sagittal plane.

METHODS

Participants

The participants were a sample of convenience of six children with CP who had never ridden horses regularly. Inclusion criteria included the diagnosis of CP, 6–17 years of age, and the participants should be able to sit upright unaided on a static surface, able to follow directions, and able to abduct hips to sit astride a horse and the testing device. They also had to be available for up to 16 weeks for 12 weekly HPOT sessions and two testing sessions within two weeks before and after the HPOT treatments. Excluded were children who previously had riding lessons (including therapeutic riding), HPOT experience, or any regular nonlesson horse riding experience. Children who might have taken one or two brief "pony rides" (e.g., at a fair or on a visit to a farm) were not excluded as we feared that would eliminate most children. Exclusion factors included neuromuscular impairments other than spastic CP (e.g., athetosis, ataxia, or apraxia); cognitive, attentional, sensory, or psychosocial diagnoses (e.g., autism, attention deficit hyperactivity disorder, mental retardation, pervasive developmental delay); inability to follow directions during pre-study assessment; uncorrected visual impairments; and (six months) recent use of antispasmodic medication, surgery (one year), or other ongoing medical interventions to modify effects of CP. Each child's physician gave approval for participation to ride horses and to participate in the study. To further ensure safety, each participant was screened by a physical therapist or occupational therapist, registered as a therapist with the North American Riding for the Handicapped Association (NARHA) for precautions and contraindications for therapeutic riding (NARHA, 2006).

The six children varied from 5 to 17 years of age and included four boys and two girls. Their gross motor function levels spanned I–IV of the gross motor function classification system (GMFCS) levels, a 5-level classification system for children with CP in which level I is least impaired and level V is most impaired (Palisano, Hanna, Rosenbaum, Russell, Walter, & Wood, 2000). A convenience sample of six people (without disability) ranging in age from 7 to 56 years, including two males and four females), were tested once to provide a normative baseline to determine if changes were occurring in a typical direction. Without disability group received no HPOT intervention. The study was approved by the IRB's of Washington University School of Medicine and Saint Louis University. All participants (with CP and without disability) and/or parents signed an approved assent or consent form.

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Intervention

Prior to the intervention, an OT/PT evaluation was conducted in which specific impairments were assessed and a treatment plan was developed to meet the unique needs of each child. No attempt was made to tightly specify the activities within the HPOT sessions except to stipulate that treatment happened on a moving horse. Horses were selected for size and movement to challenge but not to overwhelm participants. The common denominator between all of the treatment plans was the time mounted on a moving horse in walk and/or trot.

The HPOT sessions were conducted at two therapeutic riding/hippotherapy centers in the greater St. Louis, Missouri area. Each was a premier accredited center with NARHA. Each treatment session was directed by licensed occupational therapists, physical therapists, or occupational therapist assistants who were experienced with HPOT and registered as therapists with NARHA. Therapy sessions lasted 45 min weekly for 12 weeks. During the session the children performed various positions, e.g., forward astride, side sit, tall kneel, reverse astride, quadruped, including transitions between positions often while moving. HPOT is not a riding lesson and the participant did not control the horse. Horses were led or driven by an experienced leader. Therapists and side walkers ensured safety. They also assisted and coached the child in positions and functional activities while mounted. Upper extremity activities, cognitive games and exercises during the session enabled the HPOT client to integrate intentional functional tasks with rhythmic movement. Subjects were often asked to ride without holding on with the hands. They reached into all planes to grasp and place objects on the horse or hand them back and forth with therapists or side walkers or place them on stationary objects. They played ball (catch and throw) while moving on the horse. A variety of school figures, which include riding in straight lines, large and small circles, figure eights, weaving around cones, etc., might also be performed. The session might include speed changes, transitions between gaits (walk and trot), stops, starts, and half-halts. Varied terrain was sometimes used to further challenge balance and stability.

FIGURE 1. Child sitting astride testing barrel with surface markers over anatomical landmarks, safety spotters sitting below.

