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Infant overweight is associated with delayed motor development

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Abstract

Objective—To examine how infant overweight and high subcutaneous fat relate to infant motor development.

Study design—Participants are from the Infant Care, Feeding, and Risk of Obesity Project, a prospective, longitudinal study of low-income African American mother-infant dyads assessed from 3 -18 months of age (836 observations on 217 infants). Exposures were overweight (weight-for-length z-score ≥90th percentile of 2000 CDC/NCHS growth reference) and high subcutaneous fat (sum of three skinfold measurements >90th percentile of our sample). Motor development was assessed using Bayley Scales of Infant Development-II. Developmental delay was characterized as a standardized Psychomotor Development Index score <85. Longitudinal models estimated developmental outcomes as functions of time-varying overweight and subcutaneous fat, controlling for age and sex. Alternate models tested concurrent and lagged relationships (prior weight or subcutaneous fat predicting current motor development).

Results—Motor delay was 1.80 times as likely in overweight compared with non-overweight infants (95% CI:1.09, 2.97), and 2.32 times as likely in infants with high subcutaneous fat compared with lower subcutaneous fat (95% CI:1.26, 4.29). High subcutaneous fat was also associated with delay in subsequent motor development (OR=2.27, 95% CI:1.08, 4.76).

Conclusions—Pediatric overweight and high subcutaneous fat are associated with delayed infant motor development.

Keywords

Motor development; infant growth; infant behavior

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INTRODUCTION

Little research has focused on the motor developmental consequences of pediatric overweight or fatness. Studies in developing countries provide evidence of motor developmental delays and deficits associated with undernutrition [11-13], but few studies have examined motor developmental consequences associated with overnutrition. Excess body weight and excess fat may restrict motor development. Associations between motor skills and overweight have been documented in children and adolescents [14-18], but few studies have examined infants. One study [19] reported gross motor delays in overweight as compared with normal weight infants. A larger community-based study also found that rates of delayed gross motor skills were significantly higher in overweight infants[20]. A third study found that relatively heavier babies were able to sit without support earlier, but that weight status in infancy was largely unrelated to any other motor development milestones [21]. Even though these studies provide evidence of an association between gross motor skills and physical size, they are unable to make causal inferences; overweight may cause motor developmental delays, slow motor development may cause overweight, or both overweight and motor developmental delay may be caused by unobserved factors.

Understanding the determinants of motor developmental delay is important in itself, and is also important because delays in this domain may impair development in other domains, including cognitive, social and emotional development [22-24].

The aim of this study is to examine the extent to which infant overweight and high subcutaneous fat are concurrently and prospectively associated with motor development delay among low-income African-American infants. Because the association of motor development and weight status or subcutaneous fat may be bidirectional, we use lagged models to address temporality and to support causal inference. We hypothesized that overweight and high subcutaneous fat delay motor development, even at this young age.

METHODS

Participants are from the Infant Care, Feeding and Risk of Obesity Study (hereafter called Infant Care), a prospective observational cohort study designed to examine how parenting and infant feeding styles relate to infant diet and the risk of infant overweight. We recruited African American first-time mothers aged 18-35 years and their 3-month-old infants from selected Women Infant and Children (WIC) clinics in North Carolina. A mother was eligible to participate if her income was < 250% of the Department of Health and Human Services poverty guidelines. [26] Pairs were excluded if the infant was born before 35 weeks gestation, or had Down's syndrome, epilepsy, cleft lip or palate, cerebral palsy, failure to thrive, mental retardation, severe food allergies or any condition that might affect appetite, feeding or growth. Mother/infant dyads were assessed during in-home visits when infants were 3, 6, 9, 12, and 18 months of age. Data were collected from 2003-2007. [27]

A total of 217 mothers and infants were recruited at baseline (3 months). Of those, 215 infants (with 648 longitudinal observations) were included in the analytic sample. We excluded observations if the infant was over 22 months of age (11 observations) and if the infant exhibited a growth trajectory indicative of failure to thrive (1 individual, 5 observations). In our analytic sample at baseline, there were no significant differences in maternal or infant characteristics (maternal education and weight status, infant motor developmental status and body composition) among those who withdrew or were lost to follow-up after baseline and those who completed the study. The protocol was approved by the School of Public Health Institutional Review Board at the University of North Carolina at Chapel Hill.

