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Complete List of Authors:	Shoaibi, Azza; Medical University of South Carolina - College of Medicine, Public Health Sciences Neelon, Brian; The Medical University of South Carolina, Biostats Ostbye, Truls; Duke University Benjamin Neelon, Sara E.; Johns Hopkins University, Bloomberg School of Public Health

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Gross motor development, motor milestone achievement, and obesity in a racially diverse cohort of US infants

Azza Shoaibi, PhD,[1] Brian Neelon, PhD,[1] Truls Østbye, MD, PhD,[2] Sara E Benjamin-Neelon, PhD, JD.[3]

[1]Department of Public Health Sciences, Medical University of South Carolina, Charleston, South Carolina 29425; [2]Department of Community and Family Medicine, Duke University Medical Center, Durham, North Carolina 27705; [3]Department of Health, Behavior and Society, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland 21205.

Email addresses: shoaibi@musc.edu; neelon@musc.edu; truls.ostbye@duke.edu; sara.neelon@jhu.edu.

Address correspondence to:

Azza Shoaibi PhD,

Post doctorate fellow

Department of Public Health Sciences, Biomedical Informatics Center

Medical University of South Carolina,

135 cannon, Charleston, South Carolina 29425 USA

shoaibi@musc.edu. Tel: 803-201-7303

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Abstract

Objectives: To investigate longitudinal associations between gross motor development, motor milestone achievement, and obesity in a sample of infants. In a secondary aim, we explored potential bidirectional relationships, as early obesity may impede motor development and poor motor development may lead to obesity.

Design: The design was an observational birth cohort.

Setting: We used data from the Nurture study, a birth cohort of predominately black women and their infants residing in the southeastern United States.

Participants: 666 women enrolled their infants in Nurture. For the present study, we excluded infants with missing data on exposure, outcome, or main covariates, leaving a total analytic sample of 425 infants.

Primary outcome: The main outcome was weight-for-length z-score, measured when infants were 3, 6, 9, and 12 months.

Results: Among infants, 64.7% were black, 18.8% were white, and 16.9% were other/multiple race. Mean (SD) breastfeeding duration was 17.6 (19.7) weeks. Just over one-third (38.5%) had an annual household income of < $20,000. After adjusting for potential confounders, higher motor development score was associated with lower weight-for-length z-score (-0.004; 95% CI -0.001, -0.007; p=0.01), mainly driven by associations among males (-0.007; 95% CI -0.014, -0.001; p=0.03) and not females (0.001; 95% CI -0.005, 0.008; p=0.62). Earlier crawling was the only milestone associated with a lower weight-for-length z-score at 12 months (-0.328; 95% CI -0.585, 0.072; p=0.012). However, this association appeared to be driven by among male infants only (-0.461; 95% CI -0.825--0.096; P=0.01). Weight-for-length z-score was unrelated to subsequent motor development score and was thus not bidirectional in our sample.

Conclusions: Higher motor development score and earlier crawling were associated with lower subsequent weight-for-length z-score. However, male infants appeared to influence these associations. These findings contribute to the growing body of evidence suggesting that delayed motor development may be associated with later obesity.

Strengths and limitations of this study:

- This study includes multiple prospective measures of motor development and obesity, which allowed for careful assessment of the temporality of the relationship between the two.
- Previous studies have not included sufficient representation of participants from racial minority groups. This cohort consists of predominately black women and infants.
- We were not able to follow infants in the Nurture sample beyond 12 months of age.
- Nurture participants were not representative of the larger population in the southeastern US.
- We experienced attrition from birth to the 12-month follow-up; approximately 29% of mothers and their infants withdrew or were lost to follow-up.

Key words: Developmental milestones; Gross motor; Infant; Motor milestones; Obesity

Background

Early childhood is a critical period for preventing obesity and its related complications.[1-3] Identifying early predictors of excessive weight gain can help inform effective interventions to prevent later obesity.[4] As a result, recent calls to action highlight the importance of promoting gross motor activity and decreasing sedentary time for very young children.[5-9] While there is evidence of an association between gross motor activity and obesity in early childhood,[10-18] findings from previous studies have not been consistent—perhaps due to bidirectional relationships among these variables.

Some studies have shown that excess adiposity may impede movement and compromise motor development.[16-18] In one study, obesity and excess subcutaneous fat were associated with delayed motor development, but motor development was unrelated to subsequent weight status.[18] Another study found that heavier infants sat up without support earlier, but weight status was largely unrelated to other motor milestones.[19]

Other studies suggest that physical activity and gross motor movement may provide opportunities to expend energy and may help prevent obesity.[20, 21] Earlier attainment of gross motor milestones, such as crawling and walking, may provide opportunities for infants to move regularly, increasing movement and thus energy expenditure.[15] Given the conflicting findings and the potential complexity of the relationship, we investigated longitudinal associations between gross motor development and obesity, and explored potential bidirectional relationships, in a sample of racially diverse infants.

Methods

Study design and population

We used data from the Nurture study, a birth cohort of predominately black women and their infants residing in the southeastern United States (US).[22] The overall goal of Nurture is to identify factors related to feeding, physical activity, sleep, and stress that contribute to excessive weight gain in infancy, focusing on the role of various caregivers. Between 2013 and 2015, we enrolled women in the study in later pregnancy and confirmed participations shortly after birth. Women provided written, informed consent for themselves and their infants to participate in the study. The Institutional Review Board of Duke University Medical Center approved this study and its protocol.

Trained data collectors conducted home visits when infants were 3, 6, 9, and 12 months of age. In addition, women received automated interactive voice response (IVR) telephone calls in months 1, 2, 4, 5, 7, 8, 10 and 11 to assess a limited set of behaviors, including infant motor milestone achievement. Of the 666 women who enrolled their infants in Nurture after birth, 535 (80.3%) completed the 3-month home visit, 497 (74.6%) completed the 6-month visit, 457 (68.6%) completed the 9-month visit, and 468 (70.3%) completed the 12-month visit. For the present study, we excluded infants with missing data on weight-for-length z-scores at 12 months (n=35) leaving 433 infants. We further excluded those with missing information on covariates included in all models *a priori* and those with missing motor development scores or non-biologically plausible motor milestone data (n=8), leaving a total analysis sample of 425 infants.

We conducted two distinct sets of analyses. First, we examined associations between motor development measured using the Bayley Scales of Infant and Toddler Development: Third Edition[23] and weight-for-length z-score. We hypothesized that poor motor development would be associated with higher weight-for-length z-scores longitudinally throughout infancy. Second, we examined associations of gross motor milestone achievement (rolling over, sitting up, crawling, and walking) and weight-for-length z-score. We hypothesized that delayed achievement of motor milestones would be associated with higher weight for length z-score at 12 months.