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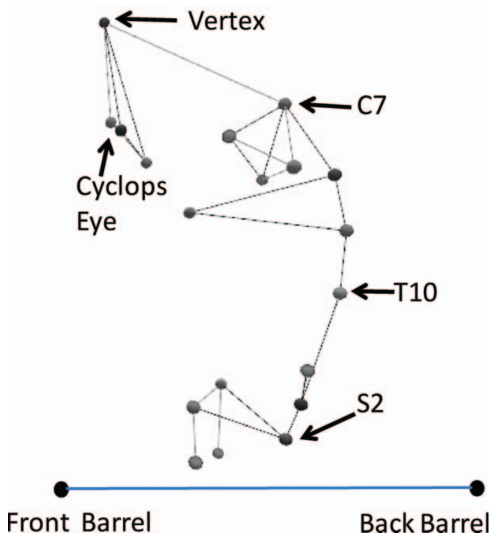
Outcome Measure

Video motion capture (VMC) has become a widely accepted tool to assess gait and movement of children with CP. It is often used before and after surgeries like selective dorsal rhisotomy, heel cord lengthenings, or spinal fusion for scoliosis to objectively determine how the intervention affected functional movement patterns (Engsberg, Lenke, Uhrich, Ross, & Bridwell, 2003; Engsberg, Ross, Collins, & Park, 2006). We used VMC to measure changes in trunk/head movement patterns after HPOT treatment. A motorized barrel was designed and built by the researchers for perturbation of the trunk and head of participants (Figure 1). The barrel had one translational degree of freedom with amplitude of 16 cm, reciprocated on wheels in an internal steel track and was powered by a variable speed 0.25-HP DC gearmotor. The fastest collection speed used in this investigation was 1 HZ. The barrel was a 68-L (18 gal) plastic drum padded with 2.5 cm (1 in.) thick, dense neoprene foam and was covered with a wool blanket (17 in. finished diameter). Strips of velcro were spaced around the circumference of the barrel. Stiff foam blocks affixed to the velcro stabilized the pelvis for positioning and safety. Spotters sat low and on each side of the barrel during each test to ensure participant safety (Figure 1) and to avoid blocking cameras, much like a side walker during a typical HPOT session. The barrel was not a "horse simulator" but simply provided a challenge perturbation to which the child could respond.

The motorized testing barrel was developed for two reasons. First, to deal with the logistics and difficulty associated with setting up equipment to collect kinematic data of multiple participants at two riding arenas at several points in time. Second, to establish a reliable and consistent method for collecting data by using a precisely replicable testing movement. Kinematics of a horse's gait vary even from stride to stride (Clayton, 2002). It is also difficult to replicate a horse's rhythm from session to session. Hence, expecting a horse to duplicate a testing movement after 12 weeks of intervention seemed very problematic. The motorized mechanical barrel challenges the participant with exactly the same testing motion at each session.

A six-camera VMC system (Eva RealTime V. 4,3,32, Motion Analysis Corp. 2004) captured 3D surface marker position during two 15-s trials at 60 Hz. with the barrel

FIGURE 2. Three-dimensional "Tinkertoy" figure created in visual motion capture software using reflective surface markers on anatomical landmarks.



reciprocating at a speed of 1 Hz. Twenty-one reflective surface markers (9 mm) were placed on the head and trunk of each participant using a marker set adapted from prior work involving trunk flexibility and movement patterns of children with scoliosis (Engsberg, Lenke, Reitenbach, Hollander, Bridwell, & Blanke, 2002). Three markers established a "barrel" frame of reference. The VMC system can record marker position in 3D space to an accuracy of 0.5 mm. Position measurements of multiple markers over a time series allow very precise tracking of movement. A color-coded "Tinkertoy" image was created in the software and could be rotated and observed in motion from any angle through the time series (Figure 2). Movement data were collected within 2 weeks prior to the HPOT intervention and within 2 weeks after completing the intervention.

