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Effects of opaque, weighted bottles on maternal sensitivity and infant intake

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Abstract

Caregivers' abilities to assess how much is in the bottle may lead to encouragement of infant bottle emptying and overfeeding. The present study assessed whether use of opaque, weighted bottles (as compared with conventional, clear bottles) improves feeding outcomes. Mothers with infants <32 weeks of age (n = 76) were assessed on two separate days. Mothers fed their infants from an opaque, weighted bottle on 1 day and a clear bottle on the other; conditions were counterbalanced. Blinded raters certified in the Nursing Child Assessment Feeding Scale scored all videos to determine maternal sensitivity. Infant intake was assessed by weighing the bottle before and after each feeding, and feeding outcomes included infant intake (mL), intake per kilogram body weight (mL/kg), meal duration (min), and feed rate (mL/min). Mothers exhibited significantly greater sensitivity (p = 0.041), fed their infants fewer millilitres per kilogram body weight (p = 0.049), and fed their infants at a significantly slower rate (p = 0.009) when using opaque compared with clear bottles. Infant clarity of cues was a significant moderator of effects of bottle type on intake per kilogram body weight (p = 0.028): Infants who exhibited greater clarity of cues were fed less during the opaque versus clear conditions whereas infants who exhibited poorer clarity of cues were fed similar amounts during both conditions. Effects of bottle type were not moderated by bottle contents (expressed breast milk vs. formula). In sum, promotion of opaque, weighted bottles for infant feeding may be a pragmatic approach to improve the quality and outcome of bottle-feeding interactions.

KEYWORDS

bottle-feeding, infant feeding, infant-feeding behaviour, maternal sensitivity, overfeeding, responsive feeding

1 | INTRODUCTION

Rapid weight gain during infancy is a strong predictor of later obesity risk (Dennison, Edmunds, Stratton, & Pruzek, 2006; Ekelund et al., 2007; Taveras et al., 2009; Young, Johnson, & Krebs, 2012). Infants who are bottle-fed are at significantly higher risk for rapid weight gain compared with infants who are exclusively breastfed (Li, Magadia, Fein, & Grummer-Strawn, 2012; Mihrshahi, Battistutta, Magarey, & Daniels, 2011; Ventura, 2017). Additionally, recent studies that attempt to separate effects of milk type (breast milk vs. formula) from effects of feeding mode (directly from the breast vs. from a bottle) illustrate that infants who are partially or exclusively bottle-fed are at greater risk regardless of whether expressed breast milk or formula is in the bottle (Li, Fein, & Grummer-Strawn, 2008; Li et al., 2012; Ventura, 2017; Wood, Skinner, Yin, Rothman, Sanders, A. M. Delamater, et al., 2016).

Given infants have the capacity to self-regulate intake (Dewey & Lonnerdal, 1986; Fomon, Filer, Thomas, Anderson, & Nelson, 1975;

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Fomon, Filer, Thomas, Rogers, & Proksch, 1969), responsive feeding—or caregivers' use of feeding practices that are in response to infant hunger and satiation cues and developmental needs—is an important support for infants' developing abilities to self-regulate (DiSantis, Hodges, Johnson, & Fisher, 2011) and a key strategy for preventing rapid weight gain (Daniels et al., 2009; Daniels et al., 2012; Paul et al., 2011; Paul et al., 2014; Savage, Birch, Marini, Anzman-Frasca, & Paul, 2016). It has been long hypothesised that breastfeeding better supports responsive feeding because the mother does not know how much the infant consumes and must learn to trust her infants' cues to determine feed adequacy (Crow, Fawcett, & Wright, 1980; Crow & Wright, 1975). In contrast, bottle-feeding affords mothers more control over the feeding because mothers decide how much milk goes into the bottle, have greater abilities to initiate and terminate the feeding, and—because most mothers use clear bottles—have more information about how much the infant has consumed due to visual and weight cues related to how much expressed breast milk or formula is in the bottle. Indeed, bottle-feeding mothers' greater abilities to assess and control how much the infant consumes may facilitate pressuring bottle-feeding practices (e.g., encouraging the infant to finish the bottle) (Blissett & Farrow, 2007; Brown, Raynor, & Lee, 2011; Crow et al., 1980; DiSantis, Hodges, & Fisher, 2013; Fisher, Birch, Smiciklas-Wright, & Picciano, 2000; Taveras et al., 2004; Ventura & Golen, 2015), which may hinder infants' developing abilities to self-regulate intake leading to overfeeding, poor satiety responsiveness, and excess weight gain (Birch, Fisher, & Davison, 2003; Brown & Lee, 2012; Disantis, Collins, Fisher, & Davey, 2011; Fisher & Birch, 2002; Li, Fein, & Grummer-Strawn, 2010; Li et al., 2012; Li, Scanlon, May, Rose, & Birch, 2014).

