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Are Infant Feeding Practices Associated with Early Childhood Overweight and Obesity? A Longitudinal Study of Participants of the Special Supplemental Nutrition Program for Women, Infants and Children

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Are Infant Feeding Practices Associated with Early Childhood Overweight and Obesity? A Longitudinal Study of Participants of the Special Supplemental Nutrition Program for Women, Infants and Children

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Community Health Sciences

by

Miranda Westfall

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ABSTRACT OF THE DISSERTATION

Are Infant Feeding Practices Associated with Early Childhood Overweight and Obesity? A Longitudinal Study of Participants of the Special Supplemental Nutrition Program for Women, Infants and Children

by

Miranda Westfall

Doctor of Philosophy in Community Health Sciences

University of California, Los Angeles, 2020

Professor Michael L. Prelip, Chair

Obesity is a significant public health issue due to its prevalence and contribution to morbidity and mortality. Obesity prevention efforts in early life are important both because obesity has profound impacts on health status in childhood, and because obesity tracks from childhood to adulthood. The first thousand days in particular – from conception through age two years – may represent a critical period for obesity prevention because taste preferences and metabolic processes are shaped during this period. As such, infant feeding practices – including breastfeeding and complementary feeding practices – may be important predictors of obesity risk. However, there are significant gaps in our knowledge of the relationship between infant feeding practices and childhood obesity.

The studies in this dissertation used longitudinal data from the WIC Infant and Toddler Feeding Practices Study-2 (WIC ITFPS-2) to understand the relationship between infant feeding practices - including breastfeeding duration and intensity, timing of introduction of complementary foods, and early introduction of sugar-sweetened foods and beverages - on weight trajectories and odds of overweight and obesity among low-income children up to age 3 years.

Study 1 examined the relationship between breastfeeding duration and weight trajectories from age 6 months to 3 years and odds of overweight/obesity at ages 2-3 years. Mixed-effects regression models indicated that any breastfeeding (exclusive or partial) for at least 6 months and exclusive breastfeeding for at least 3 months were associated with healthier weight trajectories among both boys and girls. Breastfeeding was associated with significantly reduced odds of overweight/obesity for girls but not boys. Compared to girls who were never breastfed, those who were breastfed at all for less than 6 months had 45% lower odds of overweight/obesity while those breastfed at all for 6 months or longer had 65% lower odds of overweight/obesity. Compared to girls who were never exclusively breastfed, girls exclusively breastfed for less than 3 months had 46% lower odds of overweight/obesity and those exclusively breastfed for 3 months or more had 78% lower odds of overweight/obesity. There was evidence of a dose-response relationship between breastfeeding duration and intensity among girls. Compared to girls who were never breastfed, those breastfed for less than 3 months (short duration) had 39% lower odds of overweight/obesity, those partially breastfed for at least 3 months (longer duration, low intensity) had 55% lower odds of overweight/obesity, and those exclusively breastfed for at least 3 months (longer duration, higher intensity) had 79% lower odds of overweight/obesity.

Study 2 examined the relationship between timing of introduction of complementary foods and weight trajectories from age 6 months to 3 years and odds of overweight/obesity at ages 2-3 years. Mixed-effects regression models indicated differences in weight trajectories by timing of introduction of complementary foods which varied by sex. Compared to complementary food introduction at 4-6 months, late introduction to complementary foods (at or after 7 months) was associated with less healthy weight trajectories among boys, while early introduction (<4 months) was associated with less healthy weight status among girls. However, there was no difference in odds of overweight/obesity at ages 2-3 years by timing of introduction of complementary foods among boys or girls. There was similarly no evidence that the effect of timing of introduction of complementary foods on odds of overweight/obesity differed by breastfeeding duration.

Study 3 examined the relationship between early introduction to sugar-sweetened foods and beverages and weight trajectories from age 6 months to 3 years and odds of overweight/obesity at ages 2-3 years. Mixed-effects regression models indicated no difference in weight trajectories or odds of early childhood overweight/obesity between children who received soda, other sugar-sweetened beverages, or sweets such as cake or cookies before 1 year of age compared to those who didn't receive these sugar-sweetened foods and beverages until 1 year of age or later.

The three studies contribute to our understanding of the relationship between infant feeding practices and weight trajectories in early childhood. These findings suggest that longer durations of breastfeeding may be beneficial in establishing healthy weight trajectories and preventing overweight/obesity in early childhood and have important implications for policy and practice. Key policy, systems, and environmental change strategies that may improve breastfeeding initiation and duration among low-income mothers in the U.S. include a) adoption by Local WIC Agencies of evidence-based, culturally tailored participant education focused on breastfeeding promotion; b) an increase in the proportion of hospitals with Baby Friendly designation; c) paid family leave for 12 weeks following the birth of a child; and d) expansion of workplace lactation accommodation policies to cover all mothers in the workplace. Ultimately, improving breastfeeding outcomes among mothers and infants participating in the WIC program may significantly reduce the racial/ethnic and socioeconomic disparities in childhood obesity in the U.S.

The dissertation of Miranda Westfall is approved.

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INTRODUCTION

Obesity has reached epidemic proportions globally and in the United States (U.S.), and is considered by the World Health Organization (WHO) as one of the most serious public health challenges of the 21st century (WHO, 2018b, 2002a, 2000). Obesity is associated with many of the leading causes of death in the U.S. and contributes to significant health disparities, as the prevalence of obesity is higher among individuals of lower socioeconomic status and certain racial and ethnic minority populations (Krueger & Reither, 2015; National Institutes of Health [NIH], 2013). Though obesity can generally be understood as an energy imbalance, where excessive adiposity results from greater energy intake than energy expenditure, the underlying causes are multifactorial and involve complex interactions between social, behavioral and biological mechanisms (Swinburn et al., 2011).

Childhood is a critical period for obesity prevention, as there is strong evidence that obesity tracks from childhood to adulthood (Simmonds et al., 2016; Singh et al., 2008). The "first thousand days" in particular – from conception through age two years – may provide an opportunity for targeted intervention, as exposures during this time may influence lifelong eating habits and metabolic processes (Alles et al., 2014; De Cosmi et al., 2017; Levy-Marchal et al., 2010; Ong & Loos, 2006). Duration of breastfeeding and timing of introduction of complementary foods are two nutrition exposures during the first thousand days that have been proposed by scholars and clinicians to be associated with childhood obesity (American Academy of Pediatrics [AAP], 2017, 2020; American Public Health Association [APHA], 2007); however, the evidence is mixed and recent literature reviews have concluded that research to date is insufficient to conclusively establish a relationship (Larqué et al., 2019; Victora et al., 2016).

The goal of this dissertation is to contribute to the body of literature on the influence of early infant feeding practices on childhood obesity using data from the WIC Infant and Toddler Feeding Practices Study-2 (WIC ITFPS-2), a longitudinal study which captured data on low-income children in the U.S. (Harrison et al., 2014). WIC ITFPS-2 enrolled mothers (N=4,367) from 80 WIC sites across the U.S. in 2013 and followed the mothers and their children over the first 6 years of the child's life (May et al., 2017). Data for the dissertation studies were derived from a publicly available dataset which included interviews through 36 months of age. During this time, mothers were contacted for telephone interviews up to 13 times at regular intervals ranging from every two months (during infancy) to every six months (after age 18 months). Interviews gathered detailed information about sociodemographic characteristics, maternal health and lifestyle practices, and infant feeding practices. In addition, study personnel collected weight and height data from WIC administrative records or health care providers (May et al., 2017).

The research studies in this dissertation examined the influence of infant feeding practices, including breastfeeding, formula feeding and complementary feeding practices (i.e., timing of introduction of complementary foods, early introduction of sugar-sweetened foods and beverages) on weight trajectories and risk of overweight and obesity of infants and children up to age 3 years. I used quantitative data from a sample of 1,469 children in the WIC ITFPS-2 study to:

Aim 1: Examine the influence of breastfeeding on weight trajectories and risk of early childhood overweight and obesity among low-income infants and children up to age 3 years;

Aim 2: Examine the relationship between timing of introduction of complementary foods and weight trajectories and risk of early childhood overweight and obesity among low-income infants and children up to age 3 years, controlling for breastfeeding duration; and

Aim 3: Examine the relationship between early introduction of sugar-sweetened foods and beverages and weight trajectories and risk of early childhood overweight and obesity among low-income infants and children up to age 3 years, controlling for breastfeeding duration.

The longitudinal nature of the WIC ITFPS-2 data provided a unique opportunity to fill several important gaps in the research using mixed effects regression models, which will be summarized in the following chapters. The first chapter provides a review of the literature on obesity and infant feeding practices. Chapter two describes the theoretical perspectives guiding the research and presents a conceptual framework for understanding the relationship between infant feeding practices and childhood obesity. Chapter three presents the specific aims, research questions, and hypotheses of each of the three research studies. Chapter four provides a detailed description of the data source and methodology for the studies, as well as a summary of the characteristics of the sample and the outcome measures explored in each of the three studies. This chapter is followed by the presentation and discussion of results for each of the three studies in chapters five, six, and seven. Finally, chapter eight concludes with integrated findings, strengths and limitations of the research, implications for policy and practice, and recommendations for future research.

CHAPTER 1: BACKGROUND AND SIGNIFICANCE

The Burden of Obesity

The prevalence of obesity among adults in the U.S. is approximately 40%, affecting more than one in three adults (Hales et al., 2017). Obesity is a risk factor for many of the leading causes of death and disability, including diabetes, heart disease, stroke, and some types of cancer (Bhaskaran et al., 2014; NIH, 2013). As a result, the human and economic costs associated with obesity are staggering. Obesity accounts for a significant share of adult mortality; approximately one in five of all deaths between 40 to 85 years are caused by obesity (Masters et al., 2013). Estimated annual healthcare costs associated with obesity range from $147 billion to nearly $210 billion (Cawley & Meyerhoefer, 2012). Additional indirect costs due to lost productivity and absenteeism in the workplace exceed $4 billion per year (Cawley et al., 2007).

