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Infant born preterm have delayed development of adaptive postural control in the first 5 months of life

Stacey C Dusing, PT, PhD, PCS,

Director, Motor Development Lab, Associate Professor, Department of Physical Therapy,
Associate Professor, Department of Pediatrics, Virginia Commonwealth University

Leroy R. Thacker, PhD, and

Assistant Professor, School of Nursing, Virginia Commonwealth University

James C Galloway, PT, PhD

Professor, Department of Physical Therapy, Biomechanics and Movement Sciences Program,
University of Delaware

Stacey C Dusing: scdusing@vcu.edu; Leroy R. Thacker: s2lrthac@vcu.edu; James C Galloway: jacgallo@udel.edu

1. Introduction

Healthy, typically developing infants learn about the world around them through the interaction between their abilities and their experiences.(Gibson 1988, Lobo, Kokkoni et al. 2014) However, infants born preterm often have different early experiences in the Neonatal Intensive Care Unit (NICU) and medical factors that may alter their experiences in the first year of life.(Als, Duffy et al. 2004, Vandenberg 2007) While it has been well documented that infants born preterm are at high-risk of cerebral palsy, developmental coordination disorder, and learning disabilities(Allen, Cristofalo et al. 2011, Potharst, van Wassenae-Leemhuis et al. 2013, Serenius, Kallen et al. 2013), there has been less research on how infants born preterm learn from the environment during the first year of life.(Heathcock, Bhat et al. 2004) In the following sections we will highlight the role of postural control, experience, and the ability to adapt postural control during development in healthy infants and infants born preterm. The purpose of this study is to fill knowledge gaps on the development of adaptive postural control in infants born preterm. Postural variability, postural complexity and adaptive postural control are important concepts in a modern understanding of postural development.

Address all correspondence to: Stacey C. Dusing, PhD, PT, PCS, Director, Motor Development Lab, Associate Professor, Department of Physical Therapy, Virginia Commonwealth University, PO BOX 980224, Richmond VA 23298, 804-628-3632, Fax: 804-828-8111, scdusing@vcu.edu.

This research was approved by the Internal Review Board for the Protection of Human Subjects at Virginia Commonwealth University. Parents of each enrolled infant signed an approved consent form prior to their infant's participation. This research was conducted in accordance with APA ethical standards in the treatment of the study sample.

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1.1 Postural Control Experience and Adaptation

Postural control involves controlling the body's position in order to maintain an appropriate relationship between body segments and the environment while having stability.(Prieto, Myklebust et al. 1996) Through experience, infants learn to maintain postural control while interacting within an environment. This requires a complex interaction of developing systems including the sensory, motor, and physiological systems.(Reed 1982, Goldfield 1995)

Postural variability is a measure of the magnitude of displacement of the center of pressure around a mean value, or the amount of sway utilized during a task. Historically, postural variability was considered to measure error in the postural control system.(Stergiou and Decker 2011) Postural complexity is the repeatability of the postural control strategy or degree of overlap in the sway paths during a task. Optimal postural complexity is a midrange of complexity in which the system is not completely repetitive (low complexity) or chaotic (very high complexity). Our previous research has evaluated the change in postural variability and postural complexity during the development of midline head control and reaching in supine in both infants born full term and preterm.(Dusing, Kyvelidou et al. 2009, Dusing, Thacker et al. 2012, Dusing, Izzo et al. 2014) Our work, combined with that of others, has demonstrated inconsistency in postural variability while learning early motor skills. In contrast, a consistent pattern of higher postural complexity prior to and early in skill development followed by a reduction in complexity during the learning process has been documented during development of head control, reaching and sitting.(Harbourne and Stergiou 2003, Cignetti, Kyvelidou et al. 2011, Dusing, Thacker et al. 2012, Dusing, Izzo et al. 2014) Each of these studies demonstrated that early postural complexity facilitated the learning of developmental skills such as reaching, head control, and sitting. Early in skills development, non-repetitive postural control strategies (higher postural complexity) allowed the infant to experience movement and interact with the environment from multiple vantage points.(Dusing, Izzo et al. 2014) (Dusing, Kyvelidou et al. 2009) Thus, the infant could practice a variety of strategies. As the infant learns the skills, the infant can reduce the number of strategies, developing a set of preferred strategies. While the infant may continue to use the preferred strategies most of the time, the early experience using other strategies allows the infant to utilized the previous practiced strategies if a new task requires a non-preferred strategy.(Dusing and Harbourne 2010) Infant with neonatal brain injury show altered patterns of postural complexity with either chaotic or repetitive patterns early in skills development which may impact their development of new skills.(Dusing, Izzo et al. 2014)