Testing Reliability

Raw data are captured by high speed digital video cameras, processed and integrated within a computer system which captures position of each marker in 3D space to a precision of 0.5 mm, at a speed of up to 500 frames per second. However, for this study 60 frames per second was sufficient to capture usable and accurate data. Thus, human judgment was not required for data capture, and therefore, there was no issue related to rater judgment or accuracy of recording. We have previously published intratester reliability for marker placement at $r = 0.957$ and $r = 0.996$ with intertester reliability at $r = 0.953$ (Engsberg, Lenke, Reitenbach, Hollander, Bridwell, & Blanke, 2002). For each test, two movement trials were captured several minutes apart for both with CP and without disability participants. Test–retest reliability was calculated by using the split half reliability analysis function of SPSS (version 15) yielding a test–retest reliability of $r = 0.928$.

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Testing Protocol

During data collection the children were asked to sit up and look forward to a target or toward a parent while holding a small soft toy in both hands in front of their abdomen. This reduced the tendency to reach down for stability and kept their arms from blocking the view of the cameras to lower markers. It also kept the head in a relatively neutral position during the testing and reduced erratic movements of the head such as looking around the room. The same testing protocol was used with the without disability participants who received no second test and received no intervention.

Data Processing

Surface marker data were tracked and edited to produce three-dimensional coordinates as a function of a movement cycle (Figure 2). Only the last half (7.5 s or 7–8 movement cycles) of each 15-s trial was used in this analysis, after the barrel had reached a constant reciprocating speed of 1 HZ. Two sets of sagittal plane variables were determined from the tracked data: (1) absolute head angle and (2) AP translation of five spine and head markers.

The head angle was calculated between the vertex to C7 line segment and the line segment between front and back barrel markers. Range of motion (ROM) (e.g., difference between the highest and lowest angle) and the standard deviation of all ($n = 450$) angle observations for each trial very effectively describe movement variability (MV) over time. Since changes in the ability to control head movement are at the heart of this study, the ROM and SD, therefore, became key variables. A smaller ROM and SD after intervention indicated increased control of the head, while larger values would indicate decreased head control.

Markers at the vertex; Cyclops eye (virtual marker between the eyes); markers at C7, T10, S2; and one barrel marker were used to calculate average amplitude of horizontal translation in the sagittal plane relative to a laboratory coordinate system during each testing time series.

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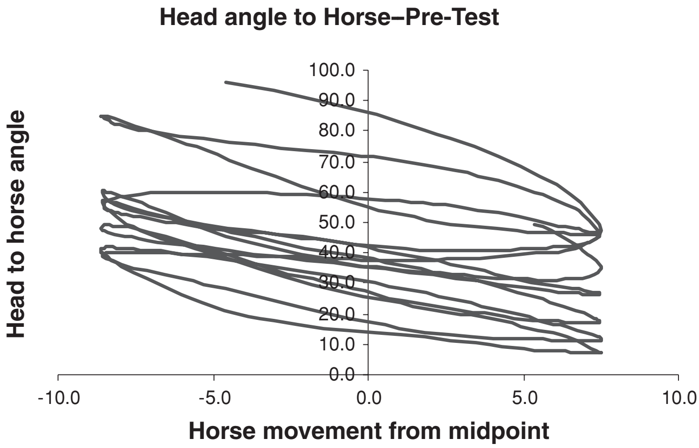
Statistical Analysis

Paired *t*-tests were used to compare ROM, SD, and translation variables before and after HPOT for the group with CP ($p < .05$). The results of participants without disability were compared to the pre- and post HPOT results for the participants with CP using independent samples *t*-tests ($p < .05$). SPSS, Version 12.0 (SPSS Inc.) was used to perform statistical tests after the raw 3D position, and angle data for all markers were exported from the VMC system and further analyzed by using Excel spreadsheets and graphics.

