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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

Maya Vadiveloo

Department of Nutrition and Food Sciences, University of Rhode Island, maya_vadiveloo@uri.edu

Alison Tovar

University of Rhode Island, alison_tovar@uri.edu

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Authors

Maya Vadiveloo, Alison Tovar, Truls Østbye, and Sara E. Benjamin-Neelon

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

3 Maya Vadiveloo,¹ Alison Tovar,¹ Truls Østbye,² Sara E. Benjamin-Neelon³

4 ¹Department of Nutrition and Food Sciences, University of Rhode Island, 41 Lower College Rd
5 Kingston, RI 02881

6 ²Department of Community and Family Medicine, Duke University Medical Center, DUMC
7 2914, Durham, NC 27710

8 ³Department of Health Behavior, and Society, Johns Hopkins Bloomberg School of Public
9 Health, 624 N. Broadway St, Baltimore, MD 21205

10

11 **Corresponding Author**

12 Maya Vadiveloo, PhD RD

13 Assistant Professor

14 Department of Nutrition and Food Sciences, 41 Lower College Rd, University of Rhode Island
15 Kingston, RI 02881

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20 introduction

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24

25 **ABSTRACT**

26 This study assesses associations of the timing and quality of solid foods introduced during
27 infancy with weight-for-length (WFL) z-scores at 12 months within the Nurture cohort. Women
28 from North Carolina self-reported sociodemographics, the timing and type of solid food
29 introduction, and reasons for introducing solids; infant anthropometrics were measured every 3
30 months through 1 year (n=666). Frequency (0 - 5x/day) infants consumed fruits and vegetables
31 was used to compute a mean (4-12 months) healthy food score (HFS), and sweets, french fries,
32 snacks, and ice cream was used to compute a mean unhealthy food score (UnHFS).
33 Multivariable-adjusted generalized linear models were used to examine the relationship of early
34 solid food introduction, HFS quartiles (Q), UnHFS quartiles, and interactions between these
35 variables with WFL z-scores at 12 months (n=449). Exploratory analyses evaluated WFL z-
36 scores among 4 groups of infants with high/low HFS and high/low UnHFS. On average, mothers
37 were 28 years with a pre-pregnancy BMI of 30.5 kg/m²; 65% were Non-Hispanic Black, and
38 59% had incomes <\$20,000. Mean HFS and UnHFS were 2.4 (range 0–7.4 of 10) and 1.8 (range
39 0-9.9 of 20), respectively. Nearly 1/3 of mothers introduced solids early, but early introduction
40 and the HFS were not associated with WFL z-scores. Infants in Q3 and Q4 of the UnHFS had
41 higher WFL z-scores (0.75-0.79 ±0.09) compared to infants in Q1 (0.42±0.0.9), p<0.05.
42 Frequent unhealthy food intake was associated with higher WFL z-scores at 12-months,
43 underscoring the importance of reducing unhealthy food intake in the first year.

44 **Word Count:** 247

45 INTRODUCTION

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

54 Although the first year is a critical period for the development of healthy weight, little is
55 known about the impact of diet quality on body weight during this time.⁵ To date, most research
56 during infancy has focused on differences between infants who were breast versus formula fed,
57 as well as the impact of the timing and sequence of solid food introduction during the transition
58 from a milk-based diet to one that incorporates solid foods.⁶ Evidence remains mixed regarding
59 the associations between breastfeeding and risk of infant adiposity, and most⁷ but not all⁶
60 research suggests that introduction of solid foods prior to 4-months of age (i.e., early
61 introduction based on recommendations from the American Academy of Pediatrics^{8,9}) is
62 associated with greater risk of excess adiposity during childhood. Although timing of food
63 introduction may be an important factor for the development of healthy weight trajectories, it is
64 unknown if the quality of the food that is being introduced influences this risk. Additional high-
65 quality evidence is needed to inform the development of infant feeding guidelines.¹⁰

