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ABSTRACT

Purpose: To determine whether infants born full term, infants born preterm with motor delays, and infants born preterm who have a diagnosis of cerebral palsy differed in postural control at the emergence of early sitting.

Methods: Thirty typical developing infants born at term, six infants born preterm, who were later diagnosed with cerebral palsy and five infants born preterm who were delayed in motor development participated in this study. Center of pressure (COP) data of unsupported sitting was recorded and analyzed using measures of both amount and temporal organization of COP variability.

Results: The results indicated that infants born full term, infants born preterm with motor delays, and infants born preterm who have a diagnosis of cerebral palsy exhibit dissimilar movement control strategies at the onset of sitting.

Conclusions: The present findings may be helpful in directing and testing intervention protocols in infants born preterm.

INTRODUCTION AND PURPOSE

The incidence of preterm births has increased gradually over the past two decades. The actual percentage of preterm births in 1981 was approximately 9%, while in 2004 this percentage increased to 12%.[1] Infants born preterm are likely to exhibit motor developmental delays, which is showing a lag in reaching motor developmental milestones such as sitting or walking at the expected age. The occurrence of motor delays increases with decreased gestational age.[2] Specifically, during the first 12 to 24 months of life infants born preterm often present delayed motor development.[3,4,5] These infants demonstrate less trunk extension in the supine position,[3] and when reaching for a toy they exhibit rigid postural patterns in contrast to full term infants.[6] In addition, infants born preterm present low scores on muscle tone, head control, trunk rotation, and reaction to movement evaluated with the Neuromotor Behavioral Inventory.[4] Moreover, infants born preterm could not modify and adjust their postural control when sitting and reaching for an object.[5] Even though these findings may be transitory, they are linked with difficulties in motor development and coordination at later ages.[7] Although postural issues may appear to resolve in terms of motor skills in infancy, a lack of postural control may be a factor contributing to other areas of developmental delay. For example, preterm infants who exhibited abnormal sitting posture at 6 months of age were noted to have lower scores on cognitive tasks at 18 months.[8] Therefore, infants born preterm may benefit from early motor intervention to eventually promote improved overall developmental outcomes. However, to properly design such interventions, we need to understand the mechanisms utilized by these infants to acquire early motor milestones and to correctly assess their differences from typically developing infants born at term.

The emergence of sitting postural control in early infancy changes the way infants interact with the world. From the sitting position, looking, reaching, and interacting become functional and allow exploration that supports learning and further development of motor skills. Therefore, independent sitting (does not need support from caregiver or pillow) is one of the first goals for every child. Although families and therapists accurately identify the needs and delays of infants based on differences from a normative model, the quantification and precise measurement of how movement changes presents challenges. Inherently, there are individual differences between children and it is characteristic to developmental disorders that signs during infancy are relatively unspecific. As such, it is not always clear why a specific child is not able to achieve sitting postural control. In addition, infants are often referred to early intervention with a history of prematurity and developmental delay, but without a specific motor diagnosis, such as cerebral palsy (CP), which makes it very difficult to construct a successful therapy plan to enhance sitting acquisition. Infants with motor developmental delays and infants with cerebral palsy can present completely different movement and posture profiles suggesting an enhanced need for a distinctive intervention approach.

Traditional assessment tools used by physical therapists provide a measure of delay or abnormality, but not information that easily transfers to direct intervention. For example, the amount of delay in sitting postural control can be determined (number of months away from the normal time of milestone achievement), but the reasons underlying this delay are not always apparent. Therapists can, of course, determine physical limitations of the musculoskeletal system such as muscle tightness, general strength deficits, or alignment problems with other tests including the Chailey Levels of Ability[9] or the Spinal Alignment and Range of Motion Measure,[10] but many other areas are left unaddressed, such as current strategies for postural

control, variability of those strategies, and how the strategies change over time. Strategies for postural control and variability imply slight adjustments made by the child many times per minute, and require a different measurement tool that is yet not described as a clinical measure. Thus, therapists do not have a precise and quantitative method to evaluate early postural control or to describe how these early attempts to control posture may be changing over time as a result of intervention.

