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Associations between timing and quality of solid food introduction with infant weight-for-length z-scores at 12 months: Findings from the Nurture cohort

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Abstract

This study assesses associations of the timing and quality of solid foods introduced during infancy with weight-for-length (WFL) z-scores at 12 months within the Nurture cohort. Women from North Carolina self-reported sociodemographics, the timing and type of solid food introduction, and reasons for introducing solids; infant anthropometrics were measured every 3 months through 1 year (n=666). Frequency (0 - 5x/day) infants consumed fruits and vegetables was used to compute a mean (4-12 months) healthy food score (HFS), and sweets, french fries, snacks, and ice cream was used to compute a mean unhealthy food score (UnHFS). Multivariable-adjusted generalized linear models were used to examine the relationship of early solid food introduction, HFS quartiles (Q), UnHFS quartiles, and interactions between these variables with WFL z-scores at 12 months (n=449). Exploratory analyses evaluated WFL z-scores among 4 groups of infants with high/low HFS and high/low UnHFS. On average, mothers were 28 years with a pre-pregnancy BMI of 30.5 kg/m^2; 65% were Non-Hispanic Black, and 59% had incomes <$20,000. Mean HFS and UnHFS were 2.4 (range 0–7.4 of 10) and 1.8 (range 0-9.9 of 20), respectively. Nearly 1/3 of mothers introduced solids early, but early introduction and the HFS were not associated with WFL z-scores. Infants in Q3 and Q4 of the UnHFS had higher WFL z-scores (0.75-0.79 ±0.09) compared to infants in Q1 (0.42±0.0.9), p<0.05. Frequent unhealthy food intake

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AUTHORSHIP

MV contributed to formulating the research question, analyzed the data, and drafted the manuscript. AT contributed to formulating the research question and edited the manuscript for important intellectual content. TO advised analyses and edited the manuscript for important intellectual content. SBN is the principal investigator of the Nurture cohort and provided guidance for the study design, analysis, and edited the manuscript for important intellectual content.

CONFLICT OF INTEREST

The authors have no conflicts of interest to report.

was associated with higher WFL z-scores at 12-months, underscoring the importance of reducing unhealthy food intake in the first year.

Keywords

timing of solid foods; fruit and vegetable intake; quality of solid foods during complementary feeding; infant weight-for-length; Nurture cohort; diet quality; solid food introduction

INTRODUCTION

Emerging evidence suggests that the neuroplastic period in the first 1000 days of life (conception – age 2 years)[1] is a critical time for establishing healthy diet and weight trajectories in children.[2] Most recent national estimates indicate that 8% of infants and toddlers have weight-for-lengths greater than the 95th percentile.[3] Obesity among preschool-aged children in the US has nearly tripled over the last 30 years with racial and socio-economic disparities observed by this age, highlighting the importance of pregnancy and infancy in the development of obesity.[3] Furthermore, racial disparities in diet and obesity begin very early in life, underscoring the need to investigate whether some of these begin in the first year of life.[4]

Although the first year is a critical period for the development of healthy weight, little is known about the impact of diet quality on body weight during this time.[5] To date, most research during infancy has focused on differences between infants who were breast versus formula fed, as well as the impact of the timing and sequence of solid food introduction during the transition from a milk-based diet to one that incorporates solid foods.[6] Evidence remains mixed regarding the associations between breastfeeding and risk of infant adiposity, and most[7] but not all[6] research suggests that introduction of solid foods prior to 4-months of age (i.e., early introduction based on recommendations from the American Academy of Pediatrics[8,9]) is associated with greater risk of excess adiposity during childhood. Although timing of food introduction may be an important factor for the development of healthy weight trajectories, it is unknown if the quality of the food that is being introduced influences this risk. Additional high-quality evidence is needed to inform the development of infant feeding guidelines.[10]

According to a recent systematic review, the only study examining the link between adherence to dietary guidelines during complementary feeding with body weight did not detect an association between dietary patterns and adiposity.[11] However, this study[12] was not conducted in the US and did not explore the interaction between the diet quality of solid foods and early introduction to solid foods. Given that low intake of fruits and vegetables[13] and high intake of unhealthy foods are related to obesogenic dietary patterns,[14-17] it is critical to understand how exposure to these foods early in life interact with maternal factors to subsequently influence childhood diet and body weight. Notably, because infants are predisposed to prefer sweet, energy-dense foods, frequent introduction to such foods early in life may alter taste preferences further, and put infants at greater risk for overconsuming unhealthy foods, under consuming healthy foods, and establishing less optimal weight patterns early in life.[18] Moreover, if timing and quality of solid food introduction are relevant risk factors for the development of childhood food preferences and establishing healthy weight, it is important to understand maternal factors that may influence the decision to introduce foods to infants. Research among predominately white, middle-class women suggests that younger women with lower education and higher BMI are more likely to introduce solid foods prior to 6 months.[19] However, it remains unclear whether these associations are similar among lower income, predominately non-white populations, as well as the underlying reasons why some groups of women are more likely to introduce solid foods early.

