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Baby Steps: Examining Predictors of Infant Rapid Weight Gain

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An abstract of
A thesis submitted to the Faculty of the
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Abstract

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Rapid weight gain (RWG) in the first six months of life has been established as a robust predictor of later obesity by numerous health and epidemiological studies. Research suggests that formula feeding and early introduction of complementary foods (i.e., infant cereal, solids) are strongly linked to greater weight gain in infancy. However, while much research has focused on feeding practices as determinants of RWG, few prospective studies have examined potential behavioral factors linked to feeding practices, namely maternal stress and infant temperament. The aims of the present study were to examine RWG in an at-risk African American (AA) sample to investigate whether 1) maternal perceived stress predicts infant overfeeding and subsequent RWG; and 2) infant fussiness interacts with maternal perceived stress to predict infant overfeeding. Study participants were mother-infant dyads (N=76) currently enrolled in a larger, ongoing project exploring maternal stress and infant development in AAs, a group that disproportionately experiences higher chronic stress and obesity. Results from growth curve analyses indicated that while introduction of complementary foods did not predict more RWG, ounces of formula per day did, suggesting that amount of formula may be a more sensitive indicator of risk. An interaction between maternal stress and infant temperament was not supported. Maternal perceived stress did significantly predict overfeeding, but in the opposite direction as hypothesized (OR = 0.94; 95% CI = 0.88-1.00; $p < .05$). Implications for feeding guidelines, particularly in at-risk populations, and limitations of the data are discussed.

Keywords: Infant rapid weight gain, maternal stress, infant temperament, infant feeding, childhood obesity

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I. Introduction

There are numerous health outcomes associated with obesity, including but not limited to, increased risk for type 2 diabetes, coronary artery disease, sleep apnea, hypertension, and non-alcoholic fatty liver disease (Mitchell, Catenacci, Wyatt, & Hill, 2011). As such, obesity remains one of the most costly burdens on the US healthcare system, with annual medical care costs estimated around $147 billion (Finkelstein, Trogdon, Cohen, & Dietz, 2009). According to research conducted by the Centers for Disease Control and Prevention (CDC), the prevalence of obesity amongst non-Hispanic black adults in the US is estimated at 48.1% (Ogden, Carroll, Fryar, & Flegal, 2015). This rate is significantly higher than that of non-Hispanic white (34.5%) and Hispanic (42.5%) adults (Ogden et al., 2015), indicating a specific need to study the risk factors for obesity in African American (AA) populations. One risk factor for adolescent and adult obesity that has long been studied, is infant rapid weight gain.

Infant Rapid Weight Gain

Rapid weight gain (RWG) is a term used to describe a greater-than-expected pattern of growth during early life, usually studied from birth to about four to six months of age, with some studies investigating growth up to 2-years-of-age. Research on RWG largely utilizes either weight-for-age or weight-for-length z-scores to measure changes based on standardized growth charts, and subsequent cutoffs (>.67 SD change) to indicate the upward crossing of percentiles (Ong & Loos, 2006). A systematic review from 2006 indicated that of 15 studies that had examined RWG over the course of early life (ranging from birth to 2-years-of-age) and later obesity (defined by BMI in most studies), all resulted in significant positive odds ratios (range 1.26 to 4.55), indicating heightened risk for obesity later in life (Ong & Loos). However, only one of these studies examined the actual predictive power of RWG, and found that despite a relatively high odds ratio (5.70), the positive predictive power was only 19%, meaning that only one of five children who were rapid growers in infancy were actually overweight at about six-years-of-age (Toschke, Grote, Koletzko, & von Kries, 2004). Nonetheless, countless more studies have demonstrated a relationship between infant RWG and later obesity. One study found that out of their sample of 300 African Americans born full-term, one third of the incidence of obesity when subjects were 20-years-old was explained by RWG in the first four months of life (N Stettler, Kumanyika, Katz, Zemel, & Stallings, 2003)

A more recent meta-analysis (Zheng et al., 2018), echoed the results of past studies. Out of the 17 studies included in this meta-analysis, 15 reported positive odds ratios, indicating that RWG was a significant predictor of later adiposity. Prevalence of RWG in these studies ranged from about 10-50%, indicating a large amount of heterogeneity across samples. However, the authors reported pooled odds ratios indicating that children who were rapid growers in the first two years of life were 3.66 times more likely to be overweight or obese later in life than children who were not rapid growers (Zheng et al., 2018). Considering the wealth of evidence indicating its relationship to later adiposity, it could be fruitful for RWG to receive more extensive study that teases apart mechanisms and potential points of intervention. Although much of the existing literature suffers from retrospective design and thus does not address potential mechanisms, recent progress has been noted in the identification of predictors of RWG in infancy.