Postural control measures have been found very valuable for various populations with motor and sensory disabilities. One method of examining postural control in adults and children is to measure the center of pressure (COP) at the base of support using a force platform during the task of remaining upright. The COP data have frequently been used to investigate postural control during standing in healthy adults and Parkinson's disease patients[11], as well as in healthy young children and children with cerebral palsy.[12] COP data have also been used to investigate postural control during sitting.[13-16] Another valuable aspect of COP data during infant sitting is that they translate to meaningful behavioral observations in the clinic, which has been described extensively in Dusing and Harbourne (2010).[17] It has also been found that with COP data, dynamic postural control during sitting can be assessed reliably in typically developing infants or infants with or at risk for CP.[14]

The purpose of this study was to determine whether infants born full term, infants born preterm with motor developmental delays, and infants born preterm who have a diagnosis of cerebral palsy differed in their postural control at the emergence of early independent sitting. Independent sitting in this case is referred to as unsupported by the caregiver or from any other type of back support, such as a pillow. Importantly, we investigated postural control by evaluating COP data during independent sitting and thus, using quantitative ways of exploring

postural sway in terms of COP movement variability .[13-15] We utilized nonlinear measures that can evaluate the temporal organization or "structure" of COP movement variability and linear measures that explore the amount of COP movement variability.[15-18] Based on previous research with typically developing infants and infants with CP[13-15] and that with preterm infants that evaluated control of the supine position,[16] we expected differences between groups in both linear and nonlinear measures of postural control. Therefore, we hypothesized that infants born preterm will exhibit larger and more repetitive COP movement patterns than infants born at term during sitting, similar to infants born preterm in the supine position.[16] Furthermore, based on the optimal movement variability hypothesis,[18] it is thought that typically developing infants develop the ability to sit by exhibiting an optimal range of movement variability whereas infants with CP or motor developmental delays may present either too much or too little variability leading to a very rigid and narrow or unpredictable set of movement solutions to achieve independent sitting. The dissimilarities of the COP patterns between infants with CP and infants with developmental delays have been clearly demonstrated previously.[19] Thus, we further hypothesized that infants born preterm and with CP will present differences in the COP measures in comparison to infants with motor developmental delays.

METHOD

Participants

Thirty typical developing (TD) infants born at term (mean age (SD), 5.04 (0.55) months, six infants born preterm (mean age (SD), 18.10 (4.49) months who were later diagnosed with spastic or athetoid cerebral palsy (CP) and five infants born preterm (mean age (SD), 11.56 (1.18) months days who exhibited motor developmental delays or hypotonia (DD), participated in this study. Infants were matched by developmental ability in sitting, which was selected as stage 1 or 1.5 as defined by Kyvelidou et al., 2009.[20] The inclusion criteria for the typically developing infants and the exclusion criteria for preterm infants are presented in table 1. The age of the infants born preterm is not corrected for preterm birth. Infants born preterm were less than or equal to 37 weeks of gestation and infants at term were born between 38 to 42 weeks of gestation. We divided the infants that were born preterm into one group including infants with delayed motor skills and a second group of infants born preterm and later diagnosed with spastic or athetoid cerebral palsy, because these two groups clinically exhibit different movement strategies. The children with a diagnosis of CP were diagnosed by a physician, usually a developmental pediatrician or a pediatric neurologist as part of their overall medical care. We did not request nor gather information regarding the timing of the diagnosis, or the tools used to diagnose them. We were informed of the diagnosis by the treating therapist (all the children were already receiving either occupational or physical therapy), or by the parents. The children who did not have a diagnosis of CP were called "developmentally delayed" for this study because they were already receiving early intervention services or physical therapy services because of motor delays, and they scored more than 1.5 SD below the mean on the Peabody Gross Motor Scale II.[21] Generally, infants with motor developmental delays would be considered hypotonic or

characterized by a "poverty" of movement, or decreased initiation or amount of movement. The "developmental delay" label is simple meant to indicate that they are delayed in the attainment of motor skills (more than 1.5 SD on the Peabody), without specific symptoms of CP such as abnormal muscle tone or pathological reflexes. Infants were recruited from employee announcements at the campus of the University of XXXXX at XXXXX and at the XXXXX Institute of the University of XXXXX. Before data collection commenced, the parents of the infants provided informed consent that was approved by the university human research ethics committee.

Instrumentation and Procedures

Each child was screened using the Peabody Gross Motor Scale II.[21] Each infant performed two experimental sessions, which were within a week at the onset of the sitting skill for all infants. Infants were selected to be at Stage 1 or 1.5 of sitting, which is defined as prop sitting, or moving briefly out of propsitting, but going back to it.[20] The duration of this session was approximately 30 min to one hour. All attempts were made to maintain a calm, alert state by allowing the infant to eat if hungry, be held by a parent for comforting, or adapting the temperature of the room to the infant's comfort level.