RESULTS

Angular excursion of the head at pre-test and post-test are illustrated for one of the participants with CP in Figures 3 and 4 and for a participant without disability in Figure 5. In the figures, the *X*-axis represents 16-cm movement cycle of the barrel. The *Y*-axis represents the head angle at each barrel position. For the child with CP, ROM was

FIGURE 3. Angular head excursion of a 7-year-old child with CP at pre-test.



89° (SD = 18.7) at pre-test (Figure 3) and 38° (SD = 9.0) at post-test (Figure 4). As illustrated in Figure 5, the child without disability had less head excursion (ROM = 24°, SD = 5.6)

For the children with CP, there were a total of 450 measures of head excursion. Movement variability of angular excursion of the head (SD of measures) decreased from 18.8° at pre-test to 9.0° at post-test ($p < .03$). Mean AP head rotation ROM differed significantly at pre-test (44°) and post-test (29°) ($p < .05$) (Table 1) and is consistent with the example illustrated in Figures 3 and 4. The mean ROM and SD of AP head rotation of the children with CP remained significantly different from children without disability after the intervention.

The average difference in translation between pre-test and post-test for children with CP is illustrated by a reduction in movement as the markers moved upward from the

FIGURE 4. Reduced angular head excursion of 7-year-old child with CP following hippotherapy.

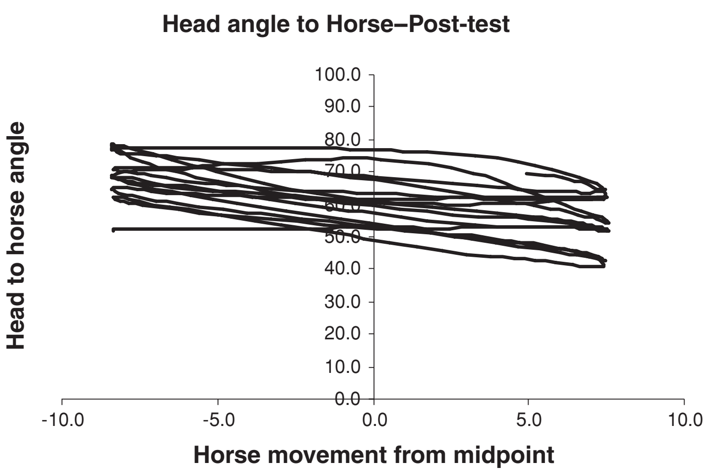


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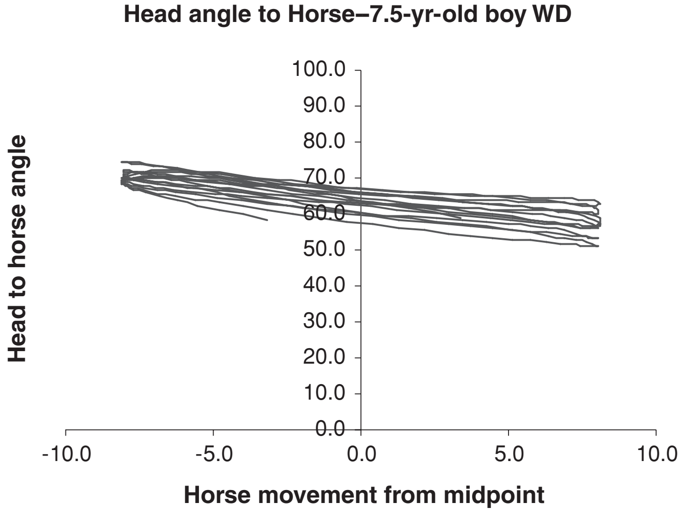
FIGURE 5. Head angular excursion of an 8-year-old boy without disability (WD).