A striking paucity of research has focused on improving the feeding practices of bottle-feeding mothers during early infancy (Bonuck, Avraham, Lo, Kahn, & Hyden, 2014 Bonuck, Huang, & Fletcher, 2010; Kahn, Bonuck, & Trombley, 2007; Kavanagh, Cohen, Heinig, & Dewey, 2008; Maguire et al., 2010). In response, our previous research explored whether a simple intervention—covering bottles with an opaque, weighted sleeve—could improve bottle-feeding interactions by more closely approximating the breastfeeding experience. In a small pilot study of formula-feeding mothers, we found that mothers who reported regular use of pressuring bottle-feeding practices showed significantly greater responsiveness to their infants' cues and fed their infants 20% less formula when using opaque, weighted bottles compared with conventional, clear bottles (Ventura & Golen, 2015). The aim of the present study was to expand this pilot work to a larger, more diverse sample that also included mothers feeding expressed breast milk. To this end, we tested the hypothesis that mothers would exhibit greater sensitivity to their infants' cues and feed their infants less formula or expressed breast milk when feeding from opaque, weighted bottles compared with conventional, clear bottles.

Key messages

- Caregivers' abilities to assess and control how much is in the bottle may lead to pressuring feeding practices (e.g., encouraging bottle emptying), which is likely one mechanism underlying associations between bottle-feeding and risk for overfeeding and rapid weight gain during infancy.
- In the present study, mothers exhibited greater sensitivity to infant cues and fed their infants at a slower rate when using opaque, weighted bottles compared with conventional, clear bottles, suggesting promotion of opaque, weighted bottles is a pragmatic approach to improve bottle-feeding outcomes.
- The effect of bottle type on infant intake was moderated by infant clarity of cues: Infants who exhibited greater clarity of cues were fed less during the opaque versus clear conditions whereas infants who exhibited poorer clarity of cues were fed similar amounts during both conditions. Thus, mothers of infants with poorer clarity of cues may need additional support or alternative approaches to reduce their risk for overfeeding during bottle-feeding.

2 | METHODS

2.1 | Participants

We conducted a laboratory-based within-subject experimental study across two sites (Philadelphia, Pennsylvania, and San Luis Obispo, California) between June 2013 and June 2017. Inclusion criteria included the following: (a) mother 18–40 years of age, (b) infant 32 weeks of age or younger (and, thus, still predominantly feeding breast milk and/or formula [Grummer-Strawn, Scanlon, & Fein, 2008]), (c) dyad had prior experience with bottle-feeding. Dyads with infants who were born preterm had current or previous medical conditions that interfered with feeding or who were exclusively breastfeeding (i.e., the infant had never received a bottle) were excluded. Mothers (n = 76) were recruited from ads in local newspapers; Special Supplemental Nutrition Program for Women, Infant and Children (WIC) program offices; fliers; local parent support groups; and online sites (e.g., Facebook). Data from 25 formula-feeding dyads have been published previously (Ventura & Golen, 2015). Study approval was received from the Institutional Review Boards at Drexel University and the California Polytechnic State University. Verbal and written informed consents were obtained from each mother at study entry.

2.2 | Study protocol

The study protocol was similar across both sites. Mother–infant dyads visited the laboratory on two separate days; one feeding observation occurred during each visit. Both visits/feeding observations were scheduled at the same time of day to control for infants' circadian rhythms and diurnal variation in intake (Matheny, Birch, & Picciano, 1990). Visits were scheduled close together (on average, 2.2 ± 1.4 days apart) to minimize effects of maturation on feeding behaviours. Mothers were asked to refrain from introducing novel foods or liquids to their infants during the 3 days prior to and throughout the experimental period.

