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Maternal pre-pregnancy obesity and achievement of infant motor developmental milestones in the Upstate KIDS Study

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Abstract

Objective—Maternal pre-pregnancy obesity is associated with several poor infant health outcomes; however studies that investigated motor development have been inconsistent. Thus, we examined maternal pre-pregnancy weight status and infants' gross motor development.

Design and Methods—Participants consisted of 4,901 mother-infant pairs from the Upstate KIDS study, a longitudinal cohort in New York. Mothers indicated dates when infants achieved each of six gross motor milestones when infants were 4, 8, 12, 18, and 24 months old. Failure time modeling under a Weibull distribution was utilized to compare time to achievement across three levels of maternal pre-pregnancy BMI. Hazard ratios below one indicate a lower "risk" of achieving the milestone and translate to later achievement.

Results—Compared to infants born to thin and normal weight mothers (BMI <25), infants born to obese mothers (BMI>30) were slower to sit without support [HR=0.91, p=0.03] and crawl on hands and knees [HR=0.86, p<0.001], after adjusting for maternal and birth characteristics. Increased gestational age was associated with faster achievement of all milestones but additional adjustment did not impact results.

Conclusions—Maternal pre-pregnancy obesity was associated with a slightly longer time for infant to sit and crawl, potentially due to a compromised intrauterine environment or reduced physically active play.

Keywords

cognitive development; maternal obesity; pregnancy; epidemiology

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Introduction

As many as one in three women in the United States are obese at the time of conception[1] and this prevalence continues to rise.[2] Increased risk for congenital anomalies[3], future obesity[4], learning and behavioral disabilities[5], and mild changes in cognitive development[6, 7] are among the long-term effects of maternal obesity on child development. Little research has investigated the relationship between maternal obesity and infant motor development, even though intrauterine alterations[7, 8], as well as postnatal environmental differences[9] are possible mechanisms for the long-term impact of maternal obesity on child development.

Motor development is a major developmental pathway of early childhood that is largely static across cultures[10] and reflects a child's physical development through muscular maturation[9] and control[11]. According to Piaget's Developmental Theory, the development of sensorimotor systems is the first stage of cognitive development by which the infant learns logic of action and spatial reasoning[12, 13]; therefore, action through motor development is the precursor to mental representation[13]. Earlier acquisition of motor capabilities is hypothesized to enhance cognitive and language development by allowing the child to discover and learn from his environment[10, 12, 14, 15]. For example, earlier achievement of the ability to stand alone is linked to improved executive function in adulthood[15], and gross motor trajectory in early childhood predicts working memory and processing speed in school-aged children[16].

Previous research that relates maternal characteristics to infant motor development has consistently utilized the Bayley Scales of Infant and Toddler Development among other cross-sectional measures[5, 7, 17]. The Bayley is administered during one sitting in children up to preschool age[15]. The motor score is reflective of the child's age and presentation on coordination, balance, and strength during a series of tasks and games[9, 18]. However, it does not measure the time to achieve motor milestones such as sitting without support, which may be a more sensitive measure to detecting small effects in gross motor development. Our goal is to better understand how maternal pre-pregnancy body mass index (BMI) is related to infant motor development measured by the time to acquire gross motor milestones. We hypothesized that children of mothers who were obese before pregnancy may have slower times to achievement of motor milestones than children of normal weight or thinner mothers.

Methods

The Upstate KIDS study is a matched exposure longitudinal cohort study.[19] Women who delivered a live birth between 2008 to 2010 in New York State (excluding New York City) were sampled by birth certificate exposure to infertility treatment and for multiple birth.[19] Singletons not conceived by infertility treatment were sampled at 1:3 ratio and frequency matched to the exposed for region of birth.[19] Participants were recruited by mail at approximately 4 months after delivery. We included all singleton births and a randomly selected twin (n=4,989), excluding higher order multiples, in analysis. Mothers completed a questionnaire upon entry, which provided information on pregnancy behaviors and newborn characteristics. The New York State Department of Health and the University of Albany Institutional Review Board (IRB) approved the study (NYSDOH IRB #07-097; UAlbany #08-179) and served as the IRB designated by the National Institutes of Health for this study under a reliance agreement. All participants provided written informed consent.