Therefore, the purpose of this secondary analysis was to: (1) describe the prevalence of early introduction to solid foods and maternal reasons for doing so, (2) explore the relationship between early solid food introduction, infant weight-for-length (WFL) z-scores, and any interactions with maternal characteristics and infant healthy and unhealthy diet scores, (3) explore patterns in the intake of healthy and unhealthy foods during the first 1 year of life and (4) explore whether infants with more and less frequent intake of healthy and unhealthy foods have differences in WFL z-scores at 1 year of age within a prospective birth cohort of lower income, predominantly minority women in the US. This analysis is based on the hypothesis that early introduction of solid foods and more frequent consumption of unhealthy foods would be associated with higher WFL z-scores at 1 year, while more frequent intake of healthy foods would be inversely associated with infant WFL z-scores. Additionally, diet quality of complementary foods introduced in the first year of life would likely modify the associations between early introduction to solids and infant WFL z-scores at 1 year, with adverse associations between early introduction and WFL z-scores only observed for unhealthy foods.

METHODS

Population

Data are from the Nurture study,[20] a prospective longitudinal cohort of mothers and their infants measured throughout the first year of life. The cohort consists of predominately Non-Hispanic Black women and infants recruited from a local county health department prenatal clinic and a private prenatal clinic in Durham, North Carolina. Mothers ≥18 years of age with healthy singleton pregnancies and with intention to remain in the area at least 12 months postpartum were recruited between 20-36 weeks' gestation from 2013 to 2015. Every 3 months throughout the first year of life, mothers responded to dietary surveys during home visits querying the frequency infants consumed 16 types of foods. Questions about foods and beverages provided to infants originated from the Infant Feeding Practices Study II study[21] and the Feeding Infants and Toddlers Study.[22] Foods queried included cereal, whole fruit, vegetables, french fries/other fried potatoes, meat, fish, yogurt, ice cream, grains, baby snacks, sweets, peanuts, egg yolks, egg whites, whole eggs, and other dairy. Beverages including 100% fruit juice were queried separately. Mothers also indicated when they began introducing anything besides breast milk or formula to their infants and their primary reasons for doing so. Infant anthropometrics were measured in triplicate by trained study personnel every 3 months during home visits (n=666). Details about the study design have been previously published.[20] This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by Duke University Medical Center IRB (human subjects committee) (Pro 0036242), and is registered at clinicaltrials.gov (NCT01788644).

Exposure Variables

Early introduction to solids: An indicator variable denoting any introduction of other liquids prior to 4 months of age and/or regular introduction of solid foods before 4 months of age in accordance with the American Academy of Pediatrics recommendations for complementary feeding.[23]

Maternal reasons for solid food introduction: 4-point Likert Scales ranging from "not at all important" to "very important" queried 12 reasons for introducing solids to infants including: (1) baby was nursing too much, (2) I did not have enough milk, (3) my baby was drinking too much formula, (4) my baby had a medical condition that might be helped by eating solids, (5) my baby was not gaining enough weight, (6) friends or relatives said my baby should begin eating solid foods, (7) solid foods would help my baby sleep longer at night, (8) a doctor or other health care professional said my baby should eat solids, (9) I wanted to feed my baby something in addition to breast milk, (10) my baby seemed hungry a lot of the time, (11) my baby was old enough to begin to eat solid food, (12) my baby wanted the food I ate or in other ways showed an interest in solid food.

Diet Quality Scores: Dietary questionnaires assessed the frequency per day – irrespective of serving size – that a mother reported her infant consumed foods from the 16 food groups in the dietary survey at 3-, 6-, 9- , and 12-months.

Healthy Food Score (HFS): Calculated at each three-month time point by summing how frequently the mother reported her infant consumed fruits (0-5x/day) or vegetables (0-5x/day); fruits excluded 100% fruit juice, and vegetables excluded french fries/fried potatoes.[24] The maximum possible score is 10, and higher scores represent more healthy food consumption. The mean HFS between 4-12 months was calculated by averaging the HFS at those time points.