Infant Feeding Practices and Rapid Weight Gain

A range of common infant feeding practices have been repeatedly shown to be associated with rapid weight gain in infancy. One consistent predictor of differential weight outcomes is method of feeding, that is breastfeeding versus formula feeding. Breastfeeding for the first six months of life (as per World Health Organization recommendations) has been shown to be a protective factor against RWG and adiposity, with breastfed infants generally leaner than their formula-fed counterparts later in life and formula-fed infants more likely to be rapid growers (Appleton et al., 2018; Dewey, 1998; Gubbels, Thijs, Stafleu, Van Buuren, & Kremers, 2011; Yang & Huffman, 2013). Another practice that has been associated with RWG in some studies is the earlier-than-recommended introduction of complementary foods into infants' diets. Currently, the American Academy of Pediatrics (2017) recommends that complementary foods, such as infant cereal, fruit juice, and other solids, not be introduced into a baby's diet until at least 4-months-of-age. The introduction of these foods earlier in life has been shown to be a predictor of RWG in some, but not all samples, indicating a need for more research into this particular feeding practice (Appleton et al., 2018; Yang & Huffman, 2013).

While these studies have helped identify some common feeding patterns as risk factors for RWG and subsequent obesity, they largely do not address behavioral or psychological factors that may influence these feeding practices. Many of the studies also rely on retrospective self-report from parents (with the exception of the NOURISH randomized control trial) and do not address multiple predictors at once. Few studies have examined actual amount of formula per day, but rather have used size of bottle or arbitrary cut-offs for amounts that are not supported by standard recommendations (Appleton et al., 2018; Hopkins, Steer, Northstone, & Emmett, 2015). As such, there is a critical need for more prospective studies investigating these feeding practices and their associations with RWG.

Maternal Stress

Complicating the relationship between infant feeding and rapid weight gain, are pregnancy outcomes and maternal stress. A robust literature has repeatedly found that maternal prenatal stress is a strong predictor of poor birth outcomes, namely, preterm birth and low birthweight (LBW), both of which are subsequently associated with RWG (Bolten et al., 2011; Cheng et al., 2016; Lobel, Dunkel-Schetter, & Scrimshaw, 1992; Wang et al., 2016). This period of rapid growth for preterm and LBW babies is often conceptualized as “catch-up” growth. That is, research supports the notion that preterm and LBW infants often gain weight at a faster rate than full-term infants within the first three months of life, and this trend may be protective for their short-term health (Gianni et al., 2012). On the other hand, these preterm and LBW infants are also at risk for later adiposity, and this period of catch-up or rapid growth may be responsible (Cooke & Griffin, 2009; Gianni et al., 2012; Wang et al., 2016).

While maternal prenatal stress has been extensively studied with regard to infant birth outcomes and growth, there has been very little research regarding maternal postnatal stress and its potential impact on infant feeding practices and subsequent growth. One study found an association between maternal stress and nonresponsive feeding styles, in that mothers experiencing greater perceived stress were more likely to employ a forceful feeding style (i.e., encouraging the baby to finish a full bottle, feeding the baby greater amounts to ensure less frequent feeding, etc.) than mothers who experienced lower amounts of perceived stress (Hurley, Black, Papas, & Caulfield, 2008). A number of studies to date have demonstrated that maternal postpartum depression, often associated with perceived stress on its own (Katon, Russo, & Gavin, 2014), is also predictive of earlier cessation of breastfeeding (Dennis & McQueen, 2007; McLearn, Minkovitz, Strobino, Marks, & Hou, 2006).

The Role of Infant Temperament

Examining further the potential behavioral links to rapid weight gain, another variable that may play a role is infant temperament, and especially, infant negativity. Infant negativity, or fussiness, has been linked to infant weight status in that infants greater in negativity are more susceptible to weight gain (Anzman-Frasca, Stifter, Paul, & Birch, 2013; Carey, 1985). A possible explanation is that mothers may use food as a means to soothe overly fussy babies, thereby disrupting normal hunger-satiety regulation (Anzman-Frasca, Stifter, & Birch, 2012; Stifter, Anzman-Frasca, Birch, & Voegtline, 2011). Notably, these studies measured infant negativity or fussiness via parental report rather than observation. In addition, these studies failed to examine potential mediators or moderators of the associations between negativity and weight gain. This apparent paucity of research into both maternal and infant psychological and behavioral factors that may play a role not only in feeding practices, but also subsequent rapid growth in infancy, highlights the need for more comprehensive examinations of predictors of RWG.