2.2.1 | Feeding observations

During both visits, a feeding observation occurred wherein mothers were instructed to feed their infants as they normally would at home. Mothers used the same bottle for both feeding observations. During one visit day, bottles were not manipulated in any way (conventional, clear bottle condition; hereafter referred to as "clear"). During the other visit day, bottles were fitted with an opaque silicone or neoprene sleeve with a 60-g metal plate base (opaque, weighted bottle condition; hereafter referred to as "opaque"). Order of bottle presentation was randomized across participants using a computer-generated randomization scheme. Mothers provided their infants' typical formula or their own expressed breast milk, and infants were fed the same formula or milk, respectively, during both feeding observations.

Feeding observations were videorecorded using a Canon VIXIA HF M41 Full HD Camcorder (Canon, New York). To minimize influence on the dyad's feeding behaviours, the video camera was placed at the far corner of the room, approximately 10 to 12 feet from the mother–infant dyad, and the research assistant was concealed behind a partition. While behind the partition, the research assistant prepared bottles of formula or expressed breast milk and assessed infant intake by weighing the bottle before and after feeding using a top-loading balance (Ohaus SP601 Scout Pro Portable Balance; Ohaus, Ontairo, Canada) to limit mothers' awareness of how much was in the opaque bottle and how much the infant consumed. Bottle weights were later converted to volume (mL) assuming a milk density of 1.03 g/mL (Abbot Nutrition, 2016; Enfamil, 2016; Gerber, 2016). Immediately after each feeding observation, mothers were asked to rate, on a scale of 1–9, how similar the feeding was to their typical feeding (score range: 1 = not at all similar to 9 = very similar) and how much their infant consumed compared with usual (score range: 1 = much less than usual to 5 = neither less nor more than usual to 9 = much more than usual). To minimize influence on mothers' feeding behaviours, mothers were blinded to study objectives and hypotheses and were only told that the purpose of the study and video-recorded feeding observations was to "better understand infant feeding behaviors during bottle-feeding."

2.2.2 | Analysis of video records

Trained raters (n = 6) blinded to study objectives and hypotheses later coded all videos using The Nursing Child Assessment Feeding Scale (NCAFS; Sumner & Spitz, 1994). This scale contains six subscales, four of which describe maternal attributes and two of which describe infant attributes (Sumner & Spitz, 1994). The present analyses focused on the Sensitivity to Cues subscale (possible score range = 0–16) because this scale primarily focuses on maternal sensitivity to infant cues (including hunger and satiation cues) during feeding interactions. The infant Clarity of Cues scale (possible score range = 0–15) was also tested as a covariate in all analysis of maternal sensitivity (Ventura & Golen, 2015; Ventura, Inamdar, & Mennella, 2015). Interrater reliability was determined by common coding of 10 videos, and intrarater reliability was determined by double coding of 10 videos. Interrater and intrarater reliability were established using Pearson's correlation coefficients; both were r = 0.85.

2.2.3 | Additional measures

Upon arrival at the laboratory and prior to each feeding observation, mothers completed a demographics questionnaire and an infant feeding history questionnaire, within which they reported the time of their infants' last feeding, the amount and type of milk/food consumed at their infants' last feeding, and their typical bottle-feeding intensity (defined as the percentage of daily milk feedings that came from a bottle). Mothers also reported whether or not their infant had been introduced to complementary foods and beverages (CFB) and, if so, the age at which CFB had been introduced.

A trained research assistant collected weight and length/height measurements in triplicate for infants and mothers using an infant scale/infantometer (Models 374 and 233; Seca, Hamburg, Germany) and adult scale/stadiometer (Model 736; Seca, Hamburg, Germany), respectively. Infant anthropometric data was normalized to z scores and percentiles using the World Health Organization (WHO) Anthro software version 3.0.1 (http://www.who.int/childgrowth/en/). Mothers' weight and height data were used to calculate body mass index (BMI), BMI = weight(kg)/height(m)^2.