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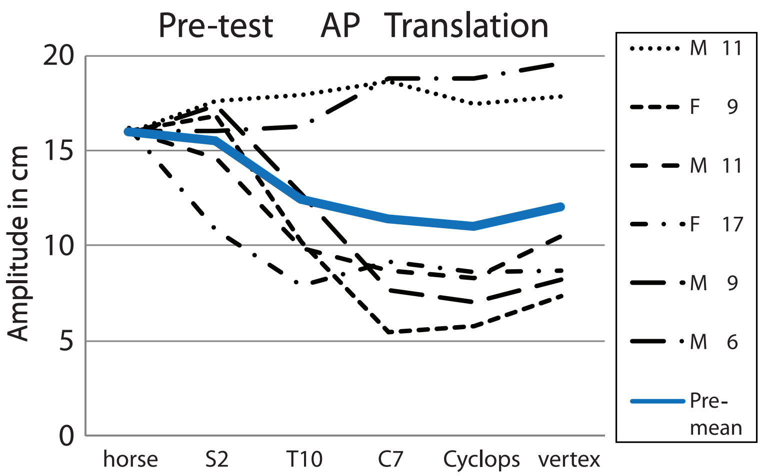
barrel and towards the head (compare Figures 6 and 7 for individual results and mean). At both pre- and post-test, translation at S2 was similar to the barrel, with less translation at T10 and C7. There are two key results. First, in the CP group after HPOT there was a significant reduction in translation amplitude at C7 ($p = .02$), Cyclops eye ($p = .03$), and the vertex ($p = .005$) (Figure 8). Second, translation at C7 between children with CP and children without disability was significantly different before ($p = .01$) but not after ($p = .11$) hippotherapy. Differences in translation at the eye and vertex between children with CP and children without disability were significant at pre-test and after hippotherapy ($p < .05$).

TABLE 1. Changes in Head Angular Excursion (Maximum–Minimum Angle Over Time Series) and Average Movement Variability (Average SD of Head Angles) Pre- and Post-Hippotherapy for Children with CP ($n = 6$) and Children without Disabilities ($n = 6$)

Group	Angular excursion (max–min angle)			Movement variability (MV) of angles (SD of 450 observations)		
Children with CP pre-test	44°(25.6)		+	10°(5.1)		+
Children with CP post-test	29°(16.2)	*	+	7°(3.7)	*	+
Children without disabilities	12°(7.7)	*	+	3°(2.0)		

*Significantly different from pre-test ($p \leq .05$).
+Significantly different from children without disabilities ($p \leq .05$).

FIGURE 6. Individual and average anterior–posterior translation amplitude during barrel test for children with CP. Sex (M, F) and age are in the legend.



DISCUSSION

The purpose of this investigation was to determine if changes in head and trunk control after 12 weeks of hippotherapy could be objectively quantified with a small pilot sample. The results indicate a significant reduction in movement variability among the children with CP. Reductions in translation and rotation indicate improvement in control of trunk and head movement in response to perturbation of the pelvis following hippotherapy. These changes support the notion that the improved trunk/head stability may be a result of motor learning gained as a consequence of learning to recover from

FIGURE 7. Individual and average anterior–posterior translation amplitude during barrel test of children with CP following hippotherapy. Sex (M, F) and age are in the legend.