Exposure: Motor development and motor milestones

We used two measures to define motor development. First, we used the Bayley Scales of Infant and Toddler Development: Third Edition to measure motor development of infants at each home visit at 3, 6, 9, and 12 months. This is an individually-administrated test that has been designed to assess children development in 5 different functional areas: fine motor, gross motor, cognition, language, social emotion, and adaptive. For this study, we used the motor composite score—the sum of the fine and gross motor scores. The fine motor score comprises of 66 items, which assess fine perceptual-motor integration, motor planning and speed, visual tracking, reaching, object grasping, object manipulation, functional hand skills, and responses to tactile information. The gross motor score comprises of 72 items, which asses the movement of limbs and torso, static positions, dynamic movement balance and motor planning. The descriptive classification of Bayley Scales of Infant and Toddler Development includes 7 ordinal categories: extremely low score (composite score of 69 and below), borderline (composite score of 70 to 79), low average (composite score of 80-89), average (composite score of 90 to 109), high average (composite score of 110 to119), superior (composite score of 120 to129), and very superior (composite score of 130 and above). To allow our results to be comparable with previous studies,[16, 18] we used the sum of the fine and gross motor scores for the first analysis. However, we also examined gross motor development score only, as we were most interested in motor development as a marker of physical activity.

Second, mothers reported whether their infants had achieved each of 4 gross motor milestones monthly during the IVR call: rolling over without assistance, sitting up without assistance, crawling using all four limbs, and walking without assistance. We categorized age of achievement into 3 groups based on World Health Organization (WHO) windows for motor milestone achievement[24] and consistent with our previous study.[15] We collapsed groups that contained fewer than 25 infants. Infants who were not able to achieve a particular milestone by the end of the study period were included in the oldest possible age category.

Outcome: Weight-for-length z-score

Trained data collectors measured infant weight and length at each home visit—recumbent length to the nearest 1/8th inch and weight to the nearest 0.1 pound in triplicate. We calculated age- and sex-specific weight-for-length z-scores using WHO reference standards.[25]

Other measures

We collected demographic information from mothers via interviews and questionnaires at recruitment, at birth, during IVR calls, and during each home visit. Infant variables of interest included age, gender, birth weight for gestational age z-score, race (black, white, other). We abstracted information on infant birth weight in grams and length in centimeters from the medical record. We calculated birth weight for gestational age z-score using international reference data put forth by Intergrowth-21st Newborn Birth Weight Standards and Z Scores.[26] Maternal variables of interest included age, education (≤high school graduate, some college, college graduate, or graduate degree), household income (<$20,000, ≥$20,000), and pre-pregnancy body mass index (BMI). We also documented breastfeeding status during each IVR call and calculated the total number of months of any breastfeeding for each infant.

Statistical analysis

We calculated means and standard deviations (SD) for continuous demographic variables and percentages for categorical variables. We explored mean trajectories of both motor development score and weight-for-length z-score at 3, 6, 9, and 12 months for male and female infants, separately. In the first analysis, we examined the association between motor development score and weight-for-length z-score at a subsequent visit using lagged repeated-measures linear regression. A first-order autoregressive covariance structure to account for association between the repeated measures among infants. We included all covariates discussed above in the model. We also ran the same model to examine the association between gross motor development score only and subsequent weight-for-length z-score. Additionally, as some studies have suggested a bidirectional association between motor development and weight status, we investigated the effect of weight-for-length z-score at an earlier visit on motor development score at a given current visit. For example, when predicting weight-for-length z-score at the 6-month visit, we used motor development score at the 3-month visit. We took this approach to ensure that the exposure preceded the outcome.

In the second analysis, we used a separate linear regressions to investigate the association between age at achievement of each of the 4 milestones and weight-for-length z-score at 12 months. We included the same covariates of interest in the models. To explore differences by gender, we ran the same models separately among female and males. We present results in terms of parameter estimates, 95% CI, and two-sided p values. We conducted all analyses using SAS 9.4 (SAS Institute, Cary, North Carolina, USA) at a significance level of <0.05.

Results

Among infants, 50.6% were female and 49.4% were male (Table 1). The mean (SD) birth weight for gestational age z-score was -0.28 (0.95). In terms of race, 64.7% of infants were black, 18.8% were white, and 16.9% were of 'other' race. The mean (SD) breastfeeding duration was 17.6 (19.7) weeks. Among mothers, 44.1% had some college, college graduate, or graduate degree, and 55.9 % were married or living with partner. Just over one-third (38.5%) had an annual household income of less than $20,000. Mothers had a mean (SD) pre-pregnancy BMI of 30.6 (9.4) and age of 28.13 (5.08) years.

[INSERT TABLE 1 HERE]

Figure 1 illustrates the mean (SD) of motor development scores and weight-for-length z-scores over time among males and females, separately. As Figure 1 (a) shows, motor development scores decreased slightly over infancy, with a mean of 109.67 (11.90) at birth and 97.87 (10.66) at 12 months. Figure 1 (b) shows an increasing trend for weight-for-length z-scores, indicating that infants got relatively heavier throughout the assessment period. In this sample, the mean weight-for-length z-score was 0.14 (1.03) at birth and increased to 0.64 (1.01) at 12 months.

[INSERT FIGURE 1 HERE]

After adjusting for potential confounders, higher motor development score was associated with lower weight-for-length z-score (-0.004; 95% CI -0.001, -0.007; p=0.01) (Table 2). For every 10-unit increase in motor development score (measured at a previous visit), weight-for-length z-score decreased by 0.04 on average. In the stratified analysis, higher motor development score was associated with lower weight-for-length z-score (at the subsequent assessment) among males (-0.007; 95% CI -0.014, -0.001; p=0.03) but not females (0.001; 95% CI -0.005, 0.008; p=0.62). Similarly, when we examined gross motor score only, higher motor development score was associated with lower weight-for-length z-score (-0.018; 95% CI -0.031, -0.004; p=0.01). This association appeared driven by male infants only (-0.033; 95% CI -0.064, -0.003; p=0.03).

[INSERT TABLE 2 HERE]

Earlier achievement of rolling over, sitting up, and walking were not associated with weight-for-length z-score at 12 months (Table 3). However, earlier crawling was associated with lower weight-for-length z-score at 12 months: infants who crawled at 6 months or younger had an average z-score 0.328 lower than those who crawled at 9 months or older (-0.328; 95% CI -0.585, 0.072; p=0.012). In stratified analyses, we observed this association in male infants only (-0.461; 95% CI -0.825, -0.096; P=0.01). Finally, weight-for-length z-score was unrelated to subsequent motor development score (0.074; 95% CI -0.805, 0.955; P=0.87), and thus the association appears to be primarily from motor development to weight status rather than vice versa.