2.3 | Statistical analysis

A priori power calculations based on our pilot data revealed a sample size of 76 would yield 95% power (α = 0.05) to detect a moderate effect size difference (Cohen, 1969) between the clear and opaque conditions for measures of maternal sensitivity and infant intake. All analyses were conducted using SAS v.9.4 (SAS Institute Inc., North Carolina). Data were thoroughly cleaned and assessed for normality prior to data analysis. Data were analysed using linear mixed models with repeated measures to account for the correlated nature of the within-subject design. The within-subject, fixed factor was bottle type; dyad and site were treated as random effects. Outcomes of interest included maternal sensitivity; infant intake (mL), intake per kilogram (kg) body weight (mL/kg), meal duration (min), and feed rate (mL/min); and maternal perceptions of how similar the feed was to the infant's typical bottle-feeding and how much the infant consumed compared with usual. In preliminary analyses, we assessed possible effects of the following variables on our outcomes of interest to determine whether any should be included as covariates or effect moderators within the linear mixed models: visit number (first vs. second), order of bottle presentation (opaque, clear vs. clear, opaque), infant age, time since last feeding, introduction of CFB (introduced vs. not), infant clarity of cues, and type of milk in the bottle (formula vs. expressed breast milk). On the basis of these preliminary analyses, all outcome analyses were controlled for infant age, time since last feeding, introduction of CFB, infant clarity of cues, and type of milk in the bottle. Additionally, given potential effects of the introduction of CFB on infant milk intakes (Heinig, Nommsen, Peerson, Lonnerdal, & Dewey, 1993), analyses of effects of bottle type on maternal sensitivity, infant intake and feeding behaviours, and maternal perceptions of the feeding were rerun excluding infants who had been introduced to CFB. We used $p < 0.05$ as a criterion for statistical significance of main and interaction effects.

3 | RESULTS

3.1 | Sample characteristics

Sample characteristics are presented in Table 1. Infants were approximately 15 weeks of age (range 1.6–31.3) and average weight-for-length percentile was 59.1 (range 3.8–99.7). Mothers were 29.4 (*SD* 5.8) years of age, and average BMI was 28.2 (*SD* 7.3). Approximately one quarter of mothers reported a family income <$15,000 per year and 47% reporting being of minority racial/ethnic groups. Average bottle-feeding intensity was 55% of daily feedings, and during the feeding observations, 55% (n = 42) of infants consumed expressed breast milk, and 45% (n = 34) of infants consumed formula. Only 12 infants had been introduced to CFB, and average age at CFB introduction was 20 weeks.

TABLE 1 No. (%) or mean (*SD*) values for sample characteristics (N = 76)

Sample Characteristics	
Infant characteristics	
Sex, % female	40 (53)
Age, weeks	14.8 (7.6)
Weight-for-length z score	0.4 (1.1)
Weight-for-length percentile	59.1 (30.6)
Maternal/familial characteristics	
Age, years	29.4 (5.8)
Body mass index, kg/m^2	28.2 (7.3)
Parity, % primiparous	40 (53)
Marital status, % married	49 (65)
Federal assistance (e.g., WIC)	35 (47)
Family income level	
<$15,000/year	18 (24)
$15,000 to <35,000/year	14 (18)
$35,000 to <75,000/year	8 (11)
>$75,000/year	29 (38)
Not reported	7 (9)
Level of education	
Did not complete high school	1 (1)
High school degree	19 (25)
Some college/vocational degree	15 (20)
Bachelors or graduate degree	39 (51)
Not reported	2 (3)
Racial/ethnic category	
Non-Hispanic white	40 (53)
Non-Hispanic Black	21 (28)
Hispanic White	7 (9)
Hispanic Black	4 (5)
Asian	4 (5)
Infant feeding history	
Typical bottle-feeding intensity	
Low (<20% of milk feedings)	26 (34)
Medium (20–80% of milk feedings)	18 (24)
High (>80% of milk feedings)	32 (42)
Typical milk type	
Only breast milk	36 (47)
Only formula	26 (34)
Both breast milk and formula	14 (18)
Complementary foods and beverages, % introduced	12 (16)
Age at solid food introduction, weeks	19.7 (3.2)

WIC = Special Supplemental Nutrition Program for Women, Infants, and Children.