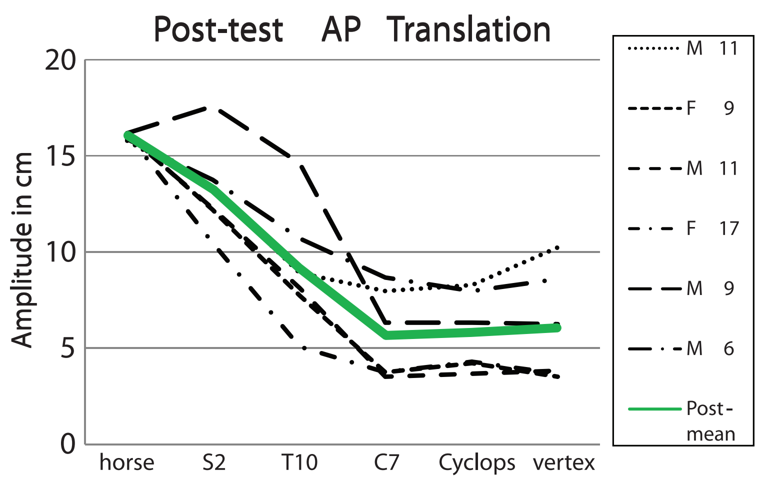


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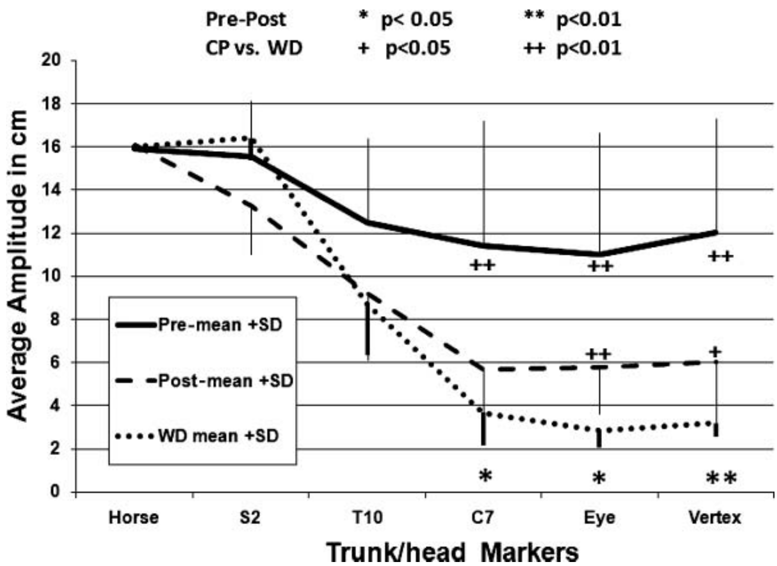
FIGURE 8. Average anterior–posterior horizontal translation amplitude during barrel test for children with CP ($n = 6$) pre- and post-hippotherapy and children without disabilities ($n = 6$). Solid line represents mean AP amplitude at each trunk/head marker at pre-test. The dashed line is the mean AP amplitude after 12 weeks of HPOT. The dotted line represents the amplitude of the comparison group without disabilities (WD).



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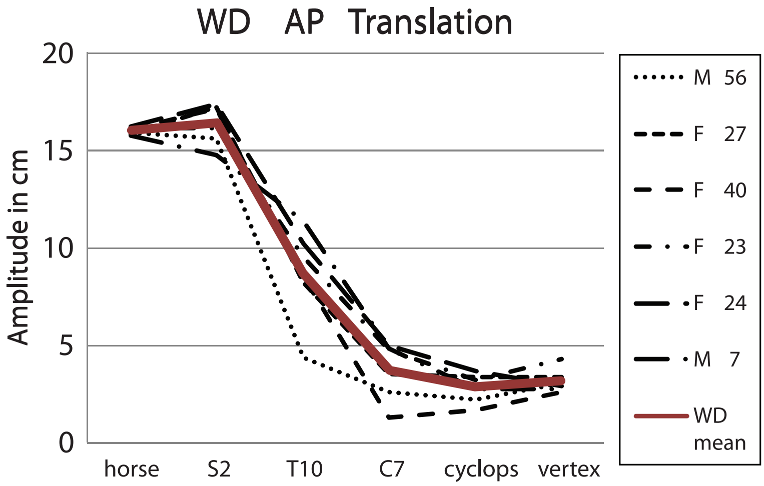
such a large number of repeated forward thrusts of the horse to the pelvis during 12 weeks of hippotherapy.

These results reinforce conclusions by Bertoti (1988) who found significant improvements in sitting balance, including the ability to right the trunk in all directions after HPOT. The results support MacPhail, Edwards, Golding, Miller, Mosier, & Zwiers's. (1998) finding that horseback riding facilitated equilibrium reactions for children with diplegic CP and support Haehl's (1999) conclusions that following hippotherapy children with CP move more like typical children and improve coordination of the trunk. Use of video motion capture and development of the mechanical barrel responded to MacPhail's recommendation that motion analysis might be an effective technology to measure change over time of children participating in hippotherapy.