66 According to a recent systematic review, the only study examining the link between
67 adherence to dietary guidelines during complementary feeding with body weight did not detect
68 an association between dietary patterns and adiposity.¹¹ However, this study¹² was not conducted
69 in the US and did not explore the interaction between the diet quality of solid foods and early
70 introduction to solid foods. Given that low intake of fruits and vegetables¹³ and high intake of
71 unhealthy foods are related to obesogenic dietary patterns,¹⁴⁻¹⁷ it is critical to understand how
72 exposure to these foods early in life interact with maternal factors to subsequently influence
73 childhood diet and body weight. Notably, because infants are predisposed to prefer sweet,
74 energy-dense foods, frequent introduction to such foods early in life may alter taste preferences

75 further, and put infants at greater risk for overconsuming unhealthy foods, under consuming
76 healthy foods, and establishing less optimal weight patterns early in life.¹⁸ Moreover, if timing
77 and quality of solid food introduction are relevant risk factors for the development of childhood
78 food preferences and establishing healthy weight, it is important to understand maternal factors
79 that may influence the decision to introduce foods to infants. Research among predominately
80 white, middle-class women suggests that younger women with lower education and higher BMI
81 are more likely to introduce solid foods prior to 6 months.¹⁹ However, it remains unclear whether
82 these associations are similar among lower income, predominately non-white populations, as
83 well as the underlying reasons why some groups of women are more likely to introduce solid
84 foods early.

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

99

100 **METHODS**

101 *Population*

102 Data are from the Nurture study,²⁰ a prospective longitudinal cohort of mothers and their infants
103 measured throughout the first year of life. The cohort consists of predominately Non-Hispanic

104 Black women and infants recruited from a local county health department prenatal clinic and a
105 private prenatal clinic in Durham, North Carolina. Mothers ≥ 18 years of age with healthy
106 singleton pregnancies and with intention to remain in the area at least 12 months postpartum
107 were recruited between 20-36 weeks' gestation from 2013 to 2015. Every 3 months throughout
108 the first year of life, mothers responded to dietary surveys during home visits querying the
109 frequency infants consumed 16 types of foods. Questions about foods and beverages provided to
110 infants originated from the Infant Feeding Practices Study II study²¹ and the Feeding Infants and
111 Toddlers Study.²² Foods queried included cereal, whole fruit, vegetables, french fries/other fried
112 potatoes, meat, fish, yogurt, ice cream, grains, baby snacks, sweets, peanuts, egg yolks, egg
113 whites, whole eggs, and other dairy. Beverages including 100% fruit juice were queried
114 separately. Mothers also indicated when they began introducing anything besides breast milk or
115 formula to their infants and their primary reasons for doing so. Infant anthropometrics were
116 measured in triplicate by trained study personnel every 3 months during home visits (n=666).
117 Details about the study design have been previously published.²⁰ This study was conducted
118 according to the guidelines laid down in the Declaration of Helsinki and all procedures involving
119 human subjects were approved by Duke University Medical Center IRB (human subjects
120 committee) (Pro 0036242), and is registered at clinicaltrials.gov (NCT01788644).

121

122 *Exposure Variables*

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

127 *Maternal reasons for solid food introduction:* 4-point Likert Scales ranging from “not at all
128 important” to “very important” queried 12 reasons for introducing solids to infants including: (1)
129 baby was nursing too much, (2) I did not have enough milk, (3) my baby was drinking too much
130 formula, (4) my baby had a medical condition that might be helped by eating solids, (5) my baby
131 was not gaining enough weight, (6) friends or relatives said my baby should begin eating solid
132 foods, (7) solid foods would help my baby sleep longer at night, (8) a doctor or other health care
133 professional said my baby should eat solids, (9) I wanted to feed my baby something in addition

134 to breast milk, (10) my baby seemed hungry a lot of the time, (11) my baby was old enough
135 begin to eat solid food, (12) my baby wanted the food I ate or in other ways showed an interest in
136 solid food.

137 Diet Quality Scores

138 Dietary questionnaires assessed the frequency per day – irrespective of serving size – that a
139 mother reported her infant consumed foods from the 16 food groups in the dietary survey at 3-,
140 6-, 9-, and 12-months.