3.2 | Effects of bottle type on feeding outcomes

There was no effect of visit number (first vs. second) on maternal sensitivity (F(1, 75) = 0.46, p = 0.498), infant intake (F(1, 75) = 0.61, p = 0.437), intake per kilogram body weight (F(1, 75) = 0.68, p = 0.413), meal duration (F(1, 75])= 0.01, p = 0.916), feed rate (F(1, 75) = 0.73, p = 0.395), or maternal perceptions of how similar the feed was to the infant's typical bottle-feeding (F(1, 75) = 0.49, p = 0.485) or how much the infant consumed compared with usual (F(1, 75) = 0.27, p = 0.603). Additionally, there was no effect of order of bottle presentation (clear, opaque vs. opaque, clear) on maternal sensitivity (F(1, 74) = 2.01, p = 0.161), infant intake (F(1,74) = 1.84, p = 0.179), intake per kilogram body weight (F(1, 74) = 2.09, p = 0.153), meal duration (F(1, 74) = 1.18, p = 0.281), feed rate (F(1, 74) = 1.04, p = 0.164), or maternal perceptions of how similar the feed was to the infant's typical bottle-feeding (F(1, 74) = 0.54, p = 0.467) or how much the infant consumed compared with usual (F(1, 74) = 0.01, p = 0.933).

Effects of bottle type on maternal sensitivity, infant intake and feeding behaviours, and maternal perceptions of the feeding are presented in Table 2. Mothers showed significantly greater sensitivity when using opaque (mean, 13.3, 95% CI [12.6, 13.9]) compared with

TABLE 2 Effect of bottle type (clear versus opaque) on mothers' sensitivity to infant cues, infant intake and feeding behaviours, and mothers' perceptions (N = 76)

Feeding Outcomes	Clear[a]	Opaque[a]	F	p
Maternal sensitivity[b]				
Sensitivity	12.8 (0.3)	13.3 (0.3)	4.32	0.041
Infant intake and feeding behaviours				
Intake (mL)	100.8 (7.1)	91.4 (6.5)	3.12	0.081
Intake per kilogram body weight (mL/kg)	17.6 (1.1)	15.9 (1.0)	4.01	0.049
Meal duration (min)	12.2 (1.1)	13.8 (1.3)	2.37	0.128
Feed rate (mL/min)	9.3 (0.7)	8.1 (0.7)	7.19	0.009
Maternal perceptions				
How much did your baby eat compared with usual?[c]	5.0 (0.3)	5.2 (0.3)	0.53	0.467
How similar was this to your baby's typical feeding?[d]	6.9 (0.4)	6.3 (0.4)	3.39	0.069

Note. Clear = conventional, clear bottle; opaque = opaque, weighted bottle. All models controlled for: age, time since last feeding, introduction of CFB, infant clarity of cues, and milk type.

[a]Column values are Mean (SD).

[b]From the Nursing Child Assessment Satellite Training Parent–Child Interaction Feeding Scale Sensitivity to Infant Cues Subscale; possible score range = 0–16.

[c]Responses range from 1 (*much less*) to 5 (*about the same*) to 9 (*much more*).

[d]Responses range from 1 (*not at all similar*) to 9 (*very similar*).

clear (mean, 12.8, 95% CI [12.2, 13.4]) bottles ($F(1, 73) = 4.32$, $p = 0.041$). Infant intake per kilogram body weight was lower during the opaque (mean, 15.9 mL/kg, 95% CI [13.9, 18.0]) compared with clear (mean, 17.6 mL/kg, 95% CI [15.4, 19.7]) conditions ($F(1, 73)] = 4.01$, $p = 0.049$). Additionally, infants were fed at a significantly slower rate during the opaque (mean, 8.1 mL/min, 95% CI [6.7, 9.4]) compared with clear (mean, 9.3 mL/min, 95% CI [7.8, 10.7]) conditions ($F(1, 73) = 7.19$, $p = 0.009$). Effects of bottle type on intake, meal duration, and maternal perceptions did not reach significance.