The Present Study

Altogether, the extant literature suggests that while RWG in infancy is a robust predictor of overweight or obesity later in life, a multitude of factors such as maternal stress, infant fussiness, and general feeding practices may influence RWG itself. Characterizing an early-life risk factor, such as RWG more thoroughly, potentially provides multiple targets for intervention that may decrease the risk for future obesity. Furthermore, research consistently demonstrates that AAs experience more chronic life stress than other racial groups, with AA women at especially greater risk for the deleterious mental and physical effects of chronic stress (Geronimus, 1992; Troxel, Matthews, Bromberger, & Sutton-Tyrrell, 2003). These racial disparities continue to persist throughout the lifetime, even after accounting for differences in socioeconomic status, indicating a great need for more research within this population (Hogan, Richardson, Ferre, Durant, & Boisseau, 2001). Research has also shown that AA women give birth to preterm infants at about twice the rate as Caucasian women (Ruiz, Fullerton, & Dudley, 2003), potentially resulting in a greater prevalence of RWG that could help to explain a proportion of the higher incidence of obesity in this population. For these reasons, the current study aims to fill the gaps in the extant literature regarding predictors of RWG in infancy while also studying an exclusively AA sample.

The specific aims of this study were to 1) examine the relationship between maternal perceived stress and infant rapid weight gain; and 2) evaluate associations between infant fussiness, maternal stress, and infant feeding. The study tested two main hypotheses. It was hypothesized that 1) infant overfeeding would mediate the association between maternal perceived stress and infant RWG; and 2) infant fussiness would moderate the relationship between maternal perceived stress and infant overfeeding, such that mothers experiencing higher perceived stress would be more likely to overfeed their infant if the infant was also highly fussy.

II. Method

Participants

Study subjects were mother-infant dyads (N=76) currently enrolled in a larger, ongoing project focusing on infant development in AAs. All of the women in the study were originally recruited during pregnancy at Emory Midtown and Grady Hospitals in Atlanta, GA through a study investigating the biobehavioral determinants of preterm birth. Inclusion criteria for the pregnancy study included: 1) AA race (as determined via self-report); 2) Maternal age of 18-40 years; 3) No chronic medical conditions; 4) Singleton pregnancy; and 5) Fluency in written and spoken English. During their participation in this pregnancy study, they were asked if they would be willing to be contacted for future studies. Women were recruited for the infant study if they were willing and if their infants were born without congenital disorders. Informed consent was obtained from the women prior to participation in the infant study using procedures approved by

Emory University's Institutional Review Board. Participants were included in the current study if they completed the study visit when the infant was 3-months-of-age.

Study Design and Procedure

Data for the present study were collected at three of five infant study time points: 1-week, 3-months, and 6-months-of-age. Maternal demographics (i.e., age, socioeconomic status, etc.) and birth outcomes (e.g., gestational age, weight, length, etc.) were collected during the pregnancy study via questionnaires and medical chart record abstraction. For the purposes of this study, time points will be referenced as: T1 (birth), T2 (1-week), T3 (3-months), and T4 (6-months). Study visits were conducted by trained research assistants either at participants' homes or during a visit to the laboratory at Emory University. During these visits, mothers completed measures of perceived stress and infant feeding practices, while research assistants measured infant growth (i.e., weight, length). Mothers and infants also completed two videotaped observation tasks.

Measures

Sociodemographic Factors and Statistical Controls. Information about mothers' age in years and socioeconomic status (operationalized as highest level of education) were collected during the pregnancy study and examined as potential control variables. Socioeconomic status has been established as a correlate of stress (Sheldon Cohen, Doyle, & Baum, 2006) and a predictor of obesity in early life (Woo Baidal et al., 2016). In addition, data regarding infants' gender, gestational-age-at-birth and preterm status were examined as potential covariates as all play a role in infant growth and development (Zheng et al., 2018). These data were obtained via medical chart record abstraction.