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

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

151 *Overall Food Score (exploratory)*: An overall healthy and unhealthy food score was calculated
152 based on the HFS and UnHFS scores in the following manner. Any mother who reported her
153 infant consumed foods included in the HFS ≥ 2 times/day received the maximum score of 10
154 points. If the infant consumed foods in the HFS fewer than 2 times/day, they were awarded 0
155 points. Any mother who reported her infant consumed foods in the UnHFS > 1 time/day received
156 -20 points; if the infant consumed foods in the UnHFS ≤ 1 time/day, they received 0 points.
157 These two scores were summed, resulting in 4 patterns, with scores ranging from a minimum of -
158 20 (unhealthy diet) to 10 (healthiest diet). These frequency cut-points were informed by
159 recommendations from the American Academy of Pediatrics, which emphasizes 2-3 nutritious
160 snacks like fruits and vegetables per day, while cautioning against the consumption of non-
161 nutritive finger and snack foods like cereal, cookies, and french fries observed before 9 months
162 of age.⁹

163 *Outcome Variables*

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

169 *Covariates*

170 Infant birthweight for gestational age z-scores were based on international reference standards²⁵
171 and maternal sociodemographic and health characteristics were tested as possible covariates.
172 Tested covariates included pre-pregnancy body mass index (BMI), education, race, age, number
173 of children in the household, and total weeks of any breastfeeding between 0-12 months. If the
174 mother was still breastfeeding at 1-year, the total number of weeks she was breastfeeding at the
175 date of her follow-up survey was recorded. Although 8% of the sample reported gestational
176 diabetes during pregnancy, due to substantial missing data in that variable, only infant
177 birthweight for gestational age z-score and maternal pre-pregnancy BMI were included as
178 possible covariates. Covariates were singly entered into generalized linear models and retained
179 if they were independent predictors of WFL z-scores.

180 *Statistical analysis*

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

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

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

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

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

210

211 RESULTS

212 The analytic sample consisted of 449 women with a mean (SD) age of 28.0 (\pm 5.9) years.
 213 Nearly two-thirds of women were Non-Hispanic Black (65.2%), low-income (59.3%), and
 214 18.9% reported having obtained less than a high school education. Mean pre-pregnancy BMI
 215 was within the obese range (30.5 kg/m²) and the average number of children in the household
 216 was 2.1. The average HFS and UnHFS were 2.4 (out of 10) and 1.8 (out of 20), respectively
 217 (Table 1).

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

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

226 *Diet Quality Characteristics among Infants with and without Early Food Introduction*

227 Table 2 shows the mean HFS and UnHFS at 3, 6, 9, and 12 months for all infants, as well as
 228 stratified by early solid food introduction. In general, the HFS and UnHFS in the first 3 months
 229 of life were very low (<0.1). Consistent with increasing energy needs, both scores increased
 230 over time, and for the entirety of the 12 months ($p<0.0001$) showing that both consumption of
 231 healthy and unhealthy foods was increasing. The HFS remained consistently higher than the
 232 UnHFS over the 12-month period ($p<0.0001$); at 12 months, the mean HFS was 3.8 (out of 10)
 233 and the mean UnHFS was 3.1 (out of 20). Infants who had early introduction of solid foods
 234 versus those that did not have early introduction of solid foods, had higher HFS and UnHFS until
 235 6 months of age ($p<0.05$), at which point, scores between the two groups were comparable.

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

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

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

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

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

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

262 A statistically significant interaction between HFS quartile and early introduction of solid foods
263 was detected ($p=0.01$), so analyses were stratified and examined among those infants who were
264 introduced to solid foods early and those who were not. Among those introduced to solids after
265 4 months of age ($n=246$), there was no association between the HFS score and WFL z-score.
266 However, among those who had early solid food introduction ($n=114$), infants in Q3 had higher
267 WFL z-scores (1.02 ± 0.07) than infants in Q1 (0.28 ± 0.18).

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

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

279 DISCUSSION

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

295 The finding that 33% of mothers are introducing solids foods before 4 months of age is
296 consistent with previous research.^{26,27} Furthermore, the reasons for early introduction provided
297 by this cohort of predominately non-Hispanic Black mothers are also consistent with research
298 conducted in predominately non-Hispanic White populations or non-US populations.^{27,28} The

299 reasons mothers reported introducing solid foods early, seemed centered around infant hunger
300 and inadequate formula supply, potentially underscoring the contribution of poverty^{29,30} to
301 associations between early introduction to solid foods and infant adiposity.