Effects of bottle type on maternal sensitivity were not moderated by visit number ($F(2, 73) = 0.57$, $p = 0.565$), order of bottle presentation ($F(2, 73) = 0.57$, $p = 0.565$), or any covariates, including infant age ($F(1, 73) = 0.12$, $p = 0.728$), time since last feeding ($F(1, 73) = 0.44$, $p = 0.512$), introduction of CFB ($F(1, 73) = 0.02$, $p = 0.891$), infant clarity of cues ($F(1, 73) = 0.01$, $p = 0.926$), and type of milk in the bottle ($F(1, 73) = 0.07$, $p = 0.790$). Similarly, effects of bottle type on infant intake, intake per kilogram body weight, meal duration, and rate of feeding were not moderated by visit number, order of bottle presentation, infant age, time since last feeding, introduction of CFB, or type of milk in the bottle. However, when infant clarity of cues was tested as a moderator of effects of bottle type on intake per kilogram body weight, we noted a significant interaction between bottle type and infant clarity of cues ($F(1, 73] = 5.05$, $p = 0.028$). As illustrated in Figure 1, infants with lower clarity of cues were fed similar amounts per kilogram body weight during the opaque and clear conditions; in contrast, infants with higher clarity of cues were fed less during the opaque compared with the clear condition. Note that there was no effect of bottle type on infants' clarity of cues ($F(1, 73) = 0.58$, $p = 0.447$), suggesting that infants were consistent in their clarity of cues across the two conditions.

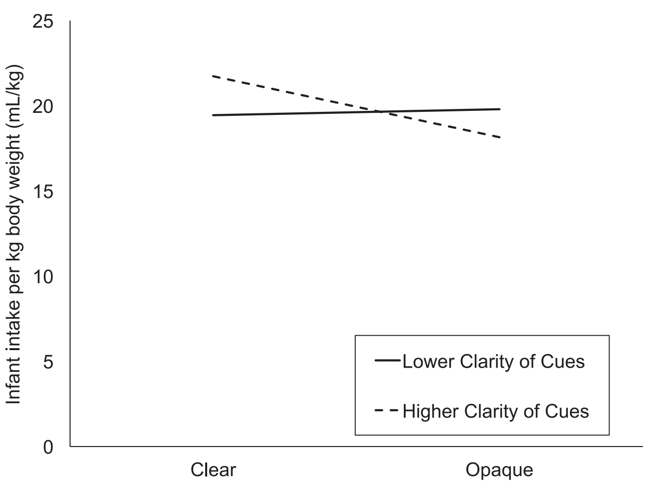

FIGURE 1 Effects of bottle type on infant intake per kilogram body weight for infants with higher versus lower clarity of cues. To illustrate the significant interaction between bottle type and infant clarity of cues, this figure presents predicted values for infant intake per kilogram (kg) body weight for infants with lower (−1 *SD* below the mean) versus higher (+1 *SD* above the mean) clarity of cues. Infants with lower clarity of cues were fed similar amounts during the clear and opaque conditions. In contrast, infants with higher clarity of cues were fed significantly less during the opaque condition compared with the clear condition

When analyses of effects of bottle type on maternal sensitivity, infant intake and feeding behaviours, and maternal perceptions of the feeding were rerun excluding infants who had been introduced to CFB, findings for effects of bottle type were attenuated but in a consistent direction for maternal sensitivity ($F(1, 62) = 3.90$, $p = 0.053$), intake per kilogram body weight ($F(1, 62) = 2.82$, $p = 0.098$), and rate of feeding ($F(1, 62) = 5.38$, $p = 0.024$), and for the interaction between bottle type and infant clarity of cues ($F(1, 62) = 3.94$, $p = 0.052$). Effects of bottle type on intake, meal duration, and maternal perceptions remained non-significant.

4 | DISCUSSION

Bottle-feeding is one of the strongest postnatal risk factors for rapid weight gain during infancy (Li et al., 2008; Li et al., 2012; Mihrshahi et al., 2011; Ventura, 2017; Wood, Skinner, Yin, Rothman, Sanders, A. M. Delamater, et al., 2016), yet a striking paucity of research has focused on reducing bottle-feeding infants' risk for overfeeding and rapid weight gain. The present study addressed this research gap by testing a pragmatic approach to promote responsive bottle-feeding: replacing conventional, clear bottles with opaque, weighted bottles that better mimic the breastfeeding experience. We found mothers exhibited significantly greater sensitivity to their infants' cues, fed their infants less, and fed their infants at significantly slower rates when using opaque compared with clear bottles. However, effects of bottle type on infant intake were dependent on infants' clarity of cues: Infants who exhibited higher clarity of cues were fed significantly less when their mothers used opaque versus clear bottles whereas infants who exhibited lower clarity of cues were fed the same amount regardless of bottle type. For all outcomes, effects of bottle type were not modified by the type of milk in the bottle (expressed breast milk vs. formula).