Mothers were provided child health journals at enrollment[19] which included a section for mothers to record the date of achievement for each motor developmental task. Mothers were prompted to copy those dates on follow-up questionnaires when infants were approximately four, eight, twelve, eighteen, and twenty-four months of age. At each interval of data collection up until 18 months, mothers were asked to indicate if their child had achieved any of the six gross motor developmental milestones, which include sitting without support, crawling on hands and knees, standing with assistance, walking with assistance, standing alone, and walking alone. To keep the questionnaires succinct, mothers were no longer queried about sitting without support and standing with assistance at 24 months. Times to achieve the gross motor milestones were calculated by subtracting the infant's date of birth, provided in the vital records, from each date of achievement.

Previous research has shown that retrospective surveys completed by the mother on the infant's gross motor milestones are a reliable source of data[20, 21]. Infant motor milestone data collected by monthly telephone interviews with mothers after six months showed no difference in mean reported ages compared to mailed retrospective surveys for milestones except for slightly earlier reporting for standing alone[20]. In a separate study, mothers were asked to recall infant motor milestones at each of the infant's well-baby visits up until two years of age[21]. Between 78% and 98% of milestones were considered accurately demonstrating that mothers are able to recall this information with an acceptable amount of variability[21].

Maternal body-mass-index (BMI) was calculated using pre-pregnancy weight and height as provided in the vital records or maternal baseline questionnaire if missing from vital records, and was categorized as thin and normal weight (<25 kg/m^2), overweight (25–29.99 kg/m^2), or obese (>30 kg/m^2). Paternal weight and height were reported by mothers and calculated with same cutoffs for weight status. Obstetric outcomes and socio-demographic characteristics were also collected from vital records and/or questionnaires. Smoking status and alcohol use were from maternal baseline questionnaires as the primary source of data, with vital records utilized if the information was missing from the baseline questionnaire. Gestational age was based on the clinical estimate collected from birth certificates, which uses all perinatal information including ultrasound and last menstrual period. An external US population reference[22] was used to calculate size for gestational age among singletons. Large (LGA) and small for gestational age (SGA) were defined as >90th and <10th percentile, respectively. Low birth weight and macrosomia were defined <2500 g and >4000 g, respectively.

Statistical Analysis

Statistical analysis was conducted using SAS 9.4 (SAS Institute, Inc., Cary, NC). Differences in baseline characteristics were compared by maternal BMI categories using analysis of variance for continuous variables and chi-square test for categorical variables.

There were 4,910 mother infant pairs in analysis after exclusions for missing pre-pregnancy weight or height information (n=11), or responses on all motor milestones (n=77). Differences in baseline characteristics between the final sample (n=4,901) and those excluded (n=88) were also examined by similar statistical tests.

An accelerated failure time model under a Weibull distribution using the Proc Life Reg procedure was used to analyze time to achievement of the six motor milestones by pre-pregnancy BMI categories. Infants with indicated achievement but lacking a date were interval censored; the receipt date of the questionnaire reporting achievement acted as the upper bound of the interval and the receipt date of the previously returned questionnaire acted as the lower bound of the interval. If the questionnaire indicating achievement was not preceded by an earlier follow-up questionnaire, the participant data was left-censored and the current survey receipt date acted as the upper bound of the interval. For mothers who did not indicate achievement of the skill when the data was last collected, the participant data was right-censored, and the last received date of the questionnaire acted as the lower bound of the interval. Times to achieve each milestone were analyzed independently and estimated effects were converted to hazard ratios with corresponding 95% confidence intervals (CI) using the delta method with the normal maternal BMI category as the reference group. Hazard ratios below one indicate a lower “risk” of achieving the milestone and translate to taking a longer amount of time to achievement.

Three models were used to examine associations; Model 1 adjusting only for maternal age, Model 2 additionally adjusting for socioeconomic status (SES) and maternal characteristics including maternal race, education, marital status, smoking status before and during pregnancy, alcohol use during pregnancy, and private insurance, and Model 3 additionally adjusting for plurality, infant gender, birth weight, and gestational age. This last model included potential mediators of associations between maternal obesity and gross motor development and therefore was examined separately to avoid collider-stratification bias[23]. Current infant weight and height were not accounted for in this analysis as achievement of gross motor milestones is independent of infant anthropometry[10]. We also tested for interaction between pre-pregnancy BMI and plurality.

