ORIGINAL ARTICLE

Reliability of Center of Pressure Measures for Assessing the Development of Sitting Postural Control

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ABSTRACT. Kyvelidou A, Harbourne RT, Stuberg WA, Sun J, Stergiou N. Reliability of center of pressure measures for assessing the development of sitting postural control. Arch Phys Med Rehabil 2009;90:1176-84.

Objectives: To determine the reliability of linear and nonlinear tools, including intrasession and intersession reliability, when used to analyze the center of pressure (COP) time series during the development of infant sitting postural control.

Design: Longitudinal study.

Setting: University hospital laboratory.

Participants: Typically developing infants (N=33; mean ± SD age at entry in the study, 152.4±17.6d).

Interventions: Not applicable.

Main Outcome Measures: Infants were tested twice in 1 week at each of the 4 months of the study. Sitting COP data were recorded for 3 trials at each session (2 each month within 1 week). The linear COP parameters of root mean square and range of sway for both the anterior-posterior and the medial-lateral directions, and the sway path, were calculated. The nonlinear parameters of approximate entropy, Lyapunov exponent, and correlation dimension for both directions were also calculated. Intrasession and intersession reliability was quantified by the intraclass correlation coefficient (ICC).

Results: The nonlinear tool of approximate entropy presented high intrasession and intersession ICC values compared with all other parameters evaluated. Generally, intrasession and intersession reliability increased in the last 2 months of the data collection and as sitting posture matured.

Conclusions: Our results showed that the evaluation of COP data is a reliable method of investigating the development of sitting postural control. The present study emphasizes the need for establishing COP reliability before using it as a method of examining intervention progress directed at improving the sitting postural abilities in infants with motor developmental delays.

Key Words: Posture; Nonlinear dynamics; Rehabilitation; Reproducibility of results.

CHILDREN WITH POSTURE and movement disorders struggle to attain the milestone of sitting, and independent sitting is often the first missed or delayed milestone indicating a posture or movement disorder.[1] Abnormal neurologic signs generally identify these children along with high risk factors occurring around birth, scores obtained on developmental screening tests, or visual analysis of their movement quality. However, currently available tests, even though they are reliable in identifying delayed development, lack in quantifying progress as a result of small changes occurring during development.[2,3] Existing tests for measuring progress assess large changes in motor skills, and are not precise enough to provide information regarding rate of acquisition of skill on a short-term basis.[2,3] Moreover, the effect of intervention on motor development is an issue needing more research,[4] but tools that measure these effects are lacking. Thus, there is a need for a method of quantifying the mechanisms of postural control during the development of sitting, to be used eventually as a tool of measuring progress during treatment of an already identified motor delay or disorder.

A simple paradigm of evaluating postural control is the use of a force platform and measuring the COP, which describes body sway. The COP is the point of application of the ground reaction force vector, and it has traditionally been used to describe the organization of posture.[5] Researchers have employed the COP in investigations of postural control during standing in healthy[6] and nonhealthy subjects,[7] as well as healthy[8] and nonhealthy older children.[9] The reproducibility of this methodology has been investigated extensively during standing for both populations. Reliability measures, such as the ICC, revealed that COP measures generally produced poor to fair reproducibility ranging from .30 to .75 under static and dynamic balance conditions.[10-13] Recently, this methodology has also been used to investigate sitting postural control.[14-16] However, the reliability of COP measures for the evaluation of sitting postural control and specifically for infant motor development has not been identified.

Furthermore, COP data can be evaluated not only with traditional linear measures, such as those used in the previous studies for standing postural control, but also with nonlinear parameters. Such parameters can provide new insights in the ways that the nervous system controls the complexity of dynamic balance.[14] In addition, nonlinear measures evaluate differ-

List of Abbreviations

ANOVA	analysis of variance
AP	anterior-posterior
ApEn	approximate entropy
COP	center of pressure
ICC	intraclass correlation coefficient
LyE	Lyapunov exponent
ML	medial-lateral
RMS	root mean square

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Supported by the National Institutes of Health (grant no. K25HD047194), the National Institute on Disability and Rehabilitation Research (grant no. H133G040118), the Nebraska Research Initiative, and the Reichenbach Fellowship from University of Nebraska Medical Center.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit on the authors or on any organization with which the authors are associated.

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0003-9993/09/9007-00832$36.00/0
doi:10.1016/j.apmr.2009.01.031