Adaptive postural control is a term used in this line of research to describe the ability of an infant to change their postural variability and/or postural complexity in response to changing task demand or conditions. In healthy full term infants, adaptive postural control allowed infants to adjust their postural control strategy to changing task demands while reaching from supine.(Dusing, Thacker et al. 2012) These healthy infants reduced their postural variability or the magnitude of their center of pressure (COP) displacement when presented with a visual stimulus. However, they did not change their postural complexity between conditions. We proposed that this represented the healthy infant ability to still their body or

reduce postural variability in order to visualize the toy and prepare for reaching, while maintaining non-repetitive postural control strategies and supplementing non-preferred but previously practiced strategies for the preferred strategies when needed. This adaptive response demonstrates flexibility in the postural control system allowing the infant to learn from their environment. To our knowledge no research has specifically assess the ability of infants born preterm to adapt their postural control to changing task demands in the first months of life. The aim of this paper is to fill this knowledge gap and provide an initial group analysis of the postural adaptability of infants born preterm.

1.2 Experience and Adaptive Motor Control

Infants and fetuses learn about the world through their early experiences. Fetuses begin active movement in utero around 7 weeks of post-conceptual age.(de Vries and Fong 2006) Once initiated the movements of a fetus persist throughout gestation and by delivery are complex and variable, providing the infant with a wealth of perceptual motor experience.(de Vries and Fong 2006, Myowa-Yamakoshi and Takeshita 2006) Infants in the first weeks of life demonstrate their ability to use sensory information to adapt their hand position to explore objects.(Molina and Jouen 2004, Lobo, Kokkoni et al. 2014) Infants as young as 3 months of age can learn to activate a mobile through their kicking in specific motor patterns, even if the pattern requires an uncoupling of typically coupled joint movements.(Sargent, Schweighofer et al. 2014) While infants demonstrate the early ability to learn from the environment and modify motor patterns, these learned adaptations are task specific and do not directly transfer from one task, such as crawling, to another, such as walking. (Berger and Adolph 2007) Thus, infants must learn to adapt their behaviors in a variety of positions in order to maximize their ability to explore the environment and learn throughout the first years of life. To our knowledge there is no evidence on postural adaptability in infants born preterm or the impact of postural adaptability on development and learning.

1.3 Adaptive Behaviors Differ in Infants Born Preterm

While there is limited information on motor learning of infants born preterm, the evidence suggests infants born preterm are not efficient in adapting their behaviors to meet task demands which may impact learning.(Jongbloed-Pereboom, Janssen et al. 2012) Associative learning assessed using the mobile paradigm demonstrated that infants born preterm kicked less frequently and used increased coupling of lower limb joints to activate the mobile when compared to infants born full term.(Fetters, Chen et al. 2004, Heathcock, Bhat et al. 2004) Infants born preterm adapt their hand position to the properties of an object at an older age than infants born full term.(Lobo, Kokkoni et al. 2014) Infants born preterm with neonatal brain injury have altered postural complexity which influences the development of motor behaviors.(Dusing, Izzo et al. 2014)

While previous research suggests infant born preterm are delayed or limited in their ability to demonstrate associative learning and hand adaptations in reaching, no research has investigated their ability to adapt their postural control. The inability to adapt postural control to the demands of a task may contribute to altered learning and reaching, as well as the development of future motor skills. Thus, research is needed to determine if infants born preterm are able to adapt their postural control, both variability and complexity, in response

to task demands. If the infants born preterm has delayed or impaired adaptations in postural variability or complexity, this may contribute to their difficulty in learning associative memory tasks. For example: the infant may not be able to alter postural variability to visually focus on the mobile and lift both legs to kick. Thus, they may appear unable to learn the mobile paradigm, when in fact their lack of postural adaptability may be the cause of the “failed learning”. Therapeutic interventions are likely to be different to address a deficit in associative learning and postural control, thus more evidence is needed to determine the underlying causes of developmental delays in infant born preterm.