The primary analysis considered all motor milestones independent of each other without assuming a pattern to the order of achievement. This decision was based on the fact that although most (86%) healthy infants in the W.H.O. Multicentre Growth Reference Study performed five of the motor milestones in the order of sitting without support, standing with assistance, walking with assistance, standing alone, and walking alone, some did not[24]. Crawling was not included in this trajectory of achievement because it is often achieved in a different order or not at all[24]. Assuming the above pattern of achievement of milestones, we conducted sensitivity analyses censoring dates to occur in that order with the goal of reducing error due to failure to specify achievement, rather than failure to achieve milestones. If mothers indicated achievement of higher order milestones (e.g., walking alone) but not achievement of lower level milestones (e.g., standing with assistance), the age of achievement of the higher level milestone replaced the upper bound of the lower level milestone; if a lower level milestone was indicated as achieved but not a higher level milestone, the achievement age of the lower milestone replaced the lower bound of the upper level milestone. Thus, the age to achieve the closest milestone in the order of achievement was used to replace the respected lower or upper bound.

Lastly, we examined how maternal obesity status affected the risk of a motor delay by defining infants as delayed in each of the 6 milestones if they achieved the specific milestone at an age older than the 95th percentile of windows recommended by the WHO[24]. We also examined the alternative cut-offs of 90th percentile. The odds of being delayed for each milestone were estimated using logistic regression.

Results

Of those who reported exact dates, the median, 5th and 95th percentiles of achievement were similar to those previously determined by direct observation[24]. (Table 1) Participants missing pre-pregnancy weight/height or achievement data (n=88) were on average 2 years younger (p=0.004), had lower socioeconomic status (i.e., less likely to have private insurance, be married, and had lower maternal education), and more likely to have had a singleton (88% vs 78%, p=0.03). Approximately 48% of mothers were classified as normal weight, while 26% were classified as overweight, and 27% as obese. (Table 2) Mothers who were classified as normal BMI were more likely to have earned an advanced degree, be a non-smoker, married, and privately insured. Obese mothers were on average slightly younger than normal and overweight mothers and were less likely to consume alcohol during pregnancy. Infants born to obese mothers did not differ by gestational age but were heavier at birth, more likely to be macrosomic (>4000g), and for singletons, to be large for gestational age than infants of mothers who were normal or overweight. Of the 4,901 mothers in the analysis, 4,011 indicated achievement of sitting without support, 3,505 for crawling on hands and knees, 3,750 for standing with assistance, 3,350 for walking with assistance, 3,078 for standing alone, and 2,971 for walking alone. Normal weight mothers were more likely than obese mothers to indicate achievement of milestones (p<0.01) and provide exact dates of achievement (p=0.02).

After adjusting for all maternal, infant, and birth characteristics, results indicate that time to achieve the gross motor developmental milestones may be partly influenced by maternal BMI. (Table 3) Infants of mothers who were obese prior to pregnancy were found to have a significantly lower risk of achieving the motor milestones sitting without support (HR=0.91, p=0.03) and crawling on hands and knees (HR=0.86, p-value<0.001); thus they achieved the motor milestones later than infants of thin and normal-weight mothers. There were no clear associations for infants of mothers who were overweight (BMI 25–30 kg/m^2) before pregnancy. Additional adjustment replacing gestational age with preterm birth, and birth weight with a categorical variable representing low birth weight or macrosomia did not impact results and there was no evidence of interaction with plurality (data not shown).

In sensitivity analyses assuming an order of achievement for censoring, crawling on hands and knees retained significance in Model 1, but became attenuated in Model 2 (HR=0.92, p=0.07). We also replicated analyses using maternal report of pre-pregnancy weight and height information rather than prioritizing information from the birth certificates with similar findings (Supplemental table 1).

Furthermore, children born to obese mothers had higher odds of delay (defined by 95th percentile of WHO reference[24] in walking compared to children born to mothers with normal BMI (adjusted odds ratio=1.56, 95%CI: 1.13, 2.14, p=0.005). The results were adjusted for Model 2 covariates and were consistent using different cut-offs. Although corroborating an indication of delayed motor development, this finding should be interpreted cautiously since it required retaining only infants with exact dates for achievement of each milestone. No associations were observed for other milestones.