Infant anthropometry was assessed at every home visit. Study personnel trained in standard anthropometric techniques measured infant weight on an electronic digital scale to the nearest 10 g. and recumbent length on a portable rigid length board to the nearest 0.1 cm. Infant skinfold thicknesses (subscapular, tricep and abdominal) were measured using Harpenden calipers. All anthropometric measurements were done in triplicate and the mean was used in analyses. Weight-for-length z-scores (WLZ) were calculated using the CDC/NCHS 2000 growth reference. [28] We defined overweight as a WLZ at or above the age- and sex-specific 90th percentile. Infant growth may affect lean and fat development differentially at different times. [29] To the extent that the composition of growth varies between individuals in terms of fat and fat-free mass, a simple weight for length index may represent overall fatness. [30, 31] To better capture overall fatness we also classified infants as having high subcutaneous fat if their sum of three skinfold thicknesses was above the 90th percentile of our sample's age and sex-specific skinfold distribution. Infant skinfold thickness measures are a non-invasive means of measuring body composition that have been shown to correlate highly with body fat assessed by direct measurement with dual-energy X-ray absorptiometry (DXA) ($R^2 = 0.936$). [32] Although the use of sample-specific distributions makes comparisons with other samples more difficult, reference data for subscapular and tricep skinfolds are not available for 18-month old infants and reference data for abdominal skinfold thickness measures are not available at any infant age. To provide context for our sample, we have included the median subscapcular and tricep skinfold values from our sample and the NHANES III reference data (when available) as well as the percent of our sample that is above the NHANES III 90th percentile for each available measurement (Table I; available at www.jpeds.com). [33]

Maternal anthropometry, assessed at the first home visit (infant age 3 mo.), were used in this analysis. Maternal weight was measured on an electronic digital scale to the nearest 0.1 kg. Maternal height was measured using a portable stadiometer to the nearest 0.1 cm.

The Motor Scale of the Bayley Scales of Infant Development, 2nd Edition (BSID-II) [34] was used to assess infants' postural and motor skills at 3, 6, 9, 12 and 18 months. The BSID-II assesses the degree of body control, large muscle coordination, fine motor (manipulation) skills of the hands and fingers, dynamic movement, and postural balance and imitation through administration of item sets organized by age. The item sets for the 5 ages contain from 14 to 21 items; of those, approximately 75% of the items on each set deal with gross motor skills. Thus, the preponderance of the items assess gross motor skills related to large body movement, which could be affected by high adiposity or overweight in a way that fine motor skills involving the hand would not. The Psychomotor Development Index (PDI) is standardized for age, based on established reference norms [34]. PDI scores between 85 and 114 are considered "within normal limits" whereas scores between 70 and 84 are considered to reflect "mildly delayed performance" and scores 69 and below, "significantly delayed performance." [34] Study personnel were trained by an experienced developmental psychologist and investigator on the project. Motor developmental status at each age was characterized separately as: 1) a continuous variable representing the Psychomotor Development Index (PDI) score; and 2) a binary variable representing low PDI (PDI Score<85).

Child sex and age, and maternal age, weight status and education were considered as potential confounders or effect measure modifiers. We did not include income because this information was not provided by more than half of the sample women, and selection criteria limited variability in income.

We used t- and chi-square statistics to compare anthropometrics and motor developmental characteristics of males and females. Effect measure modification by sex, maternal BMI, maternal education and infant age were examined by testing interaction terms using likelihood ratio tests, with $\alpha = 0.10$. We examined confounding using an *a priori* change in estimate criterion (change in main exposure effect coefficient of >10%). Random effects longitudinal models (linear regression for the PDI, and logistic regression for delayed motor development) were used to estimate motor developmental status as a function of time varying WLZ or subcutaneous fat, adjusting for infant age, age squared and sex. Maternal age, weight status and education were not found to be effect measure modifiers or confounders in our sample based on the criteria above and were therefore not included in final models. To address temporality and support causal inference, we specified a second set of models with weight status or subcutaneous fat *at the prior visit* predicting current motor developmental status. Finally, because the association of motor development and weight status or subcutaneous fat may be bidirectional, we examined the effects of motor developmental status on subsequent anthropometry. Statistical significance was defined as $P < 0.05$ and all data analyses were performed with STATA software (version 10.0, College Station, TX). [35]

RESULTS

At all time points, sample infants had positive mean WLZ scores, indicating mean relative weight was higher than the median CDC/NCHS 2000 growth reference (Table II). Mean WLZ and the percentage of overweight infants decreased as infants aged. Males had significantly higher WLZ than females only at 6 months. Sample infants also had relatively higher tricep and subscapular fat as compared with the NHANES-III reference data (Table I). There were no statistically significant sex differences in motor developmental status at any time point.