The purpose of this study was to determine if infants born preterm adapt their postural variability and postural complexity to different task demands between 2.5 and 5 months of age. We hypothesized that infants born preterm would not adapt their postural variability initially, demonstrating a delay in their ability to reduce postural variability when visualizing toy. However, we anticipated that eventually the infants born preterm would reduce postural variability in the toy condition when compared to the no toy condition. We hypothesized that the infants born preterm would demonstrate little to no change in postural complexity given the lower levels of postural complexity seem in most preterm infants early in skills development.

2. Material and methods

2.1 Postural Control Measures

In this paper we use both linear and nonlinear measures for a comprehensive quantification of the variability of postural control. We quantify postural variability or the magnitude of the variability of postural control using the linear measure of root mean squared (RMS) of the COP displacement. RMS is a traditional reflection of the amount of variability in the COP displacement. Linear measures of postural control are commonly used to describe the movement error which occurs during balance or postural assessment.(Stergiou and Decker 2011) However, research has shown that linear measures of postural control do not fully describe the postural control system as they do not quantify the repeatability of the time series or the repeatability of the postural sway pattern. The temporal structure of the variability of the COP displacement, or postural complexity, can be quantified using the nonlinear measure of Approximate Entropy (ApEn).(Dusing, Thacker et al. 2012) ApEn quantifies the repeatability or predictability of data patterns within a time series. ApEn values range from 0, meaning completely repeatable like a sine wave, to 2, meaning completely random with no detectable pattern.(Stergiou and Decker 2011) Thus, ApEn of the COP displacement time series provides a useful indicator of how regular or repetitious the postural control strategies are during a given time series. We describe this as a measure of complexity of the postural control system we term postural complexity.(Dusing and Harbourne 2010) The addition of this or other nonlinear measures to the quantification of postural control has led to a greater understanding of how humans learn to control their posture during development, learning new skills, or recovering from injury.(Deffeyes, Harbourne et al. 2009, Dusing and Harbourne 2010, Stergiou and Decker 2011)

2.2 Participants

Twenty-three infants born at 32 weeks of gestation or less consented to participate in this longitudinal study of the development of postural control in infants born preterm.(Dusing, Izzo et al. 2014) The infant's mother was required to be 18 years of age or older, live within 1 hour of the hospital, and speak English. Infants were excluded from participation if they had genetic or musculoskeletal complications diagnosed in the neonatal intensive care unit (NICU). Infants needed to be medically stable to begin participation by 6 weeks of adjusted age, after the expected date of full term delivery. Infants were not excluded based on birth weight, neurological injury, or respiratory complications as the purpose of this study was to include at-risk infants. Infants were recruited from an academic medical center with a level III NICU in an urban community. All infant who were admitted to the NICU were screened for eligibility to reduce bias. Parents signed consent for their infant(s) to participate prior to the first study visit and the study was approved by the committee for human subjects. Five of the 23 infants born preterm were dropped from the study as they could not be reached following NICU discharge, resulting in a sample of 18 infants born preterm. Changes in postural variability and postural complexity during the development of midline head control and early reaching as been previously described in this sample.(Dusing, Izzo et al. 2014) All ages in this paper are presented as adjusted ages for the infants born preterm.

2.3 Data Collection Procedures

In order to capture changes in postural control under multiple conditions and during development, study visits were twice per month through 3 months of age and monthly from 3 to 6 months of age. Visits were more frequent during the first 3 months to increase the likelihood of capturing rapid developmental change. While study visit began at 1 month prior to the infant's anticipated date of full term birth and continued through 6 months of adjusted age, data included in this analysis is from visits between 2.5 and 5 months of age. This age range was selected as it represented the period in which the infants in this study were learning to look at and reach for objects based on our previous research and in which infants tolerated the longer assessment period allowing for data collection in both conditions during a single visit.(Dusing, Izzo et al. 2014) One infant was lost to follow up after the 4 months visit, 1 was excluded from the study after the 4 months visit due to an injury which prohibited participation. No infants were excluded for having occasional missed visits due to the medical fragility of this population.