Unhealthy Food Score (UnHFS): Calculated at each time point by summing how frequently the mother reported her infant consumed french fries, ice cream, baby snacks, and sweets (0-5x/day range for each variable).[24] The maximum possible score is 20, and higher scores represent more unhealthy food consumption. The mean UnHFS between 4-12 months was calculated by averaging the UnHFS at those time points.

Overall Food Score (exploratory): An overall healthy and unhealthy food score was calculated based on the HFS and UnHFS scores in the following manner. Any mother who reported her infant consumed foods included in the HFS ≥2 times/day received the maximum score of 10 points. If the infant consumed foods in the HFS fewer than 2 times/day, they were awarded 0 points. Any mother who reported her infant consumed foods in the UnHFS >1 time/day received −20 points; if the infant consumed foods in the UnHFS ≤1 time/day, they received 0 points.

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These two scores were summed, resulting in 4 patterns, with scores ranging from a minimum of −20 (unhealthy diet) to 10 (healthiest diet). These frequency cut-points were informed by recommendations from the American Academy of Pediatrics, which emphasizes 2-3 nutritious snacks like fruits and vegetables per day, while cautioning against the consumption of non-nutritive finger and snack foods like cereal, cookies, and french fries observed before 9 months of age.[9]

Outcome Variables

Weight for length (WFL) z-score at 12 months: z-scores based on measured infant weight and length at 12 months of age (in triplicate with an average of the 3 measures used). Infant recumbent length was measured by trained data collectors using a ShorrBoard Portable Length board and weight was measured with calibrated Seca Infant Scales to the nearest 0.1 pound.[20] Age- and sex-specific WFL z-scores were computed using WHO reference standards.[25]

Covariates

Infant birthweight for gestational age z-scores were based on international reference standards[25] and maternal sociodemographic and health characteristics were tested as possible covariates. Tested covariates included pre-pregnancy body mass index (BMI), education, race, age, number of children in the household, and total weeks of any breastfeeding between 0-12 months. If the mother was still breastfeeding at 1-year, the total number of weeks she was breastfeeding at the date of her follow-up survey was recorded. Although 8% of the sample reported gestational diabetes during pregnancy, due to substantial missing data in that variable, only infant birthweight for gestational age z-score and maternal pre-pregnancy BMI were included as possible covariates. Covariates were singly entered into generalized linear models and retained if they were independent predictors of WFL z-scores.

Statistical analysis

To answer the first research question describing the prevalence of early introduction to solid foods and maternal reasons for doing so, descriptive statistics among participants with complete dietary and anthropometric data at 12 months of age were computed. Additionally, descriptive data regarding maternal self-reported reasons for early introduction to solid foods were reported. The mean (SD) HFS and UnHFS at each time point was reported, and linear regression and generalized linear models with Tukey adjustment were used to compare mean scores across time and among those with and without early solid food introduction. Pearson correlations were computed to examine the associations between the HFS, UnHFS, and the individual food groups used to compute the score. This allowed us to examine whether 1) the individual food groups were correlated with their respective scores, and 2) whether the HFS and UnHFS were positively or inversely correlated.

Next, unadjusted and multivariable adjusted generalized linear models were used to examine the relationship between early introduction to solid foods and WFL z-scores as well as the relationship between the HFS and UnHFS with WFL z-scores at 12 months.

The HFS and UnHFS were divided into quartiles and least squared mean WFL z-scores (mean ± SE) were compared across HFS and UnHFS quartiles. Post-hoc comparisons with Dunnet-Hsu adjustment were used to compare subgroups to the lowest quartile reference group when a significant main effect was detected. Covariates retained in final models included infant birthweight for gestational age z-score and maternal pre-pregnancy BMI.

Interactions between early solid food introduction and (1) each food score and (2) maternal covariates (i.e. maternal pre-pregnancy BMI, breastfeeding), and between the HFS and UnHFS were explored using a cut-point of $p<0.05$ as a threshold for significance.

Finally, linear regression was used to conduct an exploratory analysis testing the associations between the overall food score and WFL z-score at 12 months unadjusted and adjusted for covariates. Covariates retained in final models included infant birthweight for gestational age z-score, maternal pre-pregnancy BMI, and total breastfeeding weeks. Results for the exploratory analysis are reported as β-coefficients with 95% Confidence Intervals comparing participants with a moderately unhealthy diet (−10), moderately healthy diet (0), and healthiest diet (10) to participants with an unhealthy diet (−20).

RESULTS

The analytic sample consisted of 449 women with a mean (SD) age of 28.0 (±5.9) years. Nearly two-thirds of women were Non-Hispanic Black (65.2%), low-income (59.3%), and 18.9% reported having obtained less than a high school education. Mean pre-pregnancy BMI was within the obese range (30.5 kg/m^2) and the average number of children in the household was 2.1. The average HFS and UnHFS were 2.4 (out of 10) and 1.8 (out of 20), respectively (Table 1).