We identified other factors associated with time to achieve gross motor milestones. (Table 4) Gestational age was significantly associated with time to achieve all six milestones (p-value<0.05), and plurality was associated with four of the six milestones (p<0.02). Infants with a birth weight z-score of less than two standard deviations were slower to achieve walking with assistance, standing alone, and walking alone (p<0.05) compared to infants with a birth weight z-score of within one standard deviation of the mean. Infants born to mothers with less than a high school education or its equivalent were slower to achieve standing with assistance (p<0.02), walking with assistance (p<0.01), and walking alone (p<0.04) when compared to mothers with an advanced degree. Additional maternal covariates associated with longer time to achieve two or more milestones include non-Hispanic white race on crawling on hands and knees and standing alone (p<0.02), older maternal age on standing with assistance, walking with assistance, an standing alone (p<0.04), and not smoking during pregnancy on sitting without support and standing with assistance (p<0.04). Birth outcomes such as preterm birth, and macrosomia, and birth weight z-score of greater than two standard deviations also had some selected associations with delayed achievement. However, paternal obesity was not associated with motor delays (with or without adjusting for maternal BMI). (data not shown)

Discussion

Recent studies have observed long-term effects of maternal pre-pregnancy obesity and infant motor development on later child health and development[3–7]; however, these studies have consistently utilized cross-sectional measures[5, 7, 17, 25]. By using longitudinal data with time to achieve gross motor milestones, we observed slight delays for sitting without support and crawling after consideration of maternal baseline characteristics. The most robust association was found for time to achieve crawling on hands and knees (p<0.001), which may have implications for infant cognitive development, as faster time to achieve that milestone is associated with improved spatial memory[26].

Previous research investigating pre-pregnancy weight status using the Early Childhood Longitudinal Study-Birth Cohort did not find an association with infant motor development at 24 months when measured by the Bayley Scales of Development version II[7]. However, this measurement cannot accurately distinguish between fine and gross motor development[17]. Using the same cohort followed until kindergarten, severe maternal pre-pregnancy obesity (BMI>35 kg/m^2) was associated with reduced motor development, measured by a standardized test of physical capabilities such as walking backwards, while maternal overweight status was associated with small delays[5]. A separate study of 355 low-income African-American children found that maternal pre-pregnancy obesity was not a predictor of childhood gross motor development at 5 years old using the Peabody Developmental Motor Scales, which assesses balance and reflex[25]. Our findings using time to achieve specific gross motor milestones were able to detect small effects of maternal pre-pregnancy obesity on infant motor development.

Motor development is dependent upon physical and neuromuscular maturation and the interaction of rearing practices and the environment to create opportunities to advance development[9, 27]. Thus, the association between maternal pre-pregnancy obesity and infant motor development may be explained by mechanisms in the prenatal or postnatal environment. Maternal pre-pregnancy obesity may influence motor development by similar mechanisms hypothesized to influence infant cognitive development[7]. Maternal obesity and associated conditions such as inadequate micronutrient intake, physical stressors of excess weight, or metabolic conditions may cause inflammation of the intrauterine environment or alter gene expression through increased lipids and oxidative stress, which is then thought to affect fetal neurodevelopment[7, 8, 28]. Therefore, the association between maternal pre-pregnancy obesity and infant motor development may be partially explained by an affected cerebellum or other areas of the fetal brain that influence later motor development[29].

Alternatively, the dynamical systems theory describes the development of motor proficiency as influenced by the infant, the motor task, and the environment, which encompasses rearing, practice of motor milestones, and opportunities for play[9, 30]. Home environments that allow for opportunities to improve motor development through play material and physical space have been shown to improve infant and child motor development[31]. Obese individuals may perform less physical activity overall[32]. Hence, we hypothesize this lower level of overall physical activity may translate to also less physically active play with their infants, thus possibly providing fewer opportunities to practice motor developmental milestones.

As a delay in infant motor development could be detrimental for both childhood cognitive development[6, 7, 14, 15] and physical growth[4, 27], our findings may have important long-term implications on the role of maternal obesity on these outcomes. Maternal pre-pregnancy obesity and infant motor development have been independently found to predict future cognitive development[6, 7, 14, 15] and weight gain, as infants with delayed motor development have an increased risk for excess adiposity in childhood[27]. If maternal pre-pregnancy obesity influences infant cognitive and motor development via a similar pathway, infant motor development may act as an independent predictor of later cognitive development or childhood obesity and as a mediator between maternal pre-pregnancy obesity and infant cognitive development or childhood obesity. As the magnitude of the associations with sitting and crawling was small in the present study, they may not translate directly to clinical impairments that affect further learning. Nevertheless, prior research indicates that even mild impairments in motor milestones in infancy may have adverse long-term consequences on cognitive development.[33] Future research is needed to quantify how these differences in the timing of milestone achievement relate to later development.