As described in detail in our previous work, COP measurement was completed using a Conformat¹ pressure sensitive mat sampling at 5 Hz with the infant in supine for 5 minutes in each condition.(Dusing, Kyvelidou et al. 2009, Dusing, Izzo et al. 2014) The first condition was the No Toy Condition in which the infant was positioned in supine without a visual stimulus or toy for 5 continuous minutes. The second condition was the Toy Condition in which the infant remained in supine and a rattle was suspended over the infant at 75% of the infant's arm length, midway between the infant's shoulders. A new toy was presented every minute for 5 minutes to maintain infant's interest. Infants were allowed to grasp the toy, but not remove it from the examiners hand. The entire COP measurement was

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¹Tekscan 307 West First St. South Boston, AM 20127-1309, USA

video recorded from 2 views, lateral and overhead, and synchronized with the COP data. (Dusing, Izzo et al. 2014)

2.4 Data Analysis

Video of the COP assessment was used for behavioral coding of head in midline, looking at objects, and toy contacts. Head midline was coded any time the head was rotated less than 30 degrees to the left or right of midline during the Toy and No Toy Conditions. Looking was coded if the infant's eyes were clearly directed at the toy and open during the Toy Condition. Toy contact was coded when any part of the infant's hand/arm touched the toy during the toy condition. Infant were considered consistent in midline head control when their head was in midline at least 50% of the No Toy Condition. Infant were considered able to consistently contact a toy when they were in contact with the toy 15% of the Toy Condition, regardless of if they were looking at the toy or not. The criteria of 50% and 15% were selected after reviewing the data for a cohort of full term infants in a previous study to determine the percentage in which most infants continually met the criteria after initially meeting the criteria. (Dusing, Thacker et al. 2012) Behavioral coding was completed using the MacShapa version 1.1.2a² coding program and coders trained to 85% agreement with the formula: $\text{Agree}/(\text{Agree}+\text{Disagree}) \times 100$. Twenty percent of all visits were coded twice to ensure ongoing reliability. (Dusing, Izzo et al. 2014) As in our previous work, (Dusing, Kyvelidou et al. 2009, Dusing, Thacker et al. 2012, Dusing, Izzo et al. 2014) COP time series of 500 data samples or 100 seconds in length were identified from the data collection period. The behavioral coding data was used to identify continuous COP time series in which the infant was in supine, alert, no one was touching the infant and the infant was not touching the toy. Included periods in the Toy Condition did include reaching behaviors, prior to contact with the toy. However, once the infant contacted the toy the infant's COP displacement was likely to be influenced by the contact and thus was not used in the analysis of the Toy Condition. The dependent variables of RMS and ApEN in the caudal cephalic (cc) and medial lateral (ml) directions were calculated (RMScc, RMSml, ApENcc, and ApENml) as described in detail in our previous work. (Dusing, Izzo et al. 2014) Variables were calculated in the ml and cc directions to allow for separate analysis because in previous work with infants born preterm these variables were helpful in describing posture during the development of lifting the legs and accidental rolling. (Dusing, Kyvelidou et al. 2009) ApEN and RMS of the COP for an infant in supine will be influenced by a variety of movements. Midline head control and rolling appear to influence measurement in the ml direction. While kicking and trunk extension or flexing appear to have the greatest impact on the cc direction. (Dusing, Mercer et al. 2005, Dusing, Kyvelidou et al. 2009) The impact of different movement patterns on the movement of the COP in the ml and cc direction required that we complete the analysis of the dependent variables separately.

2.5 Statistical analysis

The dependent variables RMScc, RMSml, ApENcc and ApENml were transformed using a (natural) logarithmic transformation to more closely approximate a normal distribution,

²MacSHAPA v1.1.2a Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign. 1206 West Green Street, Urbana, IL 61801

Ln(RMScc), Ln(RMSml), Ln(ApENcc), and Ln(ApENml) respectively. All analyses were conducted using these transformed dependent variables. All statistical analysis was completed using SAS® version 9.2.³ A p-value of 0.05 was set for determining significance.

