Maternal Factors Related to Infant Motor Development at 4 Months of Age

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Abstract

Background: Exercise during pregnancy and breastfeeding after pregnancy both positively influence a number of infant outcomes. However, whether physical activity during late pregnancy and breastfeeding postpartum influence motor development in the offspring at 4 months of age is unknown.

Research Aim: The purposes of this study were to investigate the relationships between several important modifiable factors (i.e., maternal physical activity during late pregnancy and breastfeeding after pregnancy) on infant motor development at 4 months of age.

Materials and Methods: Thirty-three women–infant pairs participated in this prospective longitudinal study. Maternal physical activity was assessed during late pregnancy with wrist-worn accelerometers for 7 consecutive days. Surveys were provided to determine infant feeding practices and other variables that could influence infant motor development. A pediatric board-certified physical therapist assessed infant motor development at 4 months using the Alberta Infant Motor Scale.

Results: Infants who were exclusively breastfed had the highest motor development percentiles when compared with those whose mothers were supplementing with or using formula exclusively (exclusive breastfeeding: 64.3 ± 20.1 , combination of mother's own milk and formula: 43.5 ± 5.0 , exclusive formula: 31.5 ± 15.1 , $p = 0.001$). No associations between physical activity levels during late pregnancy and infant motor development percentiles at 4 months were found (sedentary time: $r = -0.057$, $p = 0.75$; light activity: $r = -0.074$, $p = 0.68$; moderate activity: $r = -0.094$, $p = 0.60$).

Conclusions: Infants who were exclusively breastfed had higher motor development percentiles at 4 months of age than those infants whose mothers supplemented with or used formula exclusively. Physical activity levels during late pregnancy were not related to infant motor development percentiles, which suggests that physical activities do not appear to be harmful to infant motor development.

Keywords: physical activity, exercise, breast milk, motor control, pregnancy

Introduction

EXERCISE DURING PREGNANCY and breastfeeding after pregnancy are two well-established ways a new mother can improve the health of her infant. Exercise during pregnancy impacts a number of infant outcomes, including birth weight, Apgar scores, body composition, and even neurological development.^{1–3} Exercise during pregnancy may stimulate improvements in brain function in the offspring as infants born to women who were physically active during pregnancy had higher neurobehavioral scores as early as 5

days after birth⁴ and had improved neurological development at 12 and 24 months of age.⁵ However, the relationship between physical activity during late pregnancy and motor development in the offspring at 4 months of age has not been studied.

Breastfeeding is another factor that may influence infant motor development. Previous research has shown that breastfeeding is intricately linked to infant brain development.⁶ Looking specifically at motor development, infants that were breastfed longer than 6 months had improved motor development outcomes as toddlers and school-aged children

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compared with infants that were breastfed for <6 months.^{7,8} Other studies suggest that infant feeding practices, specifically whether or not an infant is exclusively breastfed or introduced to solids, have little-to-no impact on infant motor development.⁹ To our knowledge, the impact of breastfeeding on motor development in early infancy (4 months) has not been established.

The attainment of motor developmental milestones is an indicator of neurologic development during infancy,¹⁰ and early motor development is linked to improved cognitive function in school-age kids.¹¹ Furthermore, infants and children who develop motor skills earlier in life are more likely to continue to be active and move throughout their childhood,^{12,13} which may play an important role in lowering the risk for future obesity and associated comorbidity development¹²; thus, the long-term implications of early motor development scores (i.e., 4 months) are substantial. Four months of age is an important time point for the emergence of early motor skills as well as an age in which most infants are still on exclusively formula, mother's own milk, or a combination of the two (i.e., solid foods have not yet been introduced).

Since the time period between conception and 2 years of age is considered the golden opportunity to influence brain development,⁶ understanding the role that modifiable factors (i.e., exercise during pregnancy and breastfeeding after delivery) could play on infant motor development is critically important. Therefore, the purpose of the study was twofold: (1) to investigate the relationship between maternal physical activity during late pregnancy and infant motor development, and (2) to determine the impact of breastfeeding on infant motor development at 4 months of age.

Materials and Methods

Participants

Pregnant participants were recruited between September 2016 and December 2017 from a larger ongoing pregnancy study in Bowling Green, Kentucky between 28 and 32 weeks pregnant. Participants for the larger study were recruited from local obstetric clinics, university-wide emails, and word of mouth.

