University of Nebraska at Omaha
DigitalCommons@UNO

Journal Articles   Department of Biomechanics

Fall 2010

Severity and Characteristics of Developmental Delay Can Be Assessed Using Variability Measures of Sitting Posture

Anastasia Kyvelidou
University of Nebraska at Omaha, akyvelidou@unomaha.edu

Regina T. Harbourne
University of Nebraska Medical Center

Nicholas Stergiou
University of Nebraska at Omaha, nstergiou@unomaha.edu

Follow this and additional works at: https://digitalcommons.unomaha.edu/biomechanicsarticles

Part of the Biomechanics Commons

Abstract

Purpose: We sought to identify measures of variability from sitting postural sway that are significantly different among typical, developmentally delayed or hypotonic infants, and infants that were later diagnosed with spastic or athetoid cerebral palsy.

Methods: Sixty-five infants were evaluated when they were just developing the ability to sit upright, by assessing center of pressure (COP) data using measures of both amount and temporal organization of COP variability.

Results: The results indicated that measures of variability of COP could discriminate between infants with developmental delay and infants with cerebral palsy and add to the description of sitting postural behavior.

Conclusions: Our method of evaluating sitting postural control could be an objective tool to help describe distinctive features of motor delay in an individual infant, and could lead in the design of selective therapeutic interventions for improving postural control of infants with motor delays.

Text

Introduction and Purpose

During sitting development in early infancy, weight may shift within the base of support due to emerging motor control skills, active exploration of postural control strategies, or body, arm and head movement used to respond to or explore the environment. The existing literature on infant sitting postural control includes kinematic and electromyographic analysis to describe sitting posture[1,2]. Prior to sitting independence, infants present high variation in the recruitment patterns of muscle activation. However, these variations decrease over time, enabling the selection of the most appropriate muscle synergy and the development of sitting[2]. These synergies in typically developing infants learning to sit can be viewed as a progression from an in-phase (moving in the same direction) to an out-of-phase (moving in an opposite direction) coordinative relationship between the thorax and the pelvis segments[1]. Infant sitting postural adjustments have also been investigated during reaching[3] and it has been found that the development of postural changes during reaching while sitting presented a nonlinear and prolonged path[3]. Recently, postural sway investigation has also been utilized to investigate sitting postural control[4,5]. In one of those previous experiments,[5] the infants sat on an inclined bicycle seat with a rigid back, which restricts infant movement and masks the true nature of the infant sitting pattern. However, Harbourne and Stergiou[4] investigated the development of sitting in healthy infants without restricting the postural behavior by exploring the variability present in center of pressure (COP) data and they identified nonlinear behavioral characteristics.

Movement variability can be viewed and interpreted differently, depending on the theoretical bases of motor control[6]. Hierarchical theories suggest that variability is error in the

control system, which operates like a thermostat to keep the temperature at one preferred value. From this perspective, the goal of postural control in sitting would be to return to the optimal point of stability with slight variation around that point. In contrast, recent theoretical approaches, such as dynamical systems, perception-action and the hypothesis of an optimal state of variability[6] suggest that variability benefits the organism by facilitating the exploration of the environment. Thus, the goal of postural control in sitting would be to explore diverse movement solutions by swaying within the stability limits[6]. Furthermore, recent literature from several disciplines, including brain function and disease dynamics have shown that many biological phenomena are the result of nonlinear interactions and have deterministic origins[7]. As such, behavior that was previously considered as error, i.e. slight variations of postural sway, may provide important information regarding the system that produced it. Such information can further our goal of improving intervention for children with posture and movement problems. For example, an infant with delayed sitting postural control may receive a different intervention depending on the theoretical perspective of the therapist regarding variability[8]. If the therapist believes that variability of postural sway is error in the system, then he will try to support the infant in biomechanical alignment (such as a supportive seat), and avoid variable sitting behavior. Conversely, a therapist who views postural variability as an inherent, healthy behavior will facilitate a more explorative type of treatment, where the infant experiences multiple postural strategies and is allowed to select sitting positions that may not be considered completely the best by the therapist. However, to determine which approach better promotes the acquisition of functional sitting skill, there is a need for a quantitative and objective experimental paradigm that will test not only how much variability an infant exhibits but also the pattern or structure of the variable behavior.