Prevalence of Early Solid Food Introduction and Maternal Reasons for Doing So

Almost one third of mothers had introduced solid food by 4 months of age (31.7%). Among the mothers who introduced solid food by 4 months, 71.0% (n=82) specified reasons for introducing solid foods. The primary factor (based on the number of women who agreed or strongly agreed) was that the baby seemed hungry (68.3%). Other factors were that the baby was drinking too much formula (51.2%), a belief that solid foods would help the baby sleep (48.8%), that the baby was old enough to begin solid foods (48.8%), and that the baby was showing an interest in solid foods (45.7%).

Diet Quality Characteristics among Infants with and without Early Food Introduction

Table 2 shows the mean HFS and UnHFS at 3, 6, 9, and 12 months for all infants, as well as stratified by early solid food introduction. In general, the HFS and UnHFS in the first 3 months of life were very low (<0.1). Consistent with increasing energy needs, both scores increased over time, and for the entirety of the 12 months ($p<0.0001$) showing that both consumption of healthy and unhealthy foods was increasing. The HFS remained consistently higher than the UnHFS over the 12-month period ($p<0.0001$); at 12 months, the mean HFS was 3.8 (out of 10) and the mean UnHFS was 3.1 (out of 20). Infants who had early introduction of solid foods versus those that did not have early introduction of solid foods, had higher HFS and UnHFS until 6 months of age ($p<0.05$), at which point, scores between the two groups were comparable.

All food groups were significantly and positively correlated with each other ($p<0.05$), and the highest Pearson correlations were observed between the HFS and both fruits and vegetables (r=0.92-0.93). The correlation between the HFS and UnHFS was 0.38. The UnHFS was most strongly correlated with french fries (r=0.82) and baby snacks (r=0.72).

Early Solid Food Introduction and Infant Weight-for-length Z-scores

Early introduction to solid foods (prior to 4 months of age) was not an independent predictor of WFL z-scores (p=0.51). However, a significant interaction was detected between early solid food introduction and maternal pre-pregnancy BMI ($\beta=-0.02$ (0.01), p=0.03), with significant main effects for both early solid food introduction ($\beta=0.79$ (0.38), p=0.04) and pre-pregnancy BMI ($\beta=0.03$ (0.01), p=0.01). In further unadjusted, exploratory, stratified analysis, early solid food introduction was positively associated with infant WFL z-scores at 12 months as maternal BMI increased, and was marginally related to higher infant WFL z-scores (p=0.06) when maternal pre-pregnancy BMI exceeded a threshold of 33.5 kg/m^2. For women who introduced solid foods after 4 months of age, there was no relationship between maternal pre-pregnancy BMI and infant WFL z-score. No other significant interactions were detected between early solid food introduction and other maternal characteristics.

Associations between the HFS, UnHFS, and Infant Weight-for-length Z-scores

In order to examine if the HFS and UnHFS scores were associated with infant adiposity, associations between quartiles of each score and mean WFL z-scores were examined (Table 3). Final models were adjusted for infant birthweight and maternal pre-pregnancy BMI. No association between quartiles of the HFS and WFL z-scores were observed. However, in both the unadjusted and adjusted model, participants with more frequent unhealthy food intake in Q3 of the UnHFS score had higher WFL z-scores than infants in Q1 (0.79±0.09 vs. 0.42 ±0.09, $p<0.05$ in fully adjusted models). Participants in Q4 also had significantly higher WFL z-scores than infants in Q1 in fully adjusted models only (0.75±0.09).

Modification of diet quality between early solid food introduction and infant adiposity

A statistically significant interaction between HFS quartile and early introduction of solid foods was detected (p=0.01), so analyses were stratified and examined among those infants who were introduced to solid foods early and those who were not. Among those introduced to solids after 4 months of age (n=246), there was no association between the HFS score and WFL z-score. However, among those who had early solid food introduction (n=114), infants in Q3 had higher WFL z-scores (1.02±0.07) than infants in Q1 (0.28±0.18).