[INSERT TABLE 3 HERE]

Discussion

Among this sample of racially diverse infants, we found that higher motor development score was associated with lower subsequent weight-for-length z-score. We also found that earlier crawling was associated with lower weight-for-length z-score at 12 months. However, earlier achievement of the other 3 gross motor milestones was not associated weight-for-length z-score at 12 months. Multiple studies found that delayed or poor motor development was associated with excessive weight among infants and young children,[15] although a few found no association.[18, 27] There are some differences in these studies in the timing and the method of assessing both motor development and obesity. For example, a study of 25,148 children in Denmark showed that later achievement of motor milestones (sitting up and walking) was not associated with overweight at age 7 years, and later achievement of motor milestones was not a substantial risk factor for later increasing BMI.[28] Infant motor milestone achievement was reported retrospectively by mothers in this study. Nevertheless, their results support our finding that sitting up and walking were not associated with later weight. However, another study reported significant associations of age of achievement of rolling over, sitting up, and walking but not crawling with adiposity at age 3 year. Motor milestone achievement was also reported retrospectively by mothers. Also relevant to our study, Slining et al.[18] found that overweight infants were more likely to have concurrent delayed motor development among a sample of low-income African-American infants. However, in contrast to our findings, motor development was unrelated to subsequent anthropometry. We used Bayley Scales of Infant and Toddler Development: Third Edition[23] (the composite motor score) to measure motor development of infant while Sling et al. used the second edition of the same scale. This might explain some of the differences in the findings. To test the sensitivity of our findings to the measure of exposure, we performed the analysis using the gross motor development score only and found similar results.

We also observed clear differences by gender. Higher motor development score was associated with lower weight-for-length z-score among males but not females in our sample of infants. Additionally, among males only, earlier crawling was associated with lower weight-for-length z-score at 12 months. Previous studies examining this research question did not present differences by gender.[18, 28] However, in studies of older children, and consistent with our findings, researchers observed differences in motor development among boys only.[12, 14, 29] In these prior studies, obesity in boys was associated with poorer gross motor performance. As a possible explanation, the researchers suggest that society may put greater pressure on boys to participate in physical activity from a young age—boys who opt out of these activities may not have the same opportunity to fully develop their motor skills.[12, 29] The researchers hypothesize that gender-specific associations between obesity and motor development impairment may be evident in even younger children, and suggest further research. A recent systematic review notes a positive relation between physical activity and motor milestone achievement, which could help explain the association.[30]

Another explanation could be physiological differences in body composition between males and females in infancy. There is some evidence that very young male and female infants show differences in body fat and fat-free mass percentages, with girls having more fat mass at one month of age.[31] However, these differences by gender were no longer evident by 6 months.[31] Other studies have essentially found no differences in infant percent body fat by gender.[32] We consistently observed associations between motor development and weight-for-length z-score in male infants only and agree that this finding warrants further exploration.

Regardless, motor development in infancy may influence a number of behaviors and outcomes in later childhood. Prior studies suggest that earlier attainment was associated with educational achievement,[33] intelligence,[34, 35] and executive function[27] in later life. Moreover, motor milestone achievement within normal windows during infancy was associated with better physical performance[36] and greater grip strength[37] in middle adulthood. Unfortunately, we were not able to follow infants in the Nurture sample beyond 12 months of age. Future studies may consider longer follow-up periods to more fully assess outcomes throughout childhood.

This study has other limitations. First, Nurture participants were not representative of the larger population in the southeastern US. We enrolled some women from an obstetric clinic that served a high percentage of low-income white women with high-risk pregnancies, but overall, our sample included a higher percentage of black women. Also, we experienced attrition from birth to the 12-month follow-up; approximately 29% of mothers and their infants withdrew or were lost to follow-up. This retention rate, however, is not unusual. In a similar birth cohort from the same geographic region, attrition at the 12-month follow-up exceeded 50%.[38] Moreover, this study reports on findings up to 12 months of follow up for the Nurture cohort. However, a relatively large percent of children walk after 12 months of age.[24] Given the relatively short study period, we were not able to assess children who walked after the end of data collection.

Conclusions

Preventing excessive weight gain in infancy is especially important, and the first year of life represents a critical window for intervention. Although rates of weight gain and obesity did not increase substantially in children ages 6 to 23 months from 1976 to 2014, there were significant increases among non-Hispanic black children.[39] Additionally, a recent study suggests that rapid weight gain in infancy may be more detrimental for black children compared to white children by the time they reach age 5 years.[40] Thus, it is a public health priority to better understand factors contributing to excess weight gain in infancy—especially among black children. Our study contributes to the growing body of evidence suggesting that delayed motor development may be associated with later obesity. Intervention efforts may be warranted to encourage movement and help facilitate gross motor development in young children.[41]

List of abbreviations

Interactive voice response (IVR); standard deviation (SD); United States (US); World Health Organization (WHO).

Declarations

Ethics approval and consent to participate: Women provided written, informed consent for themselves and their infants to participate in the study. The Institutional Review Board of Duke

University Medical Center approved this study and its protocol (reference number Pro00036242).

Patient Consent for publication: Not applicable.

Data sharing statement: The datasets generated and analyzed for the current study are not publicly available due to human subject's restrictions at Duke University Medical Center but may available from the corresponding author on reasonable request with appropriate permissions and agreements in place.

Competing interests: The authors declare that they have no competing interests.

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Contributors: AS conducted the analysis, drafted components of the manuscript, and approved the final manuscript. BN oversaw the analysis, reviewed and edited the manuscript, and approved the final manuscript. SEBN designed the study, conceived of the analysis, drafted components of the manuscript, and approved the final manuscript.

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Figures

Figure 1: Mean trajectories of motor development score (a) and weight-for-length z-score (b) throughout infancy

Tables

Table 1. Characteristics of mothers and infants participating in the Nurture study (n=433)

Infant Characteristics	***Mean (SD)***
Birth weight for gestational age *z*-score	-0.3 (1.0)
Age at 12-month home visit, days	373.9 (23.6)
Weight-for-length z-score at 12 months	0.6 (1.0)
Any breastfeeding, weeks	17.6 (19.7)
Motor development composite score at 12 months	97.9 (10.7)
	Percent (number)
Gender, female	50.6 (219)

Race	
Black	64.7 (280)
White	18.5 (80)
Other race/more than one race	16.9 (73)
Ethnicity, Latino/a	9.0 (37)
Age of rolling over	
4 months and younger	72.1 (312)
Older than 4 months	27.9 (121)
Age of sitting up	
5 months and younger	44.3 (192)
5-6 months	33.0 (143)
Older than 6	22.6 (98)
Age of crawling	
6 months and younger	19.9 (86)
7-8 months	40.4 (175)
Older than 8 months	39.7 (172)
Age of walking	
11 months and younger	34.7 (150)
12 months	28.9 (125)
Older than 12	36.3 (157)
Maternal Characteristics	***Mean (SD)***
Age, years	28.1 (5.8)
Pre-pregnancy body mass index, kg/m^2	30.6 (9.3)