In an attempt to uncover both properties of infant sitting posture, Harbourne and Stergiou[9], investigated sitting development using linear and nonlinear parameters derived from COP data based on the dynamical systems perspective. Linear methods include measures from traditional statistics, such as range and root-mean-square, and provide insight regarding the amount of variability present in the COP time series. Alternatively, nonlinear methods provide insight on the temporal organization or structure of the variability present in the data by examining the patterns and the order that exist in the COP data[6]. Nonlinear methods were found to be sensitive in detecting subtle changes occurring during the normal maturation process of infants during sitting[9]. Since there is a method that can objectively quantify sitting posture in infants, then the next logical step would be to investigate whether this experimental paradigm, proposed by Harbourne and Stergiou[9], can differentiate types of postural behavior in infants who are typically developing, or who have different types of movement or postural disorders. Quantification of postural control can lead to improved intervention for children with posture and movement problems.

Currently, a child with developmental delay is identified by abnormal neurological signs 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 have several drawbacks. These tests vary in their specificity and sensitivity[10] and are incomplete in predicting progress or developmental outcome for an individual child[11]. They may only be useful at a specific age[12] or may only measure progress by assessing large changes in motor skills, without being precise enough to provide information regarding rate of acquisition of skill on a short-term basis. It should be noted that even though these tests have been presented to be reliable methods of describing development and detecting developmental delay they are still

subjective tests. Moreover, a diagnosis of cerebral palsy for a child that is developmentally delayed is often delayed until the age of two years because many of the usual clinical signs may be transient[13,14]. Therefore, postural control measurements may be useful in helping to differentiate the degree of severity (developmentally delayed, cerebral palsy) of the disability in infants between the ages of 4 months to two years, such as in the sitting postural development paradigm proposed by Harbourne and Stergiou[9]. This paradigm is useful due to the simplicity of the model as well as the analytical method proposed. The experimental design of this paradigm requires the infant to sit on a force plate, as if sitting on the floor, thus the risk is minimal for the infant and the collection of data is accomplished without difficulty. In addition, the mathematical analysis of the COP data investigates infant sitting postural development from two different perspectives, that of amount and structure of variability, which provides a constellation of features inherent in each infant's sitting posture. As a result, the investigation of sitting postural control by using linear and nonlinear measures of the COP data promises to give insight into the individual differences which describe the severity of disability in an infant, and which may make the infant distinct from others with a similar clinical presentation.

Therefore, the purpose of the present study was to identify measures of variability from sitting postural sway that are significantly different among typical, developmentally delayed infants, and infants with cerebral palsy. A secondary goal was to identify types of postural sitting behavior that will be of importance to physical therapists when designing intervention for infants that are delayed or have cerebral palsy. We hypothesized that linear and nonlinear measures of sitting postural sway variability will be able to differentiate between infants with dissimilar severity of disability as well as describing different types of postural behavior among these three groups of infants. Ultimately these measures may be useful in the identification of infants who

would benefit from different types of early intervention as well as in the evaluation of various therapeutic protocols.

Methods

Participants

Thirty five typical developing (TD) infants, (mean age ± standard deviation,152.4 ± 8.9 days or 5.1 ± 0.3 months; gender, 18 males and 17 females), 11 infants with developmental delay (DD, mean age ± standard deviation, 360.3 ± 74.8 days or 12 ± 2.5 months) and 19 infants (mean age ± standard deviation, 486.8 ± 175.1 days or 16.2 ± 5.8 months) with developmental delay or hypotonia, who were later diagnosed with spastic or athetoid cerebral palsy (CP) participated in this study (Table 1). Infants were recruited from employee announcements at the campus of the University of Nebraska at Omaha and at the Munroe-Meyer Institute of the University of Nebraska Medical Center, as well as from early intervention programs and therapists from the University of Nebraska Medical Center and the surrounding area. 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 typically developing infants were: a) a score on the Peabody Developmental Motor Scale-2, Gross Motor Quotient, within 0.5SD of the mean, b) age between five and seven months and c) sitting independently with or without the use of hands. The exclusion criteria for the typically developing infants were: a) a score on the Peabody Developmental Motor Scale-2, Gross Motor Quotient of greater than 0.5 SD below the mean, b) diagnosed visual deficits, and c) diagnosed musculoskeletal problems. Inclusion criteria for the developmentally delayed infants (both CP and DD) were: a) age from seven months to