After the parent undressed the child, the infants were placed by their parent on the top of a force platform that was covered with a pad, which was securely adhered with tape on the force platform. The baby was placed in the sitting position in the middle of the platform when calm and happy (Figure 1). The investigator and the parent remained at one side and in front of the infant respectively during all data collection to assure the infant did not fall or become insecure. Trials were performed until we had collected three trials that were acceptable for our criteria, or until the infants were no longer cooperative. Acceptable sitting criteria were: a) infant did not

move the arms (not reaching, holding an object, or flapping their arms), b) infant did not vocalize or cry, c) infant was not in the process of falling, d) thorax was not inclined more than 45 degrees to either side, e) not being touched, f) the arm position (propping or not propping) of the infants was noted during the entire trial and only trials that have the infant using consistent base of support was used.

For data acquisition, infants sat on an AMTI force platform interfaced to a computer system running Vicon data acquisition software. COP data in both the anterior-posterior (AP) and the medial-lateral (ML) directions were acquired through the Vicon software at 240 Hz. No filtering was performed on the data because such a procedure can affect the variability present in the signal and especially the nonlinear analysis.[22] Video of each trial was collected and the cameras were positioned to record a sagittal (AP direction) and a frontal (ML direction) view of the subject. The three segments of acceptable data (8.3sec each) were selected from the videotaped record at each session and analyzed exactly as described by Kyvelidou et al., (2010).[19] This duration was chosen based on the sampling frequency used (established through a power spectra analysis of the COP data) and the amount of time that infants can sustain upright sitting at the onset of the skill. The same time series were used for linear and nonlinear analyses. The COP movement variability was analyzed using both linear and non-linear measures for each segment. The linear measure included was the Range for both the AP and the ML directions, which is the absolute value of the difference between the smallest and largest values in the time series. To calculate Range we utilized customized MatLab software according to the methodology of Prieto et al., (1996)[23]. The nonlinear measure included was the largest Lyapunov exponent (LyE) for both the AP and the ML directions using the Chaos Data Analyzer software. According to the methodology described by Harbourne and Stergiou (2003)[13] we firstly created a three-

dimensional state space from the COP time series. The LyE is the slope of the average logarithmic divergence of the neighboring trajectories of the above reconstructed time series. In summary, LyE is a measure of the rate at which nearby trajectories in state space diverge.

Statistical Analysis

The means of the acceptable segments from the nonlinear and linear measures were averaged across the two experimental sessions. These means were compared among the three groups using a one way ANOVA model. Post-hoc pair-wise comparisons were performed using the Tukey test. All statistical comparisons were completed using SPSS version 16.0 with alpha equal to 0.05.

RESULTS

We found significant differences between groups with respect to the linear measure. Range in the AP direction showed significant differences among groups ($F(2,38)=3.376$, $p=0.045$), while there were no significant differences observed in the ML direction. Post hoc testing revealed that the group with CP had significantly lower Range values in the AP direction than the group with DD (CI: 0.009-32.58, Figure 2). There were no significant differences observed between the group with TD and either the group with CP or DD (Figure 2).

We also found significant differences between groups with respect to the nonlinear measure. LyE in the AP direction showed significant differences among groups ($F(2,38)=4.983$, $p<0.012$), as well as in the ML direction ($F(2,38)=5.893$, $p<0.006$) (Figure 3). Specifically, the group with TD had significantly greater LyE values in the AP direction than the group with CP (CI: 0.001-0.025, Figure 3). There were no significant differences between the groups with TD and DD neither between the groups with DD and CP in the LyE in the AP direction. In the ML direction, the group with CP had significantly lower LyE values than the groups with TD and DD (CI: 0.003-0.019 and 0.0007-0.022), while there were no differences between the groups with TD and DD (Figure 3).

DISCUSSION

The purpose of this study was to determine whether infants born full term, infants born preterm with motor developmental delays (DD), and infants born preterm who have a diagnosis of cerebral palsy (CP) differed in their postural control at the emergence of early independent sitting. We investigated postural control by evaluating COP data during independent sitting using linear and nonlinear measures that specifically explore COP movement variability. Our results showed that the linear measure of Range of the COP in the AP direction differentiated the infants with CP from the infants with DD. The nonlinear measure of LyE in the AP direction differentiated the infants with CP from the infants with typical development. LyE in the medial lateral direction differentiated the infants with CP from both the typically developing infants and the infants with DD.

