1-2020

Linear and Nonlinear Measures of Postural Control in a Toddler With Cerebral Palsy: Brief Report

Samuel R. Pierce

Athylia C. Paremski

Julie Skorup

Nicholas Stergiou

Ben Senderling

See next page for additional authors

Authors

Samuel R. Pierce, Athylia C. Paremski, Julie Skorup, Nicholas Stergiou, Ben Senderling, and Laura A. Prosser

Linear and Nonlinear Measures of Postural Control in a Toddler With Cerebral Palsy: Brief Report

Pierce, Samuel R. PT, PhD, NCS; Paremski, Athylia C. BA; Skorup, Julie PT, DPT, PCS; Stergiou, Nicholas PhD; Senderling, Benjamin MS, MBA; Prosser, Laura A. PT, PhD

Grant Support: This research was supported by the National Institute on Disability, Independent Living, and Rehabilitation (H133G140166).

The authors declare no conflicts of interest.

Keywords:
cerebral palsy; motor development; postural control; sitting balance; toddlers

ABSTRACT

Purpose:

The purpose of this study was to describe changes in linear and nonlinear measures of postural control along with motor outcomes in a young child with cerebral palsy.

Summary of Key Points:

Posturography in sitting and standing, the Gross Motor Function Measure-66 (GMFM-66), and the Early Clinical Assessment of Balance (ECAB) were performed prior to, during, and after physical therapy. The child demonstrated independent sitting throughout the study and developed independent standing during the study. He made improvements in the GMFM-66 and ECAB throughout the study. Higher average values were found in all linear and nonlinear measures in standing when compared to sitting, which may indicate less predictable movement due to less experience with standing.

Recommendations for Clinical Practice:

Greater variability and lower predictability in postural control likely reflect early stages of skill acquisition. Research is needed to understand the optimal levels of movement variability and predictability.

INTRODUCTION

Postural control is the foundation for functional mobility, and poor postural control is a hallmark of cerebral palsy (CP).[1] The standard for the measurement of postural control

is posturography, which quantifies body sway using center of pressure (CoP) data recorded by a force plate.[2] Linear measures of postural control, which quantify the magnitude and velocity of CoP movement, have traditionally been used in children with CP.[2] One linear measure, the root mean square (RMS), has been used to quantify magnitude of variability in terms of sway to characterize postural control. This is an important feature during development because variability is needed for infants to achieve functional skills.[3] However, linear analyses of CoP data are not able to assess how postural control changes over time and specifically the complexity of postural control, which is becoming a more common feature in the study of neurological systems. Nonlinear analysis can assess complexity, which is the measurement of the predictability of variability over a time series and is described in reference to motor development by Dusing et al.[4] In the application to CoP data, nonlinear measures further describe the degree of adaptability of postural control, which is a characteristic of mature motor control. Infants born preterm and children with CP show decreased complexity in postural control as compared with children developing typically in supine[5] and sitting[6] positions. While postural control in standing position comparing different age groups of children developing typically has been reported,[7] nonlinear measures in children with CP during standing position have not been described. In addition, longitudinal changes in postural control during motor skill development in children with CP are not well understood.

The purpose of this brief report is to address these knowledge gaps and describe longitudinal linear and nonlinear measures of postural control during sitting and standing positions in a young child with CP.

METHODS

The child was a 21-month-old boy with diplegic CP who had a history of preterm birth after 31 weeks' gestation and periventricular leukomalacia. He sat without support by 10 months, pulled to stand by 13 months, crawled reciprocally by 15 months, and cruised by 16 months. Data were collected in conjunction with a randomized controlled clinical trial comparing a physical therapy (PT) program using a dynamic weight assistance technology with conventional PT in toddlers with CP (ClinicalTrials.gov Identifier: NCT02340026).[8] This study was approved by an Institutional Review Board. The child's parents provided informed consent. The child was randomly assigned to the conventional therapy group and completed sixty 30-minute PT sessions over a 6-month period focused on training gait, balance, and other gross motor skills.