302 Consistent with our pre-specified hypothesis, we found that more frequent intake of
303 unhealthy foods during complementary feeding was associated with higher WFL z-scores, which
304 is similar to other studies conducted with infants and children.^{31,32} Although few mothers
305 introduced unhealthy foods like french fries, snacks, and sweets before 4 months of age, frequent
306 intake of unhealthy foods (>1 serving/d) during the complementary feeding period was common
307 (71% of the sample) and associated with higher WFL z-scores. Although limited research has
308 explored the association with diet quality during infancy and later adiposity, the present results
309 are consistent with a pilot study,³¹ which detected a positive association between sugar
310 sweetened beverage intake between 4-13 months of age and overweight at 8 years. The present
311 findings also support the concern that early introduction to sweet, energy-dense foods may
312 interact with infants' innate preferences for sweet flavors, potentially promoting
313 overconsumption of energy-dense foods related to the development of childhood
314 obesity.¹⁸ Consistent with Anderson et al.,²⁴ the present results suggest that more frequent intake
315 of healthy foods is not inversely associated with intake of unhealthy foods, with most infants
316 having high intake of both healthy and unhealthy foods. Furthermore, higher frequency of
317 healthy foods was not associated with reduced WFL z-scores. Thus, while having high intake of
318 both healthy and unhealthy foods may still be more favorably associated with other biomarkers
319 like blood pressure and total cholesterol,³³⁻³⁶ the present results do not appear to support
320 increasing frequency of healthy food as a method for reducing WFL z-scores in infants.
321 However, given that most infants in this sample had frequent intake of both healthy and
322 unhealthy foods, further investigation is warranted.

323 The interaction between early introduction of solid foods and more frequent intake of
324 healthy foods (rather than unhealthy) warrants further consideration as it seems to imply that
325 early introduction of unhealthy foods is not associated with higher WFL z-score. However, it is
326 important to note that this counterintuitive finding may be explained by the higher proportion of
327 mothers who introduced healthier foods (i.e., fruits and vegetables) and other foods (e.g., cereals
328 and grains, eggs, meat) before 4 months of age instead of unhealthy foods (i.e., sweets, french

329 fries) (data not shown). Thus, although it was hypothesized that the influence of early solid food
330 introduction on infant adiposity at 12 months would be modified by the quality of foods
331 introduced, it was not possible to examine whether early introduction of unhealthy foods had a
332 stronger association with WFL z-score because few women introduced these foods in the first 4
333 months of life. Lastly, it is noteworthy that the mean HFS in Q3 for those with and without early
334 solid food introduction was 2.57 while the UnHFS was 1.50 among those who did not introduce
335 solids early vs. 1.86 for those who introduced solids early. Conversely in Q4, the mean HFS was
336 3.99 among those who did not introduce solid foods early vs. 4.23 for those who introduced
337 solids early while the UnHFS mean scores were similar (2.52 vs. 2.54). Taken together, this
338 suggests that the finding in Q3 is driven by higher UnHFS scores among those with early solid
339 food introduction, and the non-significant finding in Q4 is due to comparable UnHFS scores
340 among those with and without early solid food introduction.

341 The results from this study add to the limited research exploring the quality of foods
342 introduced during complementary feeding and the influence of these foods on early markers of
343 childhood obesity. These results suggest that most women are not introducing unhealthy foods
344 (i.e., french fries, ice cream, baby snacks and sweets) prior to 4 months of age and are instead
345 introducing healthier foods like fruits and vegetables, or other foods like cereals, grains, eggs,
346 and meat (data not shown). Early introduction of fruits and vegetables and other foods appear to
347 be associated with higher WFL z-scores at 1 year of age. This was particularly true if maternal
348 pre-pregnancy BMI was higher; after adjusting for birthweight, mean pre-pregnancy BMI among
349 those who introduced solid foods early was marginally higher (32.2 kg/m²) compared to mothers
350 among mothers who did not introduce solid foods early (30.0 kg/m² p=0.05). These results
351 highlight the importance of focusing intervention efforts toward women with obesity at the
352 beginning of their pregnancy, as they may be more likely to introduce solid foods early, and
353 early food introduction among this higher risk group may be related to the transmission of
354 obesity across generations.

