# Developmental Trajectories of Bottle-Feeding During Infancy and Their Association with Weight Gain

Alison K. Ventura, PhD

**ABSTRACT:** ***Objective:*** **To describe patterns of bottle-feeding across the first year postpartum and explore whether bottle-feeding trajectories are differentially associated with infant weight gain.** ***Method:*** **Data came from 1291 mothers who participated in the Infant Feeding Practices Study 2. Mothers completed a prenatal questionnaire and monthly surveys of infant feeding and growth between birth and 12 months. Group-based trajectory mixture modeling was used to describe developmental trajectories of bottle-feeding intensities across the first year. Growth curve modeling was used to explore associations between bottle-feeding intensity trajectory group membership and weight-for-age z-score (WAZ) trajectories from birth to 12 months.** ***Results:*** **Four qualitatively distinct trajectories of bottle-feeding were identified: (1)** ***High-Stable*****: ~100% of feeds from bottles across infancy; (2)** ***Rapid-Increase*****: <30% of feeds from bottles during the neonatal assessment, increasing to ~100% by 6 months; (3)** ***Gradual-Increase*****: <10% of feeds from bottles during the neonatal assessment, gradually increasing to ~100% by 12 months; and (4)** ***Low-Stable*****: <5% of feeds from bottles across the majority of infancy. Bottle-feeding groups had significantly different WAZ trajectories across infancy; by 12 months, the High-Stable and Rapid-Increase groups had significantly higher WAZs compared with the Gradual-Increase and Low-Stable groups (*****p*** **< .001). The association between bottle-feeding group membership and WAZ trajectories was not confounded by sociodemographic characteristics or the extent to which infants received breast milk.** ***Conclusion:*** **High-intensity bottle use during early infancy may place infants at higher risk for excess weight gain. Supports and policies that help mothers delay high-intensity bottle use until later infancy are warranted.**

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Excess weight gain during infancy is a strong risk factor for obesity and metabolic comorbidities during later life.[1–5] Many studies have explored risk as it relates to breast- versus formula/bottle-feeding in an effort to understand modifiable mechanisms underlying excess weight gain.[6–11] Common approaches have been to compare weight gain for infants who are breastfed (defined as any breastfeeding) versus formula-fed (defined as exclusively formula-fed from birth)[6,7,9,11] or to explore dose-response relationships between duration of breastfeeding and infant weight status or obesity risk.[12–15] Some prospective observational studies suggest that infants who are formula/bottle-fed from birth or for longer durations are more likely to show patterns of excess weight gain during infancy compared with infants who are breastfed[1,6,7,11,15,16]; however, findings for long-term effects of early feeding patterns on later obesity risk have not been consistent.[17–19] Recent data from a randomized clinical trial, wherein new mothers were randomized to breastfeeding promotion versus standardized care, illustrated that, despite significantly greater durations of breastfeeding for intervention versus control mothers, no effect of the intervention on child weight status was seen at 6.5 years.[20,21]

A common methodological limitation of previous studies is the fact that milk type (i.e., formula vs human milk) is typically confounded with mode of milk delivery (i.e., bottles vs breasts), which may limit abilities to fully understand associations between early feeding patterns and rapid weight gain. A growing body of research, albeit limited, has begun to delineate risks associated with milk type[22,23] from risks associated with modes of milk delivery,[10,24] suggesting that these factors should be considered. Research on milk type illustrates that the ways in which the composition of formula differs from human milk may promote growth for formula-fed infants[22,23,25] and that certain bioactive components that are unique to human milk may help regulate infant intake and growth.[26] However, research on modes of milk delivery suggests that bottle-feeding affords more efficient milk delivery and more control to caregivers during feeding, both of which may lead infants to overfeed, regardless of the type of milk in the bottle.[27]

These approaches that consider independent effects of milk type and feeding mode better contribute to our

From the Department of Kinesiology, California Polytechnic State University, San Luis Obispo, CA.

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Address for reprints: Alison K. Ventura, PhD, Department of Kinesiology, California Polytechnic State University, One Grand Avenue, 43A-371, San Luis Obispo, CA 93407; e-mail: akventur@calpoly.edu.

understanding of associations between early feeding exposures and infant outcomes because, for the majority of infants, feeding patterns are complex and involve varied combinations of human milk and formula feeding, as well as breast- and bottle-feeding. Data on infants' milk feeding patterns across the first year of life indicate that only ~8% of infants are exclusively breastfed from the breast (i.e., never receive formula or bottles),[28] whereas ~25% of infants are exclusively formula/bottle-fed from birth.[29] Thus, the dichotomy of breast- versus formula/bottle-fed or summarization of feeding experiences to months breast- or formula/bottle-fed may oversimplify most infants' early feeding exposures.

Methodologies that better account for individual differences in dynamic developmental trajectories are available, and their uses are becoming increasingly prevalent in clinical research.[30] Group-based trajectory mixture modeling (GBTM) is a data-driven approach that allows for the identification of developmental trajectories of phenomena without a priori assumptions regarding which individuals should be classified into which group. GBTM provides an empirical approach to identify clusters of individuals who share similar patterns of development and allows for the description of individual differences in development that can better illustrate complex patterns of change.[31] The aim of the present study was to use GBTM to describe patterns of bottle-feeding across the first year, with the goal of better understanding the individual variation that may exist in bottle-fed infants' risk for rapid weight gain. Secondary aims were to explore correlates (e.g., mother and infant characteristics) of bottle-feeding patterns and to examine whether sociodemographic factors or the type of milk fed confound associations between bottle-feeding patterns and infant weight gain trajectories.