Data were collected prior to the start of the PT program (assessment 1), after 6 weeks (assessment 2), 12 weeks (assessment 3), 18 weeks (assessment 4), and 24 weeks of intervention (assessment 5), and at follow-ups 3 months (assessment 6), 6 months (assessment 7), and 12 months after intervention (assessment 8). The Gross Motor Function Measure-66 (GMFM-66) and the Early Clinical Assessment of Balance (ECAB) were used. The reliability and validity of the GMFM-66 have been supported in children with CP.[9] The ECAB measures postural stability in children with CP,[10] and high inter- and intrarater reliabilities have been reported.[11]

CoP data were collected using a posturography system with a force plate (Neurocom SMART Balance Master; Natus Medical Inc, San Carlos, California) and were videotaped for verification of data integrity. The child was placed on the force plate, and data collection was not initiated until the child was comfortable and not moving. The child was asked to sit or stand as motionless as possible. The child's self-selected sitting position was long sit with his hands on his lap. Three to five 30-second sitting trials were performed during each assessment and standing trials were performed once the child was able to stand independently, which occurred at assessment 3. For sitting trials, the child maintained sitting posture without reaching, rocking, or requiring physical assistance. For standing trials, the child maintained standing posture without arm movement, changing foot position, or requiring physical assistance. One investigator reviewed each 30-second video trials to identify periods of 10 seconds from 3 separate trials for analysis. The average values are reported.

Linear and nonlinear analyses were completed using Matlab (R2018a; Mathworks, Inc; Natick, MA). Linear measures of movement magnitude included CoP velocity (COPV), sway path, displacement in the medial-lateral (M/L) and anterior-posterior (A/P) directions, and 95% ellipse area in which higher values indicted more movement. The linear measure of movement variability was the RMS in which higher values indicate more variability. Nonlinear analysis first included a surrogation test on each trial to verify that nonlinear methods were appropriate to use, and the time series data were different from those of a randomly generated time series. Subsequently, sample entropy of the CoP was calculated in the M/L (entropy X) and A/P (entropy Y) directions. Sample entropy is not a measure of complexity but provides information on an aspect of complexity, namely, how regular or predictable are the data in which higher entropy means lower predictability.[12]

RESULTS

The child demonstrated improvements in the GMFM-66 and ECAB during both the intervention and follow-up phases (Table). The 95% confidence intervals for the GMFM-66 scores between assessments 1 and 5 and between assessments 5 and 8 do not overlap, which suggests that the changes were not due to measurement error. GMFM-66 scores increased throughout the study period with the exception of assessment 5. The improvements in ECAB scores between assessments 1 and 5 as well as between assessment 5 and 8 were greater than the minimally detectable change scores for the test, which is reported as 10 points.[10]

TABLE - Functional, Linear Postural, and Nonlinear Posture Data

Assessment	GMFM-66	GMFM-66 95% Confidence Interval	ECAB
1	54.1	51.7-56.6	43.5
2	58.6	56.2-61.0	50.5
3	60.9	58.4-63.4	48
4	65.6	62.6-68.4	52
5	63.3	60.7-66.0	62.5

Assessment	GMFM-66	GMFM-66 95% Confidence Interval	ECAB
6	67.4	64.5-70.3	64
7	68.1	65.2-71.0	80
8	69.2	66.2-72.2	88

Sitting

Assessment	Entropy X M/L	Entropy Y A/P	COPV M/L	COPV A/P	Sway Path	RMS M/L	RMS A/P	95% Ellipse area
1	0.24	0.23	24.03	81.56	103.23	0.38	0.99	7.92
2	0.51	0.51	18.46	66.66	84.51	0.26	0.74	3.51
3	0.34	0.40	22.67	77.14	89.02	0.44	0.81	6.57
4	0.35	0.17	19.91	70.80	77.68	0.21	0.67	2.66
5	0.23	0.24	17.82	54.36	69.63	0.25	0.64	3.00
6	0.39	0.38	22.02	67.10	77.22	0.37	0.80	6.53
7	0.29	0.31	19.91	58.72	76.28	0.52	0.73	7.69
8	0.32	0.27	17.89	61.16	89.52	0.45	1.11	9.82
Average	0.33	0.31	20.34	67.19	83.39	0.36	0.81	5.96