Exploratory Analysis: Overall Diet Quality and Weight-for-length Z-scores

Finally, in exploratory analyses, the association between an overall diet quality score (combining both the HFS and UnHFS) with WFL z-scores at 12-months was tested (Table 4). Most of the sample (n=204) had a moderately unhealthy diet (score of −10) characterized by high intake of healthy foods (≥2 servings/day of foods in the HFS) and high intake of unhealthy foods (>1 serving/day of foods in the UnHFS). Compared to infants with the least healthy diet (reference group, score of −20, n=115), infants with a moderately healthy diet (score of 0) had significantly lower WFL z-scores at 12 months (β= −0.33) in a model adjusted for maternal pre-pregnancy BMI, infant birthweight, and weeks of breastfeeding. No differences in WFL z-scores were observed among infants with the healthiest diet (n=65) or moderately unhealthy diets (n=204) compared to the reference group.

DISCUSSION

The purpose of this analysis was to assess the prevalence of early introduction to solid foods and explore maternal reasons for doing so, as well as the relationship between early solid food introduction and the diet quality of foods introduced during complementary feeding on infant WFL z-scores at 12 months in a diverse group of mothers. Nearly one-third of mothers provided nutrition other than breast milk or formula in the first 4 months of life, and the main reasons for introducing solids during this time was the perception that their infant was hungry and drinking too much formula. Additionally, more frequent intake of unhealthy foods during the traditional complementary feeding period (4-12 months) was associated with higher WFL z-scores, while more frequent intake of healthier foods was unrelated to WFL z-scores. Notably, for those who introduced solid foods prior to 4 months of age, more frequent intake of healthy foods was associated with higher WFL z-score at 12 months. Finally, in exploratory analyses, results suggested that more frequent intake of unhealthy foods (even among infants with diets characterized by high intake of both healthy and unhealthy foods) was associated with higher WFL z-scores. These findings suggest that the quality of foods being consumed during the first year of life, mainly unhealthy foods, may influence greater WFL z-scores early in life.

The finding that 33% of mothers are introducing solids foods before 4 months of age is consistent with previous research.[26,27] Furthermore, the reasons for early introduction provided by this cohort of predominately non-Hispanic Black mothers are also consistent with research conducted in predominately non-Hispanic White populations or non-US populations.[27,28] The reasons mothers reported introducing solid foods early, seemed centered around infant hunger and inadequate formula supply, potentially underscoring the contribution of poverty[29,30] to associations between early introduction to solid foods and infant adiposity.

Consistent with our pre-specified hypothesis, we found that more frequent intake of unhealthy foods during complementary feeding was associated with higher WFL z-scores, which is similar to other studies conducted with infants and children.[31,32]. Although few mothers introduced unhealthy foods like french fries, snacks, and sweets before 4 months of age, frequent intake of unhealthy foods (>1 serving/d) during the complementary feeding period was common (71% of the sample) and associated with higher WFL z-scores. Although limited research has explored the association with diet quality during infancy and later adiposity, the present results are consistent with a pilot study,[31] which detected a positive association between sugar sweetened beverage intake between 4-13 months of age and overweight at 8 years. The present findings also support the concern that early introduction to sweet, energy-dense foods may interact with infants' innate preferences for sweet flavors, potentially promoting overconsumption of energy-dense foods related to the development of childhood obesity.[18]Consistent with Anderson et al.,[24] the present results suggest that more frequent intake of healthy foods is not inversely associated with intake of unhealthy foods, with most infants having high intake of both healthy and unhealthy foods. Furthermore, higher frequency of healthy foods was not associated with reduced WFL z-scores. Thus, while having high intake of both healthy and unhealthy foods may still be more favorably associated with other biomarkers like blood pressure and total cholesterol,[33-36] the present results do not appear to support increasing frequency of healthy food as a method for reducing WFL z-scores in infants. However, given that most infants in this sample had frequent intake of both healthy and unhealthy foods, further investigation is warranted.

The interaction between early introduction of solid foods and more frequent intake of healthy foods (rather than unhealthy) warrants further consideration as it seems to imply that early introduction of unhealthy foods is not associated with higher WFL z-score. However, it is important to note that this counterintuitive finding may be explained by the higher proportion of mothers who introduced healthier foods (i.e., fruits and vegetables) and other foods (e.g., cereals and grains, eggs, meat) before 4 months of age instead of unhealthy foods (i.e., sweets, French fries) (data not shown). Thus, although it was hypothesized that the influence of early solid food introduction on infant adiposity at 12 months would be modified by the quality of foods introduced, it was not possible to examine whether early introduction of unhealthy foods had a stronger association with WFL z-score because few women introduced these foods in the first 4 months of life. Lastly, it is noteworthy that the mean HFS in Q3 for those with and without early solid food introduction was 2.57 while the UnHFS was 1.50 among those who did not introduce solids early vs. 1.86 for those who introduced solids early. Conversely in Q4, the mean HFS was 3.99 among those who did not introduce solid foods early vs. 4.23 for those who introduced solids early while the UnHFS mean scores were similar (2.52 vs. 2.54). Taken together, this suggests that the finding in Q3 is driven by higher UnHFS scores among those with early solid food introduction, and the non-significant finding in Q4 is due to comparable UnHFS scores among those with and without early solid food introduction.