# METHODS

## Participants

Data for this study come from the Infant Feeding Practices Study 2 (IFPS II), a longitudinal study conducted by the Centers for Disease Control and Prevention and the Food and Drug Administration.[32] The sample consisted of women who were selected from a national consumer opinion panel consisting of 500,000 US households. Inclusion criteria included healthy women aged 18 years or older and infants born after 35 weeks gestation with a birth weight of at least 2.25 kg. Women were recruited during late pregnancy, and approximately 4000 enrolled in the study between May and December 2005. Approximately 3000 women qualified and continued their participation through their infants' first year. With the exception of a brief telephone interview near the time of the infant's birth, all IFPS II data were collected using mailed questionnaires. Assessments occurred during the third trimester and then postpartum months 1, 2, 3, 4, 5, 6, 7, 9, 10, and 12 (11 assessments total). Further details regarding the IFPS II design and response rates are published elsewhere.[33] As a secondary analysis of de-identified data, this present study was exempt from Institutional Review Board approval.

## Measures

### Infant Feeding

At each postpartum survey, mothers completed a food frequency questionnaire for their infants, in which they were asked how often in the past 7 days they fed their infants breast milk, formula, other types of milk (e.g., cow's, soy, almond), or solid foods. Mothers were also asked how often they fed their infant expressed breast milk. Hereafter, the term "milk" will include any type of milk fed to infants, including breast milk or nonhuman milks such as formula milk, cow's milk, or other milks. Solid foods included dairy foods other than milk (e.g., yogurt, cheese); soy foods other than soy milk (e.g., tofu); and all other foods such as baby cereal, other cereals and starches (e.g., breakfast cereals), fruits and vegetables, meat and poultry, fish and shellfish, nuts and nut butters, eggs, and sweet foods (e.g., cookies, cake).

The primary aim of this study was to describe developmental trajectories of modes of milk delivery (bottle vs breast). As previously described by Li et al.,[10,34] the percentage of total milk feedings that were at the breast (BF%), expressed breast milk (EBM%), or nonhuman milk (NHM%), including formula, cow's milk, or other milks, were estimated for each assessment (BF% + EBM% + NHM% = 100%). Bottle-feeding intensity was then calculated as the proportion of milk feedings given by bottle (EBM% + NHM%).

To explore possible influences of milk type, breast milk feeding intensity was also calculated from mothers' reports of infant intake. As previously described by Li et al.,[35] this was estimated by the percentage of milk feedings in which the infant received breast milk: (number of breast milk feedings/[breast milk + formula + cow's milk + other milk feedings]) × 100%. Infants' age at introduction of solids foods was determined as the age at which mothers first reported her infants consumed solid foods in addition to milk.

### Infant Weight Outcomes

Mothers reported their infants' birth weight and length during the neonatal (month 1) survey. During the 3-, 5-, 7-, and 12-month surveys, mothers reported their infant's weight and length measured at the most recent doctor's visit and visit date. Consistent with previous research that has used the IFPS II dataset, analyses focused on infant weight because of concerns about the accuracy of reported length.[10,34,35] Weights reported at each survey did not always correspond with the infants' age at the time of the survey (i.e., 3, 5, 7, and 12 mo) due to variability in the timing of infants' doctors' visits. Accordingly, included infants had 3 to 5 reported weight measurements (mean: 4.1 ± 0.8), but the age at weight measurement varied from infant to infant and most often corresponded to weight at birth and 2, 4, 6, and 12 months of age. Infants' weight measures were normalized to age- and sex-specific z-scores (i.e., weight-for-age z-score [WAZ]) based on the World Health Organization Growth Standards.[36] Z-scores greater than 5 or less than −5 were considered biologically implausible and were excluded from analyses.[36]

**Sociodemographic Covariates**

Maternal and familial demographic characteristics were assessed in the prenatal survey; consistent with previous research that has used the IFPS II dataset to examine infant outcomes associated with bottle-feeding, the following variables were included as potentially confounding factors[10,34,35]: maternal age, race/ethnicity, education, poverty-income ratio (PIR; defined as a ratio of household income to the poverty threshold by household size), marital status, parity, postpartum participation in the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) program, and prepregnancy body mass index (self-reported by mothers and calculated as weight in kilograms divided by height in meters squared). Several infant characteristics were also included as potentially confounding factors: birth weight, sex, gestational age, age at solid food introduction, and number of sweet drinks consumed per day at each assessment (including juice drinks, soft drinks, soda, sweet tea, Kool-Aid, etc).

## Statistical Analyses

All analyses were conducted using SAS, version 9.4 (SAS Institute Inc, Cary, NC). Participants who did not have bottle-feeding data for at least 7 out of the 11 assessments were excluded, yielding an analytical sample of 1291 subjects. Compared with participants who were excluded, those who were included in the sample had infants with significantly higher WAZ at birth ($p = .04$) and were significantly older ($p < .001$), with higher PIR levels ($p < .001$), lower WIC participation ($p < .001$), and higher education levels ($p = .01$). Additionally, greater proportions of included mothers were non-Hispanic white ($p < .001$), married mothers ($p < .001$), and reported prenatal intentions to breastfeed ($p < .001$) compared with excluded mothers.