Inclusion criteria included: pregnant women between the ages of 18–44, plans to deliver at the local medical center, clinician release to participate in the study, and a confirmed singleton pregnancy with no fetal abnormalities. Women were excluded if they had a multiple gestation pregnancy, currently used drugs, smoked cigarettes, took daily medications (corticosteroids or antipsychotics known to influence metabolic outcomes of the larger study), or had a history of gestational diabetes (current or previous pregnancy). Infants were excluded if they were born prematurely (<37 weeks) or diagnosed with any health issues that could influence motor development (e.g., major gastroesophageal or digestive issues). All participants with eligible infants who completed the larger study were emailed and/or called by the study team to invite them to participate in this follow-up study.

Data collection

All study procedures were approved by the Western Kentucky University Institutional Review Board. The study

was a prospective, longitudinal cross-sectional study. This study design allowed us to prospectively assess physical activity and breastfeeding status without requiring the participant to recall information from the past (to limit recall bias). Between 32 and 39 weeks gestation, all participants were informed of the benefits and risks of participation in the study and written informed consent for the mother and written assent for the infant were obtained in a private setting. Participants completed a general demographic survey at onset of study participation.

Physical activity data were objectively collected using an Actigraph Link Accelerometer (ActiGraph LLC, Pensacola, FL) on the nondominant wrist for 7 consecutive days. The ActiLife Software determined the percentage of time the wearer spends sedentary and participating in a range of activity levels (light, moderate, and vigorous). This determination was calculated using predetermined algorithms that correspond to activity counts for each level of activity: sedentary: 0–99 counts/minutes, light: 100–1,951 counts/minutes, moderate: 1,952–5,724 counts/minutes.¹⁴ Wrist-worn tri-axle accelerometers are an accurate assessment tool for measuring physical activity levels during pregnancy,¹⁵ and provide the best compliance to obtain 24 hours/day wear data.¹⁵

A basic survey was created inquiring about infant feeding practices. Participants were asked if they were breastfeeding, formula feeding, or a combination. If they reported breastfeeding, they were also asked the method of feeding (bottle, nursing, or combination). Mothers were only asked about breastfeeding practices at that point in time (4 months). For the present study, exclusive breastfeeding was defined as the infant receiving mother's own milk from the breast or expressed and received through a bottle, but that the infant is not receiving any other foods or formula.¹⁶

Surveys were delivered to the participant before the study visit inquiring about a number of factors that could influence the child's motor development. These included information about time spent in different positions (supine, prone, standing), sleeping practices, family dynamics, and existing health issues.

Infants were scheduled to come for their motor development assessment between 4 months, 0 days and 4 months, and 13 days. Four months was chosen as 4 months is an important time point for the emergence of early motor skills and solid foods are typically not yet introduced at this time point; thus, preventing food consumption from being a confounding variable. Each visit occurred in the Physical Therapy Exercise Laboratory at the Western Kentucky University Health Sciences Complex. All tests were administered by a licensed pediatric physical therapist who was blinded to maternal physical activity data and breastfeeding status.

Infant motor development was assessed using the Alberta Infant Motor Scale (AIMS), a well-established test to determine infant motor development percentiles.¹⁷ The AIMS test consists of 58 items and assesses the infant in four positions: prone (21 items), supine (9 items), sitting (12 items), and standing (16 items).¹⁷ The type of motor performance being tested consists of weightbearing, posture, and antigravity movements.¹⁸ Scoring is based upon whether the item was observed or not observed, and the motor window upon which the scores were based was comprised of the most and least advanced skill seen.¹⁷ The AIMS is considered a valid and reliable test of infant motor development.¹⁷

All testing sessions were recorded and videos were used to allow the test administrator to go back and rescore the test if any clarity was needed. If any infant was unable to complete the session, the mother–infant pair was rescheduled to come back on a different day to ensure completeness of testing. Data reported in analyses are the infant motor percentile (not the raw score) as this accounts for the exact age of the infant, which is important as motor patterns change very quickly in infants (i.e., 4 weeks, 0 days versus 4 weeks, and 13 days).

Data analyses

All data were entered into and stored in the REDcap electronic data management system.¹⁹ Sample size was determined based on the larger ongoing study.²⁰ The goal of the ongoing study was to assess metabolic health during pregnancy and how it related to maternal and infant outcomes. The power calculation was based on our primary outcome of metabolic flexibility (i.e., the ability to adjust substrate metabolism according to fuel availability, which is a critical aspect of metabolic health²¹). The sample size of the motor development study came as a result of bringing as many of the mother–infant pairs as possible back during the 2-week window at 4 months postpartum. However, to help address any concerns with sample size, a post hoc power analysis was performed based on group sizes, means, and standard deviations for the current study. The analysis revealed an effect size of 0.6175 and a power of 0.824 (82.4%) given an alpha value of 0.05, which demonstrates adequate power to report the given outcomes.