Notably, the World Obesity Federation, The Obesity Society, the American Medical Association, and other health professional organizations have recently recognized obesity as a disease rather than simply a risk factor for other chronic diseases (Bray et al., 2017; Pollack, 2013; Council of the Obesity Society, 2008). Recognition of obesity as a disease signifies the severity and public health importance of obesity. In addition, it is expected to improve attitudes and financial support for obesity prevention and treatment, as it shifts the focus from blaming individuals for poor lifestyle choices to considering broader contextual contributors, including environmental, social and economic factors (Rosen, 2014). While the disease classification has been controversial, supporters maintain that it will help solicit resources (including research and insurance reimbursement) for prevention and treatment of obesity, improve the quality of care for people with obesity, and reduce stigma and discrimination experienced by people with obesity (Allison et al., 2008; Pollack, 2013).

Childhood represents a critical period for addressing the obesity epidemic, as there is strong evidence that obesity tracks from childhood to adulthood (Simmonds et al., 2016; Singh et al., 2008). Based on the life course approach to chronic disease, exposures during certain critical developmental periods may have a greater impact on later health (Ben-Shlomo & Kuh, 2002). Consistent with this perspective, children who are overweight or obese in preschool have twice the risk for overweight or obesity at 11 years of age (Shankaran et al., 2011) and are 5 times more likely to be overweight or obese as adults compared to children who are normal weight in preschool (Kettel Khan et al., 2009). This relationship could be because dietary and physical activity patterns established in childhood and adolescence persist into adulthood (Lounassalo et al., 2019; Movassagh et al., 2017).

Childhood obesity rates have more than tripled in the U.S. since 1980 (Fryar et al., 2018). While some evidence suggests that the dramatic increases in childhood obesity rates seen over recent decades may be stabilizing (Hales et al., 2017; Wen et al., 2012) the prevalence remains high. Furthermore, though recent research had suggested that rates of obesity among the youngest age group (aged 2-4 years) were declining (Pan et al., 2016), the newest evidence incidates a quadratic trend over time, where obesity prevalence among children 2-5 years decreased from 10.1% in 2007-2008 to 8.4% in 2011-2011 but then increased again to 13.9% in 2015-2016 (Hales et al., 2018).

Currently, approximately one in five youth aged 2-19 years are obese (18.5%) (Hales et al., 2018). There are substantial disparities in childhood obesity by race, ethnicity and socioeconomic status (SES). The prevalence of obesity is higher among non-Hispanic Black (22.0%) and Hispanic (25.8%) youth compared to non-Hispanic white (14.1%) and Asian (11.0%) youth (Hales et al., 2017). Though overall trends in obesity prevalence may be plateauing, differences in obesity are widening between socioeconomic groups (Chung et al., 2016). The prevalence of obesity is lower among children in higher income households (≥350% of the federal poverty level [FPL], 10.9%) compared to children in low-income households (≤350% FPL, 18.9%) (Ogden et al., 2018). Similarly, obesity prevalence decreases with the increasing education level of the head of household, from 22.7% among children in households with less than a high school education to 9.6% among children in households with a college degree (Ogden et al., 2018). Even among low-income households, racial and ethnic disparities persist. Among children aged 2-4 years from low-income families participating in federal nutrition safety net programs, the prevalence of obesity is higher among Hispanic (16.4%) and American Indian/Alaska Native (18.5%) children compared to non-Hispanic white (12.1%), non-Hispanic Black (11.4%), and Asian/Pacific Islander (10.0%) children (Pan et al., 2019b).

In addition to increasing the risk of obesity and obesity-related chronic diseases in adulthood, childhood obesity is associated with unique physical, social and economic burdens during the critical developmental years of childhood. Children with obesity may experience many of the same physical health problems faced by adults with obesity, including insulin resistance, high blood pressure, high cholesterol, and fatty liver disease (Friedemann et al., 2012; Hannon et al., 2005; Speiser et al., 2005). Type 2 diabetes, a disease that was once considered adult-onset, is now diagnosed in approximately 5,000 children per year (Mayer-Davis et al., 2017), most of whom are obese (Ludwig & Ebbeling, 2001). The estimated medical cost attributed to obesity among children is approximately $220 (in 2006 U.S. dollars) per year per child (Finkelstein & Trogdon, 2008). Adjusted to 2020 U.S. dollars using the Consumer Price Index (U.S. Bureau of Labor Statistics, 2020), this translates to over $3.5 billion in annual healthcare costs for the 13.7 million children who are obese (Centers for Disease Control and Prevention [CDC], 2019; Hales et al., 2017).

In addition to poor physical health, children with obesity are more likely to suffer from psychosocial issues, including low self-esteem, anxiety, depression, and bullying (Beck, 2016; Halfon et al., 2013; Morrison et al., 2015). These psychosocial stressors may be responsible for the poorer academic performance observed in obese children compared to normal weight children (Branigan, 2017; Gable et al., 2012; Taras & Potts-Datema, 2005). In turn, deficits in learning in childhood may have important implications for future educational attainment, earning potential and social status. Indeed, researchers have found that obesity during adolescence negatively affects adult earnings, particularly for Black Americans and women (Amis et al., 2014).

Why Study Infancy and Early Childhood?

Emerging evidence suggests that infancy and early childhood through the age of two years should be a focus for obesity prevention efforts. The “first thousand days” – defined as the period from conception through age 2 years – represents a sensitive period for developmental processes that may influence a child’s dietary intake and metabolic factors over their entire lifetime. For example, research suggests that nutritional exposures during the first thousand days can influence lifelong eating habits, as taste preferences are formed during these early years of life and track into adulthood (Alles et al., 2014; De Cosmi et al., 2017). In addition, rapid weight gain in early childhood may have lasting metabolic impacts which increase the risk for later overweight/obesity, such as insulin resistance (Levy-Marchal et al., 2010; Ong & Loos, 2006). Insulin resistance has been implicated in the etiology of obesity, as insulin resistance results in increased secretion of insulin, a hormone which promotes creation and storage of body fat (Kahn & Flier, 2000).

What are the Causes of Early Childhood Obesity?

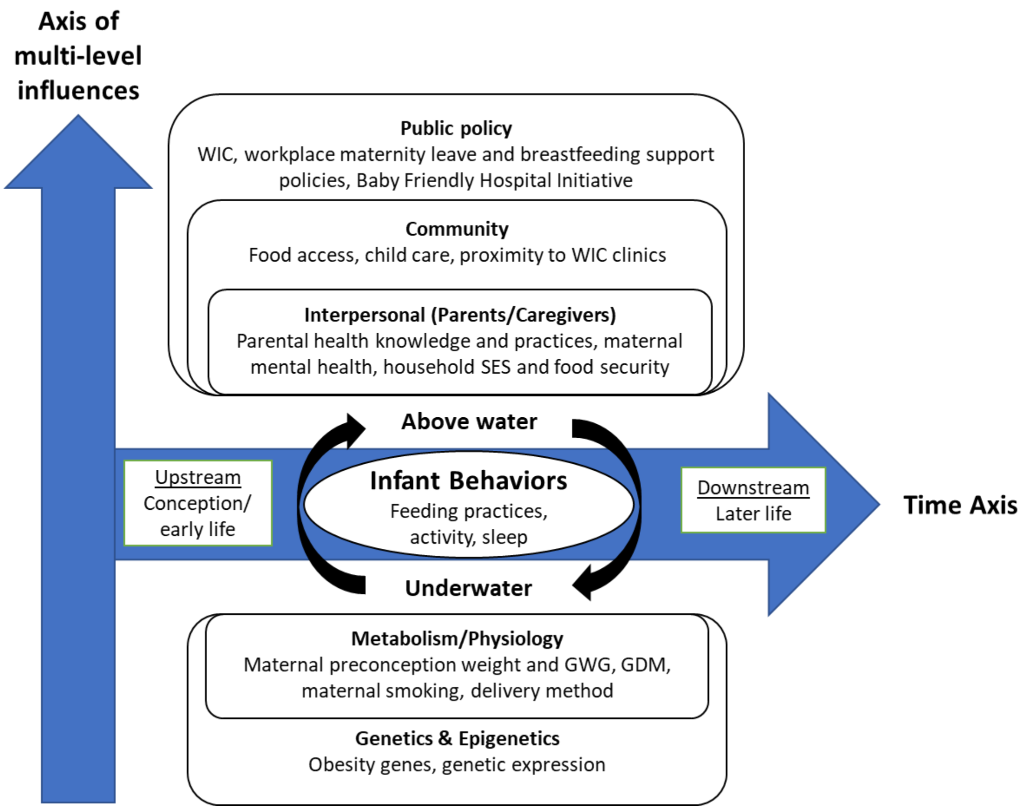
Overweight and obesity are defined as excessive adiposity, or fat accumulation, that presents a risk to health (WHO, 2019). In general, obesity can be understood as an energy imbalance, where an individual's energy intake is greater than their energy expenditure. However, the underlying causes of obesity are multifactorial, and involve a complex interaction of factors at multiple levels of influence. This is a particularly important consideration for infants and young children, as their behaviors are largely shaped by their caregivers.