Descriptive information was generated for all variables of interest, and each outcome variable was assessed for normality. GBTM techniques (SAS PROC TRAJ) were used to describe developmental trajectories of bottle-feeding intensities across the first year of life.[30,31,37] This data-driven exploratory technique allows for the estimation of a finite mixture model for longitudinal grouping without a priori assumptions about the shape of the trajectory curves or group membership. GBTM in SAS PROC TRAJ allows for estimation of models with missing data using maximum likelihood estimation under a missing at random (MAR) assumption, which allows missingness for any variable to depend on other variables that are observed but assumes missingness is not due to an individuals' value for the variable itself (e.g., it was assumed that mothers with higher bottle-feeding intensities were not more likely to be missing data for bottle-feeding intensity).[38] Thus, all available data for participants who participated in fewer than 11 (but at least 7) assessments could still be retained.

Models with 1 to 5 groups were estimated. Model estimation began with the simplest (1 group) model, and model selection criteria (Bayesian Information Criterion, BIC; Sample Size–Adjusted BIC; Akaike Information Criterion, AIC; and Lo-Mendell-Ruben Likelihood Ratio Test, LMR-LRT), along with other relevant evidence such as replicability and latent group sizes, were used to determine whether each subsequent more complex model improved the overall model fit. Model selection criteria for each model were compared, with lower values for BIC, AIC, and LMR-LRT indicating that the model with k groups better fits the data when compared with the model with k-1 groups. The 2 outputs of interest from the trajectory models were the shape of each groups' trajectories and each participant's probability of group membership. Participants were classified into their most probable groups based on posterior probabilities, given the best fit model.

Once bottle-feeding group membership was determined for each participant, repeated measures analysis of variance (ANOVA) was used to examine differences among bottle-feeding groups for patterns of change in bottle-feeding intensities over time. ANOVA with a general linear model was used to assess differences among bottle-feeding groups for infant and mother characteristics and family demographics.

To examine associations between bottle-feeding groups and infant weight gain (i.e., trajectories for WAZs between birth and 12 mo), a growth curve modeling GCM approach (SAS PROC MIXED) was used.[39,40] Nested linear and quadratic fixed effects models were compared to determine the best fit model; comparison of these models allowed for exploration of whether WAZ trajectories were linear (linear fixed effect model) or curvilinear (quadratic fixed effect model).[41] Note that due to the variability in when weight measurements were assessed, time was modeled as a continuous variable representing actual infant age at WAZ measurement. The addition of a quadratic term to the linear effects model was significant, and the log-likelihood ratio test indicated model fit was improved; thus, a model with both linear and quadratic effects was selected. Two models were then explored: for Model 1, infant WAZ trajectories were modeled as a function of both time (age at WAZ measurement) and bottle-feeding group membership. Model 2 examined the effects of addition of covariates, such as sociodemographic characteristics of the mother and infant and breast milk feeding intensity (as a time-varying covariate), to Model 1. Similar to GBTM, all available data could be used because SAS PROC MIXED allows for estimation of models with missing data using maximum likelihood estimation under an MAR assumption.[40] Where applicable, results are presented as mean ± standard error. The $p$ values $<.05$ indicated significant effects.

## RESULTS

### Sample Characteristics

Sample characteristics are presented in Table 1. Approximately 51% of infants were females, with an average gestational age of 39 weeks and birth weight-for-age z-score (WAZ) of 0.36. Mothers were approximately 29 years old and reported a prepregnancy body mass index (BMI) of 26.5, and ~28% were primiparous. Thirty-seven percent of mothers reported participating in WIC 20% reported a family income <$25,000, 19% had a high school degree or less, 84% were non-Hispanic white, and 78% were married. Approximately half (52%) of mothers returned to work during the postpartum period; on average, mothers returned to work when their infants were 13 weeks old. Sixty-three percent of women reported prenatal intentions to breastfeed, 86% ever breastfed, and average breastfeeding duration was approximately 28 weeks.

### Bottle-Feeding Intensity Trajectory Groups

The GBTM analysis revealed that a 4-group trajectory model best fit the data. Model selection criteria (Bayesian Information Criterion, BIC; Sample Size–Adjusted BIC; Akaike Information Criterion; and Lo-Mendell-Ruben Likelihood Ratio Test) are reported in Table 2. These criteria were the lowest (signifying better fit) for the 4- and 5-group models compared with the 1-, 2-, and 3-group models, but the 5-group model did not provide significant improvement over the 4-group model.

The 4 groups showed distinct bottle-feeding intensity trajectories during the first year postpartum (Fig. 1). Group labels were based on patterns of bottle-feeding intensities across the study period: (1) the *High-Stable Bottle-Use Group* (*High-Stable*; 31.1% [n = 402]) reported that ~100% of milk feedings were from bottles at all assessment points; (2) the *Rapid Increase in Bottle-Use Group* (*Rapid-Increase*; 19.4% [n = 250]) reported low levels of bottle-feeding intensity during the neonatal assessment (~30% of milk feedings), but bottle usage increased significantly at subsequent assessments; by the 6-month assessment, this group reported that ~100% of milk feedings were from a bottle, and this level of bottle-feeding remained through the 12-month assessment; (3) the *Gradual Increase in Bottle-Use Group* (*Gradual-Increase*; 24.6% [n = 318]) had similarly low levels of bottle-feeding at early assessments and a more gradual increase in bottle-feeding intensity across the study period; (4) the *Low-Stable Bottle-Use Group* (*Low-Stable*; 24.9% [n = 321]) had low levels of bottle-feeding (<10%) at all assessments, with the exception of the 12-month assessment when bottle-feeding intensity rose to ~30% of milk feedings.