Maternal Stress. Maternal stress was evaluated using the Perceived Stress Scale (PSS), a widely-used 14-item questionnaire that is designed to assess the degree to which individuals find their lives unpredictable, uncontrollable, and overloaded (S Cohen, Kamarck, & Mermelstein, 1983). This measure has been extensively used across populations and has been shown to have moderate to strong correlations with measures of anxiety and depression (Corwin et al., 2015; Davis et al., 2007; Shelton, Schminkey, & Groer, 2015) and with HPA axis activity (Ruiz et al., 2003). Respondents are asked to indicate the stressfulness of their lives over the past month on a 5-point scale from *never* (0) to *very often/always* (4) on items such as, "How often have you felt that you were on top of things?" or "How often have you felt nervous and 'stressed?'" Positive items are reverse coded, and then all items are summed to create a total score (range 0-56). Mothers completed the PSS at each time point in the study. However, as it was the aim of this study to examine stress as a predictor of RWG, data from only T2 and T3 were examined. Both T2 and T3 data were significant correlated ($r = .64$, $p < .001$). As data from more of the participants was available for all measures at T3, only the T3 PSS data was used as the proxy for postnatal stress. Acceptable internal consistency was observed (Cronbach's $\alpha = .78$), and is in-line with the extant literature regarding the reliability ($\alpha = .80$) and validity of this measure (S Cohen et al., 1983).

Infant Feeding Practices. Infant feeding practices were evaluated from T2 through T4 using modified versions of the Infant Feeding Questionnaire (IFQ) from the Infant Feeding Practices Study II, a longitudinal study conducted by the US Food and Drug Administration (FDA) and CDC (Fein et al., n.d.). For the purposes of this study, only data from T3 was used in order to assess the key variables of introduction of complementary foods and to ensure adequate variability in feeding practices. The IFQ contains 48 items that assess a range of feeding- and eating-related behaviors, including number of times per day baby is breastfed or formula-fed (and amount per feeding), frequency of adding infant cereal to the bottle, and frequency of feeding solid foods.

Using this data, a composite "overfeeding" variable was created using three feeding practices. First, infants were coded as predominantly breastfed or predominantly formula-fed based on the frequency of each type of feeding per day. Babies who were predominantly breastfed were categorized as not overfed. Second, infants were coded as overfed if they were predominantly formula-fed and if their amount of daily intake was greater than 34 ounces. Thirty-four ounces was chosen as per standard medical infant feeding guidelines, which recommend that babies around 3-months-of-age should receive around 28 to 30 ounces per day, with an acceptable range up to 34 ounces (American Academy of Pediatrics, 2017). Finally, data indicating complementary foods (i.e., infant cereal, fruits, vegetables, etc.) were combined into a dichotomous categorical variable, in which the endorsement of any of these foods was coded as early introduction of complementary foods, with one exception. Infants with acid reflux, as per maternal report, were not categorized as "early introduction" if their only complementary food was infant cereal, as infant cereal is commonly added to the bottle in order to thicken formula and reduce reflux (National Institute of Diabetes and Digestive and Kidney Diseases, n.d.). As per the American Academy of Pediatrics (2017), introduction of complementary foods is not recommended before 4-months-of-age. As such, infants with early introduction of complementary foods at T3 were categorized as overfed.

Altogether, these three components (i.e., breastfed versus formula-fed, amount of daily intake, early introduction of complementary foods) were combined into the overfeeding composite variable. Infants were categorized as overfed if: 1) they were predominantly formula-fed *and* receiving greater than 34 ounces of formula; *or* 2) they were being fed complementary foods. Infants were categorized as not overfed if: 1) they were predominantly breastfed *or* were receiving less than 34 ounces of formula; *and* 2) they were not receiving complementary foods. Each of the three feeding variables was also analyzed as a distinct predictor in order to evaluate potential differential effects on weight gain trajectories.

Infant Fussiness. Infant temperament was assessed at T3 using both a structured and unstructured mother-infant interaction. In the structured task, mothers are instructed to encourage the baby to play with a rattle for five minutes. For the unstructured task, the mother and child engage in free play for five minutes. The videotapes of these tasks were then coded by trained research assistants on nine different dimensions, such as parental sensitivity, parental positive regard toward the child, and child negativity. Child negativity was operationalized as the child's display of anger or resistance toward the parent and included overt fussiness (e.g., frustrated sounds, whining, crying). Child negativity scores ranged from *not at all characteristic* (1) to *highly characteristic* (4), with higher scores indicating more fussiness. As the aim of this study was to examine whether infant fussiness in the home may prompt overfeeding as a means to soothe the infant, only the child negativity dimension from the unstructured task (a more naturalistic representation of typical mother-infant interaction) was used in analyses. The intraclass correlation for this dimension was high at 0.94.