Increasing maternal sensitivity to infant cues and responsive feeding practices are important goals, given maternal sensitivity and contingent responsiveness to infant behaviours are critical contributors to positive cognitive and socioemotional outcomes (Harrist & Waugh, 2002; Isabella & Belsky, 1991; Reyna & Pickler, 2009). When considering types of mother–infant interactions that occur during early infancy, feeding interactions are central and have both nutritional and social significance (Black & Aboud, 2011; Sumner & Spitz, 1994). A growing body of research highlights the importance of maternal sensitivity during feeding for promoting infants' abilities to self-regulate intake (DiSantis, Hodges, et al., 2011) and healthy infant weight gain trajectories (Farrow & Blissett, 2006; Worobey, Lopez, & Hoffman, 2009). Additionally, current recommendations (American Dietetic Association, 2004; Institute of Medicine, 2011; Lumeng, Taveras, Birch, & Yanovski, 2015; Pan American Health Organization & WHO, 2003) and prevention programs (Daniels et al., 2009; Daniels et al., 2012; Paul et al., 2011; Paul et al., 2014; Savage et al., 2016) focus on promoting responsive feeding practices to prevent rapid weight gain. The present research illustrates the potential effectiveness of opaque bottles for promoting responsive feeding during bottle-feeding.

Our finding that effects of bottle type on intake were moderated by infant clarity of cues provides a novel perspective on factors that may increase risk for overfeeding during bottle-feeding. Traditionally, it has been assumed that infants can develop the ability self-regulate intake during the first few months postpartum (Adair, 1984; Davis, 1928, 1939; Dewey & Lonnerdal, 1986; Fomon et al., 1975), and the main hindrance to the development of effective self-regulatory abilities is caregiver feeding practices that are unresponsive to infant cues (DiSantis, Hodges, et al., 2011). Although studies examining infants' abilities to self-regulate intake and communicate hunger and satiation are scant (Dewey & Lonnerdal, 1986; Fomon et al., 1969; Fomon et al., 1975; McNally et al., 2016), the present research is consistent with these limited previous studies in showing that variability exists for infants' ability to communicate satiation, and this variability is associated with feeding outcomes. As follows, some infants may be more difficult to feed responsively, and bottle-feeding mothers of infants with lower clarity of cues may need additional forms of support or education to ensure they do not overfeed. Further research is needed to better understand reasons why infants differ in their ability to communicate during feeding and self-regulate intake (e.g., genetics, Llewellyn, van Jaarsveld, Johnson, Carnell, & Wardle, 2010, or prenatal exposures, Ross & Desai, 2014) and what types of tailored approaches might best promote optimal feeding outcomes for these infants.

The clinical promise of effects of bottle type on intake for infants with greater clarity of cues is suggested by the possibility that the difference in intake between the opaque and clear conditions (~3.6 mL/kg or ~17 kcal per feed), if maintained over the course of a day (8–12 feedings), would lead to a deficit of approximately 137–205 kcal/day; this magnitude of deficit is more than sufficient to translate into reductions in rapid weight gain (Saavedra, Deming, Dattilo, & Reidy, 2013). Previous research has illustrated that other features of bottles likely also influence risk for overfeeding, such as faster nipple flow rate (al-Sayed, Schrank, & Thach, 1994; Mathew, Belan, & Thoppil, 1992; Schrank, Al-Sayed, Beahm, & Thach, 1998) and larger bottle size (Wood, Skinner, Yin, Rothman, Sanders, A. Delamater, et al., 2016; Wood, Skinner, Yin, Rothman, Sanders, A. M. Delamater, et al., 2016). Thus, additional research is needed to understand whether a multipronged approach could further optimize the bottle to best mimic the breast, thus yielding even greater positive impacts on feeding interactions and mitigation of risk for rapid weight gain. A focus on promoting "better bottles" is particularly attractive for translation to both community and clinical settings given the relative ease of this approach compared with education-based behaviour change approaches, which have been found ineffective in previous research.[15] That mothers would accept opaque bottles for infant feeding is supported by our findings that mothers' perceptions of the feed adequacy and similarity were not affected by bottle type and qualitative data from our previous pilot study illustrated that most mothers regarded opaque bottles positively and indicated that they would use the bottles at home (Ventura & Golen, 2015).