During the neonatal and month 2 through 5 assessments, all groups were significantly different for their bottle-feeding intensities (all $p \leq .01$). For the remaining assessments, bottle-feeding trajectories for the *High-Stable* and *Rapid-Increase* groups were not significantly different. Trajectories for the *Gradual-Increase* and *Low-Stable* groups were significantly different from each other and from the *High-Stable* and *Rapid-Increase* groups ($p < .01$), with the exception of the 12-month assessment, in which the *Gradual-Increase* group was not significantly different than the *High-Stable* and Early-Increase groups.

### Characteristics of Bottle-Feeding Groups

Table 3 describes characteristics of the bottle-feeding groups. Groups did not differ for infant sex or gestational age at birth, but infants in the *High-Stable* and *Rapid-Increase* groups had significantly lower WAZ at birth than infants in the *Gradual-Increase* and *Low-Stable* groups. Mothers in the *High-Stable* and *Rapid-Increase* groups were significantly younger than mothers in the *Gradual-Increase* and *Low-Stable* groups. Mothers in the *High-Stable* group, but not the *Rapid-Increase* group, had significantly higher prepregnancy BMI than mothers in the *Gradual-Increase* and *Low-Stable* groups. Significantly higher proportions of mothers in the *High-Stable* and *Rapid-Increase* groups were primiparous compared with mothers in the *Gradual-Increase* and *Low-Stable* groups. Mothers in the *High-Stable* and *Low-Stable* groups had lower poverty-income ratio levels compared with mothers in the *Rapid-Increase* and *Gradual-Increase* groups. The *High-Stable* group had significantly higher proportions of mothers participating in WIC and reporting low education levels (high school degree or less), followed by mothers in the *Rapid-Increase* group and then by the *Gradual-Increase* and *Low-Stable* groups. Proportions of mothers who were non-Hispanic white were similar in *High-Stable, Rapid-Increase,* and *Low-Stable* groups but significantly lower in the *Gradual-Increase* group. Proportions of mothers who were married in the *High-Stable* and *Rapid-Increase* groups were significantly lower than the *Gradual-Increase* and *Low-Stable* groups. The *High-Stable* and *Rapid-Increase* groups had significantly higher proportions of mothers who returned to work during the postpartum period, followed by the *Gradual-Increase* and then *Low-Stable* groups.

With respect to the infants' feeding history, the *High-Stable* group had the lowest proportions of mothers with prenatal intentions to breastfeed, followed by the *Rapid-Increase, Gradual-Increase,* and *Low-Stable* groups, respectively. Bottle-feeding durations were not significantly different among the *High-Stable, Rapid-Increase,* and *Gradual-Increase* groups; the *Low-Stable* group had significantly shorter bottle-feeding duration than all other groups. Additionally, the *High-Stable* group also had the significantly shortest breastfeeding duration and earliest introduction of solid foods, whereas the *Low-Stable* group had the longest breastfeeding duration and latest introduction of solid foods.

### Associations Between Bottle-Feeding Group Membership and Infant Weight-for-Age z-Score Trajectories

In the unadjusted GCM (Model 1), linear ($F[1,3705] = 210.11$, $p < .001$) and quadratic ($F[1,3695] = 233.68$,

**Table 1.** Percent (n) or Mean ± Standard Error Values for Sample Characteristics (N = 1291)

| | |
|---|---|
| Infant characteristics | |
| Sex, % female | 51.3% (662) |
| Gestational age, wks | 39.4 ± 0.1 |
| Birth weight-for-age z-score | 0.36 ± 0.03 |
| Maternal/familial characteristics | |
| Age at study entry, yrs | 29.3 ± 0.2 |
| Prepregnancy body mass index, $kg/m^2$ | 26.5 ± 0.2 |
| Parity, % primiparous | 27.6 (356) |
| Poverty-income ratio level, % poverty level | 268.0 ± 5.6 |
| Federal assistance (Special Supplemental Nutrition Program for Women, Infants, and Children), % participating | 36.9 (476) |
| Annual family income level | |
| <$25,000 | 20.1 (260) |
| $25,000–74,999 | 60.7 (783) |
| ≥$75,000 | 19.2 (248) |
| Level of education | |
| Did not complete high school | 2.3 (30) |
| High school degree | 16.5 (213) |
| Some college or college degree | 75.8 (978) |
| Not reported | 5.4 (70) |
| Racial/ethnic category | |
| Non-Hispanic white | 84.3 (1088) |
| Non-Hispanic black | 2.9 (38) |
| Hispanic white | 5.9 (76) |
| Asian/pacific islander | 2.7 (35) |
| Other | 2.0 (26) |
| Not reported | 2.2 (28) |
| Marital status | |
| Married | 77.5 (1001) |
| Widowed | 0.2 (2) |
| Divorced | 2.6 (34) |
| Separated | 1.2 (16) |
| Never married | 13.5 (174) |
| Not reported | 5.0 (64) |
| Employment, % returned to work postpartum | 52.2 (674) |
| Postpartum week returned to work | 13.1 (0.4) |
| Infant feeding history | |
| Mothers' prenatal feeding intentions | |
| Breastfeeding only | 63.1 (815) |
| Formula feeding only | 12.7 (164) |
| Both breastfeeding and formula feeding | 21.4 (275) |
| Undecided | 2.6 (34) |
| Not reported | 0.2 (3) |
| Ever breastfed | 85.9 (1109) |
| Exclusive breastfeeding duration, wks | 6.5 ± 0.3 |
| Breastfeeding duration, wks | 27.5 ± 0.6 |
| Bottle-feeding duration, wks | 30.5 ± 0.5 |
| Age at solid food introduction, mo | 5.7 ± 0.1 |