The study was limited to a small heterogeneous convenience sample of children with CP, 7 to 17 years in GMFCS Levels I–IV. More children with CP who were more closely matched or stratified by gross motor function may have provided more consistent results or results which might be directed toward a differing effect of HPOT on varying ability levels. The 12 week long intervention is another limitation (amounting to only 6–8 hours on a moving horse). Many children who participate in HPOT continue for many more weeks and often participate for years. Some participate once per week, some participate more times per week. This offers many questions about effects of varying dosage. Future studies should investigate interventions of varying length (in minutes), varying interval between sessions (1, 2, or more per week), and total number of hippotherapy sessions over months or years.

The characteristics of the comparison group were also a limitation. Since the VMC measure using the motorized barrel to perturb the participant is new, we decided it

FIGURE 9. Individual and average anterior–posterior translation amplitude during barrel test for comparison participants without disability (WD). Sex (M, F) and age are in the legend.



was essential to know how those without disabilities would respond to this challenge to trunk stability. Therefore, an equal number ($n = 6$) of people without disabilities served as a comparison group. The assumption was that, if changes in children with CP following hippotherapy reduced differences from those without disabilities, then the change was positive. Since this was a pilot study, we considered it sufficient to use a convenience sample, including some adults, who had participated in developing and testing the measurement system. Typically developing children achieve adult gait patterns between 4 and 7 years of age (Sutherland, Olshen, Biden, & Wyatt, 1988). Since gait is described as a whole-body function, which includes trunk stability, we felt that the literature supported our use of a non age-matched group for a pilot study. This suggested to us that any person above age 7 would likely respond in similar ways in our trunk stability measure. This was supported by our results of people without disability for AP translation. The comparison group results on all of our variables were remarkably similar, regardless of age (Figure 9). Nevertheless, an age-matched comparison group will be recruited for future work.

Further research is recommended to investigate the relationship between improved trunk and head stability after hippotherapy. It is also important to investigate any changes in other functional variables such as the effect on upper extremity (UE) function of stabilizing the trunk, which stabilizes the proximal foundation for the UE's and improves distal stability. Thus, the ability to perform functional tasks may also improve. It is also important to investigate any carryover effect after stopping therapy. It is also important to know how HPOT affects children in the rest of their life, after they leave the riding arena. In addition to objective impairment level data, as in the present investigation, researchers also need to investigate the effect of HPOT on additional categories of the International Classification of Function (ICF), e.g., improvements in functional skills and activity participation. Improvements in domains of self perception/self confidence, social interaction, quality of life, and occupational performance outside of the riding arena have also been reported anecdotally by therapists and caregivers and attributed by them to the HPOT experience (AHA, 2009). When these domains were studied

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for therapeutic riding, a similar but less rigorous intervention than HPOT, standardized assessments showed inconclusive results (MacKinnon, Noh, Lariviere, MacPhail, Allan, & Laliberte, 1995). Further studies of these domains to better understand such changes using more sensitive instruments are needed to fully understand broader and less tangible effects of HPOT in the lives of children with CP.

CONCLUSION

Children with CP demonstrated reduction in anterior–posterior trunk translation and reduced head/neck ROM and head angle variability (SD of head angle) while being perturbed by a motorized barrel after 12 weeks of hippotherapy. The findings support the efficacy of the hippotherapy intervention to improve trunk and head control in response to rhythmic movement. We objectively quantified head/trunk stability in children with spastic diplegia using video motion capture. The motorized testing barrel challenged head and trunk control by providing precisely replicable rhythmic perturbations at the pelvis. Development of additional objective kinematic measures (e.g., response to lateral perturbation, response to varying speed of perturbation, measurement of trunk/head motor control changes measured on live horses) could augment the clinical rating scales and measures used in previous investigations and provide additional understanding about the efficacy of hippotherapy for children with CP to families, therapists, physicians, and third-party payers.

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