The Model of Multi-Level Influences, proposed by Glass and McAtee (2006) and applied by Woo Baidal et al. (2016) to childhood obesity provides a framework for considering the multiple, interacting factors during the first thousand days that may contribute to the development of obesity in early childhood (Figure 1). The model integrates principles from the social ecological model and the life course theory. This section will begin with a brief summary of the model, as it will guide the organization of the literature review on the determinants of childhood obesity.

The model centers on individual health behaviors that are risk factors for disease processes, and helps to inform how these behaviors arise, become maintained, and can change (Glass & McAtee, 2006). The model is based on two axes: time (horizontal axis) and a nested hierarchy of biological and social systems that influence behaviors, from genes to social environments (vertical axis). The time axis represents the life course trajectory, and can be thought of as a stream, where experiences in early life phases ("upstream") can have effects later in life ("downstream"). According to the model, the impact of exposures differs based on timing

(Glass & McAtee, 2006), thus integrating a key principle of the life course theory: sensitive periods. Sensitive periods are windows of time where an exposure has a greater impact on development and disease outcomes than at other times throughout life, though the exposure may still have effects outside of this window of time (Ben-Shlomo & Kuh, 2002).

Figure 1. Model of Multi-Level Influences



Adapted from Glass and McAtee (2006) and Woo Baidal et al. (2016)

In addition to using the stream metaphor to understand how early life (upstream) factors influence health later in life (downstream), Glass and McAtee (2006) extend the metaphor to understand the relationship between social and biological factors. Factors "above water," including the social and built environment, represent opportunities and constraints that shape human behavior (Glass & McAtee, 2006). This concept of above water factors integrates key principles of the social ecological model, which emphasizes that broader factors at the interpersonal, institutional, community, and public policy levels influence individual behavior (McLeroy et al., 1988). These concepts are also consistent with the principle of agency in the life course theory, which stresses that, while individuals make choices that shape their life trajectory, the choices available to them are limited based on structural factors, including the historical and social contexts in which they live (Elder et al., 2003).

Above water factors are understood in this model as “risk regulators” as opposed to “risk factors” as they may not directly cause a disease or health condition, but they influence individual action and indirectly affect the probability of disease (Glass & McAtee, 2006). In other words, social conditions up- or down-regulate the likelihood of health behaviors that promote health or disease. For example, SES is a particularly strong above-water/structural factor which affects a broad range of health conditions, as individuals of higher SES have more knowledge, time and resources that allow them to engage in healthy behaviors/lifestyle practices (Cockerham, 2005).

Underwater factors represent genetics and biological factors which may predispose certain people to diseases (Glass & McAtee, 2006). An important component of this model is the emphasis on interaction and feedback loops between physiology (underwater factors) and social context (above water factors). While genetics may predispose an individual to a disease, certain social/environmental factors may need to be present in order for a disease-causing gene to be “turned on,” a concept known as epigenetics (National Human Genome Research Institute, 2016). It is through this process that social factors may become embodied and have physiologic consequences (Glass & McAtee, 2006). This notion of embodiment has also been described as “weathering,” whereby repeated exposure to social adversity results in changes to bodily systems (Geronimus, 1992).

The following sections include a review of the literature on the causes of childhood obesity organized according to the Model of Multi-level Influences, beginning with underwater factors, progressing to above water factors, and ending with a focus on specific infant feeding practices in the first thousand days. This literature review identifies gaps in knowledge of early life influences on childhood obesity, as well as highlights variables that are important to consider in statistical analyses based on established associations with childhood obesity.

Underwater Factors

Maternal Physiology

According to the developmental origins of health and disease theory, maternal health conditions during pregnancy may "program" the developing fetus to have a greater risk of obesity (Armitage et al., 2008; Barker, 2007). Scholars have identified maternal weight, both at the time of conception and during pregnancy, as a factor that has a particularly strong influence on childhood obesity risk (Godfrey et al., 2017; Tie et al., 2014; Yu et al., 2013). In the U.S., over half of women (51.4%) enter pregnancy overweight or obese (Deputy et al., 2018). Maternal weight may increase the risk of childhood obesity through several mechanisms. Infants born to mothers who are obese are more likely to be large-for-gestational age (LGA; >90th percentile weight-for-gestational age) or macrosomic (birth weight >4000 g) (Institute of Medicine & National Academies Press, 2009), which is associated with excessive weight gain in childhood (Gaudet et al., 2014; Li et al., 2007). A study of birth outcomes of children born to women before and after bariatric weight loss surgery revealed that those born after weight loss surgery had lower prevalence of macrosomia (1.8 vs. 14.8%) and severe obesity (11 vs. 35%) at follow-up (between 2.5-25 years of age) (Smith et al., 2009). Children born to women post-bariatric surgery also had improved metabolic profiles at follow-up, including greater insulin sensitivity, improved blood lipid panels, and higher levels of satiety hormones (Smith et al., 2009).

In addition, women who are overweight entering pregnancy are more likely to gain more than the recommended amount of weight during pregnancy. In 2009, the Institute of Medicine (IOM) published revised guidelines for the appropriate amount of weight women should gain during pregnancy (known as gestational weight gain), which for the first time included recommendations that women who enter pregnancy overweight or obese should gain less weight than women who enter pregnancy at a normal weight (Rasmussen & Yaktine, 2009). Preconception overweight has been found to increase the odds of gaining weight in excess of the IOM recommendations by nearly threefold (Weisman et al., 2010). Researchers have found that children of women with gestational weight gain in excess of the IOM recommendations had a 46% increase in odds of obesity at 2-5 years of age, even when controlling for factors including maternal pre-pregnancy weight, race/ethnicity, birthweight, gestational diabetes and other important confounders (Sridhar et al., 2014).

A mother’s weight may have significant effects on her physiology, affecting the conditions that the baby is exposed to in utero. Both preconception overweight/obesity and excessive gestational weight gain increase the risk of gestational diabetes mellitus (GDM) (Hedderson et al., 2010; Torloni et al., 2009). Compared to women with normal pre-pregnancy weight, those who are overweight have twice the odds of GDM, and those who are obese have 3 to 5.5 times the odds of GDM (Torloni et al., 2009). Similarly, women who gain more than the recommended amount of weight during their pregnancy have 50% higher odds of GDM compared to those who gain below or within the recommended amount (Hedderson et al., 2010). The developing fetal organs respond to stimuli in the in-utero environment, which may have lasting effects on metabolic functions. In the case of GDM, the developing pancreas responds to increased levels of glucose by producing more insulin, which functions as a growth hormone (Oken & Gillman, 2003) and can predispose children to increased adiposity (Logan et al., 2017).

Finally, maternal obesity during pregnancy is associated with cesarean deliveries, which may increase the risk of obesity for the infant. Cesarean deliveries account for approximately one third of all births in the U.S. (Hamilton et al., 2018). The odds of a cesarean delivery are over twice as high for pregnant women who are obese compared to normal weight pregnant women (Chu et al., 2007). A systematic review and meta-analysis found that cesarean delivery is associated with a 34% increased risk of obesity during childhood (2-18 years) when compared to vaginal delivery (Kuhle et al., 2015). The impact of delivery type on the infant microbiome has been proposed as one important mechanism linking cesarean deliveries with childhood obesity. In a cesarean delivery, the infant gut microbiome is colonized by the mother's skin bacteria as opposed to vaginal bacteria (Mueller et al., 2015). Differences in gut microbe composition has been associated with obesity (Angelakis et al., 2012). This phenomenon has been attributed to greater energy harvest from short-chain fatty acids produced by certain gut microbes (Kozyrskyj et al., 2016). Differences in microbial species between cesarean section and vaginally delivered babies have been observed to persist into childhood (Salminen et al., 2004).

Health behaviors of the mother during pregnancy may have an impact on the risk of childhood obesity. Less healthy diets during pregnancy have been associated with increased risk of early childhood overweight/obesity. Data from a prospective cohort study of mothers and children in the U.S. found that children of mothers who consumed healthy diets during pregnancy characterized by fruits, vegetables, whole grains, and lean proteins had lower risk of overweight and obesity at age 3 years compared to children of mothers who consumed unhealthy diets characterized by refined grains, red and processed meats, and fried foods (Martin et al., 2016). There may be biological mechanisms underlying the relationship between the mother's diet and her child's later risk of obesity. Through the intrauterine environment, a growing fetus is exposed to many of the same environmental factors that the mother is; thus, an intrauterine environment characterized by poor nutrition could cause hormonal disturbances in the infant, such as low insulin and leptin concentrations, which could then alter appetite and growth in early postnatal life (McMillen et al., 2006).

Smoking is another health behavior during pregnancy that increases the risk for childhood obesity. Systematic reviews and meta-analyses of the association between maternal smoking and childhood overweight and obesity have consistently found a significant positive association (Ino, 2010; Rayfield & Plugge, 2017). After adjusting for confounders, including parental education, breastfeeding, and socioeconomic status, smoking during pregnancy is associated with 55% higher odds of childhood obesity (Rayfield & Plugge, 2017). In the U.S., approximately 7% of women report smoking cigarettes during pregnancy, with smoking prevalence higher among younger women and those with less than a high school education (Kondracki, 2019). Research has suggested that intrauterine exposure to nicotine may decrease impulse control, which may result in increased appetite and reduced satiation in children of women who smoked during pregnancy (Toschke et al., 2002).

Genetics

Evidence suggests that genetic susceptibility plays a substantial role in obesity development, as shown by BMI heritability estimates (which indicate what proportion of variation in BMI is due to genes versus the environment) ranging from 40-85% during childhood and adolescence (Mărginean et al., 2018; Silventoinen et al., 2016). The first discovery of a genetic locus - a spot on a chromosome at which a gene for a particular trait is located (Turner, 2013) – associated with BMI and obesity risk was in 2007 (Scuteri et al., 2007); since then, over 500 genetic loci associated with adiposity traits including obesity, BMI, and waist-to-hip ratio have been identified (Loos, 2018; Loos, 2012). Obesity-related genes, such as the fat mass and obesity-associated (FTO) gene, leptin gene, and tumor necrosis factor alpha gene affect physiological processes such as appetite, regulation of food intake and energy balance, and metabolism (Mărginean et al., 2018).