**Table 2.** Model Selection Criteria (N = 1291)

| Model Type | BIC | Sample-Adjusted BIC | AIC | Log Likelihood |
|---|---|---|---|---|
| 1 group | −25,455.87 | −25,452.75 | −25,445.00 | 25,442.00 |
| 2 groups | −21,243.01 | −21,235.72 | −21,217.65 | −21,210.65 |
| 3 groups | −20,264.76 | −20,254.35 | −20,228.53 | −20,218.53 |
| 4 groups | −20,016.68 | −20,005.22 | −19,976.83 | −19,965.83 |
| 5 groups | −20,050.24 | −20,034.64 | −19,995.92 | −19,980.92 |

AIC, Akaike Information Criterion; BIC, Bayesian Information Criterion.

$p < .001$) effects were significant, indicating that WAZ trajectories followed a curvilinear shape. There was also a significant effect of bottle-feeding group membership (F[3,2275] = 5.00, $p$ = .0019), indicating that groups differed in their mean WAZ across infancy. Interactions between bottle-feeding group membership and linear (F[3,3704] = 10.65, $p < .001$) and quadratic (F[3,3693] = 5.16, $p$ = .0015) slopes were also significant, indicating an effect of bottle-feeding group membership on the shape of WAZ trajectories.

Subsequent adjustment for relevant covariates (Model 2: addition of sociodemographic characteristics and breast milk feeding intensity to Model 1) did not attenuate linear (F[1,3301] = 216.33, $p < .001$) and quadratic (F[1,3304] = 230.58, $p < .001$) effects or interactions between bottle-feeding group membership and linear (F[3,3299] = 8.95, $p < .001$) and quadratic (F[3,3299] = 6.08, $p < .001$) effects; however, the fixed effect of bottle-feeding group membership was no longer significant in this model (F[3,2651] = 1.29, $p$ = .28). In sum, even after controlling for relevant sociodemographic covariates and breast milk feeding intensity at each assessment, the effect of bottle-feeding group membership on the shape of WAZ trajectories remained.

Figure 2 presents predicted WAZ trajectories from the fully adjusted model (Model 2), illustrating WAZ trajectories for the bottle-feeding groups after controlling for relevant covariates and breast milk feeding intensity. As illustrated in Figure 2, the type of quadratic relationship between time (age) and WAZs was dependent on bottle-feeding group membership. The *High-Stable* group had a somewhat flat trajectory between birth and 4 months, followed by accelerated weight gain between 6 and 12 months. By 6 months, the *High-Stable* group had significantly higher WAZs than the *Gradual-Increase* ($p <$ .001) and *Low-Stable* ($p$ = .0082) groups, and this difference remained through month 12. The *Rapid-Increase* group showed moderate decline in WAZs between birth and ~5 months, followed by accelerated weight gain between 6 and 12 months. Although WAZs for the *Rapid-Increase* group were significantly lower than the *High-Stable* group by 4 months ($p$ = .0256), WAZs for the *Rapid-Increase* and *High-Stable* groups were no different by 12 months. By 7 months, WAZs for