A mixed linear model was used to quantify the impact of Condition over time (Age) on the change in the magnitude and temporal structure of the variability of the COP time series or postural variability and postural complexity, respectively. The model included Condition (Toy and No Toy Conditions), Age and an interaction term to predict the transformed dependent measures of Ln(RMScc), Ln(RMSml), Ln(ApENcc), and Ln(ApENml). The Age term included 2.5 to 5 months of age and was fit as a continuous variable. Limitations in the sample size due to missing data from one condition on some visits prohibited fitting the Age term as a categorical variable as was done in our previous research.(Dusing, Izzo et al. 2014)

3. Results

The infants included in this study gradually learned to keep their head in midline, reach and look for toys suspended over their chest (Table 2). As a group the infants looked at the toy, even before they could hold their head in midline consistently, and looked at the toy months before they consistently reached. This data suggests the infants born preterm in this study had interest in the toy suspended over their chest. By 3 to 4 months infants held their head in midline for a longer period of time when a toy was presented at midline.

The mixed linear model evaluated the impact of Condition (No Toy and Toy) and Age on the postural variability and complexity from 2 to 5 months of age. There was a significant interaction between Condition and Age on the postural variability in the caudal cephalic direction: Ln(RMScc) ($F_{1,72} = 5.05$, $p=0.03$, Figure 1A). Post-hoc analysis revealed that Ln(RMScc) was significantly lower at 4.0 and 5 months of age in the Toy Condition than in the No Toy Condition, $p = 0.01$ and $p < 0.01$, respectively. There was no significant interaction between Condition and Age on the postural variability in the medial lateral direction, Ln(RMSml), thus the model was run without the interaction term. There was a condition effect ($F_{1,11} = 7.09$, $p = 0.02$) but no age effect ($F_{1,73} = 0.82$, $p = 0.37$, Figure 1b). These finding suggest that the infants born preterm did not alter the postural variability in response to a visual stimulus before 4 months of age in the caudal cephalic direction. However, they were able to adapt their postural variability in the medial lateral direction by 2.5 months of age when presented with a visual stimulus.

There was no significant interaction between Condition and Age on postural complexity in either direction. There was no main effect for Condition on the postural complexity in either direction: Ln(ApENcc) and Ln(ApENml) $F_{1,11} = 2.09$, $p=0.18$ and $F_{1,11} = 0.06$, $p=0.81$ respectively (Figure 2A). There was no significant main effect for Age on postural complexity on either direction: Ln(ApENcc) and Ln(ApENml) $F_{1,73} = 1.93$, $p=0.17$ and $F_{1,73} = 0.88$, $p=0.35$ respectively (Figure 2B). This suggests that this sample of infants born preterm did not alter their postural complexity between conditions or with increasing age between 2.5 and 5 months of age.

³SAS Institute INC. , Cary NC, USA

4. Discussion

4.1 Infants born preterm were delayed in reducing postural variability in response to changing task demands

Our previous research has suggested that infant born full term modify postural variability, or the magnitude of the variability of their COP displacement, in both the caudal cephalic and medial lateral direction from 1 to 4 months of age when a toy is presented. Infants born full term can make these modifications while maintaining a consistent degree of postural complexity. Harbourne and others have proposed that these healthy full term infants are utilizing an optimal degree of postural complexity or the “right” number and degree of repetition of strategies to meet the task demands. (Stergiou, Harbourne et al. 2006, Dusing and Harbourne 2010, Dusing, Thacker et al. 2012) As has been suggested by multiple research groups, the ability to move through the organized progression of 1) Exploration of postural control strategies, 2) Strategy selection and 3) Reduced use of non-preferred strategies to accomplish a behavior during the emergence of early skills is a hallmark of typical development. (Edelman 1987, Gibson 2000, Dusing and Harbourne 2010)

The infants born preterm in this study demonstrated a delayed, yet similar pattern of postural control in response to task demands. In contrast to our hypothesis, the infants born preterm demonstrated an adaptive response in their postural variability in the medial lateral direction, with reduced postural variability starting at 2.5 months of age in the medial lateral direction. However, consistent with our hypothesis, they did not reduce postural variability in the caudal cephalic direction until 4 months of age. While postural variability in the caudal cephalic direction was lower at 4 and 5 months of adjusted age, it was not different from 2.5 to 3.5 months of age suggesting that as a group the infants born preterm were not able to adapt their postural variability in the caudal cephalic direction at these younger ages. In contrast to infants born full term in the previous study, the infants born preterm in this study did not adapt their postural variability in the caudal cephalic direction until after they had midline head control (2.7 ± 1.2 months) and were learning to reach (4.7 ± 0.9 months). This may represent difficulty focusing on stabilizing the torso while also focusing on learning to control the head or reach. An alternative is that infant born preterm had a different strategy of postural control compared to the infants born full term that was not assessed in this study.