Infant Rapid Weight Gain. Infant growth measurements were obtained at T2 through T4 (T1 growth measures were obtained via medical chart records), and were taken by research assistants trained in accurate measurement. Infant weight was measured using a portable, specialized scale for infant weight and was recorded in kilograms. Recumbent infant height was measured using a measuring sheet designed for accurate length measurements. Infants are placed in the proper location on the sheet by one research assistant while the other research assistant marks the length of the child (from top of head to heels) in centimeters.

Although the majority of the extant literature has determined RWG using weight-for-length z-scores based on the World Health Organization growth chart standards (Ong & Loos, 2006), due to the amount of missing data and inconsistency of study participation at each time point, an alternative method was used. Weight-for-length residual scores were calculated at each time point by regressing infant weight onto length. However, these scores were non-normally distributed and highly correlated with the original weight scores ($r = 0.89 – 0.97$, all *p's* < 0.001). Thus, raw infant weight scores (which were normally distributed) were used in all analyses in order to meet assumptions of the statistical models. Due to the amount of missing data within subjects, Hierarchical Linear Modeling (HLM) was used, as the program adjusts for nested data (repeated measures over time within individuals) and can accommodate missing data across time points (Woltman, Feldstain, Mackay, & Rocchi, 2012).

Data Analyses

Descriptive analyses were performed to determine sample characteristics (see Table 1). Using tolerance statistics and univariate procedures, data were then evaluated for normality and multicollinearity, and transformations were applied as needed. Bivariate analyses (i.e., independent t-tests, chi-squared tests) were conducted to identify potential covariates. To examine the hypothesis that overfeeding would mediate the relationship between stress and weight gain, binary logistic regression and multiple linear regression analyses were run using IBM SPSS Statistics for Macintosh Version 25 (IBM Corporation, 2017). Hierarchical Linear Modeling was then used to examine the outcome of weight gain over time. A time variable was created for these analyses indicating the number of days from T1 (birth) at each assessment point at level 1, and all covariates and predictors were entered at level 2. Continuous predictors (i.e., amount of daily formula intake, stress, etc.) were each centered around their mean, and categorical predictors were included as uncentered variables. HLM 7 was then used to perform growth curve analyses (Raudenbush, Bryk, Cheong, Congdon, & Du Toit, 2011). All tests were considered statistically significant at $p < 0.05$.

To examine the moderation hypothesis, an interaction term was computed by centering the independent variables and calculating the product (i.e., maternal stress × child negativity). Binary logistic regression was conducted in SPSS to assess whether maternal stress interacted with child negativity to predict overfeeding. Multiple linear regression analyses were then conducted in SPSS to assess whether the same interaction predicted each feeding variable considered separately.

III. Results

Preliminary Analyses

Correlations between each predictor variable and infant weight at each time point are shown in Table 2. To examine whether the assumption of normality was met, infant weight at each time point was examined. The Shapiro-Wilk test of normality indicated that raw infant weight scores at all time points were normally distributed (*ps* > 0.05). Thus for all subsequent analyses in HLM, raw weight at each time point was used.

First, an unconditional growth model was run using weight as the outcome and time as the predictor at level 1 in order to examine whether weight changed significantly over the course of the study. The estimated mean slope for the weight variable was 0.026 (SE=0.0007), indicating that infant weight increased at an average rate of 0.023 kilograms per day from birth to six-months-of-age. This was significant at $p < 0.001$, and indicated significant increases in weight over time within the sample. In addition, there was significant variation among slopes of weight gain in this sample (χ^2=163.55; $p < 0.001$).

Before examining the indirect effect of overfeeding on the relationship between maternal stress and RWG, associations between maternal age, gestational age, preterm status, infant sex, socioeconomic status, and overfeeding were examined using bivariate analyses. Results indicated that only preterm status was significantly associated with overfeeding ($p = 0.046$). None of the other potential control variables was related to overfeeding (*ps* > 0.05). When preparing to examine any main effects of maternal stress and overfeeding on weight gain, all potential covariates were each entered separately as predictors of infant weight (intercept and slope) in HLM. Results indicated that preterm status and gestational age were both significantly associated with birthweight ($p < 0.001$). Entering both variables as covariates would have been redundant, as preterm status is a dichotomized variable created from gestational age. Thus, only gestational age was entered as a covariate at the intercept in all following HLM analyses. No other variables were associated with either birthweight (i.e., intercept) or the slope of weight gain.