As previously observed[34, 35], we found that increasing gestational age and higher levels of maternal education are associated with faster motor development, while increasing maternal age and infants born small for gestational age are associated with longer time to motor development. Previous research has also documented singleton infants having accelerated motor development over multiples[35]. Our analysis was not comparable to previous research investigating maternal race[34] due to few minorities. Maternal smoking has generally not been found to be associated with motor development[34] and the unexpected finding of quicker achievement remains unclear. We also found that male infants may be slightly faster to achieve crawling on hands and knees than female infants, which contradict previous research dispelling gender differences in crawling[36]. Infants who are classified as macrosomic or large for gestational age were slower to achieve milestones, possibly indicating that maternal over-nutrition or metabolic dysregulation during pregnancy may play a role in infant motor development.

The loss of response over time was a major limitation to this analysis. Across each milestone, between 18% and 40% of participants were right-censored, with on average the proportion of right-censoring participants increasing as milestones increased in skill level. However, we used survival analysis to statistically model associations which provides unbiased results even in cases of non-response[37]. Another limitation is that we did not have clinical measures of pre-pregnancy BMI and relied on the birth certificates combined with maternal report. We also relied on maternal report of milestone achievement, which may be inaccurate. Nevertheless, objective assessment of motor milestones in infancy is not feasible in large-scale studies and has disadvantages too[38]. Questionnaires administered repeatedly and with short intervals make it less likely that mothers erred in their reporting. Our population of predominantly white participants may also limit generalizability. Lastly, as the data are observational, residual confounding could not be ruled out.

While prior research has investigated motor development as predictors of cognitive and language development, little research has described the predictors of motor development using the sensitive measure of time to achieve motor milestones. The present analysis was able to examine how maternal pre-pregnancy BMI among other maternal, infant, and birth characteristics are related to infant motor development. Results indicate that maternal obesity may have small effects on delaying infant motor development, as infants born to obese mothers may be slower to achieve sitting without support and crawling on hands and knees. Future research may investigate if time to achieve motor milestones relates to future risk for other developmental delays.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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1. What is already known about this subject:
    a. Up to one in three pregnant women are obese at the time of conception.
    b. Maternal obesity is associated with poor infant health and development including delayed cognitive development.
    c. Motor development reflects a child's physical development and predicts later cognitive and language development.
2. What this study adds:
    a. Maternal obesity is associated with slight delays in sitting without support and crawling on hands and knees.
    b. Rather than using a single assessment for motor development, using longitudinal reports of timing to motor milestones may be more sensitive to detecting small effects.

Table 1

Time (in months) to achievement of six gross motor milestones in Upstate KIDS.

	5th percentile	Median	95th percentile
Sitting Without Support	4.1	6.4	8.9
Standing With Assistance	5.3	8.2	11.8
Hands-And-Knees Crawling	5.6	8.2	11.6
Walking With Assistance	6.6	9.5	13.1
Standing Alone	7.8	10.8	14.7
Walking Alone	9.3	12.2	16.8

Table 2

Baseline characteristics by Maternal BMI categories in Upstate KIDS.