Although therapists often describe posture or motor control problems qualitatively, quantification of postural control in infants has been lacking. The use of linear and nonlinear variables that quantify the movement of the path of the COP provides a reflection of overall postural control, and strongly supports what clinicians already know in qualitative terms.[18] Infants with CP have less excursion of the COP in the AP direction than infants with DD. This is likely because most of the infants with CP were spastic and due to the overall stiffness caused by reducing the degrees of freedom during sitting to better maintain stability. On the other hand, infants with DD were overall delayed without exhibiting any spastic characteristics. Significant differences were not found in the medial lateral direction, which may be due to the fact that the children were not reaching or challenging themselves in any way during data collection. Considering that they are at the onset of sitting, reaching is certainly the least of their concerns, while maintain upright posture is fundamental. Furthermore, for the most part, infants sat in a

circle sit posture (Figure 1), which biomechanically provides a stable base and little sway possibility in the medial lateral direction.

For the nonlinear measure of LyE, infants with CP had lower values than either the infants with TD or the infants with DD. This supports what therapists understand as fewer strategies for controlling the COP. It seems that children with CP do not have as many options for movement as children with typical development or infants with simple delays in development. The problems of children with CP include stiffness, an inability to selectively control multiple combinations of muscles during activity, as well as a problem with speed in turning muscles on and off quickly enough to respond to postural demands.[24] Lower values of the LyE in both directions of sway indicate fewer options, or a tendency for less divergence of the movement trajectory of the COP with more repetitive COP movement patterns, as the infants attempt to maintain sitting postural control.

Implications for potential applications to interventions are suggested by these findings. Variability has not traditionally been a feature of sitting that is a direct focus in physical therapy. Usually the focus is getting a child to be stable in the sitting position, such as providing adaptive seating or some type of sitting support, not necessarily working towards increased variability in sitting. Therapists may note that a child lacks multiple strategies for maintaining sitting posture, which leads to both goal setting options (increase number of strategies) as well as ideas for intervention (trying multiple ways to encourage adaptation of sitting posture during daily activities). This would be a different strategy than providing specialized seating with many supports, and rather would allow the child to make multiple adjustments in order to expand strategy selection.

The findings from the COP analysis may also be useful in planning intervention. Noting that infants with developmental delay have increased range of sway in the AP direction than infants with typical development, activities and guidance for these children could focus on limiting or confining the region of sway during sitting. On the other hand, infants with CP have significantly decreased range of sway, and need to be encouraged to reach outside their region of sway, or expand their sway region during sitting. Likewise, infants with CP need not only to expand the range of sway, but also the number of strategies used. Infants with CP are essentially too stable and rigid, and need to learn to control movement variability and solve the problems that will occur with expanding their exploration in the sitting position. Thus, it is critical to physical therapists to be able to individualize their treatment approach based on their clinical findings and not due to prematurity.

It is important to mention that one of the limitations of the present study is that it represents a retrospective evaluation of data previously collected in addition to the limited sample size per group. Therefore, we were not able to collect important clinical data, such as gestational age, birth weight, neonatal morbidity and brain sequelae, which are important clinical characteristics when examining infants born prematurely. This sample also does not represent children who may have more severe limitations and could not achieve sitting for several seconds. Infants with more severe postural control problems are likely to be appropriately evaluated and treated using some of the clinical tests currently utilized by therapists, including standardized assessments such as the GMFM,[25] and the Chailey levels of ability.[9]

Conclusions

In achieving independent sitting, preterm infants with DD and preterm infants with CP exhibit different types of problems in their sitting postural control as revealed by linear and

nonlinear analysis of the COP movement variability. These problems can be quantified by analysis of COP movement variability, which may be helpful in directing intervention.

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Table 1.

Inclusion Criteria for Infants Developing Typically and Exclusion Criteria for Infants Born Preterm

Inclusion criteria for infants developing typically
Score on the Peabody Gross Motor Scale II within 0.5 SD of the mean
Age between 4 and 5 mo
Ability to sit independently even with the use of hands
Exclusion criteria for infants born preterm
Score on the Peabody Gross Motor Scale II greater than 1.5 SD below the mean for corrected age
Older than 2 y
Diagnosed visual impairment or diagnosed hip dislocation or subluxation greater than 50%

FIGURE LEGENDS

Figure 1. Position of the infant during data collection.