Above Water Factors

Researchers have identified several factors in the social environment that play a role in childhood obesity. Consistent with Figure 1, I organize the literature review of these above water factors into interpersonal-, community-, and policy-level influences.

Interpersonal (Parent/Caregiver)

Infant behaviors are largely determined by their parents and other individuals responsible for their care. Parental nutrition knowledge has been associated with lower prevalence of childhood overweight (Variyam, 2001). Nutrition knowledge of parents may influence the weight status of their children through its impact on the food environment, as higher levels of nutrition knowledge have been associated with healthier food purchasing behaviors (McKinnon et al., 2014). Maternal factors in particular are important predictors of a child's weight status. Even with more women in the workplace and changing gender norms with regard to housework and childcare, mothers are often the nutritional gatekeepers of the home, taking more responsibility for purchasing and preparing food for the family compared to fathers (Musick et al., 2016). The extent to which healthy foods, such as fruits and vegetables, are made available and accessible to children shapes their preference and consumption of those foods (Cullen et al., 2003). In addition, mothers with greater nutrition knowledge may eat healthier themselves, and research has shown that caregivers modeling eating behavior plays a role in the establishment of dietary patterns among children (Kral & Rauh, 2010).

Another maternal factor associated with childhood overweight/obesity is the mental health status of the mother in the postpartum stage. In the U.S., about 1 in 9 women experience postpartum depression (Ko et al., 2017). A prospective cohort study of women in the U.S. found that postpartum depression was associated with higher adiposity of children at 3 years of age (Ertel et al., 2010). Postpartum depression may impair mother-infant bonding, which can affect infant feeding practices and other interactions between the mother and child which influence diet and activity in early childhood (Ertel et al., 2010). However, evidence suggests that the relationship between maternal depression and childhood overweight exists only for chronic, not episodic depression, indicating that depressive symptoms must have a prolonged impact on parenting practices related to children's nutrition and physical activity in order to influence weight outcomes (Lampard et al., 2014).

Finally, caregivers' SES has a significant influence on childhood obesity. Low household SES increases the risk of childhood obesity by limiting health-promoting resources. Findings from the Early Childhood Longitudinal Birth Cohort in the U.S. showed that children in the lowest quintile of SES (assessed using a composite variable encompassing family income, maternal and paternal educational attainment, and maternal and paternal occupational prestige) were 70% more likely to be overweight or obese than children in the highest SES quintile (Williams et al., 2018). Low SES households are at risk for food insecurity, which means that they have difficulty providing adequate food to all household members due to lack of money or other resources (Coleman-Jensen et al., 2018). Food insecurity during pregnancy is common among women living in poverty (Braveman et al., 2010). Reasons include increased nutritional requirements, which put a strain on the household food budget, combined with women often leaving the workforce (Laraia et al., 2006).

Though it seems contradictory, household food insecurity – which represents a state of insufficient access to food - has been associated with obesity – which reflects a state of overconsumption of energy. Among low-income preschool-aged children (aged 2-5 years) in the U.S., persistent food insecurity was associated with 22% greater odds of obesity (Metallinos-Katsaras et al., 2012). Notably, research shows that in food insecure households, caregivers go to great lengths to protect young children from going hungry, with food intake decreasing among adults before young children when resources are scarce (Coleman-Jensen et al., 2013, 2019). Therefore, as opposed to reduced quantity of food intake, changes in the quality of foods consumed is one proposed mechanism of this paradoxical relationship between food insecurity and obesity. Diets composed of highly processed energy-dense foods made with refined carbohydrates, added sugars and fats cost significantly less than healthy diets composed of fresh fruits and vegetables and lean meats (Drewnowski & Specter, 2004). Thus, the low cost of energy-dense foods may mediate the relationship between food insecurity and obesity.

Community

Multiple community-level factors influence childhood obesity risk. The community environment shapes the resources available to families as they make decisions about how to care for their child. With regard to obesity, these resources encompass features of the community environment that facilitate or hinder healthy food intake and physical activity for both the child and the family. Among the most important community-level factors that can influence a child's weight include accessibility of healthy food and access to safe spaces for play and activity, practices of childcare facilities, proximity to professional support systems such as WIC, and social support systems (White House Task Force on Childhood Obesity, 2010).

As rates of obesity have continued to increase in the U.S., there has been a shift in focus from addressing individual health behaviors to understanding how the settings in which people live are “obesogenic”, meaning that factors in the built environment promote high energy intake and sedentary behaviors, and make it increasingly difficult for individuals to practice healthy behaviors (Lake & Townshend, 2006; Swinburn et al., 1999; Townshend & Lake, 2017). The community food environment naturally shapes the foods that infants and children are exposed to in the household. In particular, availability and accessibility of fruits and vegetables, food costs, and density of fast food outlets may be related to dietary intake and obesity among children (Mayer, 2009; Townshend & Lake, 2017). Additional elements of the built environment, including access to green spaces and neighborhood safety may affect children’s ability to be physically active and have been similarly associated with weight status in childhood (Borrell et al., 2016; Wolch et al., 2011).

The household food environment is not the only food environment which children are exposed to in their early lives. Nearly one quarter (22%) of 1-2 year old children and 11% of children under one year of age participate in center-based childcare arrangements, such as day care centers, Head Start programs, and early childhood education programs, spending an average of 21-26 hours per week in these facilities (Redford et al., 2017). This time represents an opportunity for children to be exposed to healthy, or less healthy options. Some child care centers participate in the Child and Adult Care Food Program (CACFP), which provides reimbursements for nutritious meals and snacks that follow meal patterns consistent with the Dietary Guidelines for Americans for eligible child care centers (United States Department of

Agriculture [USDA] Food and Nutrition Service, 2013). In 2017, child care centers enrolled in CACFP served over 3.6 million children (Food Research and Action Center, 2018). Researchers have found that nutrition environments in CACFP facilities are healthier, serving more fruits and vegetables and fewer sweets and snack-type items than non-CACFP sites (Ritchie et al., 2012). This program presents an important opportunity to decrease socioeconomic disparities in dietary practices and obesity rates. However, it has been estimated that CACFP reaches only eight percent of low-income two-year-olds (Gordon et al., 2011).

Macro-level (Policy):

Several federal policies and programs have a significant impact on the environment in which infants are conceived, born, and raised. One of the most notable programs is the Supplemental Nutrition Program for Women, Infants, and Children (WIC). WIC, administered by the federal government through the USDA Food and Nutrition Service, provides food, nutrition education, breastfeeding support, and referrals to social and health care services to low-income pregnant women, new mothers, infants, and children up to 5 years of age (USDA, 2019b). Ensuring that women have access to healthy foods during pregnancy is critically important to obesity prevention efforts. As discussed previously, excessive weight gain during pregnancy and gestational diabetes, both related to diet, increase the risk that the child will develop obesity (Kim et al., 2012).

The WIC program provides food packages directly to low-income families to meet the unique nutrition requirements during pregnancy, lactation, infancy and childhood in the form of vouchers or Electronic Benefit Transfer systems which allow WIC participants to purchase specific foods at certain approved retailers (Phillips et al., 2014). Research has suggested that recent policy changes which updated the content of WIC food packages have had a measurable impact in lowering obesity risk for children. In 2009, WIC food packages were revised to offer more fruits, vegetables, and whole grains; less juice and whole milk; and lower amounts of formula for women who intend to breastfeed (Taylor et al., 2006). Researchers evaluated the impact of these improvements in nutritional quality and found that children who received the new WIC food package had significantly lower risk of obesity at 5 years of age compared to those who received the old food package (Chaparro et al., 2019).

Another macro-level factor which may be related to childhood obesity is employment policies. The U.S. is the only wealthy nation that does not provide a legal guarantee that new parents can take paid time off to be with their child (U.S. Department of Labor, 2015). In 2016, just 14% of U.S. workers had access to paid family leave (Isaacs et al., 2017). U.S. law does provide up to 12 weeks of unpaid time off for new parents through the Family Medical Leave Act, but only for employees who work in companies with greater than 50 employees and who have been employed for more than 12 months (U.S. Department of Labor, 2012). Estimates suggest that fewer than half of American workers are eligible for this unpaid leave (Han et al., 2009).

Among women who work during their pregnancy, 59% return to work within three months of giving birth (Laughlin, 2011). Returning to work presents a significant challenge to achieving the recommended 6 months of exclusive breastfeeding, and is consistently cited as a reason for early breastfeeding cessation (Baker & Milligan, 2008; Huang & Yang, 2015). A recent literature review concluded that maternity leave of over three months increases the likelihood of maintaining breastfeeding at three months by three times compared to returning to work within three months (Navarro-Rosenblatt & Garmendia, 2018).

Given that the majority of working mothers return to work soon after birth, workplace policies are important to consider. Workplace policies can be instrumental in shaping infant feeding practices, particularly those related to breastfeeding support. The Affordable Care Act (ACA) of 2010 requires employers to provide a private space and reasonable break time for breastfeeding mothers to express milk during the workday (U.S. Department of Labor, 2018). However, like the FMLA, this mandate only applies to employers with 50 or more employees, and to workers subject to overtime pay requirements, which generally means that the benefits extend to hourly workers but not salaried employees (Hawkins et al., 2015). A nationally representative survey of women returning to work postpartum found that only 59% reported adequate break time and 45% reported a private space to express milk (Kozhimannil et al., 2016).