As we hypothesized, the infants born preterm maintained the same level of postural complexity over time, similar to the infants born full term in previous work. This suggests that the infants continued to use a variety of non-repetitive postural control strategies from 2 to 5 months, but they did not pick strategies which reduced with COP displacement in the caudal cephalic directions until 4 month. This delay in finding a strategy that is effective for infant born full term may contribute to the delay in reaching onset and other behaviors seen in infants born preterm. The delayed adaptation in postural variability was present in the caudal cephalic direction which is consistent with previous research suggesting impaired ability to lift the lower extremities off the surface and flex the trunk in infants born preterm. (Dusing, Mercer et al. 2005, Dusing, Kyvelidou et al. 2009) The large increase in the duration of toy contacts at 5 months (Table 1) suggests that the reduction in COP displacement in the caudal cephalic direction during the toy condition at 4 months may have

helped these infants born preterm learn to reach. However, it took them longer to find a successful strategy for postural control while reaching than infant born full term. These findings support previous research which identified that infants born preterm at 4 and 6 months of age who use a “still” trunk posture in supine at were more likely to have minor neurological dysfunction at 6 years.(Fallang, Saugstad et al. 2003, Fallang, Oien et al. 2005) In combination, these findings suggest the need for future work to determine if a lack of postural variability, reduced postural complexity, or delayed/absent adaptability are predictors of developmental disability.

4.2 Early experience with multiple postural control strategies may influence the strategies selected

Previous research found that children with cerebral palsy and infants at risk for cerebral palsy demonstrated less than optimal levels of postural complexity early in development. (Deffeyes, Harbourne et al. 2009, Dusing, Izzo et al. 2014) In a study of 3 infants with neonatal brain injury, the degree of postural complexity early in development was related to cognitive outcomes, suggesting that the ability to use multiple strategies for exploration of movement may enhance learning.(Dusing, Izzo et al. 2014) In a comparison of infants with typical development and those with developmental delay, Deffeyes reported lower ApEn scores in sitting for infant with developmental delays.(Deffeyes, Harbourne et al. 2009)

The infant in this study had a Ln(ApENcc) of 0.77 in the No Toy condition at 2.5 months of age. Infants born full term in our previous work has a Ln(ApENcc) of 0.79 at the same age. (Dusing, Thacker et al. 2012) Similarly, the infant born preterm in this study has a Ln(ApENml) of 0.67 while infant born full term had a Ln(ApENml) of 0.74 at 2.5 months of age in the no toy condition. While we did statistically compare these groups, the data suggests the infants born preterm in this study had a lower level of postural complexity than full term infants at the youngest age presented in this study. This comparison is consistent with the finding that infants born preterm demonstrate lower postural complexity in the month preceding the development of midline head control as well. (Dusing, Izzo et al. 2014) This suggests that the infant born preterm had less opportunity to practice moving with a variety of non-repetitive postural control strategies early in their development. This lack of early practice using a variety of postural control strategies may have contributed to the infant's inefficiency in selecting a strategy that supports reaching in supine. The infants born preterm continued to use multiple postural control strategies, but they did not select the strategy that is effective for infants born full term; reducing postural variability or the magnitude of COP displacement on the medial lateral and caudal cephalic directions. While the infant in this study initially reduced their postural variability in the medial lateral directions, it required several months of additional practice until they selected a strategy of reduced COP displacement in both the medial lateral and caudal cephalic direction. Not having enough previously rehearsed postural control strategy to select from when a toy was presented may have delayed reaching onset and postural control.

4.3 Clinical implications

Infant born preterm are at higher risk of developmental disabilities. This study demonstrates they are also at risk for decreased or delayed adaptability of the postural control system.

While this study was not designed to evaluate a causal relationship, it is possible that the delayed postural adaptability may be one cause of the coordination impairments or developmental delays seen in infant born preterm. As such, developmentalists and therapist who assess infant born preterm should consider the infants ability to use postural control strategies in a variety of conditions. Therapists should work with infants and their family to provide ample opportunities to practice postural control skills under a variety of conditions, all directed toward functional skills such as reaching, sitting, head control, and standing. In addition, this study furthers the theory that early postural complexity is important to the development of later postural control. Thus, infants born preterm who are removed early from the fluid intrauterine environment may need assistance from therapists or parents to ensure they have opportunities to practice a variety of postural control strategies in the first months of life.