two years, b) score less than 1.5 SD below the mean for their corrected age on the Peabody Developmental Motor Scale-2, Gross Motor Quotient, and c) sitting independently even with the use of hands. Exclusion criteria for developmentally delayed infants were: a) age over two years, b) a score greater than 1.5 SD below the mean for their corrected age on the Peabody Developmental Motor Scale-2, Gross Motor Quotient, and c) a diagnosed visual impairment, or a diagnosed hip dislocation or subluxation greater than 50%.

Experimental Design and Protocol

Each infant participated in two sessions. The first session lasted for 45 minutes and was used to perform the Peabody Developmental Motor Scale-2. This standardized test is norm-and criterion-referenced, which examines gross motor function in children from birth to 83 months. The experimental session took place within a week.

For the experimental session, 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. A standard set of infant toys was used for distraction and comfort. 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 child was undressed by the mother (only diapers on), two sets of triangles with one reflective marker in each corner were glued with a double face tape in two locations (Figure 1A). However, the marker data were not analyzed for this study.

The infants were then placed by their parent on the top of a force plate that was covered with a special pad for warmth, which was securely adhered with tape on the force plate. The baby was held in the sitting position in the middle of the plate when calm and happy (Figure 1B). 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. The child was held at the thorax for support, and gradually the infant was guided into a prop sitting position while being distracted by toys presented by the parent or the investigator. Once the examiner could completely let go of the infant, data were collected continuously while the child attempted to maintain postural control (Figure 1B). Trials were performed until we had collected three trials that were acceptable for our criteria (see below), or until the infants were indicating that they were done. At any time the child became irritated; the data collection was halted for comforting by the parent, or a chance for feeding, and then resumed only when the child was again in a calm state.

---------------------------------Place Figures 1A and 1B here---

Data analysis

For data acquisition, infants sat on an AMTI force plate (Watertown, MA), interfaced to a computer system running Vicon data acquisition software (Lake Forest, CA). COP data from both the anterior-posterior (AP) and the medial-lateral (ML) directions were acquired through the Vicon software at 240 Hz, in order to be above a factor of ten higher than the highest frequency contained in the signal. No filtering was performed on the data because such a procedure can affect the nonlinear results[16]. Video of each trial was collected using two Panasonic recorders (Model 5100 HS) interfaced with a Panasonic Digital AV Mixer (Model WJ-MX30). The cameras were positioned to record a sagittal and a frontal view of the subject (Figures 1A and 1B).

Three acceptable trials (8.3sec) were selected from the videotape record using the following criteria: 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) trunk 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.

Linear measures of the variability present in postural sway were calculated from the selected trials using customized MatLab software (Mathworks, Natick, MA) from the COP time series, based on the methodology of Prieto, Myklebust, Hoffmann, Lovett, and Myklebust[17]. The linear measures calculated were the root-mean-square (RMS) and the maximum minus minimum (range) for the AP and the ML directions, as well as the length of the path traced by the COP (sway path). These parameters were selected according to Chiari et al.[18] and they are all independent to the effect of biomechanical factors such as weight, which changes dramatically during development. These linear measures characterized the amount of variability present in the COP data[6].