Pre-Pregnancy BMI Categories	Total 4901	Normal <25 kg/m2 2348 (47.9)	Overweight ≥25 kg/m2 1252 (25.6)	Obese ≥30 kg/m2 1301 (26.6)	P-Value
Maternal Characteristics					
Age	30.5 ± 6.1	30.4 ± 6.1	30.9 ± 6.1	30.1 ± 5.9	<0.01
Race/Ethnicity					0.43
Non-Hispanic White	4082 (83.3)	1984 (83.7)	1028 (82.1)	1090 (83.8)	
Not White or Other	819 (16.7)	384 (16.4)	224 (17.9)	211 (16.2)	
Highest Level of Education					
Less than high school	293 (6.0)	146 (6.2)	67 (5.4)	80 (6.2)	<0.01
HS or GED equivalent	632 (12.9)	270 (11.5)	144 (11.5)	218 (16.7)	
Some college	1497 (30.5)	572 (24.4)	395 (31.6)	530 (40.7)	
College	1080 (22.0)	577 (24.6)	276 (22.0)	227 (17.5)	
Advanced degree	1399 (28.6)	783 (33.4)	370 (29.6)	246 (18.9)	
Private Insurance	3761 (75.0)	1803 (76.9)	296 (76.3)	913 (70.2)	<0.01
Married	4146 (88.4)	2027 (90.0)	1062 (88.1)	1075 (85.7)	<0.01
Smoking Status During Pregnancy					<0.01
Never smoked	3046 (62.2)	1517 (64.2)	785 (62.7)	744 (7.2)	
Smoked previously but not during pregnancy	1162 (23.7)	533 (22.7)	298 (23.8)	331 (5.5)	
Smoked during pregnancy	692 (14.1)	298 (12.7)	169 (13.5)	225 (17.3)	
Alcohol Consumed During Pregnancy	598 (12.2)	337 (14.4)	143 (11.4)	117 (9.0)	<0.01
Indicated exact dates of achievement for all milestones	1720 (35.0)	854 (36.4)	450 (35.9)	416 (32.0)	0.02
Indicated achievement for all milestones	2304 (47.0)	1130 (48.1)	610 (48.7)	564 (43.4)	<0.01
Infant Characteristics					
Twin Births	1073 (21.9)	493 (21.0)	280 (22.4)	300 (23.1)	0.32
Female Infant Gender	2367 (48.3)	1151 (49.0)	608 (48.6)	608 (46.7)	0.41
Birth Characteristics					
Gestational age (weeks)	38.1 ± 2.5	38.1 ± 2.4	38.1 ± 2.5	38.0 ± 2.5	0.36
Birth weight (grams)	3187.3 ± 692.1	3123.7 ± 662.3	3216.7 ± 704.0	3239.9 ± 725.2	<0.01
Low Birth Weight (<2500 grams)	738 (15.1)	379 (16.1)	185 (14.8)	174 (13.4)	0.08

Pre-Pregnancy BMI Categories	Total 4901	Normal <25 kg/m2 2348 (47.9)	Overweight ≥25 kg/m2 1252 (25.6)	Obese ≥30 kg/m2 1301 (26.6)	P-Value
Macrosomia (>4000 grams)	427 (8.7)	156 (6.6)	118 (9.4)	153 (11.7)	<0.01
Preterm birth	869 (17.7)	409 (17.4)	217 (17.3)	243 (18.9)	0.58
Small for gestational age*	314 (8.2)	165 (8.9)	68 (7.0)	81 (8.1)	0.22
Large for gestational age*	435 (11.4)	146 (7.9)	119 (12.2)	170 (17.0)	<0.01
Birth weight z-score*					<0.01
(<−2)	460 (12.0)	242 (13.1)	110 (11.3)	108 (0.8)	
[−2,−1)	63 (1.7)	34 (1.8)	15 (1.5)	14 (1.4)	
[−1,1]	2680 (70.0)	1357 (73.2)	668 (68.7)	655 (5.4)	
(1–2]	504 (13.2)	194 (10.5)	146 (15.0)	164 (16.4)	
(>2)	121 (3.2)	28 (1.5)	33 (3.4)	60 (6.0)	

*Restricted to singletons in the cohort

Mean ± SD for continuous variables and N (%) for categorical.

Note: missing information occurred in some covariates: 188 missing marital status information, 1 missing smoking status and alcohol use, and 4 missing insurance data.

Table 3

Hazard ratios and corresponding 95% confidence intervals of maternal BMI category and time to achieve gross motor milestones using normal BMI as the reference category.