ent aspects of the COP data. Linear measures, such as the range and the length of path traced by the COP, quantify the amount of movement of the COP during a specific task or the quantity of variation present in a set of values independently of their order in the distribution. In contrast, nonlinear measures best capture variation in COP regarding how motor behavior emerges in time, for which the temporal organization in the distribution of values is of interest. Temporal organization or structure is quantified by the degree to which values emerge in an orderly (ie, predictable) manner, often across a range of time scales.[14] Examples of nonlinear measures are the LyE and the ApEn.[14] These nonlinear tools are being used increasingly to describe complex conditions for which linear techniques have been inadequate, confounding scientific study and the development of meaningful therapeutic options. For example, nonlinear analysis has recently appeared in research of heart rate irregularities, sudden cardiac death syndrome, blood pressure control, brain ischemia, epileptic seizures, and posture,[17-22] to understand their complexity and eventually develop prognostic and diagnostic tools. Similarly, nonlinear analyses of the COP data as sitting develops can provide a window into the neurologic status of the infant, and allow insight into the complex strategies infants use to control movement and posture. In standing posture, nonlinear analysis has provided insight into the type of characteristics/mechanisms of control used. For example, Newell[23] used COP data from children, adults, and the elderly by measuring standing postural sway and found that children had decreased complexity and dimensionality of the COP. Postural sway complexity and dimensionality increased from 3-year-olds to 5-year-olds, was approximately the same in 5-year-olds and adult subjects, and then decreased again in elderly subjects.[23] These data suggested that as children grow and learn about their bodies, they can have more flexible control over the body's degrees of freedom, and greater complexity and dimensionality emerges in posture and movement. Nonlinear analysis of COP data has also been used to examine differences in standing posture between healthy controls and patients with tardive dyskinesia, and it has been found that the patients exhibited decreased complexity in their sway patterns.[24] The examples from these studies and several others[16,25,26] indicate that nonlinear analysis can reveal the richness or shortage of behavioral control options[27] or describe the strategies employed for the organization of the body's degrees of freedom.[14] However, the reliability of this methodology for evaluating COP data during sitting posture in infants has not been investigated.

Therefore, the purpose of this study was to determine the reliability of linear and nonlinear tools, including intrasession and intersession reliability, when used to analyze the COP time series during the development of infant sitting postural control. Independent sitting requires dynamic stabilization of all the linked segments of the body. Through learning and adaptation, an individual's nervous system anticipates any disturbance to posture, and links segments of the body to anticipate forces before the onset of movement. We can most readily study the learning of postural control in the infant population, and especially in the sitting position, which is the first time that the infant controls the trunk in an upright posture. This learning process in the normal infant provides important clues for developing treatment tools that enhance sitting and postural skills in children with movement disorders, and may also be valuable in treating adults with acquired central nervous system injury. Based on the previous research conducted in our laboratory and described here,[14] we hypothesized that the nonlinear tools will be more reliable in assessing development of infant sitting postural control. The identification of the reliability of linear and nonlinear tools from COP data is the first but essential step for the study of therapeutic interventions directed at improving the sitting postural abilities in infants with motor developmental delays.

METHODS

Participants

Thirty-four typically developing infants were recruited for the present study. After 1 infant dropped out, 33 infants participated in this study (mean $\pm$ SD age at entry in the study, 152.4$\pm$17.6d; sex, 14 boys 19 girls; mean $\pm$ SD weight at entry in the study, 7.37$\pm$0.71kg; mean $\pm$ SD weight at end of the study, 8.53$\pm$1.03kg). The infants were followed from the age of around 5 months to 8 months, the time when infants are learning to sit independently. Infants were recruited from employee announcements at the campus of the University of Nebraska at Omaha and at the Munroe-Meyer Institute, University of Nebraska Medical Center. Before data collection commenced, the parents of the infants provided informed consent that was approved by the university human research ethics committee. The inclusion criteria for entry into the study for the infants were a score on the Peabody Gross Motor Scale II within 0.5 SD of the mean, age of about 5 months at the time of initial data collection, the ability of the child to hold up the head when supported at the thorax, beginning ability to reach for objects dangled in front of the child in supported sitting or lying on the back, propping on the elbows when in prone for 30 seconds, and propping on both arms during sitting. The exclusion criteria were (1) a score on the Peabody Gross Motor Scale II of greater than 0.5 SD below the mean, (2) diagnosed visual deficits, and (3) diagnosed musculoskeletal problems.

Experimental Design

Each infant participated in 9 sessions. The first session lasted for 45 minutes and was used to perform the Peabody Gross Motor Scale (table 1). The Peabody Gross Motor Scale II is a norm-referenced and criterion-referenced test that examines gross motor function in children from birth to 83 months.[28] The other 8 sessions were distributed over a period of 4 months. The infants were tested twice in 1 week at each of the 4 months of the study. Three trials at each session were used to determine intrasession reliability. The repeat testing within 1 week of each month's testing was used for the estimation of the intersession reliability. We were able to collect data for all 8 sessions over a period of 4 months for all infants, with the exception of 2 infants who did not come for the second session of the first month or for whom the data collected were not appropriate according to our criteria explained in the data analysis section.

Protocol

For all sessions, the infants were allowed time to get used to the laboratory setting, and were at their parent's side or on their lap for preparation and data collection. The duration of the sessions was approximately 30 minutes to 1 hour. A standard set of infant toys was used for distraction and comfort, accompanied by a DVD player, which presented infant movies. All attempts were made to maintain a calm, alert state by allowing the infant to eat if hungry and to be held by a parent for comforting, and by adapting the temperature of the room to the infant's comfort level. Infants were placed by their parent on the top of a forceplate that was covered with a special pad for warmth and securely adhered with tape on the forceplate. The baby was held in the sitting position in the middle of the plate