All data were checked for normality using Kolmogorov–Smirnov tests. For normally distributed data, relationships between continuous variables were examined using Pearson Product Moment Correlation Coefficients. For non-normally distributed variables, relationships between variables were determined through Spearman Rank Correlation Coefficients. To compare motor scores between groups (breastfeeding exclusively versus combination feeding versus formula feeding), independent *t*-tests and one-way analyses of variance (ANOVAs) with Least Significant Difference post hoc testing were conducted. All statistics were run through SPSS version 25 (Armonk, New York) with significance set at a *p*-value of *p* < 0.05. All values shown are two-tailed.

Results

Maternal and infant characteristics can be found in Tables 1 and 2, respectively (Tables 1 and 2) (*N* = 66, 33 mother–infant pairs). Infants who were exclusively breastfed had the highest motor development percentiles when compared with those whose mothers were supplementing with or using formula exclusively (exclusive breastfeeding: 64.3 ± 20.1 , combination of mother's own milk and formula: 43.5 ± 5.0 , exclusive formula: 31.5 ± 15.1 , *p* = 0.001). Post hoc analyses revealed that there was no statistically significant difference in motor percentiles between exclusively formula-fed and combination-fed infants (*p* = 0.32), but that exclusively breastfed infants had significantly higher motor percentiles compared with exclusively formula-fed infants (*p* = 0.001) and compared with combination-fed infants (*p* = 0.045) (Fig. 1). There was no statistically significant difference in motor development percentiles between infants

TABLE 1. MATERNAL CHARACTERISTICS (*N* = 33)

	Mean $\pm$ SD or no. of women (%)
Age (years)	30.4 $\pm$ 4.0
Body fat (%)	23.5 $\pm$ 5.8
Prepregnancy BMI (kg/m ²)	25.1 $\pm$ 5.8
Gestational weight gain (kg)	14.1 $\pm$ 5.8
Income (\$)	92,335.7 $\pm$ 47,890.4
Parity	
Nulliparous	13 (39.4)
Multiparous	20 (60.6)
Physical activity	
Sedentary behavior (%)	57.3 $\pm$ 12.1
Light activity (%)	31.5 $\pm$ 8.9
Moderate activity (%)	11.2 $\pm$ 4.5
Education	
High school diploma	1 (3.0)
Some college	3 (9.1)
College degree	12 (36.4)
Postgraduate degree	17 (51.5)
Ethnicity	
Caucasian	32 (96.9)
African American	1 (3.0)
Breastfeeding practices	
Exclusive breastfeeding	23 (69.7)
Exclusive formula feeding	6 (18.2)
Combination of breastfeeding and formula feeding	4 (12.1)
Mode of feeding ^a	
Exclusive bottle feeding of expressed mother's own milk	4 (14.8)
Exclusive nursing	4 (14.8)
Combination of bottle feeding and nursing	19 (70.4)

^aExclusively formula-fed infants were excluded from this analysis as exclusively formula-fed infants were all fed exclusively from bottles.

BMI, body mass index; SD, standard deviation.

TABLE 2. INFANT CHARACTERISTICS (*N* = 33)

	Mean $\pm$ SD or no. of infants (%)
Birth weight (kg)	3.5 $\pm$ 0.4
Birth length (cm)	51.7 $\pm$ 2.5
Gender	
Female	12 (36.3)
Male	21 (63.6)
Gestation age at delivery (week)	39.5 $\pm$ 1.2
Head circumference (cm)	33.0 $\pm$ 2.5
Abdominal circumference (cm)	31.4 $\pm$ 3.0
Infant body fat at birth (%)	12.7 $\pm$ 3.6
Weight at 4 months (kg)	6.4 $\pm$ 0.7
Length at 4 months (cm)	62.9 $\pm$ 2.8
AIMS percentile (%)	55.8 $\pm$ 22.3
AIMS motor score	18.1 $\pm$ 3.3
Tummy time at 4 months (minute/day)	47.1 $\pm$ 37.7

AIMS, Alberta Infant Motor Scale; SD, standard deviation.