Standing

Assessment	Entropy X M/L	Entropy Y A/P	COPV M/L	COPV A/P	Sway Path	RMS M/L	RMS A/P	95% Ellipse area
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3	0.51	0.34	22.95	75.89	94.21	0.38	0.80	5.72
4	0.34	0.39	22.63	69.68	89.44	0.67	0.96	11.90
5	0.26	0.32	21.40	68.47	85.06	0.90	0.90	14.53
6	0.36	0.37	22.30	61.08	76.00	0.74	0.91	12.66
7	0.37	0.45	23.19	68.22	94.51	0.59	0.99	11.69
8	0.30	0.40	19.84	61.65	85.78	1.05	1.19	22.64
Average	0.36	0.38	22.05	67.50	87.50	0.72	0.96	13.19

Abbreviations: COPV A/P, center of pressure anterior/posterior; COPV M/L, center of pressure medial/lateral; ECAB, Early Clinical Assessment of Balance; GMFM, Gross Motor Function Measure; RMS A/P, root mean square anterior/posterior; RMS M/L, root mean square medial/lateral.

Sitting posture data indicated that entropy X (M/L direction) and entropy Y (A/P direction) were greatest at assessment 2 and then fluctuated. COPV M/L, COPV A/P, and sway path were highest at assessment 1 and then also variable. The RMS M/L, RMS A/P, and 95% ellipse area were generally large at assessment 1, decreased as therapy continued through assessment 5, and then increased past baseline values during the follow-up period.

Higher average values were found in all linear and nonlinear measures in standing position than in sitting position. Entropy X (M/L direction) was greatest when standing data were first able to be collected at assessment 3 and then fluctuated over remaining data collections. Entropy Y (A/P direction) varied within a narrower range and was highest at assessment 7. COPV M/L, COPV A/P, and sway path also fluctuated over a narrow range and generally declined over time. RMS M/L, RMS A/P, and 95% ellipse

area demonstrated their lowest values after assessment 3 and their highest values after assessment 8.

DISCUSSION

This report describes the longitudinal measurement of sitting and standing postural control in a young child with diplegic CP. The emergence of independent standing position after 12 weeks provided an opportunity to examine how postural control develops as functional mobility is improving. Our finding of higher average values for the linear measures in standing position than in sitting position indicates that there was more movement and more variable movement during standing position. Increased RMS and 95% ellipse area values in both sitting and standing positions at assessment 8 suggest that the child changed posture without losing balance (which would have disqualified the trial), thus indicating greater postural control.

The higher values for nonlinear measures indicate less predictable movement in standing position than in sitting position, which is probably due to the child's lack of experience with standing position. However, a simple pattern of gradually decreasing linear and nonlinear values was not observed over time. In sitting position, low values of entropy in the M/L and A/P directions were found at assessment 1, which then increased to their highest levels at the next assessment. One interpretation for this finding is that the child was learning the limits of postural stability in sitting position at assessment 2, which decreased the predictability of movements. It is unknown what the effect of the PT program or his previous experience in sitting position had on his postural control. Since independent standing posture then emerged by assessment 3, the decrease in predictability may have facilitated the learning of new motor skills. Greater variability and lower predictability in postural control measures likely reflect early stages of skill acquisition when motor control patterns are not yet refined. As postural control improves, more refined patterns of motor control are expected that are characterized by adaptable patterns with higher predictability and lower variability. In addition, one potential cause for the narrow range of entropy found in the A/P direction was that it may reflect decreased proximal control of the pelvis and hip, which is a common impairment in children with diplegic CP.[13] Research is needed to understand the optimal structures of movement variability and predictability to facilitate motor learning. The importance of variability or decreased predictability in order to allow infants to explore their environments and attain functional skills has been discussed in the literature.[3]