Figure 2. Range in the anterior/posterior (AP) and medial/lateral (ML) direction. The *Asterisk indicates statistically significant differences between the infants with DD and CP. Error bars represent standard deviation.

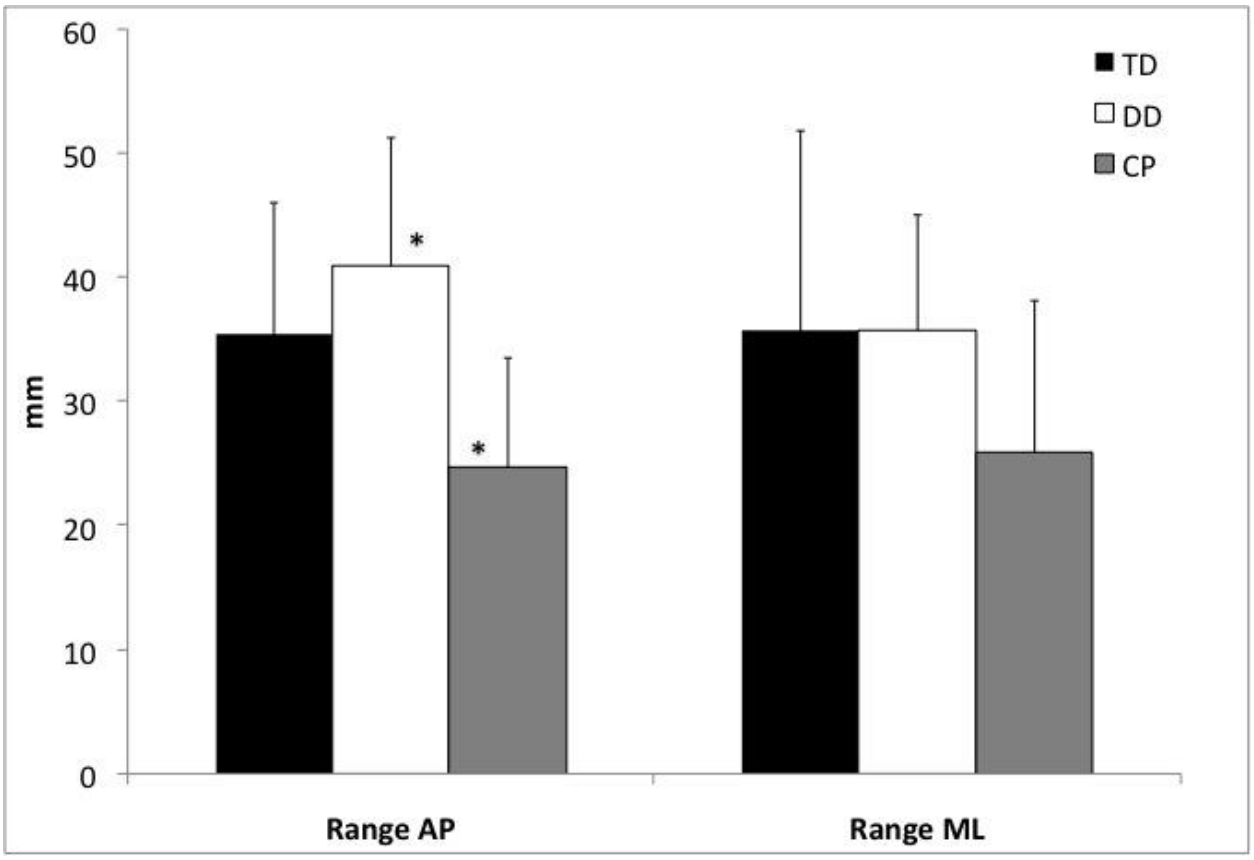

Figure 3. LyE in the anterior/posterior (AP) and medial/lateral (ML) direction. The *Asterisk indicates statistically significant differences between the infants with TD and CP in the AP direction. The # Pound symbol indicates statistically significant differences between the infants with DD and CP in the ML direction. The & And symbol indicates statistically significant differences between the infants with TD and CP in the ML direction. Error bars represent standard deviation.