The results from this study add to the limited research exploring the quality of foods introduced during complementary feeding and the influence of these foods on early markers of childhood obesity. These results suggest that most women are not introducing unhealthy foods (i.e., french fries, ice cream, baby snacks and sweets) prior to 4 months of age and are instead introducing healthier foods like fruits and vegetables, or other foods like cereals, grains, eggs, and meat (data not shown). Early introduction of fruits and vegetables and other foods appear to be associated with higher WFL z-scores at 1 year of age. This was particularly true if maternal pre-pregnancy BMI was higher; after adjusting for birthweight, mean pre-pregnancy BMI among those who introduced solid foods early was marginally higher (32.2 kg/m^2 compared to mothers among mothers who did not introduce solid foods early (30.0 kg/m^2 p=0.05). These results highlight the importance of focusing intervention efforts toward women with obesity at the beginning of their pregnancy, as they may be more likely to introduce solid foods early, and early food introduction among this higher risk group may be related to the transmission of obesity across generations.

The results from the present study also introduce some new considerations to the existing, and somewhat mixed research exploring the influence of early solid food introduction and risk of childhood obesity.[6] There was no observed independent association between early solid food introduction and infant WFL z-scores at 12-months, nor did breastfeeding modify the association between early solid food introduction and WFL z-scores. This finding is consistent with previous research in the IFPS II examining associations between early solid food introduction and childhood obesity risk at 6-years of age,[37] but contradicts some previous research,[38]potentially due to differences in breastfeeding duration between the samples. However, the present findings do support existing research positing that the associations between early solid food introduction and infant WFL z-scores operate through biobehavioral pathways.[39] For example, early food introduction was especially problematic in mothers with higher pre-pregnancy BMI, indicating that a behavioral risk factor (i.e., early solid food introduction possibly related to socioeconomic status) in combination with a biologic risk factor (i.e., higher maternal BMI)[40] work in concert to adversely influence infant weight. Given the consistent association between maternal weight, higher birth weight, and higher infant weight gain with later childhood overweight,[40]it is likely that optimal caregiver feeding practices are especially important among infants with a stronger genetic predisposition to obesity.

Some limitations of the present study must be noted. Many women did not respond to questions regarding early infant feeding, and descriptive reasons for early solid food introduction may not be representative of the sample, or other populations. Serving sizes were not assessed in the dietary questionnaires, so it was not possible to estimate food quantity or energy intake, which are important confounding variables. Additionally, data are currently only available through the first year of life, and it is possible that it is too early to detect an association between diet quality and risk of adiposity – particularly given that the effects of diet tend to be cumulative over time. Moreover, very few infants had WFL z-scores that would categorize them as overweight hence using WFL z-score as a continuous measure was more appropriate for this analysis. That said, the positive associations between more frequent unhealthy food intake and WFL z-scores observed combined with the biologic plausibility of this relationship suggests that higher intake of certain food groups may be important preliminary risk markers for the development of less optimal childhood weight outcomes.

Some strengths of the present analysis also warrant mention. First, this study utilized prospective data from a birth cohort consisting of predominately lower income, non-Hispanic Black women, who are currently underrepresented in the research literature. Additionally, this study holistically examined the drivers and influence of early introduction of solid foods on infant WFL z-scores at 1 year as well as how the diet quality of complementary foods influences growth in the first year. Dietary data was collected every 3 months during the first year of life, providing an opportunity to examine changes in diet quality over the first year of life.

In conclusion, this analysis of the Nurture birth cohort suggests that certain dietary patterns during the first year of life may be associated with higher WFL z-scores at 1-year. Early introduction to solid foods may be especially problematic for children born to mothers with obesity. More importantly, regular introduction (>1 time/day) during the first year of life to non-essential, unhealthy foods like french fries, sweets, and other snack foods seems to both be prevalent (71% of the present sample) and a risk factor for higher WFL z-scores, irrespective of healthy food intake. More research is needed to determine whether frequent, early exposure to unhealthy foods shapes food preferences, eating behavior, or operates through other pathways to adversely influence childhood weight trajectories. Nevertheless, public health efforts to reduce early introduction of solids to infants- particularly among women who may be at higher risk due to poverty or starting pregnancy with obesity remains a priority. Furthermore, infant feeding guidelines should emphasize limiting regular consumption of non-nutrient dense, energy-dense foods during the first year of life to promote diet-related health trajectories.