FIG. 1. Motor development percentiles between infants of mothers who were exclusively breastfeeding, exclusively formula feeding, or providing their infant with a combination of mother's own milk and formula (mean $\pm$ standard deviation). Infants who were exclusively breastfed at 4 months of age had higher motor development percentiles compared with combination-fed and formula-fed infants. Exclusive breastfeeding: an infant who is consuming only mother's own milk. Combination: an infant receiving any combination of mother's own milk and formula. Formula: infants who are consuming only formula. * $p < 0.05$.

who received mother's own milk through a bottle, nursing, or through a combination of bottle feeding and nursing (bottle only: 52.5 ± 26.2 , nursing only: 73.3 ± 15.4 , combination: 56.2 ± 18.8 , $p = 0.25$).

No associations between physical activity levels during late pregnancy and motor development percentiles at 4 months were found (sedentary behavior: $r = -0.057$, $p = 0.75$; light activity: $r = -0.074$, $p = 0.68$; moderate activity: $r = -0.094$, $p = 0.60$).

Previous studies suggest that maternal parity, age, income, infant gender, whether or not the infant is in daycare, and the amount of time an infant time spent awake in prone (i.e., tummy time) may influence motor outcomes.⁹ Therefore, these variables were analyzed to determine if they were potentially confounding our data.

No statistical difference in motor percentiles between infants born to nulliparous and multiparous women was found (57.4 ± 17.9 versus 54.8 ± 25.2 , respectively; $p = 0.75$). No significant correlations between motor score percentiles and maternal age ($r = -0.28$, $p = 0.10$) or family income ($r = -0.24$, $p = 0.19$) were detected. There was no statistical difference in motor percentiles between males and females in the present study (52.7 ± 22.0 versus 61.3 ± 22.8 , respectively; $p = 0.30$). Also, no statistical differences were found in motor percentiles between infants who went to daycare and those who did not (55.2 ± 17.7 versus 56.5 ± 27.0 , respectively, $p = 0.87$). Fur-

thermore, the relationship between time the infant spent awake in prone and motor development percentiles was not statistically significant ($r = -0.15$, $p = 0.94$).

Discussion

The main finding of the study was that infants who were exclusively breastfed at 4 months of age had higher infant motor development percentiles. Physical activity during late pregnancy was not related to infant motor development scores at 4 months of age.

Previous research suggests that breastfeeding positively influences brain development in the infant²² and our findings are consistent with this. Because motor output is functionally related to cognitive processing,^{23,24} improved motor scores among breastfed infants suggests that breastfeeding may improve neurological development in infants at 4 months of age. With motor development during infancy being intricately linked to long-term outcomes,^{11,25,26} the implications of this research are substantial. This study suggests that health care providers should encourage patients to breastfeed, at least in the early months, to positively impact the motor development of their infant.

The infant brain develops at a rapid rate during the early months of life. In fact, scientists and policy makers have termed the first 1,000 days of life (from conception until ~ 2 years of age) as The Golden Opportunity to influence brain structure and capacity.^{6,24} Previous studies also suggest that nutritional factors have a strong influence on brain development.^{6,22} It is well established that nutritional deficiencies early in life have unfavorable effects on infant brain development.⁶ With this in mind, it is plausible that breastfeeding provides the infant with valuable nutrients or even non-nutrient factors present in mother's own milk that are absent in formula²²; however, these specific factors have not been well-identified. Additional work to determine the specific mechanisms connecting breastfeeding with infant brain motor development are warranted.

Based on the present study design, it is impossible to determine if the different motor development percentiles between groups were due from the mother's own milk composition itself (nutrients) versus differences in mother and infant interactions/bonding practices between mothers who breastfeed and mothers who do not.²² This is important to note as parent-child interactions can influence infant motor development.²⁷ However, the present study saw no difference in motor scores between mothers who nursed versus those who fed their infants mother's own milk from a bottle ($p = 0.25$), which helps support the notion that the differences in nutrient composition may be the key player in eliciting changes in infant motor development. However, a larger sample size would be needed to make this determination.

Our results suggest that physical activities, even moderate intensity, do not appear to be harmful to infant motor development. This is an important and noteworthy finding that supports clinician-approved maternal physical activity during pregnancy. Many women do not exercise for fear of harm to their unborn baby²⁸; this study is one more piece of mounting evidence that suggests physical activity during pregnancy does not appear to be harmful to infant development,² and that infants may even be protected from potential negative effects of unhealthy sedentary behaviors.²⁹

Furthermore, our study design did not allow for determining causes of motor outcomes or the effects of exercise.

Previous work by McMillan et al. found that infants born to women in an exercise program had higher neuromotor skills at 1 month of age compared with infants born to inactive women.¹² While our findings are not consistent with theirs, both studies taken together support the notion that exercise during pregnancy is, at least, not harmful to the unborn child's neuromotor development, and that it could even be beneficial.