	Percent (frequency)
Race	
Black	67.4 (292)
White	22.2 (96)
Other race/more than one race	10.4 (45)
Ethnicity, Latina	5.6 (24)
Education	
≤High school graduate	44.1 (191)
Some college, college graduate, or graduate degree	55.9 (242)
Marital status	
Married or living with partner	59.1 (253)
Never married, divorced, separated, other	40.9 (175)
Household Characteristics	*Percent (frequency)*
Annual household income	
< $20,000	38.3 (166)
≥ $20,000	61.7 (267)

Table 2. Adjusted[a] longitudinal regression estimates and 95% confidence intervals (CI) in analyses examining motor development score and subsequent weight-for-length z-score from 3 to 12 months

	Infant weight-for-length z-score			
Motor development score	**Estimate**	**95% CI**		**p-value**
All infants (n=425)	-0.004	-0.007	-0.001	0.03

Male infants only (n=213)	-0.007	-0.01	-0.001	0.03
Female infants only (n=211)	0.001	-0.005	0.008	0.62
Gross motor development score				
All infants (n=425)	-0.018	-0.031	-0.004	0.01
Male infants only (n=213)	-0.033	-0.064	-0.003	0.03
Female infants only (n=211)	0.005	-0.024	0.034	0.74

[a]Adjusted for maternal pre-pregnancy body mass index, age, and education; household income; infant race, gender, birth weight for gestational age z-score, breastfeeding, and motor development score at previous visit.

Table 3. Adjusted[a] longitudinal regression estimates and 95% confidence intervals (CI) in analyses examining motor milestone achievement and subsequent weight-for-length z-score from 3 to 12 months

Age of motor milestone achievement	Estimate	95% CI		p-value
All infants (n=425)				
Rolling over (ref=older than 4 months)				
4 months or younger	-0.19	-0.40	0.008	0.06
Sitting up (ref=older than 6 months)				
5 months or younger	0.19	-0.06	0.43	0.13
5 to 6 months	0.22	-0.03	0.48	0.09
Crawling (ref=9 months and older)				
6 months or younger	-0.34	-0.59	-0.09	0.008
7 to 8 months	0.01	-0.20	0.21	0.94

Walking (ref=older than 12 months)				
11 months and younger	-0.17	-0.39	0.06	0.14
12 months	0.13	-0.10	0.37	0.27
Male infants only (n=208)				
Rolling over (ref=older than 4 months)				
4 months or younger	-0.29	-0.60	0.02	0.06
Sitting up (ref=older than 6 months)				
5 months or younger	0.18	-0.17	0.54	0.31
5 to 6 months	0.27	-0.10	0.64	0.15
Crawling (ref=9 months and older)				
6 months or younger	-0.46	-0.83	-0.10	0.01
7 to 8 months	-0.06	-0.37	0.25	0.91
Walking (ref=older than 12 months)				
11 months and younger	-0.09	-0.44	0.26	0.63
12 months	0.08	-0.28	0.44	0.66
Female infants only (n=217)				
Rolling over (ref=older than 4 months)				
4 months or younger	-0.12	-0.40	0.16	0.39
Sitting up (ref=older than 6 months)				
5 months or younger	0.18	-0.16	0.52	0.30
5 to 6 months	0.16	-0.20	0.53	0.37
Crawling (ref=9 months and older)				
6 months or younger	-0.27	-0.63	0.08	0.13

7 to 8 months	0.05	-0.24	0.33	0.75
Walking (ref=older than 12 months)				
11 months and younger	-0.25	-0.56	0.05	0.10
12 months	0.20	-0.14	0.54	0.24

[a]Adjusted for maternal pre-pregnancy body mass index, age, and education; household income; infant race, gender, birth weight for gestational age z-score, and breastfeeding.

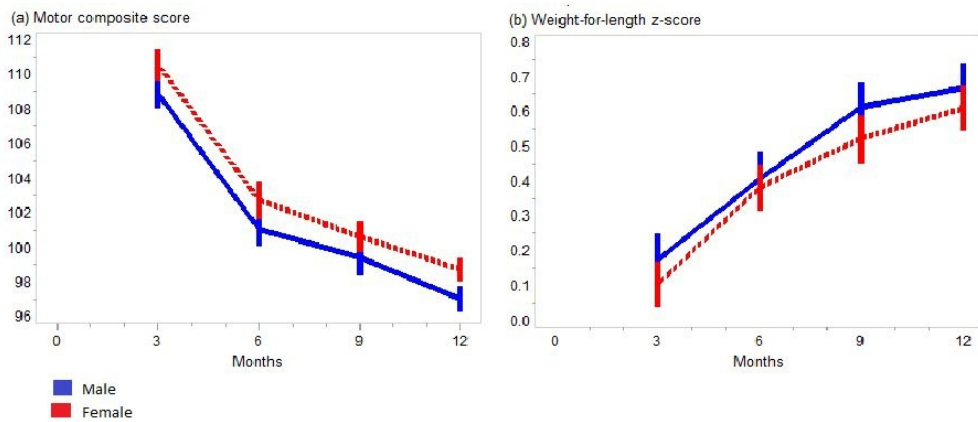

Figure 1: Mean trajectories of motor development score (a) and weight-for-length z-score (b) throughout infancy

76x33mm (300 x 300 DPI)

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Longitudinal associations of gross motor development, motor milestone achievement, and weight-for-length z-score in a racially diverse cohort of US infants

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Longitudinal associations of gross motor development, motor milestone achievement, and weight-for-length z-score in a racially diverse cohort of US infants

Azza Shoaibi, PhD,[1] Brian Neelon, PhD,[1] Truls Østbye, MD, PhD,[2] Sara E Benjamin-Neelon, PhD, JD.[3]

[1]Department of Public Health Sciences, Medical University of South Carolina, Charleston, South Carolina 29425; [2]Department of Community and Family Medicine, Duke University Medical Center, Durham, North Carolina 27705; [3]Department of Health, Behavior and Society, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland 21205.

Email addresses: shoaibi@musc.edu; neelon@musc.edu; truls.ostbye@duke.edu; sara.neelon@jhu.edu.

Address correspondence to:

Azza Shoaibi PhD,

Post doctorate fellow

Department of Public Health Sciences, Biomedical Informatics Center

Medical University of South Carolina,

135 cannon, Charleston, South Carolina 29425 USA

shoaibi@musc.edu. Tel: 803-201-7303

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Abstract

Objectives: To investigate longitudinal associations between gross motor development, motor milestone achievement, and weight-for-length z-scores in a sample of infants. In a secondary aim, we explored potential bidirectional relationships, as higher weight-for-length z-scores may impede motor development and poor motor development may lead to obesity.

Design: The design was an observational birth cohort.

Setting: We used data from the Nurture study, a birth cohort of predominately black women and their infants residing in the southeastern United States.

Participants: 666 women enrolled their infants in Nurture. We excluded infants with missing data on exposure, outcome, or main covariates, leaving a total analytic sample of 425 infants.