355 The results from the present study also introduce some new considerations to the existing,
356 and somewhat mixed research exploring the influence of early solid food introduction and risk of
357 childhood obesity.⁶ There was no observed independent association between early solid food
358 introduction and infant WFL z-scores at 12-months, nor did breastfeeding modify the association

359 between early solid food introduction and WFL z-scores. This finding is consistent with previous
360 research in the IFPS II examining associations between early solid food introduction and
361 childhood obesity risk at 6-years of age,³⁷ but contradicts some previous research,³⁸ potentially
362 due to differences in breastfeeding duration between the samples. However, the present findings
363 do support existing research positing that the associations between early solid food introduction
364 and infant WFL z-scores operate through biobehavioral pathways.³⁹ For example, early food
365 introduction was especially problematic in mothers with higher pre-pregnancy BMI, indicating
366 that a behavioral risk factor (i.e., early solid food introduction possibly related to socioeconomic
367 status) in combination with a biologic risk factor (i.e., higher maternal BMI)⁴⁰ work in concert to
368 adversely influence infant weight. Given the consistent association between maternal weight,
369 higher birth weight, and higher infant weight gain with later childhood overweight,⁴⁰ it is likely
370 that optimal caregiver feeding practices are especially important among infants with a stronger
371 genetic predisposition to obesity.

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

385 Some strengths of the present analysis also warrant mention. First, this study utilized
386 prospective data from a birth cohort consisting of predominately lower income, non-Hispanic
387 Black women, who are currently underrepresented in the research literature. Additionally, this
388 study holistically examined the drivers and influence of early introduction of solid foods on

389 infant WFL z-scores at 1 year as well as how the diet quality of complementary foods influences
390 growth in the first year. Dietary data was collected every 3 months during the first year of life,
391 providing an opportunity to examine changes in diet quality over the first year of life.

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

405

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408 **CONFLICT OF INTEREST**

409 The authors have no conflicts of interest to report.

410 **AUTHORSHIP**

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

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521

522 **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

523 ¹Low income was defined as a household income <\$20,000 per year

524 ² The Healthy Food Score (HFS) was calculated at each three-month time point by summing how frequently the
525 mother reported her child consumed fruits (0-5x/day) or vegetables (0-5x/day).²⁴ The maximum possible score is
526 10, and higher scores represent more healthy food consumption. The mean HFS between 4-12 months was
527 calculated by averaging the HFS at those time points.

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

532 ⁴Early solid food introduction includes any introduction of other liquids (besides breast milk or formula) prior to 4-
533 months of age and/or regular introduction of solid foods before 4-months of age. Although 455 participants have
534 information on early solid food introduction, 89 women are missing information on weight-for-length z-score at 12-

535 months and are not included in the descriptive characteristics of the analytic sample. However, a similar percentage
536 of those without z-weight-for-length are introducing solid food early (32.8%)

537 **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 score²	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 score⁴	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

538 ¹Means with different superscript letters in the same row significantly differ from one another (p<0.0001); an asterisk (*) denotes a significant difference
539 (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
540 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
541 † 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
542 unhealthy food score, respectively.

543 ²Healthy 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).
544 Higher scores represent more healthy food consumption.

545 ³Early introduction counts anyone who reported that they were not exclusively breast or formula feeding infants < 4 months of age or where regular solid food
546 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
547 months 1-3 if the mother fed her child some solid foods, but did not do so regularly.

548 †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
549 total score of 20). Higher scores represent less healthy food consumption.

550

551 **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

552 ¹Diet scores are calculated as the mean values between 4-12 months. Healthy food scores count the frequency of fruit and vegetable intake (frequencies range
553 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
554 times/day)

555 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-
556 113 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).

557 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 (*)
558 demotes a significant difference from the reference group (Q1)

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

560 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
561 were stratified by early introduction to solid foods

562 **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

563 * 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
564 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).
565 Unhealthy food scores count sweets, french fries, infant snacks, and ice cream (frequencies range from 0 to 5+ times/day).

566 ¹Healthiest 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
567 (n=65)

568 ²Moderately 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
569 Food Score (n=65)

570 ³Moderately 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
571 Food Score (n=204)

572 ⁴Unhealthy 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
573 (n=115)

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