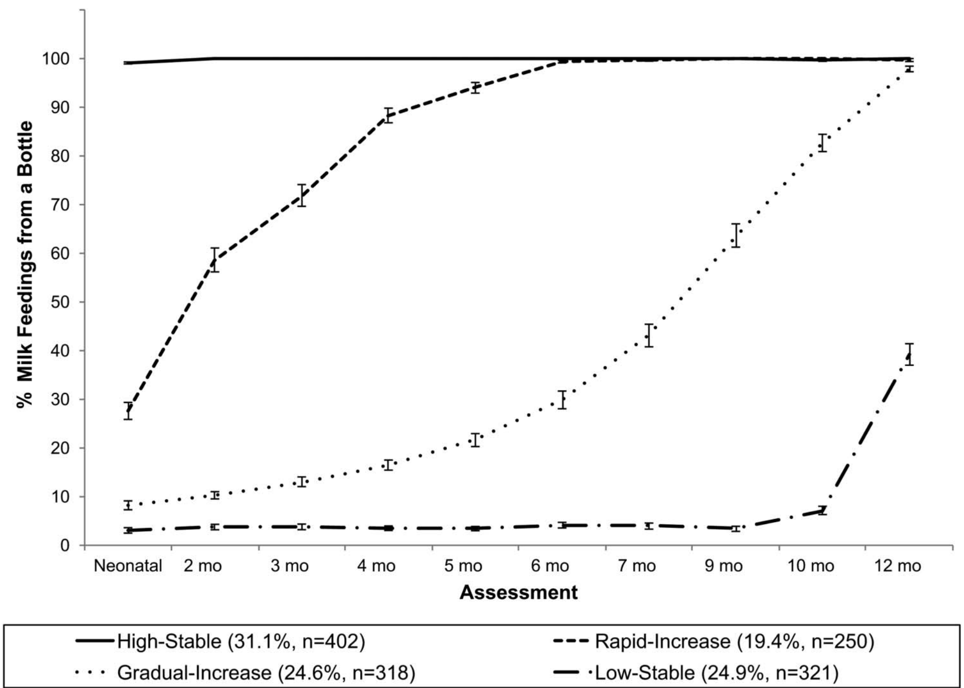


**Figure 1.** Trajectories of bottle-feeding intensity across the first year postpartum. Bottle-feeding intensity calculated as (number of milk feedings from a bottle)/(total number of milk feedings). Milk was defined as breast milk, infant formula, cow's milk, or other milks (soy, almond, etc).

**Table 3.** Percent (n) or Mean (Standard Error) Values for Characteristics of Bottle-Feeding Intensity Trajectory Groups (N = 1291)

| | Bottle-Feeding Intensity Trajectory Group | | | | | |
|---|---|---|---|---|---|---|
| | High-Stable | Rapid-Increase | Gradual-Increase | Low-Stable | $\chi^2$ or F Value | *p* |
| Infant characteristics | | | | | | |
| Sex, % female | 54.6 (219) | 49.2 (123) | 49.1 (156) | 50.9 (164) | 2.86 | .41 |
| Gestational age, wks | 39.4 (0.1) | 39.4 (0.1) | 39.5 (0.1) | 39.4 (0.1) | 0.66 | .58 |
| Birth weight-for-age z-score | 0.22[a] (0.1) | 0.35[a] (0.1) | 0.43[b] (0.1) | 0.48[b] (0.1) | 5.02 | .0018 |
| Maternal/familial characteristics | | | | | | |
| Age at study entry, yrs | 28.5[a] (0.3) | 28.9[a] (0.3) | 30.0[b] (0.3) | 29.9[b] (0.3) | 7.26 | .0001 |
| Prepregnancy body mass index, kg/m$^2$ | 27.5[a] (0.3) | 26.8[ab] (0.4) | 25.9[b] (0.4) | 25.7[b] (0.4) | 5.42 | .0011 |
| Parity, % primiparous | 33.5[a] (131) | 39.3[a] (94) | 23.7[b] (75) | 17.6[b] (56) | 41.46 | <.0001 |
| Poverty-income ratio level, % poverty level | 249.9[a] (10.0) | 306.6[b] (12.7) | 291.9[b] (11.2) | 237.0[a] (11.2) | 8.25 | <.0001 |
| Federal assistance (Special Supplemental Nutrition Program for Women, Infants, and Children) | 49.4[a] (198) | 40.4[b] (101) | 26.1[c] (83) | 29.2[c] (94) | 52.28 | <.0001 |
| % High school degree or less | 31.8[a] (114) | 18.1[b] (43) | 13.6[c] (42) | 14.0[c] (44) | 48.66 | <.0001 |
| % Non-Hispanic white | 88.0[a] (342) | 78.9[b] (194) | 85.3[a] (267) | 90.5[a] (285) | 36.98 | .0002 |
| % Married | 74.6[a] (273) | 71.2[a] (168) | 90.3[b] (280) | 88.9[b] (280) | 62.66 | <.0001 |
| % Returned to work postpartum | 78.1[a] (232) | 83.3[a] (165) | 67.6[b] (171) | 44.7[c] (106) | 94.97 | <.0001 |
| Postpartum week returned to work | 12.5 (0.7) | 12.6 (0.8) | 12.9 (0.8) | 15.2 (1.1) | 1.67 | .1713 |
| Infant feeding history | | | | | | |
| % Prenatal intention to breastfeed | 25.4[a] (102) | 65.2[b] (163) | 79.8[c] (253) | 92.5[d] (296) | 572.82 | <.0001 |
| Bottle-feeding duration, wks | 34.7[a] (0.8) | 34.4[a] (1.1) | 34.7[a] (0.9) | 17.9[b] (0.9) | 79.15 | <.0001 |
| Breastfeeding duration, wks | 3.4[a] (0.4) | 15.5[b] (0.5) | 39.6[c] (0.5) | 51.6[d] (0.5) | 2239.95 | <.0001 |
| Age at solid food introduction, mo | 5.1[a] (0.1) | 5.4[b] (0.1) | 6.0[c] (0.1) | 6.5[d] (0.1) | 31.36 | <.0001 |

Groups with different superscript letters were significantly different in the post hoc comparisons.

the *Gradual-Increase* group were significantly lower than all other groups (*High-Stable*: $p = .0012$; *Rapid-Increase*: $p = .01$; *Low-Stable*: $p = .0014$); by 12 months, the *Gradual-Increase* group had similar WAZs to the *Low-Stable* group, but WAZs remained significantly lower than the *High-Stable* ($p < .001$) and *Rapid-Increase* ($p < .001$) groups. Finally, the *Low-Stable* group exhibited a decline in WAZs between birth and ~7 months, with scores plateauing at ~0 between 7 and 12 months. By the end of the first year, WAZs were significantly higher for infants in the *High-Stable* and *Rapid-Increase* groups compared with those in the *Gradual-Increase* and *Low-Stable* groups ($p < .001$).