Primary outcome: The outcome was weight-for-length z-score, measured when infants were 3, 6, 9, and 12 months.

Results: Among infants, 64.7% were black, 18.8% were white, and 16.9% were other/multiple race. Mean (SD) breastfeeding duration was 17.6 (19.7) weeks. Just over one-third (38.5%) had an annual household income of < $20,000. After adjusting for potential confounders, higher motor development score was associated with lower weight-for-length z-score (-0.004; 95% CI -0.001, -0.007; p=0.01), mainly driven by associations among males (-0.007; 95% CI -0.014, -0.001; p=0.03) and not females (0.001; 95% CI -0.005, 0.008; p=0.62). Earlier crawling was the only milestone associated with a lower weight-for-length z-score at 12 months (-0.328; 95% CI -0.585, 0.072; p=0.012). However, this association appeared to be driven by male infants only (-0.461; 95% CI -0.825--0.096; p=0.01). Weight-for-length z-score was unrelated to subsequent motor development score and was thus not bidirectional in our sample.

Conclusions: Higher motor development score and earlier crawling were associated with lower subsequent weight-for-length z-score. However, this was primary true for male infants only. These findings contribute to the growing body of evidence suggesting that delayed motor development may be associated with later obesity.

Strengths and limitations of this study:

- This study includes multiple prospective measures of motor development and weight-for-length z-scores, which allowed for careful assessment of the temporality of the relationship between the two.
- Previous studies have not included sufficient representation of participants from racial minority groups. This cohort consists of predominately black women and infants.
- We were not able to follow infants in the Nurture sample beyond 12 months of age.
- Nurture participants were not representative of the larger population in the southeastern US.
- We experienced attrition from birth to the 12-month follow-up; approximately 29% of mothers and their infants withdrew or were lost to follow-up.

Key words: Developmental milestones; Gross motor; Infant; Motor milestones; Obesity.

Background

Early childhood is a critical period for preventing obesity and its related complications.[1-3] Identifying early predictors of excessive weight gain can help inform effective interventions to prevent later obesity.[4] As a result, recent calls to action highlight the importance of promoting gross motor activity and decreasing sedentary time for very young children.[5-9] While there is evidence of an association between gross motor activity and obesity in early childhood,[10-18] findings from previous studies have not been consistent—perhaps due to bidirectional relationships among these variables.

Some studies have shown that excess adiposity may impede movement and compromise motor development.[16-18] In one study, obesity and excess subcutaneous fat were associated with delayed motor development, but motor development was unrelated to subsequent weight status.[18] Another study found that heavier infants sat up without support earlier, but weight status was largely unrelated to other motor milestones.[19]

Other studies suggest that physical activity and gross motor skills may provide opportunities to expend energy and may help prevent obesity.[20, 21] Earlier attainment of gross motor milestones, such as crawling and walking, may provide opportunities for infants to move regularly, increasing movement and thus energy expenditure.[15] Given the conflicting findings and the potential complexity of the relationship, we investigated longitudinal associations between gross motor development and weight-for-length, and explored potential bidirectional relationships, in a sample of racially diverse infants.

Methods

Study design and population

We used data from the Nurture study, a birth cohort of predominately black women and their infants residing in the southeastern United States (US).[22] The overall goal of Nurture is to identify factors related to feeding, physical activity, sleep, and stress that contribute to excessive weight gain in infancy, focusing on the role of various caregivers. Between 2013 and 2015, we enrolled women in the study in later pregnancy and confirmed participations shortly after birth. Women provided written, informed consent for themselves and their infants to participate in the study. The Institutional Review Board of Duke University Medical Center approved this study and its protocol.

Trained data collectors conducted home visits when infants were 3, 6, 9, and 12 months of age. In addition, women received automated interactive voice response (IVR) telephone calls in months 1, 2, 4, 5, 7, 8, 10 and 11 to assess a limited set of behaviors, including infant motor milestone achievement. Of the 666 women who enrolled their infants in Nurture after birth, 535 (80.3%) completed the 3-month home visit, 497 (74.6%) completed the 6-month visit, 457 (68.6%) completed the 9-month visit, and 468 (70.3%) completed the 12-month visit. For the present study, we excluded infants with missing data on weight-for-length z-scores at 12 months (n=35) leaving 433 infants. We further excluded those with missing information on covariates included in all models *a priori* and those with missing motor development scores or values outside the World Health Organization (WHO) windows for motor milestone of achievement (n=8), leaving a total analysis sample of 425 infants.

We conducted two distinct sets of analyses. First, we examined associations between motor development measured using the Bayley Scales of Infant and Toddler Development: Third Edition[23] and weight-for-length z-score. We hypothesized that poor motor development would be associated with higher weight-for-length z-scores longitudinally throughout infancy. Second, we examined associations of gross motor milestone achievement (rolling over, sitting up, crawling, and walking) and weight-for-length z-score. We hypothesized that delayed achievement of motor milestones would be associated with higher weight for length z-score at 12 months.

Exposure: Motor development and motor milestones

We used two measures to define motor development. First, we used the Bayley Scales of Infant and Toddler Development: Third Edition to measure motor development of infants at each home visit at 3, 6, 9, and 12 months. This is an individually-administrated test that has been designed to assess children development in 5 different functional areas: fine motor, gross motor, cognition, language, social emotion, and adaptive. For this study, we used the motor composite score—the sum of the fine and gross motor scores. The fine motor score is comprised of 66 items, which assess fine perceptual-motor integration, motor planning and speed, visual tracking, reaching, object grasping, object manipulation, functional hand skills, and responses to tactile information. The gross motor score is comprised of 72 items, which asses the movement of limbs and torso, static positions, dynamic movement balance and motor planning. The descriptive classification of Bayley Scales of Infant and Toddler Development includes 7 ordinal categories: extremely low score (composite score of 69 and below), borderline (composite score of 70 to 79), low average (composite score of 80-89), average (composite score of 90 to 109), high average (composite score of 110 to119), superior (composite score of 120 to129), and very superior (composite score of 130 and above). To allow our results to be comparable with previous studies,[16, 18] we used the sum of the fine and gross motor scores for the first analysis. However, we also examined the scaled gross motor development score only, as we were most interested in motor development as a marker of physical activity.

Second, mothers reported whether their infants had achieved each of 4 gross motor milestones monthly during the IVR call: rolling over without assistance, sitting up without assistance, crawling using all 4 limbs, and walking without assistance. Consistent with our previous study [24] and based on the WHO windows for motor milestone achievement[15], we categorized age of achievement into 3 groups. We collapsed groups that contained fewer than 25 infants. Infants who were not able to achieve a particular milestone by the end of the study period were included in the oldest possible age category.