In addition, three nonlinear measures of variability were calculated from the selected trials: the approximate entropy (ApEn), the largest Lyapunov exponent (LyE), and the correlation dimension (CoD) for both the AP and the ML directions. Rather than quantifying the magnitude of variability as the linear measures do, the nonlinear measures are sensitive to temporal ordering in the data. Nonlinear measures of the variability present in postural sway were calculated from the COP time series as described by Harbourne and Stergiou[9], and the methodology for these calculations have been published previously[19, 20].

Statistical Analysis

All results from the individual trials and experimental sessions were averaged for each infant and for all linear and nonlinear parameters. Thereafter, one-way analysis of variance (ANOVA) with a test for linear trend was performed for comparisons among groups. A Tukey multiple comparison post hoc analysis was used to identify the location of the significant differences for all tests resulting in a significant F-ratio. The level of significance was set at 0.05.

Results

Linear Parameters

Range in the ML direction ($F(2,62)=3.276$, $p=0.044$) and sway path ($F(2,62)=7.620$, $p=0.001$) presented significant differences among groups of infants. No significant differences were found for range in AP direction and RMS in AP and ML directions. Post hoc analysis revealed that range in the ML direction was significantly different between TD and CP infants (Figure 2) with infants with CP presenting smaller values than TD. For sway path the post hoc analysis revealed significant differences between the TD and the CP groups as well as between the DD and the CP groups. No differences were found between the TD and DD groups. Infants with CP had lower sway path values than the TD and the DD infants (Figure 3). Lastly, there was no statistically significant trend in any of the linear parameters examined.

-------------------------------Insert Figures 2 and 3 here--

Nonlinear Parameters

LyE in AP ($F(2,62)=4.912$, $p=0.01$) and ML ($F(2,62)=3.618$, $p=0.033$) direction presented significant differences among groups of infants. No significant differences were found for ApEn and CoD in AP and ML directions. Post hoc analysis revealed that LyE in the AP direction was

significantly different between TD and CP infants (Figure 4) with CP infants presenting smaller LyE values than TD. For LyE in the ML direction the post hoc analysis revealed significant differences between TD and CP infants (Figure 5) with CP infants presenting smaller LyE values than TD. No differences were found between the TD and DD infant groups as well as between the DD and CP infant groups. Lastly, there was a statistically significant linear trend for LyE in both AP ($F_{(2,62)}$=8.742, p=0.004) and ML ($F_{(2,62)}$=7.009, p=0.01) directions.

--------------------------------Insert Figures 4 and 5 here---

For all linear and nonlinear variables that presented statistical significant differences, more than 60% of the children followed the group findings.

Discussion

The purpose of the present study was to identify measures of variability in sitting postural sway that are significantly different among typical, developmentally delayed or hypotonic infants and infants with spastic or athetoid cerebral palsy. We hypothesized that linear and nonlinear measures of sitting postural sway variability differentiate infants with varying degrees of disability as well as describe different types of postural behavior among these three groups of infants, and this hypothesis was supported. Two linear (range in the ML direction, sway path) and two nonlinear (LyE in AP and ML directions) parameters presented significant differences between infants who were typically developing and infants with cerebral palsy, while these same variables did not show a significant difference between typically developing infants and infants with developmental delay.

A secondary goal was to identify types of postural sitting behavior that are of importance to physical therapists when treating infants who are delayed or have cerebral palsy. TD and DD infants present similar amounts of variability as described by the range variable, while infants with CP have a reduced amount of range. Our analysis indicated that range, specifically in the ML direction, was decreased in infants with CP. These results suggest that infants with CP, who acquire the sitting skill, present a rather stiff posture, especially in the ML direction, indicating a particular lack of variability for movement within the frontal plane. Another linear variable, sway path, indicated decreased amount and velocity of movement adjustments to the COP in infants with cerebral palsy as compared to the TD and DD infants. Thus, both range in the medial-lateral direction and velocity of changes in the path of the COP could be targeted for improvements in infants with CP who are learning to sit.