		Model 1		Model 2		Model 3	
		Hazard Ratio (95% CI)	P-Value	Hazard Ratio (95% CI)	P-Value	Hazard Ratio (95% CI)	P-Value
Sit without Support	Obese	0.92 (0.85, 0.99)	0.04+	0.90 (0.83, 0.98)	0.01+	0.91 (0.84, 0.99)	0.03+
	Overweight	1.03 (0.95, 1.10)	0.52	1.02 (0.94, 1.10)	0.58	1.01 (0.93, 1.09)	0.77
Crawl on Hands and Knees	Obese	0.87 (0.80, 0.95)	0.01+	0.86 (0.79, 0.93)	<0.01+	0.86 (0.79, 0.93)	<0.01+
	Overweight	1.01 (0.93, 1.09)	0.80	1.00 (0.92, 1.09)	0.92	1.00 (0.91, 1.08)	0.95
Stand with Assistance	Obese	0.96 (0.88, 1.03)	0.27	0.94 (0.86, 1.02)	0.13	0.93 (0.85, 1.01)	0.09
	Overweight	1.05 (0.96, 1.13)	0.26	1.03 (0.95, 1.12)	0.41	1.01 (0.93, 1.09)	0.78
Walk With Assistance	Obese	0.98 (0.90, 1.06)	0.62	0.96 (0.88, 1.05)	0.42	0.96 (0.88, 1.04)	0.37
	Overweight	1.09 (1.00, 1.18)	0.04+	1.09 (1.00, 1.18)	0.04+	1.08 (0.98, 1.17)	0.09
Stand Alone	Obese	1.02 (0.93, 1.11)	0.70	1.01 (0.92, 1.10)	0.89	1.00 (0.91, 1.09)	0.97
	Overweight	1.04 (0.95, 1.13)	0.38	1.03 (0.94, 1.12)	0.52	1.02 (0.93, 1.11)	0.68
Walk Alone	Obese	0.95 (0.87, 1.04)	0.27	0.96 (0.87, 1.05)	0.40	0.96 (0.87, 1.05)	0.41
	Overweight	1.02 (0.93, 1.11)	0.65	1.03 (0.93, 1.12)	0.57	1.02 (0.93, 1.11)	0.72

+Statistically significant at the p=0.05 level

Model 1: Adjusted by maternal age only.

Model 2: Adjusted by maternal age, maternal race, maternal education, marital status, smoking status before and during pregnancy, alcohol use during pregnancy, and private insurance.

Model 3: Adjusted for covariates in the Model 2 + plurality, infant gender, birth weight, and gestational age.

Table 4

Adjusted hazard ratios and corresponding p-values of covariates significantly associated with time to achieve gross motor milestones

	Sit without support	Crawl on hands and knees	Stand with assistance	Walk with assistance	Stand alone	Walk alone
Non-Hispanice White race		0.83 p<0.001	–	–	0.87 P=0.011	–
Increasing maternal age	–	–	0.98 p<0.0001	0.98 p<0.0001	–	0.99 p=0.04
Private insurance	1.12 p=0.017	–	–	–	–	–
Less than a HS education*	–	–	0.75 P=0.003	0.67 p<0.001	–	0.62 p<.0001
HS/GED Equivalent*	–	–	0.86 P=0.024	0.81 p=0.006	–	0.78 p=0.002
Some college*	0.91 p=0.049	–	–	–	–	0.90 P=0.039
Non-Smoking Status	0.89 p=0.045	–	0.87 p=0.018	–	–	–
Singleton infants[a]	1.12 p=0.018	1.14 p=0.015	1.18 p=0.002	1.29 p<0.001	–	–
Male infant gender[a]	–	1.10 p=0.006	–	–	–	–
Increasing gestational age[a]	1.07 p<0.0001	1.04 p=0.002	1.06 p<0.0001	1.04 p<0.0001	1.03 P=0.045	1.04 p=0.001
Macrosomia[b]	–	–	0.88 P=0.037	–	–	1.14 p=0.041
Low birth weight[b]	–	–	–	–	0.83 P=0.014	–
Preterm[c]	0.74 p<0.0001	–	0.83 P=0.002	–	–	–
SGA[d]	0.83 p=0.007	–	–	–	–	–
BWZ score[e] (<−2)	–	–	–	0.70 p=0.032	0.67 p=0.025	0.70 p=0.050
BWZ score[e] [−2, −1)	1.12 p=0.049	–	–	–	–	–
BWZ score[e] (>2)	0.78 p=0.025	–	0.67 p<0.001	–	–	–

All associations are based on model 2 except as specified below.

[a]Model 3

[b]Model 3, replaced birth weight with categorical variable representing low birth weight or macrosomia.

[c]Model 3, replacing gestational age with preterm birth variable.

[d]Restricted to singletons, inclusion of SGA and LGA (n=3,823).

[e]Restricted to singletons, inclusion of 5 categories of birth weight z-score: $(-\infty, -2)$, $[-2,-1)$, $[-1,1]$, $(1\text{–}2]$, $(2, \infty)$. (n=3,823), compared to $[-1,1]$ as the reference group.

[*]Compared with mothers with advanced education as the reference group.