Results of the random effects longitudinal analyses are presented in Tables III, IV, and V. We first examined the concurrent relationship between anthropometry and motor development (Table III). No significant interactions were found between infant anthropometry and infant sex, maternal BMI, maternal education or infant age, therefore models include only main effects. Overweight infants were nearly twice as likely as non-overweight infants to have a low (<85) PDI score reflecting concurrent delayed motor development. Infants with high subcutaneous fat were over twice as likely as those without high subcutaneous fat to have a low PDI score and high subcutaneous fat was associated with nearly a 3-unit lower PDI score.

Second, high subcutaneous fat was associated with an average 4-unit lower PDI score 6 months later (Table IV). Finally, motor development was unrelated to subsequent anthropometry (Table V).

DISCUSSION

Little research has examined the motor developmental consequences of pediatric obesity. We hypothesized that overweight and high subcutaneous fat would associate with decreased motor development. Our results are consistent with two previous cross-sectional studies that examined Israeli infants ≤ 24 months of age, finding significant delay in concurrent motor development among overweight as compared with normal weight babies [19]. The current findings obtained from longitudinal models add strength to the evidence that overweight is causally related to decreased motor development.

In the current study we did not find consistent, significant associations between infant anthropometry and either concurrent or subsequent standardized psychomotor development index (PDI) scores when scores were modeled as a continuous variable. As highlighted by the WHO MGRS group, "the consistent achievement of gross motor milestones at later ages within normal 'windows of achievement' likely has limited predictive value of good or bad outcomes in motor and other developmental domains for individuals within healthy populations [21]." In contrast, consistent, significant differences appeared when we looked outside the "normal" window, and focused on low (delayed) motor development, overweight and relative high subcutaneous fat.

Although the Infant Care project intentionally selected a sample from a population expected to be at high risk for the development of overweight, the prevalence of overweight (WLZ>90th CDC 2000 percentile) ranged from 29% to 11% between 3 and 18 months of age. Furthermore, our infants approximated the referent, healthy population in psychomotor development (mean PDI 95.99, SD 11.5). Therefore, similar to findings from the WHO MGRS study, in our mostly healthy sample of infants, the models that examined the relationships between anthropometry and a continuous PDI score showed infant size and motor development scores to be largely independent. In contrast, when we examined the relationship among those *not* in the healthy range (overweight, high subcutaneous fat and low motor development), the odds of low motor development were found to strongly associate with concurrent overweight and high subcutaneous fat.

The use of lagged anthropometric variables allows for the examination of directionality and temporality in longitudinal models. As hypothesized, results provide better support for the association between anthropometry and subsequent decreased motor development than for the association between decreased motor development and subsequent anthropometry. High subcutaneous fat was associated with subsequent decreased motor development but the reverse was not true; motor developmental status was not associated with subsequent anthropometry.

Our results suggest that infant fatness, as compared with infant relative weight, has a more consistent relationship with motor development. High subcutaneous fat was significantly associated with a lower PDI score and increased odds of a PDI<85, and infant overweight was only associated with increased odds of a PDI<85. Furthermore, only high subcutaneous fat was associated with a subsequent lower PDI score. Because high weight-for-length may not represent fatness important to delayed gross motor skill acquisition, [29, 31] these results suggest that efforts should be made to help clinicians transition to using one of a variety of widely-available techniques for the measurement of body composition in the office setting to identify infants who have high subcutaneous fat, and are not just relatively heavy. [36-38]

Although this dataset offers a unique opportunity to provide information about low-income African American infants, a population at high risk of overweight, results may not apply to all infants. Furthermore, comparison of our results with previous studies may be limited by the dissimilarities of the study populations.