Interaction Between Biological and Social Factors

A key concept of the Model of Multi-level Influences is the interaction between one's biology and their social environment. While genetic factors may predispose an individual to obesity, evidence suggests that certain environmental factors often also must be present for obesity to manifest. In epidemiologic terms, genetic predisposition is often a necessary but not sufficient risk factor for obesity (Parascandola & Weed, 2001). For example, in addition to the presence of genes that increase risk for obesity, an obesogenic environment that supports high energy intake and low energy expenditure often must also be present for an individual to become obese (Mărginean et al., 2018). Returning to the concept of epigenetics, certain factors in the environment determine whether genes that predispose an individual to obesity are expressed or not. Similarly, exposure to an obesogenic environment may not result in obesity for individuals without genetic risk factors for obesity (Mărginean et al., 2018). It is the interaction between biological and social factors that influence the risk of overweight/obesity.

As with factors in the physical/built environment, factors in the social environment can be embodied, leading to physiologic changes that increase the risk of obesity. For example, exposure to stressful experiences has been proposed to increase the risk of obesity by altering appetite regulation pathways (Bose et al., 2009; Lucassen et al., 2013). Early life stress can program the hypothalamic-pituitary-adrenal (HPA) axis, a neuroendocrine system in the body which plays a role in regulating energy storage and satiety signals (Spencer, 2013).

Individual Behavior (Infant)

There is significant evidence that genetics and biology may predispose certain people to overweight/obesity, and that specific elements in the environment increase the risk of energy imbalance by promoting unhealthy behaviors. In addition, it has been well established that weight status in one's early life is a predictor of weight status and health across the life span (Simmonds et al., 2016; Singh et al., 2008). However, there is less known about which specific behaviors in early life are the most important predictors of obesity. Particularly with regard to infant feeding practices, recommendations are largely based on preventing acute morbidity and mortality rather than establishing a healthy trajectory of growth and development for the infant (WHO, 2001).

There is a need to understand which behaviors and practices at the individual level during the first thousand days most influence obesity risk later in childhood. During just the first 6 months of an infant's life, there are several decisions that parents and caregivers make that may have lifelong impacts on children's growth, development, and health. The transition to parenthood is a complicated period, often characterized by high stress and low confidence

(Kristensen et al., 2018). Parents decide whether to feed their infant breast milk, formula, or both. Then they determine when their infant is ready to progress to solid foods, and which foods are appropriate in terms of taste, texture, and nutrient content. While bringing an infant home is a period of celebration and joy, it is undoubtedly also a period of stress, sleep deprivation and intense pressure (Epifanio et al., 2015). In addition, new parents receive information and advice on how to feed and care for their infant from health professionals, family, friends, and society, which in many cases is contradictory (Harrison et al., 2017).

Feeding an infant is a practice that occurs every day, multiple times per day. Newborns feed approximately every 2 to 3 hours, or 8 to 12 times per day (DiMaggio et al., 2017). Given the immense stresses that mothers are under during the first months postpartum, including recovering from labor, continuing to manage daily responsibilities, and learning how to care for and nurture an infant who is entirely dependent on others, additional research is needed to inform the most important feeding practices for healthy growth trajectories.

Infant Feeding Recommendations

Breastfeeding is widely recognized as the gold standard for infant feeding, as it has demonstrated benefits for both infants and mothers. Breastfeeding provides immunological benefits to the infant, significantly reducing the risk of infection and infant mortality (Victora et al., 2016). Benefits to the mother include protection against breast and ovarian cancer and improved birth spacing (Victora et al., 2016). The American Academy of Pediatrics (AAP) currently recommends exclusive breastfeeding for the first six months of life, followed by continued breastfeeding (with introduction of complementary foods) up until at least one year of age (AAP Section on Breastfeeding, 2012). Several health organizations, including the AAP and the American Public Health Association (APHA) cite reduced risk for childhood obesity as one of the potential benefits of breastfeeding (AAP, 2017; APHA, 2007). However, the evidence is conflicting, and recent literature reviews have concluded that there is no scientific consensus that breastfeeding is associated with healthy weight outcomes (Larqué et al., 2019; Victora et al., 2016).

In 2001, the WHO revised their recommendations on the optimal duration of exclusive breastfeeding, defined as an infant receiving no other food or drink except breast milk, from 4-6 months to 6 months following a systematic review of the evidence (WHO, 2001). The outcome measures examined in the systematic review included weight and length gain, weight-for-age and length-for-age z-scores, head circumference, iron status, gastrointestinal and respiratory infectious morbidity, atopic eczema, asthma, neuromotor development, duration of lactational amenorrhea, and maternal postpartum weight loss, comparing exclusive breastfeeding for 6 months vs exclusive breastfeeding for 3-4 months (Kramer & Kakuma, 2002).

Optimal duration of exclusive breastfeeding has long been debated. The previous recommendation to introduce complementary foods at 4-6 months was based on calculations made by the Food and Agriculture Organization and WHO in 1973 that suggested that human milk did not provide adequate energy to meet requirements of the infant after 3-4 months (Kramer & Kakuma, 2004); however, later studies revealed that the calculations significantly overestimated energy requirements in infancy (Brown et al., 1998; Garza & Butte, 1990; Whitehead & Paul, 1981). There has been ambiguity in recommendations in the U.S., with the 1998 Pediatric Nutrition Handbook published by the AAP alternatively recommending breast milk "as the exclusive nutrient source… during the first 6 months" (p. 18) and "to delay introduction of solid foods until 4 to 6 months" (p. 38) (AAP, 1998).

The WHO's conclusion to extend exclusive breastfeeding through 6 months was based primarily off a concern coined "the weanling's dilemma," described as the choice between risk of infection and malnutrition associated with early cessation of breastfeeding weighed against the risk of breast milk failing to meet the nutritional requirements of the growing infant (Rowland, 1986). Recent evidence suggests that infants breastfed exclusively for 6 months do not have deficits in weight or length gain (known as "growth faltering") compared to those exclusively breastfed for 3-4 months, and that exclusive breastfeeding for 6 months has protective effects against gastrointestinal infection; in essence, there was no evidence in support of the weanling's dilemma (Kramer & Kakuma, 2002). Other benefits of exclusive breastfeeding for 6 months as opposed to 4-6 months suggested by the WHO review included prolonged lactational amenorrhea, which may help with pregnancy spacing, and accelerated maternal postpartum weight loss. In addition, the malnutrition and growth faltering associated with early weaning has been observed primarily in developing countries, and is related to introduction of complementary foods that are nutritionally inadequate and unhygienic (Rowland, 1986). Therefore, these recommendations may not necessarily be applicable to developed country settings.

This argument has been advanced by nutrition researchers who contend that the scientific evidence is insufficient to extend the recommendation of 6 months as the optimal duration of breastfeeding to developed countries (Fewtrell et al., 2011; Fewtrell et al., 2007). Instead, they conclude that the literature suggests that breast milk may indeed not fully meet the nutritional requirements of the average infant at 6 months of age. The researchers cite a second review conducted by the WHO which concluded that, while exclusive breast milk for 6 months appears to provide adequate energy, it may not provide sufficient amounts of micronutrients, such as

Vitamin D, and the micronutrient stores that infants have at birth may be depleted before 6 months of age (Butte et al., 2002).

In addition, other researchers have found that the assumed values for energy content of breast milk used in the WHO estimates may be higher than the actual energy content of breast milk (Reilly et al., 2005). Based on these findings, they concluded that exclusive breastfeeding would supply approximately 90% of energy requirements at age 6 months. This has implications not only for the assessment of the nutritional adequacy of breast milk through 6 months, but also for the energy content of infant formulas, which are designed to mimic the composition of breast milk. Reilly et al. (2005) also argue that milk transfer data from infants exclusively breastfed at 5-6 months are extremely scarce (their review consisted of data from 171 mother-infant pairs exclusively breastfed at 5-6 months, compared to 1,041 mother-infant pairs exclusively breastfed at 3-4 months) and more empirical research is needed to understand the energy balance of exclusively breastfed older infants.

Breastfeeding Intensity and Duration

Despite recommendations from health organizations, only 25% of infants in the U.S. are exclusively breastfed through 6 months (CDC, 2018a). Therefore, it is important to understand the effect of early cessation of breastfeeding on health outcomes, including weight trajectories.

In 2013, a meta-analysis commissioned by the WHO concluded that longer durations of breastfeeding were associated with an approximately 10% reduction in prevalence of overweight/obesity in childhood (Horta & Victora, 2013). A second meta-analysis, conducted to update the WHO-commissioned report with literature published between 2011-2014, similarly concluded that breastfeeding decreased the odds of overweight or obesity by 13% in childhood and adolescence (Horta et al., 2015). One limitation of these meta-analyses is that they review studies from both high-income and low-income countries, so residual confounding by socioeconomic status cannot be ruled out. In high-income countries, breastfeeding is more common among higher-income and more highly educated mothers, whereas in low-income countries the opposite is observed (Victora et al., 2015). Furthermore, the time of the outcome measurement varies significantly in the studies, with overweight/obesity being assessed between ages 1 and 62 years (Victora et al., 2015). Another significant limitation of these meta-analyses is the varying definitions of breastfeeding intensity and duration. Few studies in high income countries report on exclusivity of breastfeeding, so the predictor is often any breastfeeding for 6 months or 12 months of life, regardless of whether breastfeeding was exclusive (Victora et al., 2016).