## DISCUSSION

This study used a data-driven, group-based trajectory mixture modeling approach to characterize patterns of bottle-feeding during the first year of infancy; 4 qualitatively distinct patterns were identified. Approximately 30% of the sample experienced high bottle use across infancy (*High-Stable* group), whereas another quarter of the sample experienced low bottle use across infancy (*Low-Stable* group). The remaining 45% of the sample experienced more change in their bottle use across infancy, with approximately 20% reporting low bottle use initially and a sharp increase in bottle use between 0 and 6 months (*Rapid-Increase* group) and the final 25% reporting similarly low bottle use initially but a more gradual increase in bottle use across infancy (*Gradual-Increase* group).

The present study is unique in its focus on and description of patterns of bottle-feeding across the first year postpartum. Unlike approaches that categorize infants into breast- versus formula-fed or conceptualize feeding history as duration of breast- or bottle-feeding,[6,7,9,11–15] the data-driven approach used in the present study allowed for a more complex and accurate visualization of the balance between breast- and bottle-feeding that occurs for different infants, as well as how this balance may change across infancy. Although a little over half of the sample (~55%) could have accurately been classified as breast- or formula-fed because they reported consistently low or high intensities of bottle-feeding, respectively, this dichotomization would have been inaccurate for the remaining half of the sample, who reported a combination of breast- and bottle-feeding throughout infancy and a shift from mostly breastfeeding to mostly bottle-feeding over time. The potential usefulness of the approach used in the present study is illustrated by the finding that, although infants in the *High-Stable, Rapid-Increase,* and *Gradual-Increase*

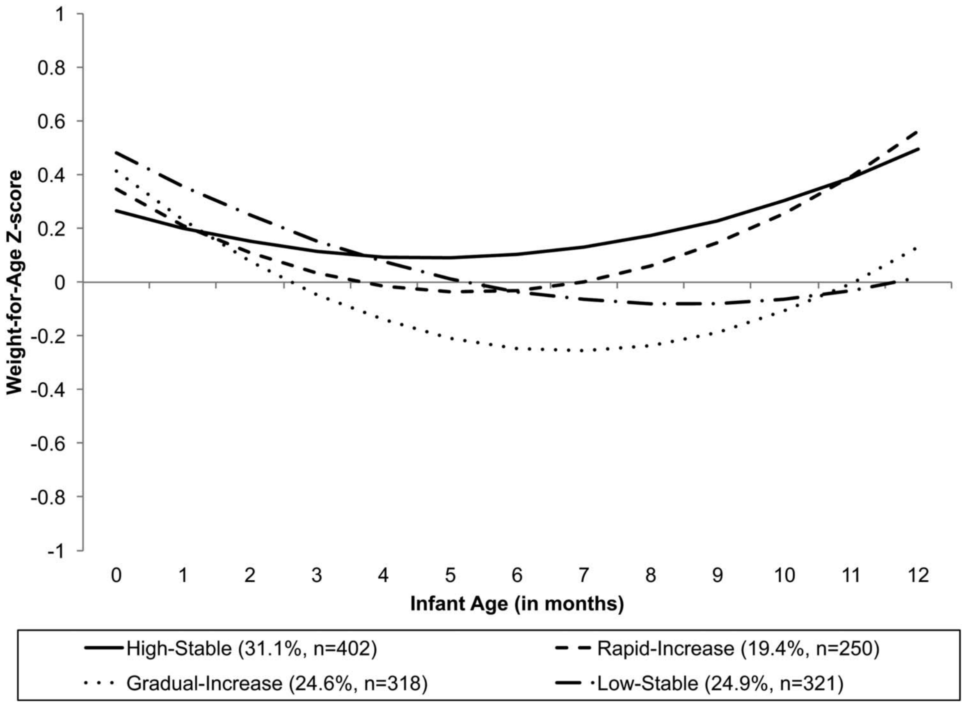


**Figure 2.** Associations between bottle-feeding intensity trajectory groups and weight for age z-score trajectories. Model adjusted for infants' birth weight, gestational age at birth, sex, age at solid food introduction, sugar-sweetened beverage intake, and breast milk feeding intensity at each assessment and mothers' education, income, marital status, prepregnancy body mass index, parity, age, Special Supplemental Nutrition Program for Women, Infants, and Children participation, and race/ethnicity.

groups were not different in their duration of bottle-feeding, only infants in the *High-Stable* and *Rapid-Increase* groups had more problematic WAZ trajectories during infancy, with significantly higher WAZs by 12 months of age, when compared with infants who experienced less bottle-feeding. Thus, when able to consider both bottle-feeding duration and the timing of when high-intensity bottle-feeding was introduced, an association between early, high-intensity bottle-feeding and problematic WAZ trajectories emerged. Although correlational, these findings are consistent with previous research highlighting the first 6 months of infancy as a sensitive period for development across a number of domains,[42–44] wherein exposures experienced during this time may be especially predictive of later outcomes.