Anthropometric measurements, such as skinfold thickness, may have greater operator imprecision compared with laboratory techniques. Although we minimized errors in anthropometric measurements through staff training and frequent reliability checks, we cannot exclude the possibility of measurement error. The BSID-II requires the infant to display specific behaviors during the assessment period. To the extent that infant arousal and feeding schedules conflict with the timing of the assessment, it is possible that infants may not have displayed behaviors of which they were capable. In addition, the BSID-II, which was the most current version of the BSID available at the time of the study, contains a single motor scale that encompasses fine and gross motor skills. That single scale, while predominantly tapping the gross motor, weight-bearing, locomotor skills that are those most likely affected by excess weight, may be a less sensitive index than the separate, Gross

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Motor Scale of the more recent BSID-III, published in 2006. Because fine motor skills are less likely than gross motor skills to be influenced by obesity, our use of a scale which includes fine motor skills may have hampered our ability to find true effects.

A potential limitation of these analyses is that variables such as maternal mental health and parental expectations that might influence infant motor development were not examined. Further, we examined associations across several variables and models, raising concern that multiple testing increased the likelihood of finding a significant effect. Finally, although our use of longitudinal modeling techniques with lagged variables add strength to the evidence that overweight is causally related to decreased motor development, our models remain correlational and cannot prove causality.

For infants, being overweight and especially having high subcutaneous fat are a concern, as it is possible that they may contribute to a cascade of risk in which delayed gross motor development could possibly lead to reduced physical activity and reduced age-appropriate exploration of the environment beyond arm's reach.

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Abbreviations

PDI	Psychomotor Development Index
WLZ	Weight-for-length z-scores
BSID-II	Bayley Scales of Infant Development, 2nd Edition
MGRS	Multicentre Growth Reference Study

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Table 1

Comparison of Sample Tricep and Subscapular Skinfold Measurements to NHANES III, 1988-1994 reference data.

	3 month visit		6 month visit		9 month visit		12 month visit	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Sample Tricep skinfold thickness, median	10.1	9.9	10.7	10.8	10.3	9.3	9.5	9.4
NHANES-III Tricep skinfold thickness, median	10.7	10.3	9.9	9.4	9.2	9.2	9.1	9.6
Sample High tricep skinfold thickness* *n (%)*	4 (4.0%)	11 (10%)	33 (33%)	*n/a* †	37 (37%)	40 (35%)	38 (38%)	44 (38%)
Sample Subscapular skinfold thickness, median	8.4	8.2	8.3	7.8	7.8	7.8	7.4	7.3
NHANES-III Subscapular skinfold thickness, median	7.6	7.8	7.4	7.4	7	7.5	6.7	6.8
Sample High subscapular skinfold thickness‡ *n (%)*	16 (16%)	15 (13%)	37 (37%)	*n/a*	31 (31%)	50 (44%)	47 (47%)	44 (38%)

* >90th percentile of NHANES-III tricep skinfold reference data

† NHANES-III 90th percentile reference data not available

‡ >90th percentile of NHANES-III subscapular skinfold reference data

Table 2

Characteristics of mothers and infants in a longitudinal study of infant feeding styles and obesity among low income African-Americans in North Carolina.