Limitations of the present research highlight important future directions. First, these studies were conducted in controlled, laboratory settings, and it is possible that mothers changed their feeding behaviours because they knew they were being observed in an unfamiliar setting. Further research is needed to assess whether these findings translate to other settings or nonmaternal caregivers. A limitation of the NCAFS Sensitivity to Infant Cues subscale is that it is a general measure of maternal sensitivity to any infant cues, not just hunger and satiation cues; thus, the fact that we did not include a measure that was more focused on maternal sensitivity to satiation cues may explain why effects of bottle type on maternal sensitivity were small (0.5 difference between clear and opaque conditions), and further analysis of feeding interactions with a more focused measure of maternal sensitivity to infant hunger and satiation cues may be needed to fully understand the potential implications and benefits of using opaque bottles for infant feeding. Additionally, the short-term nature of these studies limits our understanding of how opaque bottles may impact the development of mothers' responsive feeding practices, infants' abilities to self-regulate intake, and infants' risk for rapid weight gain across infancy. It is unclear whether effects of opaque, weighted bottles on feeding outcomes were a novelty effect and whether these effects would persist over time if mothers used opaque, weighted bottles on a regular basis. Because our bottles were both opaque and weighted, we were not able to determine which factors (opacity vs. weight vs. both) were most important; further experimental research using multifactorial designs is needed to fully understand the mechanism underlying effects of opaque, weighted bottles on feeding outcomes. Our study also included a wide age range of infants, some of which had been introduced to complementary foods and beverages, which may have diminished effects of bottle type on mothers' sensitivity and infant intake. However, the within-subject design of this study was a strength, as it allowed us to control for individual differences that may have influenced feeding outcomes. Additional study strengths include our inclusion of a diverse sample of both breast-milk- and formula-feeding mothers and use of objective measures of maternal sensitivity and infant intakes.

5 | CONCLUSIONS

Efforts to promote breastfeeding remain critical given the numerous benefits of breast milk composition and constituents (Dewey, Heinig, & Nommsen-Rivers, 1995; Fields, Schneider, & Pavela, 2016; Kelishadi & Farajian, 2014; Kelly & Coutts, 2000; Lawrence & Lawrence, 2011; Mennella & Beauchamp, 1997; Mennella, Jagnow, & Beauchamp, 2001) and the superiority of feeding breast milk from a breast as compared with feeding formula from a bottle (Disantis, Collins, et al., 2011; Li et al., 2012; Mandic, Piricki, Kenjeric, Hanicar, & Tanasic, 2011; Ventura & Terndrup, 2016). Public health and intervention efforts in the United States have been moderately successful in increasing rates of breastfeeding initiation and duration (Centers for Disease Control and Prevention, 2016), yet data on infant feeding patterns illustrate bottles remain a ubiquitous part of infant feeding, even for breastfeeding mothers (Felice et al., 2017a, 2017b; Grummer-Strawn et al., 2008; Labiner-Wolfe, Fein, Shealy, & Wang, 2008; Ventura, 2017). Findings from the present study illustrate that a simple modification to the bottle-feeding experience—use of opaque, weighted bottles—promotes greater maternal sensitivity to infant cues and slower rate of feeding for all dyads, as well as lower intakes for infants with greater clarity of cues. Mothers of infants with poorer clarity of cues may need additional support or alternative approaches to reduce their risk for overfeeding during bottle-feeding.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

AKV conceptualized and designed the study, obtained funding for the study, analysed the data, and drafted, reviewed, and revised the manuscript. AH collected the data and assisted with data analysis and manuscript review and revision. We confirm that all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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