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Table 1:

Sample characteristics of mothers and infants in the Nurture cohort

	n	Mean (SD) or %
Maternal age	449	28.0 (5.86)
% Non-Hispanic Black (child)	442	65.2
Household income (% low income)[1]	415	59.3
Maternal education (% high school graduate or more)	449	81.1
Maternal pre-pregnancy BMI	429	30.5 (9.42)
Number of children	409	2.11 (1.27)
Maternal smoking (%)	400	16.5
Weeks of Breastfeeding	449	17.7 (19.8)
Infant birth weight for gestational age z-score	446	−0.29 (0.96)
Infant weight-for-length z-score (12-months)	449	0.64 (1.01)
Healthy food score (4-12 months)[2]	449	2.39 (1.22)
Unhealthy food score (4-12 months)[3]	449	1.79 (1.26)
Early solid food introduction[4] (%)	366	31.7

[1]Low income was defined as a household income <$20,000 per year

[2]The Healthy Food Score (HFS) was calculated at each three-month time point by summing how frequently the mother reported her child consumed fruits (0-5x/day) or vegetables (0-5x/day).[24] The maximum possible score is 10, and higher scores represent more healthy food consumption. The mean HFS between 4-12 months was calculated by averaging the HFS at those time points.

[3]The Unhealthy Food Score (UnHFS) was calculated at each time point by summing how frequently the mother reported her child consumed french fries, ice cream, baby snacks, and sweets (0-5x/day range for each variable).[24] The maximum possible score is 20, and higher scores represent more unhealthy food consumption. The mean UnHFS between 4-12 months was calculated by averaging the UnHFS at those time points.

[4]Early solid food introduction includes any introduction of other liquids (besides breast milk or formula) prior to 4-months of age and/or regular introduction of solid foods before 4-months of age. Although 455 participants have information on early solid food introduction, 89 women are missing information on weight-for-length z-score at 12-months and are not included in the descriptive characteristics of the analytic sample. However, a similar percentage of those without z-weight-for-length are introducing solid food early (32.8%)

Table 2:

Healthy and unhealthy food scores at 3, 6, 9, and 12-months (mean (SE))

Mean (SD)[1]	**3-mo n=534**	**6-mo n=491**	**9-mo n=451**	**12-mo n=465**
Healthy food score[2]	0.07 (0.38)[a*]	1.63 (1.91)[b*]	3.27 (2.01)[c*]	3.79 (2.04)[d*]
Early Introduction[3] (n=149)	0.20 (0.60)[a*†]	1.92 (1.94)[b*†]	3.27 (2.10)[c*]	3.84 (2.24)[d*]
Not Early Introduction (n=306)	0.01 (0.10)[a*]	1.52 (1.89)[b*]	3.27 (1.99)[c*]	3.77 (1.97)[d*]
Unhealthy food score[4]	0.04 (0.26)[a]	0.84 (1.62)[b]	2.62 (2.24)[c]	3.13 (2.18)[d]
Early Introduction[2] (n=149)	0.12 (0.48)[a†]	1.12 (1.84)[b†]	2.84 (2.18)[c]	3.34 (2.08)[d]
Not Early Introduction (n=306)	0.005 (0.08)[a]	0.73 (1.53)[b]	2.55 (2.26)[c]	3.05 (2.21)[d]

[1]Means with different superscript letters in the same row significantly differ from one another ($p<0.0001$); an asterisk (*) denotes a significant difference ($p<0.0001$) between the Healthy Food Score and the Unhealthy Food Score at a given time point overall and among those within the same complementary feeding group (i.e. among those with early introduction of healthy foods at 3-months and among those with early introduction of unhealthy foods at 3-months) ; a † denotes a significant difference ($p<0.05$) between those with and without early solid food introduction at a given time point for the healthy food score and unhealthy food score, respectively.

[2]Healthy food scores count the frequency of fruit and vegetable intake (frequencies range from never to 5 or more times/day, maximum total score of 10). Higher scores represent more healthy food consumption.

[3]Early introduction counts anyone who reported that they were not exclusively breast or formula feeding infants < 4 months of age or where regular solid food intake at the 3-month interview was reported or where other liquids besides formula or breast milk were reported. Note: some food introduction could be in months 1-3 if the mother fed her child some solid foods, but did not do so regularly.

[4]Unhealthy food scores count frequency of sweets, french fries, infant snacks, and ice cream (frequencies range from never to 5 or more times/day, maximum total score of 20). Higher scores represent less healthy food consumption.