Hypothesis Testing

Prior to examining any associations in HLM, a binary logistic regression analysis was conducted to examine whether maternal stress was associated with the overfeeding composite variable. A significant association would support a portion of the mediation hypothesis. Results indicated that maternal stress significantly predicted overfeeding, but in the opposite direction as predicted (OR = 0.94; 95% CI = 0.88-1.00; $p < .05$; See Table 3), such that higher maternal stress decreased the odds of being overfed. Two HLM models were then constructed with maternal stress and overfeeding entered as separate predictors at level 2 to test the main effects of each on weight gain. Results indicated that neither maternal stress nor the overfeeding composite variable were significant predictors of the slope of weight gain ($p = 0.70$ and $p = 0.27$, respectively; see Table 4).

Continuing with analyses, the overfeeding variable was subsequently split into its component parts (i.e., formula feeding, amount of daily formula intake, early introduction of complementary foods) in order to test specific mechanisms that may be associated with weight gain. Using the same procedure as described above, maternal stress was not found to be associated with any of the three separate feeding variables (*ps* > 0.25). Three separate models were then created in HLM with each feeding variable entered as a separate predictor. The amount of daily formula intake variable excluded infants who were exclusively breastfed (n = 8) and statistical outliers (n = 5). Formula feeding and early introduction of complementary foods were not associated with the slope of weight gain ($p = 0.07$ and $p = 0.98$, respectively), although the former was trending towards significance. Amount of daily formula intake (in ounces) was a significant predictor of slope of weight gain, such that greater intake predicted more rapid weight gain ($\beta = 0.00013$; $p = 0.007$; df = 61; SE = 0.00005).

To test the moderation hypothesis, a binary logistic regression was conducted in SPSS using maternal stress, infant fussiness, and the interaction term of stress and fussiness as predictors of the overfeeding composite variable. Within this model, there were no significant main effects of stress or fussiness, nor a significant interaction between the two predictors (*ps* > 0.15). Similarly, no main effects or interactions of maternal stress and fussiness were found when the individual feeding variables were each examined as the outcome in separate regression analyses (*ps* > 0.26).

IV. Discussion

Numerous studies have shown that rapid weight gain in infancy is a robust predictor of later obesity (Ong & Loos, 2006; Stettler, Kumanyika, Katz, Zemel, & Stallings, 2003; Toschke et al., 2004; Zheng et al., 2018). Of the many potential predictors of RWG, infant feeding practices have received the most attention, with formula feeding and early introduction of complementary foods indicated as contributors to RWG (Appleton et al., 2018). A small number of studies have also examined the effects of maternal psychological symptoms (i.e., depression, anxiety, stress) and infant temperament on specific feeding styles, but have not examined the interaction between these two variables or their effects on subsequent RWG (Anzman-Frasca et al., 2012; Dennis & McQueen, 2007; Hurley et al., 2008; McLearn et al., 2006). The current study aimed to combine aspects of the extant literature and examine whether maternal stress influences infant RWG and whether infant temperament may interact with maternal stress to influence feeding practices.

Findings suggest that these associations may be complex or nuanced in nature. Of the potential feeding practices explored in this study, only amount of daily formula intake was associated with weight gain, such that infants receiving more formula gained weight more rapidly. Formula feeding (versus breastfeeding) was not a significant predictor of RWG, which contradicts the extensive literature on the differential effects of formula and breastmilk on growth (Dewey, 1998; Gubbels et al., 2011; Yang & Huffman, 2013). In addition, early introduction of complementary foods was not associated with RWG. The literature on this practice and its association with RWG is mixed (Appleton et al., 2018; Yang & Huffman, 2013), and further exploration into types and amounts of complementary foods (i.e., cereal versus fruit juice, etc.) could help to tease apart which foods may be important for weight trajectories.

In general, the current findings suggest that amount of formula intake may be a more sensitive predictor of weight outcomes than dichotomous indicators of formula feeding. Of note, 46% of the formula-feeding mothers in this sample reported feeding their infants over 34 ounces of formula per day (M = 31.7, SD = 12.99, range 5 – 56 ounces), well above the highest acceptable amount as per standard medical recommendations for 3-month-old infants (American Academy of Pediatrics, 2017). AA populations historically have lower rates of ever breastfeeding and breastfeeding through 6-months-of-age as recommended when compared to all other racial or ethnic groups (Centers for Disease Control and Prevention, 2017). Thus, the development of more intensive or targeted information that provides a convincing rationale for limiting amount of formula could be an important area of continuing interventions.