An additional limitation of the current literature is the predominance of cross-sectional studies, which cannot determine causality. While many of the cross-sectional studies show a positive association between breastfeeding and reduced risk of obesity, these conclusions are not universally supported by higher quality studies, such as longitudinal studies or randomized controlled trials (RCTs). Notably, a large RCT (n>17,000) of a breastfeeding promotion intervention (PROBIT) found that the intervention – which resulted in substantially increased duration and exclusivity of breastfeeding compared to the control group – did not have a protective effect on overweight and obesity in childhood (age 6.5 years) (Kramer et al., 2007) or adolescence (age 16 years) (Martin et al., 2017). In fact, at 16 years of age, those in the intervention group had slightly higher rates of overweight/obesity (OR 1.14, 95% CI, 1.02-1.28). However, the PROBIT intervention took place in Belarus, which has substantially lower rates of overweight and obesity compared to the U.S. and significantly less racial and ethnic diversity, so results may not be generalizable to the U.S. population. A meta-analysis of 35 studies reporting on the effect of breastfeeding promotion interventions (including the aforementioned study) found that breastfeeding had a modest, but significant reduction in body mass index or weight-for-height z-scores (z-score mean difference: -0.06), although the average age of weight assessment was only 6 months (Giugliani et al., 2015).

The first systematic review and meta-analysis using only prospective studies to investigate early risk factors for overweight and obesity was conducted by Weng et al. (2012). The authors identified ten prospective studies which evaluated the effect of breastfeeding on childhood overweight and found mixed evidence: five found no significant associations while five concluded that breastfeeding had significant protective effects. The meta-analysis (which used estimates from all 10 studies) revealed that ever breastfeeding in the first year of life decreased the odds of overweight in childhood by 15% compared to never breastfeeding. Of five studies which specifically evaluated the impact of breastfeeding duration on childhood overweight, only one found a significant relationship: Weyerman et al (2006) concluded that infants breastfed for more than 6 months had 60% lower odds of overweight at 2 years of age compared to those breastfed for less than 3 months.

The causal relationship between breastfeeding and obesity was questioned by Smithers et al. (2015), who assessed the mixed evidence on breastfeeding and obesity by placing more weight on stronger study designs in making their conclusions. The authors found no effect of breastfeeding on obesity based on RCTs, sibling-pair, and cross-population studies (Smithers et al., 2015). The authors challenged findings of longitudinal cohort studies because they are subject to potential bias from confounding. In particular, they cited failure to adjust for, or inadequate measure of, socioeconomic status, maternal obesity, and smoking as important confounders which are related to both breastfeeding and obesity. Larqué et al. (2019) similarly emphasize that early life risk factors for childhood obesity coexist and interact with each other; for example, high gestational weight gain (GWG) and shorter duration of breastfeeding are more common in women with obesity compared to women with normal body weight. A study that assessed the cumulative effect of five early-life risk factors – maternal obesity, excess GWG, smoking during pregnancy, short duration of breastfeeding and low maternal vitamin D status – found that the relative risk of overweight/obesity was 3.99 at 4 years and 4.65 at 6 years in children having four or more risk factors compared to children with none (Robinson et al., 2015).

Patro-Golab et al. (2016) conducted a systematic review of the effects of nutritional exposures or interventions in children up to 3 years of age on risk of overweight, obesity and adiposity. The review was performed as part of the international EarlyNutrition research project (2012-2017), a collaborative effort among researchers from the U.S., the European Union and Australia to investigate early life origins of obesity. Breastfeeding was one of the nutritional exposures studied. First, the authors reviewed studies that examined the effect of breastfeeding on children's weight, regardless of the intensity and duration. They concluded that breastfeeding is associated with a modest reduction (13%) in the odds of overweight and obesity in childhood and adulthood, though they noted that the possibility of residual confounding could not be excluded. Next, they reviewed studies examining the effect of duration of exclusive breastfeeding, and found no conclusive evidence that exclusive breastfeeding, regardless of the duration, has a significant protective effect on children's later risk of overweight/obesity. Finally, the authors examined the impact of the duration of any breastfeeding (not necessarily exclusive breastfeeding) on children's weight. They concluded that there are some indications that a longer duration of breastfeeding has a greater protective effect on the later risk of overweight/obesity compared to breastfeeding of a very short duration, though they again noted that the possibility of residual confounding could not be excluded. In addition, of the five studies included in the final analysis, two did not assess the quality of the studies included in their reviews which decreases the reliability of their conclusions, and one of the studies had a low methodological quality rating.

Published in *Nature Reviews Endocrinology,* the most recent literature review similarly found an inconclusive effect of breastfeeding on reducing obesity risk later in life (Larqué et al., 2019). The authors reviewed systematic reviews, original papers and scientific reports to interpret the current knowledge on determinants for the development of childhood obesity. While several meta-analyses have reported that breastfeeding reduces the risk of obesity, a large breastfeeding intervention trial reported that increased duration and exclusivity of breastfeeding were not associated with reduced obesity risk in adolescence (PROBIT). In addition, systematic reviews that have placed greater weight on higher quality studies have concluded that breastfeeding has no effect on obesity (Smithers et al., 2015).

This literature review reveals mixed findings and significant gaps in knowledge about the effect of breastfeeding on obesity. Weaknesses of the current evidence include potential confounding by SES, as well as a reliance on cross-sectional studies, which suggest that the use of longitudinal study data from a cohort of low-income children may provide an important contribution to the literature. In addition, contradictory findings may be related to the operationalization of weight. Meta-analyses that find a protective effect of breastfeeding tend to classify the outcome as obesity, whereas those with null findings assess BMI as a continuous outcome (Beyerlein et al., 2008). Researchers have suggested that the difference in findings suggests an effect of breastfeeding on only the upper percentiles of the BMI distribution (Beyerlein et al., 2008; Koletzko & Von Kries, 2001). Thus, the studies in this dissertation examine weight outcomes using both operationilizations: continuous BMI-for-age and dichotomous overweight/obesity.

In addition, there are relatively few studies which specifically examine the intensity of breastfeeding. A high quality Cochrane review published in 2012 which compared the effects of exclusive breastfeeding for 6 months vs 3-4 months (with continued breastfeeding to 6 months) concluded that exclusive breastfeeding for 6 months had no long term impact on obesity (Kramer & Kakuma, 2012). The validity of their conclusions however have been questioned because they were based largely on the PROBIT intervention study, which had insufficient power to detect the effects of BF duration or intensity on childhood obesity (Rückinger & von Kries, 2009). The primary outcome of the PROBIT intervention was the risk of gastrointestinal infection, and it was therefore powered to detect the effect of breastfeeding duration and exclusivity on gastrointestinal infection, not childhood obesity (Kramer et al., 2001). Thus, another strength of the studies in this dissertation is the ability to examine exclusivity of breastfeeding duration.

Introduction of Complementary Foods

A second infant feeding practice that may be related to weight gain among children is the timing of introduction of complementary foods. Complementary feeding is the transition from exclusive breast milk or infant formula to introducing other foods and liquids to infants (USDA, 2019a). The AAP recommends introduction of complementary foods at approximately 6 months, though recognizes that due to some circumstances, such as medical history and developmental status, complementary feeding may begin earlier (AAP Section on Breastfeeding, 2012).

The WHO identifies four components of appropriate complementary feeding: 1) *timely* – meaning that foods are introduced at the time when the infant's needs for energy and nutrients exceeds what may be provided through exclusive and frequent breastfeeding; 2) *adequate* –

meaning that foods provide enough energy, protein, and nutrients to meet the nutritional requirements of the growing child; 3) *safe* – meaning that foods are appropriately stored and prepared and are served with clean hands and utensils; and 4) *properly fed* – meaning that feeding frequency and method (i.e., fingers, spoon or self-feeding) are age-appropriate and foods are given according to the child's hunger and satiety cues (WHO, 2002a).

The first nationally representative report describing the timing of introduction of complementary foods to U.S. infants was recently published and found that only approximately one-third of infants are introduced to complementary foods at the recommended six months (Barrera et al., 2018). Early introduction to complementary foods may be a modifiable infant feeding practice contributing to childhood obesity. Introduction to complementary foods occurs before 4 months of age for 16% of U.S. infants and between 4 and under 6 months of age for an additional 38% of U.S. infants (Barrera et al., 2018). In comparison, only 13% of children are exposed to late introduction of complementary foods (≥7 months of age). In addition, the report revealed disparities in early introduction of complementary foods by race and SES. The odds of being introduced to complementary foods earlier than 4 months were higher among non-Hispanic Black infants compared to non-Hispanic white infants, and among infants receiving WIC compared to infants not eligible for WIC (Barrera et al., 2018).

A recent literature review on the early life risk factors for childhood obesity found some evidence that very early introduction of complementary foods (<4 months) may increase the risk of childhood obesity (Larqué et al., 2019). However, the authors concluded that the evidence is inconsistent, and that not enough data currently exist to conclusively link the timing of introduction of complementary foods to overweight and obesity in early childhood. A review of prospective cohort studies similarly found mixed evidence on the influence of early introduction of complementary foods on childhood obesity. Among six cohort studies reviewed, Woo Baidal et al., (2016) found that the evidence from three of the studies suggested a role for early introduction of complementary foods on the development of overweight/obesity in childhood, while three found no association.

Data from a nationally representative sample of children in the U.S. from the Early Childhood Longitudinal Study Birth Cohort support the role of timing of introduction of complementary food on weight status in early childhood (Moss & Yeaton, 2014). In this study, children introduced to solid foods earlier than 4 months of age were less likely to have healthy weight at 2 and 4 years of age compared to infants introduced to solid foods later. Delaying complementary food introduction until at least 4 months of age decreased the odds of obesity at 2 years of age by 38% and decreased the odds of obesity at 4 years of age by 23%. One limitation of this study is that mothers were asked to retrospectively report the age at which infants were introduced solid foods when the infants were approximately 9 months old, so there may be issues with recall bias given how many transitions and milestones occur in the first months of an infants life.