Findings from the present study also contribute to a growing body of research that attempts to delineate the effects of milk type[22,23] and modes of milk delivery[10,24] on infants' risk for overfeeding and rapid weight gain. A larger body of research has explored effects of milk composition on infant outcomes by comparing intakes and growth of infants receiving formulas of differing compositions.[45] As a whole, this research illustrates that the compositional characteristics of standard cow's milk–based formulas (e.g., higher protein content, lower free amino acid content) place infants at higher risk for overfeeding and excess weight gain compared with formulas with compositions that more closely match breast milk.[22,23,46] Promising emergent research on bioactive components of breast milk also highlights a number of nonnutritive factors that are unique to breast milk and may regulate the intake and growth of breastfed infants.[47] In contrast, the few published studies that have attempted to explore independent effects of feeding mode have reported mixed findings. Using Infant Feeding Practices Study 2 data and a priori classification of infants into 1 of 6 mutually exclusive feeding categories ([1] breastfed only, [2] breastfed and human milk by bottle, [3] breastfed and nonhuman milk by bottle, [4] human milk by bottle only, [5] human and nonhuman milk by bottle, and [6] nonhuman milk by bottle only), Li et al.[10] illustrated that infants who received human milk by bottle only gained weight more rapidly than infants who were only breastfed. In a smaller 6-month prospective study of 37 infants fed breast milk either predominantly from the breast or predominantly from bottles, Bartok reported no differences in weight gain for breast- versus bottle-fed infants.[24] The present study used the same dataset, but a different approach, from Li et al.[10] and also supported a connection between high-intensity bottle-feeding and rapid weight gain, even when controlling for milk type. However, given the paucity of research in this field, more studies are needed to further understand possible independent and/or combined effects of milk type and feed mode on infants' risk for rapid weight gain.

Consistent with previous research illustrating associations between maternal and familial characteristics and early feeding decisions,[48–50] findings from the present study illustrated that a number of maternal and infant characteristics distinguished the bottle-feeding intensity trajectory groups. These trends have been well documented in prior work: mothers who initiate breastfeeding and breastfeed for longer durations tend to be older, be multiparous, have higher income and education levels, have more social support, and have longer maternity leaves or increased ability to stay at home to care for their infants.[48,51,52] Although many of these factors likely contributed to mothers' feeding decisions, differences among groups for whether and when mothers returned to work was likely one particularly important factor for helping mothers delay high-intensity bottle-feeding until later in infancy. The Low-Intensity group had the lowest proportions (~45%) of mothers who returned to work during their infants' first year, followed by the *Gradual-Increase* group (~68%) and then the *Rapid-Increase* (~83%) and *High-Stable* (~78%) groups. Although there were no overall differences in the postpartum week mothers reported returning to work, mothers in the *Low-Intensity* group reported returning to work, on average, ~3 weeks later than mothers in all other groups. Policies related to maternity leave significantly affect breastfeeding success: mothers who have unpaid leave or who have to return to work sooner are less likely to initiate breastfeeding and have shorter breastfeeding durations.[53,54] With increasing recognition of the many benefits of paid parental leave, there have been calls for improvements in leave policies to support early growth and development of infants[55]; findings from the present study support the potential benefit of protecting mothers' abilities to breastfeed for longer durations or, at the very least, to postpone high-intensity bottle use through maternity leaves that extend through the first 6 months postpartum.

Of note, a greater proportion of mothers in the *Low-Intensity* group reported during the prenatal assessment that they intended to breastfeed, followed by the *Gradual-Increase, Rapid-Increase,* and High-Intensity groups. The importance of maternal expectations for later feeding outcomes is underlined by previous studies illustrating that maternal feeding expectations and attitudes during the prenatal period are strong predictors of mothers' success with initiating and maintaining breastfeeding.[56,57] The present study also suggests that mothers' prenatal intentions to breastfeed are associated with delay of intensive bottle-feeding; an important question for future research is whether education about appropriate and responsive bottle-feeding practices occurring during the prenatal period could lower infants' risk for excess weight gain.

This study illustrates a novel application of GBTM for understanding individual variation in infant bottle-feeding patterns; however, this study is not without limitations. First, infant weight was reported by mothers, thus may have been subject to recall bias. This study focused on WAZ in an attempt to minimize bias related to misreported lengths,[10,34,35] but additional biases may have been introduced by not considering infant length given well-documented socioeconomic and racial/ethnic differences in infant feeding practices[48–50] and length and/or height.[58–60] Additionally, abilities to generalize these findings are limited by the underrepresentation of black and Hispanic mothers in the study population, as well as by the finding that there were a number of differences between participants who were included versus excluded from analysis. In light of these differences between included and excluded participants, it is also difficult to know whether the missing at random assumption for missing data used during both the GBTM and growth GCM analyses was accurate.[38] Further research using GBTM and GCM to understand associations between bottle-feeding and infant outcomes should explore whether the findings of the present study hold when alternative methods for handling missing data, such as multiple imputation,[38] are used. Although race/ethnicity, other relevant covariates, and breast milk feeding intensity were controlled, it is also possible that other confounds that were unmeasured or unaccounted for were responsible for associations between bottle use and infant WAZ trajectories. Given the complexity of influences on infant feeding and WAZ trajectories and the observational nature of this study, further research with more diverse samples, objective measures of infant growth, and causal designs that may better parse out the independent effects of modes of feeding and milk type on infant weight gain is warranted.

## CONCLUSION

Findings from the present study help broaden our understanding of associations between bottle-feeding and infant outcomes. A key finding of this study was that bottle-feeding was associated with more problematic weight gain trajectories and higher weight status by 12 months from some, but not all, infants, with only high-intensity bottle-feeding occurring in the first 6 months postpartum predictive of higher WAZ at 12 months postpartum. Further research is needed to understand whether these same associations between early bottle-feeding and weight gain trajectories persist beyond the first year of infancy.

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