In addition, the temporal organization of the postural sitting behavior declined with severity from TD to DD to the infants with CP. TD infants had more divergence in the postural sway trajectories (higher LyE values), which indicates greater adaptability and flexibility to achieve the sitting skill by choosing from a wealth of postural solutions. In contrast, DD infants were less flexible than TD infants (smaller LyE values; Figures 4 and 5), while infants with CP are the least flexible. Infants with CP seem to lock into a very limited repertoire of postural solutions, which makes it difficult to adapt to changing environmental conditions and to sit independently. If we will consider that the TD infants are behaving in a more optimal state of variability, then the severity of disease pushes the system further away from this behavior and this state.[8] Interventions could target a transition towards this optimal state by incorporating environmental challenges and enhancing postural solutions. This can enhance adaptability and flexibility.[8]

Characterizing the temporal organization of the variability present in the COP patterns (i.e. nonlinear analysis) or, in other words, how the movement evolves over time we were able to show how the postural sway of DD infants is different from TD and CP. The significant linear trend of LyE in both AP and ML direction suggests that typically developing infants are able to maintain their sitting posture successfully when internal perturbations affect the dynamics of the system. Decreasing values of LyE across groups of developmental delay suggests decreased dynamic control and ability to explore the environment in contrast with infants with no delay that show optimal dynamic control. Therefore, in terms of early intervention approaches, therapists should be enhancing exploration of multiple postural behaviors to make both infants with DD and infants with CP more diverse and thus adaptable to different conditions.

There are a few limitations that need to be acknowledged. First, because we enrolled infants just as they were able to sit upright, the DD and CP infants were older than the infants with typical development. The difference in age may contribute to differences in postural strategies. However, our assessments of motor skills ensured a similar entry point in the research study. Another limitation was that we did not include infants who had mild delays (between .5 and 1.5 SD from the mean in the Peabody Gross Motor Scale) and inclusion of these infants may alter the findings. We plan to explore such infants in future studies. We realize that these are the very children that are a dilemma for the physicians and early assessment clinics. Furthermore, because nonlinear measurement tools require the use of mathematical equations and software to evaluate time series data, nonlinear analysis is primarily done in the research setting. This makes the translation of the concepts to the clinic difficult. However, we anticipate that in the future, improvements in technology and the decreasing cost of high tech devices will become more prevalent, and that clinical decision making will incorporate technical advances such as

nonlinear measures of time series data to determine optimal intervention, and the success of these interventions. It is possible that these procedures will be used with a portable force platform to improve assessment within the home and outside of the clinic. The cost of such equipment will likely be offset by improvements in the prognosis and prescription of intervention services.

Conclusions

This research determined that linear and nonlinear analysis of COP time series during sitting in TD, DD and CP infants could be a useful, objective and quantitative method of distinguishing between different degrees of developmental delay and types of postural behaviors. Therefore, the evaluation of sitting postural control using linear and nonlinear tools of COP time series appears to be a viable method for the early quantification of postural control which can be used to document incremental changes in sitting postural control due to an intervention in infants with motor deficiencies. In addition, our findings have clinical implications supporting the notion that therapists should encourage variability and multiple postural strategies during intervention toward goals related to sitting independence.

References

1. Kyvelidou A, Stuberg WA, Harbourne RT, Deffeyes JE, Blanke D, Stergiou N. Development of upper body coordination during sitting in typically developing infants. *Pediatr Res*. 2009;65:553-558.

2. Hadders-Algra M, Brogren E, Forssberg H. Ontogeny of postural adjustments during sitting in infancy: variation, selection and modulation. *J Physiol*. 1996;493:273-288.

3. van der Heide JC, Otten B, van Eykern LA, Hadders-Algra M. Development of postural adjustments during reaching in sitting children. *Exp Brain Res*. 2003;151:32-45.

4. Harbourne RT, Stergiou N. Nonlinear analysis of the development of sitting postural control. *Dev Psychobiol*. 2003;42:368-377.

5. Bertenthal BI, Rose JL, Bai DL. Perception-action coupling in the development of visual control of posture. *J Exp Psychol Hum Percept Perform*. 1997;23:1631-1643.