Overall, findings from this study did not support the hypotheses related to maternal stress or infant fussiness. Maternal perceived stress was significantly associated with the overfeeding composite variable, but not RWG. This association was also in the opposite direction as hypothesized, with higher stress indicating reduced risk of being overfed. In addition, the hypothesized interaction between maternal stress and infant fussiness was not supported by the results. One study from the literature may explain these findings. Hurley et al. (2008) found that among infants perceived as fussy by their mothers, higher maternal stress was associated with restrictive feeding rather than indulgent feeding (i.e., overfeeding). The authors posited that under conditions of stress, mothers may misinterpret hunger cues as fussiness, and thus respond incorrectly by restricting (Hurley et al., 2008). It is important to note that restrictive feeding styles are associated with childhood overweight, which may be due to children tending to overcompensate for parental restriction (Faith & Kerns, 2005; Faith, Scanlon, Birch, Francis, & Sherry, 2004). The current study may not have found an interaction between maternal perceived stress and infant fussiness because only one end of the feeding spectrum (i.e., overfeeding rather than restrictive feeding) was considered. These findings suggest that feeding styles on either end of the spectrum (i.e., overfeeding and restrictive feeding) may be associated with differential weight trajectories and warrant further investigation.

This study has multiple notable strengths. For one, this study is the first to examine prospectively a range of potential predictors, from maternal characteristics to feeding practices, of RWG in infancy. By creating a latent overfeeding variable representing the effects of individual feeding practices within the context of other related practices, this study filled a gap in the extant literature. Previous studies have failed to account for multiple factors associated with RWG, and have focused on individual predictors outside of the general feeding context. In addition, this study focused on a predominantly low-socioeconomic African American sample, a population that is at greater risk for obesity and the experience of life stress overall. Finally, many studies examining the effects of infant temperament on feeding practices have relied solely on maternal or parental report of infant temperament. This study used behavioral observation coding in order to obtain a more objective measure of infant fussiness.

While the findings from the current study are meaningful, this study suffered from several limitations. First, analyses were performed on a relatively small to moderate sample size, and were thus under-powered. Relatedly, as HLM was used in order to account for the substantial amount of missing data within subjects, generalizability and across-study comparison is not possible. The majority of studies in the extant literature use weight-for-age or weight-for-length percentiles based on standardized growth charts, and greater than 0.67 standard deviation changes across time as the indicator of RWG (Ong & Loos, 2006; Zheng et al., 2018). This study examined the slope of weight gain, such that higher slopes indicated more or less RWG. Future analyses could use the traditional method and examine differential results based on these different statistical methods. In addition, although a strength of this study was its focus on an at-risk population, generalizability to other, more diverse, populations is not possible. Furthermore, maternal pre-pregnancy body-mass-index (BMI) was not included as a covariate in analyses, as data were not available. Maternal pre-pregnancy BMI has been repeatedly shown to predict infant weight outcomes (Yu et al., 2013) and should be included as a covariate in the future. Finally, both maternal perceived stress and infant fussiness were each measured using one modality, which are both limited in scope. Mother-infant interactions are coded based on one five-minute interval at one time point in the study. Future explorations should include other measures of perceived stress (e.g., discrimination, life events) and psychopathology (e.g., depression, anxiety) as well as measures of infant temperament across time points.

Future studies should also consider following these infants further into development. The current study drew on a sample from a larger study examining infant development up to 18-months-of-age. Investigators could continue to examine feeding practices across the time points in order to elucidate critical periods in development—for instance, examining whether overfeeding at multiple time points versus single time points in development more strongly predicts weight gain. Furthermore, other parenting characteristics could be important to examine. Maternal sensitivity to infant cues is one factor that has been associated with weight outcomes, such that lower sensitivity resulted in greater weight gain between six- and 12-months in infants (Worobey, Islas Lopez, & Hoffman, 2009). Maternal sensitivity was one dimension assessed during the mother-infant interaction observations and could be included in future analyses as a protective factor against RWG.