4.4 Limitations of this study and future directions

This study has some limitations that may have influenced our findings. The loss of infants to follow up after NICU discharge and due to medical complications results in a smaller sample than anticipated. Due to the smaller than anticipated sample size we were not able to utilize the developmental outcome data to compare infants who had developmental delays and those without delays as 12 months. In addition, some infants were not able to complete the toy condition following the no toy condition at younger ages. This missing data at younger ages required us to restrict our ages of inclusion to start at 2.5 months rather than the 1 month age used in the full term research. Developmental outcome data was only available through 12 months of age limiting our ability to compare the degree of adaptability to long term developmental outcomes or the rate of cerebral palsy or learning disabilities. A full term comparison group was not included in any of the analysis as previously published data on the full term cohort used Age as categorical variable, while the sample size for this study required the use of age as a continuous variable.

Future research is needed to evaluate the ability of infants with and without disabilities to adapt to changing task demands during early infancy. This will require the longitudinal follow up of a group of high risk infants, with individual level analysis of those who go on to have disabilities such as cerebral palsy or developmental coordination disorder. This type of research will help developmentalists and therapist identify if adaptability of the postural control system is an early predictor of disabilities and/or an impairment that could be the focus of future intervention strategies.

5. Conclusions

The finding from this study suggest that as a group infants born preterm may not have the early experiences to adapt postural control and facilitate the development of motor behaviors in the first months of life. While they may acquire the motor behaviors with additional practice, the need for more practice in order to learn may contribute to the prevalence of developmental coordination disorder, learning disabilities, and other developmental delays which are more frequently observed in infants born preterm.

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Abbreviations used in this paper

RMS	Root Mean Squared
COP	Center of Pressure
ApEN	Approximate Entropy
cc	caudal cephalic direction
ml	medical lateral direction

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Highlights

- Infants born preterm look at objects months before reaching for the object
- Delayed adaptation of postural variability influences ability to reach

Reduced early postural complexity may contribute to delayed adaptation in infancy

Figure 1. Predicted Models of Postural Variability (A) in the caudal cephalic and (B) medial lateral direction with Increasing Age. * represents a significant condition difference at the specified ages. + represents a significant condition main effect.

Figure 2. Predicted Models of Postural Complexity (A) in the caudal cephalic and (B) medial lateral direction with Increasing Age.

Table 1

Demographics

Gestational age at birth (weeks) M $\pm$ SD Range	Birth Weight (grams) M $\pm$ SD Range	Twins	Sex Female (%)	Race C- Caucasian AA- African American	NICU LOS (days) M $\pm$ SD Range	Medical Dx
28.3 $\pm$ 3.1 24.0–32.0	1178 $\pm$ 493 480–2435	4	55%	5%-C 95%- AA	83 $\pm$ 50 22–164	3 – Grade 3/4 IVH 2 – Ventricular Peritoneal shunt 4–Chronic lung Dz
Developmental Outcomes	TIMP z- score at 2.5 months M $\pm$ SD Range N=14	TIMP z- score at 4 months M $\pm$ SD Range N=17	Bayley Motor Composite at 12 months M $\pm$ SD Range n= 15	Bayley Cognitive Composite at 12 months M $\pm$ SD Range n= 14	Bayley Language Composite at 12 months M $\pm$ SD Range n= 14	Bayley Motor Composite at 12 months M $\pm$ SD Range n= 14
	–0.39 $\pm$ 1.13 –3.38–0.71	–0.38 $\pm$ 1.5 –4.6–1.3	94.5 $\pm$ 17.7 61–130	85.9 $\pm$ 12.8 60–105	78.3 $\pm$ 13.6 59–103	85.5 $\pm$ 17.9 46–107

Table 2

Percent of the condition infant demonstrated specific behaviors.

	No Toy Condition	Toy Condition		
	Head in Midline	Head in Midline	Looking at Toy	Hand Contact Toy
2.5 months n= 15	38.71%	29.34%	44.21%	0.21%
3 months n= 18	54.98%	77.98%	64.70%	0.26%
4 months n= 18	66.56%	87.83%	72.31%	12.48%
5 months n= 16	73.97%	92.25%	70.44%	53.06%