6. Stergiou N, Harbourne R, Cavanaugh J. Optimal movement variability: a new theoretical perspective for neurologic physical therapy. *J Neurol Phys Ther*. 2006;30:120-129.

7. Pincus SM, Gladstone IM, Ehrenkranz RA. A regularity statistic for medical data analysis. *J Clin Monit*. 1991;7:335-345.

8. Harbourne RT, Stergiou N. Movement variability and the use of nonlinear tools: principles to guide physical therapist practice. *Phys Ther*. 2009;89:267-282.

9. Harbourne RT, Stergiou N. Nonlinear analysis of the development of sitting postural control. *Dev Psychobiol*. 2003;42:368-377.

10. Campbell SK. The infant at risk for developmental disability. In: Campbell SK, ed.*Decision Making in Pediatric Neurologic Physical Therapy*.Philadelphia, PA: Churchhill Livingstone; 1999:260-332.

11. Campbell SK, Wilhelm IJ. Development from birth to 3 years of age of 15 children at high risk for central nervous system dysfunction. Interim report. *Phys Ther*. 1985;65:463-469.

12. Hadders-Algra M. Evaluation of motor function in young infants by means of the assessment of general movements: a review. *Pediatr Phys Ther*. 2001;13:27-36.

13. Palmer FB. Strategies for the early diagnosis of cerebral palsy. *J Pediatr.* 2004;145:S8-S1.

14. Nelson KB, Ellenberg JH. Children who ''outgrew'' cerebral palsy. *Pediatrics* 1982;69:529-536.

15. Hadders-Algra M, van der Heide JC, Fock JM, Stremmelaar E, van Eykern LA, Otten B. Effect of seat surface inclination on postural control during reaching in preterm children with cerebral palsy. *Phys Ther*. 2007;87:861-871.

16. Stergiou N, Buzzi UH, Kurz MJ, Heidel J. Nonlinear tools in human movement. In: Stergiou N, ed. *Innovative analyses for human movment.* Champaign, IL: Human Kinetics Publishers; 2004:63-90.

17. Prieto TE, Myklebust JB, Hoffmann RG, Lovett EG, Myklebust BM. Measures of postural steadiness: differences between healthy young and elderly adults. *IEEE Trans Biomed Eng*. 1996;43:956-966.

18. Chiari L, Rocchi L, Cappello A. Stabilometric parameters are affected by anthropometry and foot placement. *Clin Biomech (Bristol, Avon)*. 2002;17:666-677.

19. Kyvelidou A, Harbourne RT, Stuberg WA, Sun J, Stergiou N. Reliability of center of pressure measures for assessing the development of infant sitting postural control. *Arch Phys Med Rehabil*. 2009;90:1176-1184

20. Harbourne RT, Deffeyes JE, Kyvelidou A, Stergiou N. Complexity of postural control in infants: linear and nonlinear features revealed by principal component analysis. *Nonlinear Dynamics Psychol Life Sci.* 2009;13:123-144.

Figure Legends

Figure 1A - Rear view of the position of the infant during data collection. Kinematic data were not evaluated in this study.

Figure 1B - Side view of the position of the infant during data collection

Figure 2. Range in the mediolateral (ML) direction presented significant differences among the groups of infants. *Asterisk indicates significant differences.
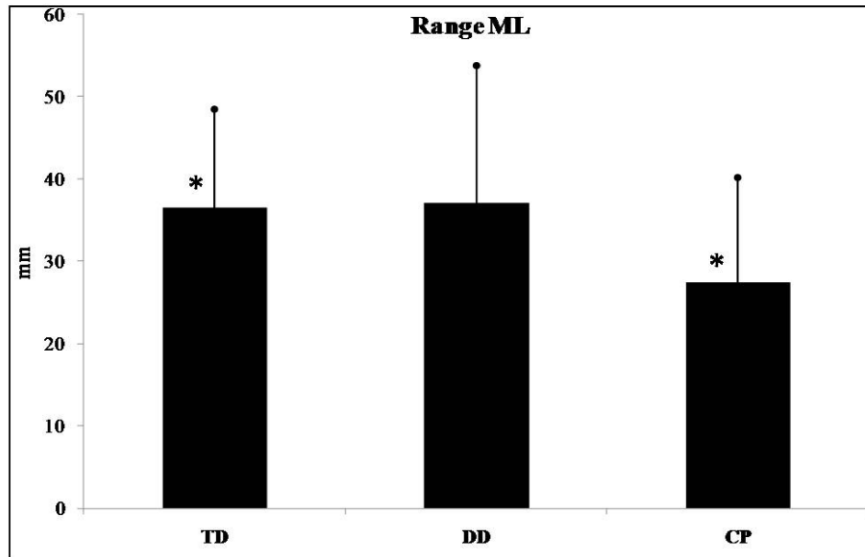