	birth	3 month visit	6 month visit	9 month visit	12 month visit	18 month visit
Infants						
Total, *n*		215	162	166	149	125
Female, *n (%)*		115 (53%)	84 (52%)	84 (51%)	80 (54%)	67 (54%)
Age in months, *mean (SD)*		3.25 (0.31)	6.35 (0.50)	9.37 (0.47)	12.63 (0.70)	18.72 (0.97)
Gestational age, *mean (SD)*	39.48 (1.47)					
Gestational age, *range (min, max)*	(36, 43)					
Anthropometrics						
Birth weight kg, *mean (SD)*	3.23 (0.48)					
Weight for length Z-score , *mean (SD)*		0.59 ± 0.99	0.61 ± 1.04 [‡]	0.54 ± 1.06	0.48 ± 1.09	0.38 ± 1.02
Infant Overweight[*], *n (%)*		62 (29%)	30 (19%) [‡]	25 (15%)	21 (14%)	14 (11%)
Sum of 3 skinfold measures, *mean (SD)*		25.32 ± 4.69	25.45 ± 5.40	24.56 ± 5.83	23.47 ± 5.00	22.74 ± 4.31
High subcutaneous fat[†], *n (%)*		20 (10%)	14 (9%)	15 (9%)	14 (9%)	12 (10%)
Developmental Status						
Psychomotor Development Index (PDI), *mean (SD)*		92.37 ± 8.53	93.90 ± 12.84	103.58 ± 9.52	98.62 ± 10.03	93.03 ± 9.90
PDI , *range (min, max)*		(68, 121)	(53, 126)	(56, 127)	(69, 125)	(68, 115)
Low Psychomotor Development Index [§], *n (%)*		40 (19%)	35 (22%)	2 (1%)	9 (6%)	26 (21%)
Mothers, *n (%)*						
Anthropometrics						
BMI <25		62 (29%)				
BMI 25-29.9		58 (27%)				
BMI =>30		96 (44%)				
Sociodemographics						
Maternal education						
Less than high school		58 (27%)				
High school graduate or GED		65 (30%)				
Some college		69 (32%)				
College graduate or higher		21 (10%)				

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*WLZ≥90th CDC/NCHS 2000 percentile

†>90th percentile of study sample

‡Statistically significant (p<0.05) difference between males and females

§Psychomotor development index<85

Table 3

Longitudinal regression models examining the concurrent relationship between anthropomety and motor development from 3 to 18 months of age.*

Developmental Status Outcomes	**Anthropometric Exposures**			
	Weight-for-length z-score	**Overweight †**	**Sum of Skinfolds**	**High Subcutaneous Fat ‡**
Psychomotor Development Index				
β (95% CI)	0.79 (−0.01, 1.58)	1.21 (−0.78, 3.20)	−0.01 (−0.16, 0.15)	**−2.79 (−5.32, −0.26)**
Low psychomotor development §				
Odds Ratio (95% CI)	1.21 (0.97, 1.50)	**1.67 (1.01, 2.79)**	1.03 (0.99, 1.08)	**2.21 (1.18, 4.14)**

*The multivariate models adjust for infant age, infant age squared term, and infant sex.

†Weight-for-length z-score≥90th CDC/NCHS 2000 percentile

‡>90th percentile of study sample

§Psychomotor Development Index Score<85

Table 4

Longitudinal regression models examining the relationship between anthropomety and subsequent motor development from 3 to 18 months.*

Developmental Status Outcomes	LAGGED Anthropometric Exposures			
	Weight-for-length z-score	**Overweight †**	**Sum of Skinfolds**	**High Subcutaneous Fat ‡**
Psychomotor Development Index				
β (95% CI)	0.76 (−0.22, 1.75)	−0.60 (−3.08, 1.89)	−0.07 (−0.26, 0.12)	**−4.16 (−7.37, −0.97)**
Low psychomotor development §				
Odds Ratio (95% CI)	1.06 (0.83, 1.36)	1.63 (0.89, 2.98)	1.02 (0.98, 1.07)	2.07 (0.98, 4.36)

*The multivariate models adjust for infant age, infant age squared term, and infant sex.

†Weight-for-length z-score≥90th CDC/NCHS 2000 percentile

‡>90th percentile of study sample

§Psychomotor Development Index Score<85

Table 5

Longitudinal regression models examining the relationship between motor development and subsequent anthropometry from 3 to 18 months.*

Anthropometric Outcomes	LAGGED Developmental Status Exposures	
	Psychomotor Development Index	**Low psychomotor development §**
Weight-for-length z-score		
β (95% CI)	0.002 (−0.003, 0.007)	−0.03 (−0.19, 0.13)
Overweight †		
Odds Ratio (95% CI)	1.01 (0.96, 1.05)	0.57 (0.14, 2.29)
Sum of Skinfolds		
β (95% CI)	0.01 (−0.02, 0.05)	0.01 (−0.92, 0.94)
High Subcutaneous Fat ‡		
Odds Ratio (95% CI)	0.98 (0.94, 1.02)	2.86 (0.94, 8.66)

*The multivariate models adjust for infant age, infant age squared term, and infant sex.

†Weight-for-length z-score≥90th CDC/NCHS 2000 percentile

‡>90th percentile of study sample

§Psychomotor Development Index Score<85