The nonlinear data during standing position show a different pattern in which M/L entropy was highest when the child was first able to stand but then decreased. A/P entropy in standing position fluctuated over a narrower range but then increased at later assessments. The child's increased predictability in M/L movement over time may be due to initial difficulty maintaining balance in the M/L direction, followed by greater stability in this direction. The decrease in A/P predictability over time may indicate that the child was more comfortable in standing position and able to shift weight more easily

without losing balance. The relationship between movement predictability and postural control children with CP is worthy of further investigation.

This single case investigation has limitations. A larger sample of children with CP is essential to support our data. It is unknown whether our findings will generalize to children with CP with different levels of mobility. Normative longitudinal data collected from children developing typically would also be useful for comparison with children with CP using nonlinear analysis since changes in large groups of children over time have not been reported in order to explore changes in sitting and standing positions that occur with development. The development of novel and time-efficient methods to assess the development of postural control in children with CP would be a valuable addition to the literature.

REFERENCES

1. Pavão SL, dos Santos AN, Woollacott MH, Rocha NA. Assessment of postural control in children with cerebral palsy: a review. Res Dev Disabil. 2013;34(5):1367–1375.
2. Wickstrom J, Stergiou N, Kyvelidou A. Reliability of center of pressure measures for assessing the development of sitting postural control through the stages of sitting. Gait Posture. 2017;56:8–13.
3. Stergiou N, Decker LM. Human movement variability, nonlinear dynamics, and pathology: is there a connection? Hum Mov Sci. 2011;30(5):869–888.
4. Dusing SC, Izzo TA, Thacker LR, Galloway JC. Postural complexity differs between infant born full term and preterm during the development of early behaviors. Early Hum Dev. 2014:90(3):149–156.
5. Dusing SC, Kyvelidou A, Mercer VS, Stergiou N. Infants born preterm exhibit different patterns of center-of-pressure movement than infants born at full term. Phys Ther. 2009;89(12):1354–1362.
6. Kyvelidou A, Harbourne RT, Willett SL, Stergiou N. Sitting postural control in infants with typical development, motor delay, or cerebral palsy. Pediatr Phys Ther. 2013;25(1):46–51
7. Lobo da Costa PH, Verbecque E, Hallemans A, Vieira MF. Standing balance in preschoolers using nonlinear dynamics and sway density curve analysis. J Biomech. 2018;82:96–102.
8. Prosser LA, Pierce SR, Dillingham TR, Bernbaum JC, Jawad AF. iMOVE: Intensive Mobility training with Variability and Error compared to conventional rehabilitation for young children with cerebral palsy: the protocol for a single blind randomized controlled trial. BMC Pediatr. 2018;18(1):329. doi:10.1186/s12887-018-1303-8.
9. Russell DJ, Rosenbaum PL, Wright M, Avery LM. Gross Motor Function Measure (GMFM-66 & GMFM-88) User's Manual. 2nd ed. London, England: MacKeith Press; 2013.
10. McCoy SW, Bartlett DJ, Yocum A, et al. Development and validity of the early clinical assessment of balance for young children with cerebral palsy. Dev Neurorehabil. 2014;17(6):375–383.

11. Randall KE, Bartlett DJ, McCoy SW. Measuring postural stability in young children with cerebral palsy: a comparison of 2 instruments. Pediatr Phys Ther. 2014;26(3):332–337.
12. Richman JS, Moorman JR. Physiological time-series analysis using approximate entropy and sample entropy. Am J Physiol Heart Circ Physiol. 2000;278:H2039–H2049.
13. Fowler EG, Staudt LA, Greenberg MB, Oppenheim WL. Selective Control Assessment of the Lower Extremity (SCALE): development, validation, and interrater reliability of a clinical tool for patients with cerebral palsy. Dev Med Child Neurol. 2009;51(8):607–614.