Figure 3. Sway path presented significant differences among the groups of infants. *Asterisk indicates significant differences.
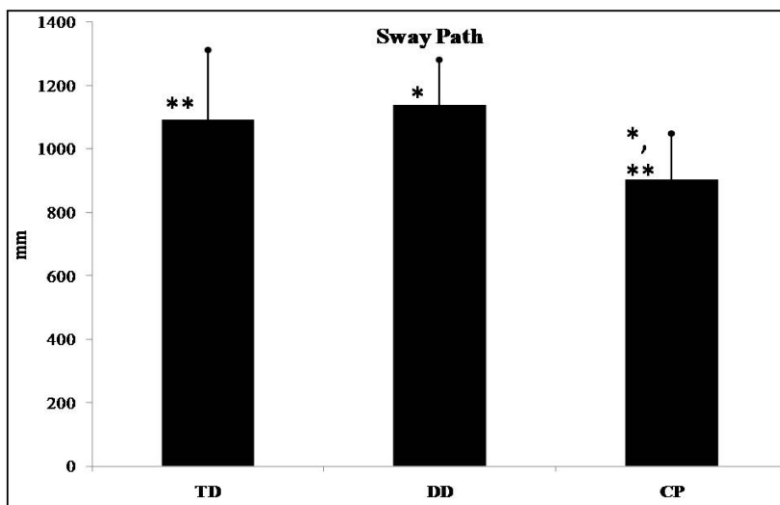
Figure 4. LyE in the anterior/posterior (AP) direction presented significant differences among the groups of infants. *Asterisk indicates significant differences.
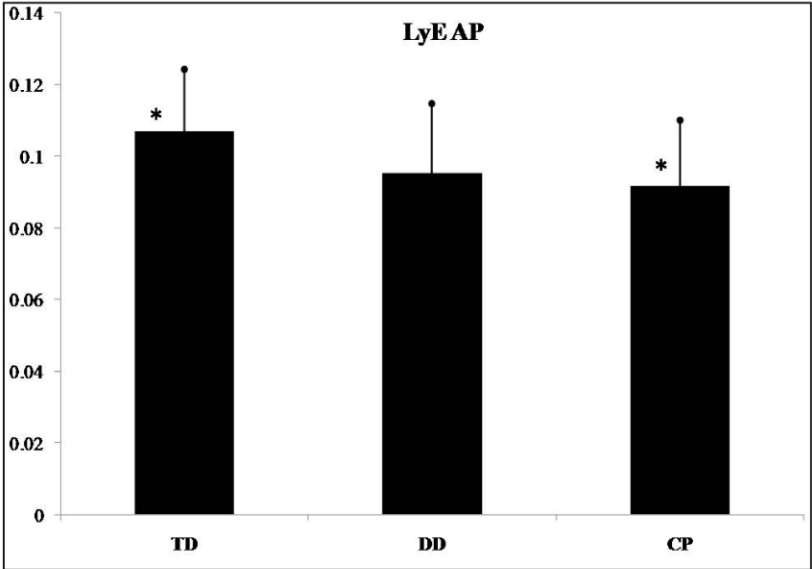

Figure 5. LyE in the mediolateral (ML) direction presented significant differences among the groups of infants. *Asterisk indicates significant differences.