Table 3:

Mean (SE) weight-for-length (WFL) z-scores at 12-months across quartiles of the healthy and unhealthy food score

WFL z-scores (12-months)	Q1 (reference)	Q2	Q3	Q4	Model p-value
Healthy Food Score (HFS) (mean (SE)) [1-3]					
Unadjusted Model	0.54 (0.10)	0.68 (0.10)	0.60 (0.09)	0.73 (0.10)	0.52
Model 1[4]	0.56 (0.09)	0.64 (0.10)	0.66 (0.09)	0.73 (0.10)	0.65
No Early Food Introduction[5] (n=246)	0.67 (0.12)	0.62 (0.12)	0.52 (0.13)	0.69 (0.12)	0.79
Early Food Introduction[5] (n=114)	0.28 (0.18)	0.77 (0.18)	1.02 (0.17)*	0.51 (0.17)	0.02
Unhealthy Food Score (UnHFS) (mean (SE)) [1-3]					
Unadjusted model	0.43 (0.09)	0.62 (0.09)	0.83 (0.09)*	0.66 (0.09)	0.03
Model 1[4]	0.42 (0.09)	0.63 (0.09)	0.79 (0.09)*	0.75 (0.09)*	0.02

[1] Diet scores are calculated as the mean values between 4-12 months. Healthy food scores count the frequency of fruit and vegetable intake (frequencies range from never to 5 or more times/day). Unhealthy food scores count sweets, french fries, infant snacks, and ice cream (frequencies range from never to 5 or more times/day)

[2] There are 111-114 per quartile of the Healthy Food Score with ranges of values of (Q1: 0.02-1.57; Q2: 1.57-2.25; Q3: 2.25-2.05; Q4: 2.05-7.40).There are 112-113 per quartile of the Unhealthy Food score, with ranges of values of (Q1: 0-0.88; Q2: 0.90-1.48; Q3: 1.48-2.38; Q4: 2.39-9.89).

[3] Least squared mean values for infants in Q2, Q3, and Q4 of the HFS and UnHFS are compared using Dunnet-Hsu adjustment against Q1; An asterisk (*) demotes a significant difference from the reference group (Q1)

[4] Model 1 adjusts for infant birth weight for gestational age z-score and pre-pregnancy BMI

[5] A statistically significant interaction between Healthy Diet Score Quartile and Early Solid Food intake was detected (p=0.01), so final models for healthy food were stratified by early introduction to solid foods

Table 4:

Associations between an overall healthy and unhealthy food score with weight-for-length z-scores at 12-months

β	Unadjusted Model	95% CI	Adjusted Model[5]	95% Confidence Interval
Intercept	0.66*	0.47-0.84	0.70*	0.32 – 1.08
Healthiest Diet[1] (10)	−0.03	−0.34– 0.27	0.02	−0.30 – 0.33
Moderately Healthy Diet[2] (0)	−0.31*	−0.62 - −0.002	−0.33*	−0.63 - −0.03
Moderately Unhealthy Diet[3] (−10)	0.07	−0.16-0.30	0.06	−0.17 – 0.29
Unhealthy Diet[4] (−20)	ref	ref	ref	ref
Pre-pregnancy BMI			0.005	−0.01 – 0.01
Birthweight			0.31*	0.21 – 0.41
Breastfeeding			−0.005*	−0.01 - −0.0003

*Denotes a p-value <0.05. The reference diet group has a score of '−20' (low in healthy food and high in unhealthy food). Diet scores are calculated as the mean values between 4-12 months. Healthy food scores count the frequency of fruit and vegetable intake (frequencies range from never to 5 or more times/day). Unhealthy food scores count sweets, french fries, infant snacks, and ice cream (frequencies range from 0 to 5+ times/day).

[1] Healthiest diet (10 points) = ≥ 2 servings/day of foods included in the Healthy Food Score AND ≤ 1 serving/day of foods included in the Unhealthy Food Score (n=65)

[2] Moderately healthy diet (0 points) = ≥ 2 servings/day of foods included in the Healthy Food Score AND ≤ 1 serving/day of foods included in the Unhealthy Food Score (n=65)

[3] Moderately unhealthy diet (−10 points)= > 2 servings/day of foods included in the Healthy Food Score AND > 1 serving/day of foods included in the Unhealthy Food Score (n=204)

[4] Unealthy Diet (−20 points)= < 2 servings/day of foods included in the Healthy Food Score AND > 1 serving/day of foods included in the Unhealthy Food Score (n=115)

[5] Adjusted model adjusts for infant birth weight for gestational age z-score and pre-pregnancy BMI, and total breastfeeding weeks