Outcome: Weight-for-length z-score

Trained data collectors measured infant weight and length at each home visit—recumbent length to the nearest 1/8th inch and weight to the nearest 0.1 pound in triplicate. We then used the average of the three measures. We calculated age- and sex-specific weight-for-length z-scores using WHO reference standards.[25]

Other measures

We collected demographic information from mothers via interviews and questionnaires at recruitment, at birth, during IVR calls, and during each home visit. Infant variables of interest included age, gender, birth weight for gestational age z-score, and race (black, white, other). We abstracted information on infant birth weight in grams and length in centimeters from the medical record. We calculated birth weight for gestational age z-score using international reference data put forth by Intergrowth-21st Newborn Birth Weight Standards and Z Scores.[26] Maternal variables of interest included age, education (≤high school graduate, some college, college graduate, or graduate degree), household income (<$20,000, ≥$20,000), and pre-pregnancy body mass index (BMI). We also documented breastfeeding status during each IVR call and calculated the total number of months of any breastfeeding for each infant.

Statistical analysis

We calculated means and standard deviations (SD) for continuous demographic variables and percentages for categorical variables. We explored mean trajectories of both motor development score and weight-for-length z-score at 3, 6, 9, and 12 months for male and female infants, separately. In the first analysis, we examined the association between motor development score and weight-for-length z-score at a subsequent visit using lagged repeated-measures linear regression. A first-order autoregressive covariance structure to account for association between the repeated measures among infants. We included all covariates discussed above in the model. We also ran the same model to examine the association between gross motor development score only and subsequent weight-for-length z-score. Additionally, as some studies have suggested a bidirectional association between motor development and weight status, we investigated the effect of weight-for-length z-score at an earlier visit on motor development score at a given current visit. For example, when predicting weight-for-length z-score at the 6-month visit, we used motor development score at the 3-month visit. We took this approach to ensure that the exposure preceded the outcome.

In the second analysis, we used separate linear regressions to investigate the association between age at achievement of each of the 4 milestones and weight-for-length z-score at 12 months. We included the same covariates of interest in the models. To explore differences by gender, we ran the same models separately among female and males. We present results in terms of parameter estimates, 95% CI, and two-sided p values. We conducted all analyses using SAS 9.4 (SAS Institute, Cary, North Carolina, USA) at a significance level of <0.05.

Patient and Public Involvement

Research participants were not involved in the development, recruitment, or conduct of the study. We will disseminate results of the study through scientific publications and mailings to research participants.

Results

Among infants, 50.6% were female and 49.4% were male (Table 1). The mean (SD) birth weight for gestational age z-score was -0.3 (1.0). In terms of race, 64.7% of infants were black, 18.8% were white, and 16.9% were of 'other' race. The mean (SD) breastfeeding duration was 17.6 (19.7) weeks. Among mothers, 44.1% had some college, college graduate, or graduate degree, and 55.9 % were married or living with partner. Just over one-third (38.5%) had an annual household income of less than $20,000. Mothers had a mean (SD) pre-pregnancy BMI of 30.6 (9.4) and age of 28.13 (5.1) years. At 12 months, 66.5% of infants were normal weight and over one third were considered at risk of overweight, overweight, or obese.

[INSERT TABLE 1 HERE]

Figure 1 illustrates the mean (SD) of motor development scores and weight-for-length z-scores over time among males and females, separately. As Figure 1 (a) shows, motor development scores decreased slightly over infancy, with a mean of 109.7 (11.9) at birth and 97.9 (10.7) at 12 months. Figure 1 (b) shows an increasing trend for weight-for-length z-scores, indicating that infants got relatively heavier throughout the assessment period. In this sample, the mean weight-for-length z-score was 0.1 (1.0) at birth and increased to 0.6 (1.0) at 12 months. There was no evidence of outlying observations when we examined the scaled residuals from the final model.[27]

[INSERT FIGURE 1 HERE]

After adjusting for potential confounders, higher motor development score was associated with lower weight-for-length z-score (-0.004; 95% CI -0.001, -0.007; p=0.01) (Table 2). For every 10-unit increase in motor development score (measured at a previous visit), weight-for-length z-score decreased by 0.04 on average. In the stratified analysis, higher motor development score was associated with lower weight-for-length z-score (at the subsequent assessment) among males (-0.007; 95% CI -0.01, -0.001; p=0.03) but not females (0.001; 95% CI -0.005, 0.008; p=0.62). Similarly, when we examined gross motor score only, higher motor development score was associated with lower weight-for-length z-score (-0.02; 95% CI -0.03, -0.004; p=0.01). This association appeared driven by male infants only (-0.03; 95% CI -0.06, -0.003; p=0.03).

[INSERT TABLE 2 HERE]

Earlier achievement of rolling over, sitting up, and walking were not associated with weight-for-length z-score at 12 months (Table 3). However, earlier crawling was associated with lower weight-for-length z-score at 12 months: infants who crawled at 6 months or younger had an average z-score 0.33 lower than those who crawled at 9 months or older (-0.33; 95% CI -0.59, 0.07; p=0.01). In stratified analyses, we observed this association in male infants only (-0.46; 95% CI -0.83, -0.10; P=0.01). Finally, weight-for-length z-score was unrelated to subsequent motor development score (0.07; 95% CI -0.81, 0.96; P=0.87), and thus the association appears to be primarily from motor development to weight status rather than vice versa.

[INSERT TABLE 3 HERE]

Discussion

Among this sample of racially diverse infants, we found that higher motor development score was associated with lower subsequent weight-for-length z-score. We also found that earlier crawling was associated with lower weight-for-length z-score at 12 months. However, earlier achievement of the other 3 gross motor milestones was not associated weight-for-length z-score at 12 months. Multiple studies found that delayed or poor motor development was associated with excessive weight among infants and young children,[15] although a few found no association.[18, 28] There are some differences in these studies in the timing and the method of assessing both motor development and obesity. For example, a study of 25,148 children in

Denmark showed that later achievement of motor milestones (sitting up and walking) was not associated with overweight at age 7 years, and later achievement of motor milestones was not a substantial risk factor for later increasing BMI.[29] Infant motor milestone achievement was reported retrospectively by mothers in this study. Nevertheless, their results support our finding that sitting up and walking were not associated with later weight. However, another study reported significant associations of age of achievement of rolling over, sitting up, and walking but not crawling with adiposity at age 3 years. Motor milestone achievement was also reported retrospectively by mothers. Also relevant to our study, Slining et al.[18] found that overweight infants were more likely to have concurrent delayed motor development among a sample of low-income African-American infants. However, in contrast to our findings, motor development was unrelated to subsequent anthropometry. We used Bayley Scales of Infant and Toddler Development: Third Edition[23] (the composite motor score) to measure motor development of infant while Slining et al. used the second edition of the same scale. This might explain some of the differences in the findings. To test the sensitivity of our findings to the measure of exposure, we performed the analysis using the gross motor development score only and found similar results.