There is some evidence that there may be an interaction between breastfeeding duration and timing of introduction of complementary foods on children's weight status. In a prospective cohort study, Huh et al. (2011) found that introduction of complementary foods before 4 months was associated with obesity at 3 years of age among formula-fed infants (and those who stopped BF before 4 months), but timing of introduction of complementary foods was not associated with obesity at 3 years of age among infants breastfed for >4 months. Similarly, using data from the Early Childhood Longitudinal Study, Moss and Yeaton (2014) found that, while longer breastfeeding duration and delayed introduction of complementary foods had independent effects on weight outcomes in early childhood, the greatest benefits were seen when both practices occurred simultaneously. Compared to infants who were not breastfed and introduced to solid foods <4 months, those who were breastfed and introduced to solid foods ≥ 6 months had 62% lower odds of obesity at 2 years of age (Moss & Yeaton, 2014).

Of note, in the U.S., the Dietary Guidelines for Americans have historically been written for adults and children 2 years of age and older. However, the most recent Farm Bill mandated that the Dietary Guidelines expand to include dietary guidance for pregnant women, infants and toddlers up to age 2 years, beginning with the 2020-2025 edition (Lucas, 2014). To inform these dietary recommendations, the USDA and the U.S. Department of Health and Human Services (HHS) initiated the "Pregnancy and Birth to 24 Months project" ("P/B-24") to conduct systematic reviews on diet and health of these special populations (USDA Food and Nutrition Service, 2019). Among the research questions developed for the P/B-24 project is the relationship between complementary feeding and growth size and body composition. Thus, the studies in this dissertation are timely and may serve to inform federal recommendations on infant feeding practices.

Early Introduction of Foods and Beverages with Added Sugars

In addition to the timing of introduction of any complementary foods, early introduction of specific complementary foods may have an especially strong impact on weight outcomes. In particular, foods and beverages with added sugars, such as sodas and dessert foods, may have a particularly strong impact on obesity risk. In the U.S., 84.4% of infants and toddlers consume added sugars on any given day (Herrick et al., 2020).

As mentioned previously, there is currently no national guidance for added sugar intake during infancy and early toddlerhood, as the Dietary Guidelines have historically been developed for children 2 years of age and older and adults. Only one professional organization has provided guidance: a 2017 statement from the American Heart Association recommends children younger than 2 years old avoid consuming any added sugars (Vos et al., 2017). The Dietary Guidelines have not provided guidance for infants primarily due to a lack of high-quality data (Raiten et al., 2014).

However, nationally-representative data from the National Health and Nutrition Examination Survey (NHANES) suggest that virtually all toddlers aged 12 to 23 months (98%) and more than half (60.6%) of infants aged 6 to 11 months consume added sugars in a given day (Herrick et al., 2020). Added sugars, in fact, contribute approximately 8% of the total energy intake for toddlers, with fruit drinks and other sugar-sweetened beverages (SSBs) being among the top sources of added sugars. The Feeding Infant and Toddlers Study 2016 found that among infants and children in the U.S., nearly one in three (29%) aged 12 to 23.9 months and one in ten (9%) aged 6 to 11.9 months consumed SSBs in a given day (Kay et al., 2018). Data from another infant feeding practices study in the U.S. showed a positive association between early introduction of SSBs and weight in childhood (Pan et al., 2014). The odds of obesity at 6 years of age was 92% higher for children who had received SSBs before 6 months of age compared to those with later introduction to SSBs.

Physiological mechanisms may help explain why early introduction to sweet foods and beverages may increase the risk for obesity. Infants have an innate preference for sweet flavors, whereas bitter and sour flavor compounds, which are common in vegetables and other healthy foods, may initially be rejected (Beauchamp & Mennella, 2009). It is hypothesized that this biological predisposition to sweet foods may have developed in order to attract children to energy-dense foods in environments characterized by food scarcity (Forestell, 2017). Early exposure to foods with added sugars may reinforce this innate preference, and the effects of these early-life taste experiences have been shown to persist into early childhood (Beauchamp & Mennella, 2009). Thus, these early life experiences may program the body to want to consume foods with added sugars. High intake of added sugars, particularly in the form of SSBs, have been linked to increased adiposity and risk of obesity in children (Ludwig et al., 2001; Vos et al., 2017).

How is Childhood Overweight and Obesity Measured?

This section will provide a brief overview of the ways in which growth and weight status of children in the U.S. are measured and classified. Anthropometry – derived from the Greek words "anthropo" meaning "human" and "metron" meaning "measure" – is the study of the measurement of the human body (CDC, 2017). Weight, length, and stature (standing height) are examples of anthropometric measurements used in infancy and childhood. Anthropometric indices are combinations of measurements that aid in the interpretation of anthropometric measurements and may be used to evaluate adequacy of growth and development (WHO, 1995). For example, a measure of a child's body weight cannot be assessed without relating it to another measure, such as their age or height. A common anthropometric index is the Body Mass Index (BMI), which is weight in relation to height:

$$BMI = weight\ (kg)\ / height\ (m)^2$$

Anthropometric indices can be expressed in terms of z-scores or percentiles which can then be used to compare individuals to a reference population (WHO, 1995). A z-score represents the deviation of an individual's value from the median value of the reference population, divided by the standard deviation for the reference population:

$$z - score = \frac{[(observed\ value) - (median\ reference\ value)]}{standard\ deviation\ of\ reference\ population}$$

For example, a BMI z-score of 2 means that the child is 2 standard deviations above the median (average) BMI of the reference population. In contrast, a percentile represents the position of an individual's value compared to the reference population distribution, expressed as what percentage of the group the individual meets or exceeds. For example, a child with a BMI-for-age in the 20th percentile has the same or higher BMI than 20% of the reference population of children of the same age. Percentiles are commonly used in clinical settings because of the ease of interpretation; however, summary statistics such as means and standard deviations cannot be calculated because a fixed interval of percentile values corresponds to different changes in absolute height or weight (WHO, 1995). In contrast, a fixed z-score interval corresponds to a fixed height or weight difference, so means and standard deviations can be calculated (WHO, 1995). In research settings, BMI z-scores are preferred to BMI percentiles to model weight trajectories longitudinally and compare between groups (Must & Anderson, 2006). According to the WHO (1997), advantages of using BMI z-scores include a) the ability to combine sex groups in analyses since z-scores are sex-independent, and b) the ability to compute summary statistics such as means, standard deviations, and standard error since the z-score scale is linear.

Obesity and overweight are defined on the basis of age- and sex-specific growth reference charts (Barlow & Expert Committee, 2007). The growth charts are age- and sex-specific because there are differences in body composition between boys and girls, and body composition also changes as children get older (CDC, 2018b). Therefore, growth and weight status in childhood are expressed relative to other children of the same sex and age. There are two commonly used growth reference charts to assess overweight an obesity among children under 19 years of age: the WHO growth standards and the 2000 CDC growth reference charts.

The CDC recommends the use of WHO growth standard charts for children younger than age 2 years and the 2000 CDC growth reference charts for children aged 2 through aged 20 years to monitor growth status. The WHO growth standard charts were derived from the WHO Multicentre Growth Reference Study (MGRS), which collected growth data from approximately 8,500 children across six countries (the U.S., Brazil, Ghana, India, Norway and Oman) (de Onis et al., 2004). The purpose of the MGRS was to provide a single international reference that represents how children *should* grow under optimal health conditions, across different ethnic backgrounds and cultural settings, rather than a description of how children *are* growing (de Onis et al., 2004; Cutberto Garza & de Onis, 2004). To ensure optimal health conditions, eligibility criteria for study sites included socioeconomic conditions favorable to growth, including low infant mortality rate and low prevalence of stunting and wasting; a minimum of 20% of mothers in the study population expressing willingness to follow international feeding recommendations to breastfeed exclusively for 4 months with continued (non-exclusive) breastfeeding to age 12 months; and existence of breastfeeding support systems within the community, such as Baby-Friendly hospitals, breastfeeding support groups, and experienced lactation consultants (de Onis et al., 2004). In addition to eligibility criteria for study sites, individual mothers and infants were screened for eligibility. Mothers who smoked or who were unwilling to follow feeding recommendations were excluded, and infants who were born preterm or with significant morbidities were excluded (de Onis et al., 2004). This study represented an important goal of the WHO to establish breastfed infants as the normative standard for infant growth.

In contrast, the CDC growth reference charts were based primarily on formula-fed infants. The CDC growth charts were derived from national health examination surveys in the

U.S. (National Health Examination Survey and National Health and Nutrition Examination Survey) conducted from 1963 to 1994, and therefore represent how a sample of children grew in a specific place and time, rather than how children may be expected to grow in optimal conditions. During this period in the U.S., breastfeeding initiation was less common that it is now (only about 50% of infants were ever breastfed compared to over 80% now), so the growth among infants in this sample may not adequately reflect the growth of infants now.

Summary

Obesity affects more than 1 in 3 adults in the U.S., and is associated with several of the leading causes of death and disability, including diabetes, heart disease, stroke, and certain types of cancer (Bhaskaran et al., 2014; Hales et al., 2017a; NHLBI, 2013). Childhood is an important time for obesity prevention efforts, as weight status in childhood tracks into adulthood, and as health behaviors such as diet and physical activity are largely shaped during these early years of life (Simmonds et al., 2016; Singh et al., 2008). Childhood obesity rates in the U.S. have more than tripled since 1980, and currently one in five children aged 2-19 years are obese (Fryar et al., 2018; Ogden et al., 2018).