One possible explanation for the discrepancy is that the present study investigated relationships between physical activity during pregnancy and infant motor outcomes and not the effect of planned, structured activity, which may have a more profound influence on infant motor development than quantifying general activity levels. In addition, motor development was assessed at 4 months of age in the present study versus 1 month of age in the previous study. It is possible that the influence of maternal physical activity during pregnancy on motor development may dilute as the infant grows and the ex utero environment has a stronger influence on development than the in utero environment.

Another factor that may have influenced the lack of association between physical activity and infant motor development is that we only assessed physical activity during late pregnancy. While we used high-quality, objective assessments, it is possible that physical activity during early pregnancy would have a more profound impact on infant motor development as structural brain development occurs up until 18 weeks gestation.³⁰ Labonte-Lemoyne et al. conducted a randomized controlled trial to investigate the impact of exercise during the second and third trimester on the development of the fetal brain.³¹ They found that the infants born to mothers that exercised regularly throughout pregnancy were born with enhanced brain maturation (despite no significant differences in gestation age at delivery) and hypothesized the enhanced brain maturation could be due to an increase in the amount of brain-derived neurotrophic factor (a critical molecule for neurogenesis and brain development) supplied to the fetus.³¹

Limitations

A limitation of the present study is the lack of detail gathered regarding infant feeding practices (i.e., we asked two very simple questions). When the study was designed, breastfeeding was not an intended primary outcome; therefore, we did not seek out extensive and validated breastfeeding questionnaires. Future studies should utilize similar procedures with a more detailed survey for infant feeding practices, including amounts and/or percentages of mother's own milk and formula.

Furthermore, mothers were simply asked about breastfeeding practices at one point in time (4 months). Thus, our results do not account for changes in feeding practices over the entire first 4 months of life (e.g., if babies were fed formula in the hospital and never again, if mothers were away for a weekend and resumed feeding practices upon return).¹⁶ However, consistent definitions for breastfeeding were used.¹⁶ In addition, infants at 4 months are rarely introduced to solid foods (most solids are introduced closer to 6 months¹⁶); thus, the definitions were likely not convoluted with infants receiving and not receiving solid foods in addition to formula and/or mother's own milk.

An additional limitation is that only one infant motor development testing session was performed. Ideally, two testing sessions would be done to ensure test-retest reliability. However, infant sessions were videoed for review by the pediatric physical therapist to assist with high-quality scoring if anything was not entirely clear during the testing session. Having a certified professional conduct all of our testing was a strength of the study as she was the only tester (no interrater variability) and had extensive clinical experience conducting this test. Unfortunately, bringing in infants for one visit at 4 months of age (often when working parents are back to work and still adjusting to being a new parent) proved to be a challenge and two visits were not feasible. In addition, we accounted for infant temperament and carefully timed study visits around naps, feedings, and other factors that could influence infant behavior (e.g., 4-month shots) and negatively impact the reliability and validity of testing scores.

Future directions

Despite several limitations, this study was an important and novel step toward understanding infant motor development and the factors that may influence it. The present study is continuing to follow children through 1 year of age to determine whether or not breastfeeding status influences motor development at 1 year. Future studies should consider investigating the longer-term impact of breastfeeding practices on infant and childhood motor development (>4 months of age).

Studies designed to test motor development in infants born to mothers who breastfeed for shorter or longer periods of time may be useful to determine critical windows in which breastfeeding may have a more significant impact in infant motor development (e.g., the first 4 months versus the first 6 months versus the first year). Given how time consuming and difficult breastfeeding is for many women,³² data to substantiate the lifelong benefits are critical to encouraging parents to provide mother's own milk when possible. Since infants and children who develop motor skills earlier in life are more likely to continue to be active and move throughout their childhood,^{12,13,33} the factors that influence early motor development are critical to identify and modify clinically. Future studies in this area are important and warranted to improve infant motor development and health across the lifespan.

Conclusion

This study adds to the growing body of literature that supports the widespread benefits of exclusive breastfeeding on offspring health, particularly motor development at 4 months of age. Our findings suggest that providing infants with mother's own milk can have short-term benefits for infant motor development. The study also suggests that physical activities, even moderate intensity, do not appear to be harmful to infant motor development, which supports clinician-approved maternal physical activity during pregnancy. With early motor development linked to more physical activity in later years, the implications of this work are substantial. Health care providers should encourage patients to breastfeed, especially during the early months, in order to positively impact the motor development of their infant.

Disclosure Statement

No competing financial interests exist.

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