We also observed clear differences by gender. Higher motor development score was associated with lower weight-for-length z-score among males but not females in our sample of infants. Additionally, among males only, earlier crawling was associated with lower weight-for-length z-score at 12 months. Previous studies examining this research question did not present differences by gender.[18, 29] However, in studies of older children, and consistent with our findings, researchers observed differences in motor development among boys only.[12, 14, 30]

In these prior studies, obesity in boys was associated with poorer gross motor performance. As a possible explanation, the researchers suggest that society may put greater pressure on boys to participate in physical activity from a young age—boys who opt out of these activities may not have the same opportunity to fully develop their motor skills.[12, 30] The researchers hypothesize that gender-specific associations between obesity and motor development impairment may be evident in even younger children, and suggest further research. A recent systematic review in children ages 4 to 6 years notes a positive relation between physical activity and motor milestone achievement, which could help explain the association.[31] Parental support of physical activity may also play a role in motor development differences between boys and girls. In a longitudinal study among 12-year-old children [32], girls reported less parental support of physical activity when compared to boys. Findings from the same study suggested that higher levels of parental support were translated to higher levels of physical activity in boys but not girls. These differences may be evident even earlier in childhood, although evidence is lacking.

Another explanation could be physiological differences in body composition between males and females in infancy. There is some evidence that very young male and female infants show differences in body fat and fat-free mass percentages, with girls having more fat mass at one month of age.[33] However, these differences by gender were no longer evident by 6 months.[33] Other studies have essentially found no differences in infant percent body fat by gender.[34] We consistently observed associations between motor development and weight-for-length z-score in male infants only and agree that this finding warrants further exploration.

Breastfeeding may also influence the relationship between obesity and motor development in infancy. Some evidence suggests improved motor development in breastfeed infants and toddlers [35], but findings have not been consistent across multiple studies. [36] In our study, 28.51% of infants were breastfed at 6 months of age, which is lower than the national prevalence of 57.6%. [37] Further research is needed to investigate the exact role of breastfeeding on the relationship between early obesity and motor development. In our study, we controlled for breastfeeding in the final model.

Regardless, motor development in infancy may influence a number of behaviors and outcomes in later childhood. Prior studies suggest that earlier attainment was associated with educational achievement,[38] intelligence,[39, 40] and executive function[28] in later life. Moreover, motor milestone achievement within normal windows during infancy was associated with better physical performance[41] and greater grip strength[42] in middle adulthood. Unfortunately, we were not able to follow infants in the Nurture sample beyond 12 months of age. Future studies may consider longer follow-up periods to more fully assess outcomes throughout childhood.

This study has other limitations. First, Nurture participants were not representative of the larger population in the southeastern US. We enrolled some women from an obstetric clinic that served a high percentage of low-income white women with high-risk pregnancies, but overall, our sample included a higher percentage of black women. Also, we experienced attrition from birth to the 12-month follow-up; approximately 29% of mothers and their infants withdrew or were lost to follow-up. This retention rate, however, is not unusual. In a similar birth cohort from the same geographic region, attrition at the 12-month follow-up exceeded 50%.[43] Moreover, this study reports on findings up to 12 months of follow up for the Nurture cohort. However, a relatively large percent of children walk after 12 months of age.[24] Given the relatively short study period, we were not able to assess children who walked after the end of data collection.

Conclusions

Preventing excessive weight gain in infancy is especially important, and the first year of life represents a critical window for intervention. Although rates of weight gain and obesity did not increase substantially in children ages 6 to 23 months from 1976 to 2014, there were significant increases among non-Hispanic black children.[44] Additionally, a recent study suggests that rapid weight gain in infancy may be more detrimental for black children compared to white children by the time they reach age 5 years.[45] Thus, it is a public health priority to better understand factors contributing to excess weight gain in infancy—especially among black children. Our study contributes to the growing body of evidence suggesting that delayed motor development may be associated with higher weight-for-length z-scores in the future. Intervention efforts may be warranted to encourage movement and help facilitate gross motor development in young children.[46]

List of abbreviations

Interactive voice response (IVR); standard deviation (SD); United States (US); World Health Organization (WHO).

Declarations

Ethics approval and consent to participate: Women provided written, informed consent for themselves and their infants to participate in the study. The Institutional Review Board of Duke University Medical Center approved this study and its protocol (reference number Pro00036242).

Patient Consent for publication: Not applicable.

Data sharing statement: The datasets generated and analyzed for the current study are not publicly available due to human subject restrictions at Duke University Medical Center but may available from the corresponding author on reasonable request with appropriate permissions and agreements in place.

Competing interests: The authors declare that they have no competing interests.

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Contributors: AS conducted the analysis, drafted components of the manuscript, and approved the final manuscript. BN oversaw the analysis, reviewed and edited the manuscript, and approved the final manuscript. SEBN designed the study, conceived of the analysis, drafted components of the manuscript, and approved the final manuscript. TØ contributed to the design of the study, reviewed and edited the manuscript, and approved the final manuscript.

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Figures

Figure 1: Mean trajectories of motor development score (a) and weight-for-length z-score (b) throughout infancy

Tables

Table 1. Characteristics of mothers and infants participating in the Nurture study (n=433)

Infant Characteristics	***Mean (SD)***
Birth weight for gestational age z-score	-0.3 (1.0)
Age at 12-month home visit, days	373.9 (23.6)
Weight-for-length z-score at 12 months	0.6 (1.0)
Any breastfeeding, weeks	17.6 (19.7)
Motor development composite score at 12 months	97.9 (10.7)
	Percent (number)
Gender, female	50.6 (219)
Race	
Black	64.7 (280)
White	18.5 (80)
Other race/more than one race	16.9 (73)
Ethnicity, Latino/a	9.0 (37)
Weight-for-length z-score at 12 months by WHO category	
Severely wasted (severely underweight)	—
Wasted (underweight)	0.5 (2)
Normal	66.5 (288)
Possible risk of overweight	24.7 (107)
Overweight	6.7 (29)

Obese	1.6 (7)
Age of rolling over	
4 months and younger	72.1 (312)
Older than 4 months	27.9 (121)
Age of sitting up	
5 months and younger	44.3 (192)
5-6 months	33.0 (143)
Older than 6 months	22.6 (98)
Age of crawling	
6 months and younger	19.9 (86)
7-8 months	40.4 (175)
Older than 8 months	39.7 (172)
Age of walking	
11 months and younger	34.7 (150)
12 months	28.9 (125)
Older than 12	36.3 (157)
Maternal Characteristics	***Mean (SD)***
Age, years	28.1 (5.8)
Pre-pregnancy body mass index, kg/m^2	30.6 (9.3)
	Percent (frequency)
Race	
Black	67.4 (292)
White	22.2 (96)

Other race/more than one race	10.4 (45)
Ethnicity, Latina	5.6 (24)
Education	
≤High school graduate	44.1 (191)
Some college, college graduate, or graduate degree	55.9 (242)
Marital status	
Married or living with partner	59.1 (253)
Never married, divorced, separated, other	40.9 (175)
Household Characteristics	***Percent (frequency)***
Annual household income	
< $20,000	38.3 (166)
≥ $20,000	61.7 (267)