Overall, the two major hypotheses of the current study were not supported. However, the two findings, that higher maternal stress predicted lower risk of overfeeding and amount of daily formula intake predicted RWG, are nonetheless clinically meaningful. Both of these findings could inform future or existing interventions. If higher maternal stress is associated with restrictive feeding, which is in turn predictive of later overweight (Faith & Kerns, 2005; Faith et al., 2004), interventions should raise awareness of this and help provide mothers with strategies for stress reduction and management. In addition, basic health education regarding amount of formula that is both age-appropriate and reasonable for daily intake could be included in interventions targeting at-risk populations who also have low rates of breastfeeding. Put together, interventions geared towards both ends of the feeding spectrum could help to ameliorate these effects on rapid weight gain.

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Table 1. Sample Descriptive Statistics (N=76)

Variable	N	%	Mean (SD)	Range (Min – Max)
Infants				
Male	43	56.6		
Female	33	43.4		
Preterm				
Yes	10	13.2		
No	66	86.8		
Gestational Age (weeks)			38.70 (2.20)	25.0 – 41.2
Mother Age (years)			24.97 (5.13)	18 – 40
Education (SES)				
Some HS or less	6	7.9		
Graduated HS or GED	36	47.4		
Some college or technical school	22	28.9		
Graduated college or higher	12	15.8		
Weight (KG) T1	73		3.12 (0.51)	0.96 – 4.68
Weight (KG) T2	59		3.66 (0.58)	2.40 – 5.27
Weight (KG) T3	70		6.27 (0.90)	4.31 – 8.70
Weight (KG) T4	54		8.00 (1.12)	5.97 – 10.83

Table 2. Intercorrelations among Study Variables[1,2]

Variable	1	2	3	4	5	6	7	8	9	10
Predictor Variables										
1. Maternal Stress	-	-0.12	-0.22	-0.09	-0.13	-0.01	0.05	-0.15	-0.08	0.05
2. Infant Fussiness		-	-0.12	0.01	0.06	0.13	-0.10	0.12	0.08	0.12
3. Overfeeding			-	0.52**	0.62**	0.50**	-0.22	0.08	0.13	0.19
4. Formula Y/N[3]				-	0.25*	0.64**	-0.02	0.07	0.25*	0.28*
5. Early Food[4]					-	-0.002	-0.21	0.06	0.07	-0.06
6. Daily Formula[5]						-	-0.07	0.33*	0.28*	0.30*
Outcome Variables										
7. Weight, T1							-	0.38**	0.21	0.19
8. Weight, T2								-	0.43**	0.35*
9. Weight, T3									-	0.70**
10. Weight, T4										-

[1] **p* < 0.05; ***p* < 0.01
[2] T1 = Birthweight; T2 = 1-week; T3 = 3-months; T4 = 6-months
[3] Formula Y/N = predominantly formula-fed (dichotomous).
[4] Early Food = early introduction of complementary foods (dichotomous).
[5] Daily Formula = amount of daily formula intake in ounces (continuous).

Table 3. Summary of Results from Mediation Regression Analyses (Maternal Stress as Predictor)[6]

Dependent Variable	OR (95%CI for Exp β)	*p*-value	b (SE)	*p*-value
Overfeeding	**0.94 (0.88 – 1.00)**	**0.046**		
Formula Y/N[7]	0.98 (0.92 – 1.04)	0.45		
Early Food[8]	0.96 (0.91 – 1.03)	0.24		
Amount of Daily Formula			-0.01 (0.20)	0.96

[6] All analyses run separately. Values presented in bold are statistically significant at $p < 0.05$.
[7] Formula Y/N = predominantly formula-fed (dichotomous). No significant covariates in the model.
[8] Early Food = early introduction of complementary foods (dichotomous). Gestational age and SES entered as covariates in the model due to significant bivariate analyses.

Table 4. Summary of Results from HLM Analyses Examining Slope of Weight Gain[9]

	Coefficient	SE	*t*-statistic	*p*-value
Main Effects Models				
Intercept	0.03	0.0007	35.97	<0.001
Maternal Stress	0.00004	0.00009	0.39	0.67
Intercept	0.03	0.001	20.90	<0.001
Overfeeding	0.002	0.001	1.12	0.27
Intercept	0.02	0.001	17.06	<0.001
Formula Y/N	0.003	0.002	1.86	0.07
Intercept	0.03	0.0009	29.81	<0.001
Early Introduction	-0.00005	0.002	-0.03	0.98
Intercept	0.03	0.0007	37.53	<0.001
Amount of Daily Formula	**0.0001**	**0.00005**	**2.80**	**0.007**

[9] All analyses run separately. Each model controls for gestational age at level 2. Values presented in bold are statistically significant at $p < 0.05$.