WHO; World Health Organization

Table 2. Adjusted[a] longitudinal regression estimates and 95% confidence intervals (CI) in analyses examining motor development score and subsequent weight-for-length z-score from 3 to 12 months

	Infant weight-for-length z-score			
Motor development score	**Estimate**	**95% CI**		**p-value**
All infants (n=425)	-0.004	-0.007	-0.001	0.03
Male infants only (n=213)	-0.007	-0.01	-0.001	0.03
Female infants only (n=211)	0.001	-0.005	0.008	0.62

Gross motor development score				
All infants (n=425)	-0.02	-0.031	-0.004	0.01
Male infants only (n=213)	-0.03	-0.06	-0.003	0.03
Female infants only (n=211)	0.005	-0.02	0.034	0.74

[a]Adjusted for maternal pre-pregnancy body mass index, age, and education; household income; infant race, gender, birth weight for gestational age z-score, breastfeeding, and motor development score at previous visit.

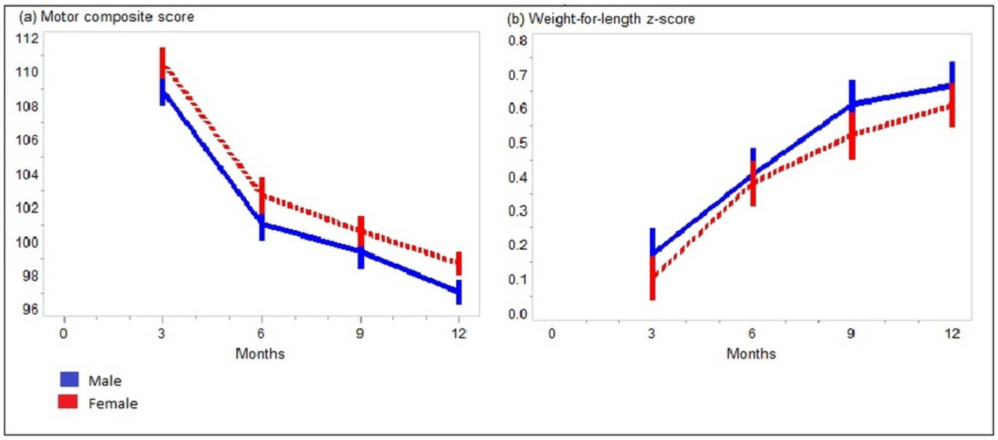
Table 3. Adjusted[a] longitudinal regression estimates and 95% confidence intervals (CI) in analyses examining motor milestone achievement and subsequent weight-for-length z-score from 3 to 12 months

Age of motor milestone achievement	Estimate	95% CI		p-value
All infants (n=425)				
Rolling over (ref=older than 4 months)				
4 months or younger	-0.19	-0.40	0.008	0.06
Sitting up (ref=older than 6 months)				
5 months or younger	0.19	-0.06	0.43	0.13
5 to 6 months	0.22	-0.03	0.48	0.09
Crawling (ref=9 months and older)				
6 months or younger	-0.34	-0.59	-0.09	0.008
7 to 8 months	0.01	-0.20	0.21	0.94
Walking (ref=older than 12 months)				
11 months and younger	-0.17	-0.39	0.06	0.14

12 months	0.13	-0.10	0.37	0.27
Male infants only (n=208)				
Rolling over (ref=older than 4 months)				
4 months or younger	-0.29	-0.60	0.02	0.06
Sitting up (ref=older than 6 months)				
5 months or younger	0.18	-0.17	0.54	0.31
5 to 6 months	0.27	-0.10	0.64	0.15
Crawling (ref=9 months and older)				
6 months or younger	-0.46	-0.83	-0.10	0.01
7 to 8 months	-0.06	-0.37	0.25	0.91
Walking (ref=older than 12 months)				
11 months and younger	-0.09	-0.44	0.26	0.63
12 months	0.08	-0.28	0.44	0.66
Female infants only (n=217)				
Rolling over (ref=older than 4 months)				
4 months or younger	-0.12	-0.40	0.16	0.39
Sitting up (ref=older than 6 months)				
5 months or younger	0.18	-0.16	0.52	0.30
5 to 6 months	0.16	-0.20	0.53	0.37
Crawling (ref=9 months and older)				
6 months or younger	-0.27	-0.63	0.08	0.13
7 to 8 months	0.05	-0.24	0.33	0.75
Walking (ref=older than 12 months)				

11 months and younger	-0.25	-0.56	0.05	0.10
12 months	0.20	-0.14	0.54	0.24

[a]Adjusted for maternal pre-pregnancy body mass index, age, and education; household income; infant race, gender, birth weight for gestational age z-score, and breastfeeding.



Mean trajectories of motor development score (a) and weight-for-length z-score (b) throughout infancy

90x39mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Page/line
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1/5 and 1/15
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4/5-45
Objectives	3	State specific objectives, including any prespecified hypotheses	4/45-52
Methods			
Study design	4	Present key elements of study design early in the paper	5/5-24
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5/15-35
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	5/35-52
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*6-8*
Bias	9	Describe any efforts to address potential sources of bias	8/45-9/3
Study size	10	Explain how the study size was arrived at	5/36-45
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7/22-27
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-9
		(*b*) Describe any methods used to examine subgroups and interactions	9/13-15
		(*c*) Explain how missing data were addressed	5/36-45
		(*d*) If applicable, explain how loss to follow-up was addressed	Ref 22**
		(*e*) Describe any sensitivity analyses	NA
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Ref 22**
		(b) Give reasons for non-participation at each stage	Ref 22**
		(c) Consider use of a flow diagram	Ref 22**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	9/38-27
		(b) Indicate number of participants with missing data for each variable of interest	5/36-45
		(c) Summarise follow-up time (eg, average and total amount)	5/36-45
Outcome data	15*	Report numbers of outcome events or summary measures over time	9/52-10/27
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted	10/35-

		estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11/27
		(*b*) Report category boundaries when continuous variables were categorized	NA
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
Discussion			
Key results	18	Summarise key results with reference to study objectives	11/37-47
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14/40-15/9
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	11/47-14/36
Generalisability	21	Discuss the generalisability (external validity) of the study results	14/40-47
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	16/36

*Give information separately for exposed and unexposed groups.
** A detailed description of the Nurture study cohort is discussed and published previously and referenced in this manuscript- Reference number [22]. (Benjamin Neelon SE, Ostbye T, Bennett GG, Kravitz RM, Clancy SM, Stroo M, Iversen E, Hoyo C: Cohort profile for the Nurture Observational Study examining associations of multiple caregivers on infant growth in the Southeastern USA. BMJ open 2017, 7(2):e013939)

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.