There is evidence that the first thousand days in particular, spanning from conception through the second year of life, may represent a critical period for obesity prevention, as exposures during this period can have lifelong impacts on taste preferences and metabolic processes (Alles et al., 2014; De Cosmi et al., 2017; Levy-Marchal et al., 2010; Ong & Loos, 2006). Parents make several decisions about infant feeding during this window of time, including whether to feed breast milk, formula, or both, as well as when to introduce complementary foods, and what types of foods to introduce. However, our understanding of the impact of these infant feeding practices on risk of obesity is incomplete.

For example, the WHO and AAP recommend that infants be exclusively breastfed through the first six months of age, and reduced risk for childhood obesity is often cited as one of the potential benefits of breastfeeding (AAP Section on Breastfeeding, 2012; APHA, 2007; WHO, 2001). However, recent literature reviews have determined that no conclusive evidence exists that breastfeeding is associated with healthy weight outcomes (Larqué et al., 2019; Victora et al., 2016). There is similarly inconsistent evidence regarding the influence of timing of introduction of complementary foods on childhood obesity (Larqué et al., 2019; Woo Baidal et al., 2016). Given the severe consequences of childhood obesity, it is important to better understand how infant feeding practices from birth through the age of two years influences obesity risk.

The next chapter provides a description of key theoretical frameworks guiding the dissertation. The chapter concludes with an integrated conceptual framework for examining the relationship between infant feeding practices and early childhood obesity.

CHAPTER 2: THEORY

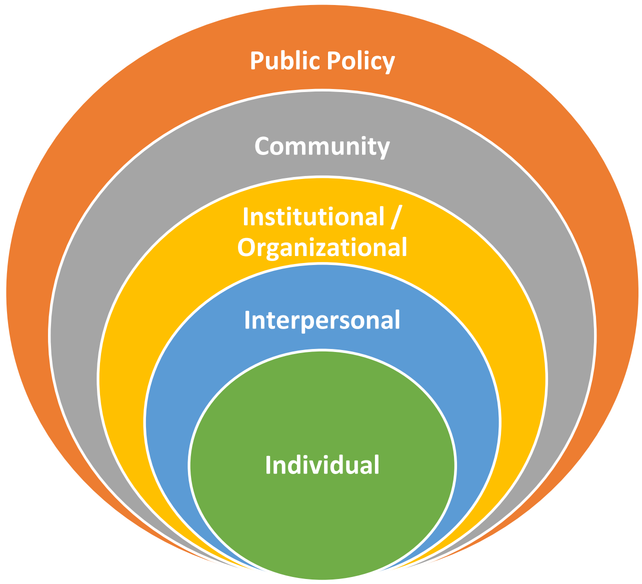
This dissertation examines the relationship between nutrition exposures during the first thousand days and early childhood obesity. Dietary intake at this early age is determined by parents and caregivers, who in turn are influenced by a broad range of contextual factors. In addition, the period from conception through infancy represents a unique period in an individual's life where nutrients play a critical role in growth and development, and if nutrition status is inadequate during this period it can have irreversible lifelong impacts. Thus, the theories presented here emphasize both the contextual factors, including the family, community, and policy landscape, that influence the nutrition status of the infant, as well as the crucial role of nutrition status during this sensitive period in determining health potential across the life course. In this chapter, I discuss the Social Ecological Model, the Life Course Theory, and the Biopsychosocial Model. I then propose a conceptual framework integrating these three theories which I apply to examine the relationship between breastfeeding, complementary feeding practices and early childhood obesity.

Social Ecological Model

The social ecological model is a common theoretical framework applied by health researchers, as the model emphasizes that behaviors are not determined solely by the individual, but instead result from interactions between the individual and the physical and sociocultural environment in which they live (McLeroy et al., 1988). The social ecological model has origins in the ecology of human development perspective, developed by Urie Bronfenbrenner (1977). Bronfenbrenner (1977) contended that at the time, scientific studies of human behavior failed to account for the multiple environments and systems in which a person lives, as well as the social and cultural contexts that influence these environments. According to the ecology of human development perspective, individuals exist within immediate settings, such as their home, school, or workplace (microsystem); at each particular point in life, there are interrelations between these microsystems (mesosystem); in turn, there are broader social structures that influence what happens in the immediate settings in which people live, such as the neighborhood context, mass media, and government agencies (exosystem); finally, there are norms that determine the patterns for the systems, both explicit, such as laws and regulations, as well as implicit, such as social norms and ideologies (macrosystem) (Bronfenbrenner, 1977).

A key concept of the social ecological model is that there are multiple levels of influence on any single behavior (National Cancer Institute, 2005). McLeroy and colleagues (1988) expanded on Bronfenbrenner's perspective by proposing five specific levels of influence which interact to determine health behaviors: (1) intrapersonal factors; (2) interpersonal factors; (3) institutional or organizational factors; (4) community factors; and (5) public policy factors (see Figure 2). Intrapersonal factors include individual characteristics, such as knowledge, attitudes and skills. Interpersonal processes include formal and informal social networks, including family, friends and coworkers. Institutional factors include social institutions, and the rules that guide operation of these institutions. Community factors include relationships among organizations, institutions and informal networks within defined spatial boundaries. Finally, public policy encompasses laws and policies at the local, state and national level.

Figure 2. The Social Ecological Model



Adapted from the CDC, http://www.cdc.gov/violenceprevention/overview/social-ecologicalmodel.html

The social ecological model is appropriate for understanding nutrition during the first thousand days because, unlike at most other times throughout life, in infancy the individual has extremely limited autonomy in their dietary intake. Rather, dietary intake during this period is entirely determined by the infants' interpersonal context. What an infant consumes is decided by those around them, including parents, other caregivers such as family members or day care providers, and health care professionals. In turn, these adults' decisions about infant feeding practices are shaped by their physical and social environment.

Interpersonal Level

Scholars have identified maternal factors as particularly important in determining infant feeding practices. A mother's knowledge, attitudes, and beliefs influence what she feeds herself and what she feeds her baby, both of which can affect the infant's nutritional status. Researchers have found that mothers with greater knowledge about breastfeeding benefits are over 10 times more likely to initiate breastfeeding compared to mothers with lower levels of knowledge

(Kornides & Kitsantas, 2013). A mothers' attitudes toward breastfeeding in public, shaped largely by societal attitudes, may also influence breastfeeding initiation and duration (Amir, 2014; Scott et al., 2015). Additionally, experiences feeding children born previously will influence a woman's knowledge and attitudes about infant feeding. For example, women who experience difficulty breastfeeding their first infants are less likely to breastfeed subsequent babies than mothers who did not experience breastfeeding difficulties (Ingram et al., 2001). A mother's personal beliefs also influence her feeding practices. One of the most common reasons for early breastfeeding cessation is a perception of insufficient milk supply (Brown et al., 2014; Ingram et al., 2001). In addition to breastfeeding practices, maternal knowledge influences complementary feeding practices. For example, there is a common misconception that adding infant cereal to an evening feeding will help the infant sleep through the night, leading to earlier cessation of exclusive breastfeeding and introduction of solid foods (Kahan & Adesman, 2019).

Immediate and extended family members also can be highly influential in infant feeding practices. Older generations, particularly the infant's grandmothers, often impose their own beliefs on new parents and can exert significant influence (Negin et al., 2016). For example, if a grandmother breastfed her children, she may provide more support for breastfeeding to the mom, sharing knowledge and encouragement. In contrast, a grandmother who did not breastfeed may sabotage a mom's efforts to breastfeed by not being supportive or even by giving the infant formula or other foods and beverages without the parents' consent. A literature review of the influence of grandmothers on breastfeeding found that when grandmothers had their own breastfeeding experience or were positively inclined toward breastfeeding, mothers were up to 12 times more likely to exclusively breastfeed; in contrast, when grandmothers had negative attitudes toward breastfeeding, mothers were approximately four times more likely to not initiate breastfeeding or to practice non-exclusive breastfeeding (Negin et al., 2016).

In addition, the extent to which a mother's social networks, including the infant's father and grandparents, support the mother by assisting with daily tasks such as household chores and errands can influence infant feeding practices (deMontigny et al., 2018; Souza et al., 2016). For example, though fathers cannot physically breastfeed, they may perform domestic chores as a way to lighten their spouse's burden to facilitate breastfeeding (deMontigny et al., 2018). In addition, parents often rely on others to care for the infant, such as family members or licensed child care providers, who then share the responsibility of feeding the infant (Wasser et al., 2013). These individuals' personal attitudes and beliefs about infant feeding then may have a significant impact. Finally, interpersonal relationships with health care providers can influence infant feeding practices. Data from the Infant Feeding Practices Study II, a longitudinal study of mothers in the U.S., show that mothers who believed their doctor either had no opinion about breastfeeding, or supported combined breastfeeding and formula feeding, were more likely to not initiate breastfeeding compared to those who believed their doctor supported exclusive breastfeeding (Odom et al., 2014).

Institutional Level

At the institutional level, several factors influence infant feeding practices. For example, institutional practices at the hospital in which the baby is born may encourage or discourage breastfeeding. In the past, many hospitals received substantial support from infant formula companies, including free formula, equipment, and educational grants (Naylor, 2001). In addition, hospitals would often provide mothers discharge packs containing free formula samples, creating a culture in which formula feeding appeared to be the supported practice

(APHA, 2007; U.S. Government Accountability Office, 2006). However, in recent years an increasing number of hospitals are becoming designated as “Baby-Friendly” institutions, signifying an environment that is supportive of breastfeeding (WHO, 2018a). As of 2018, when the 500th facility in the U.S. was designated Baby-Friendly, approximately one-quarter of babies born in the U.S. were born at a Baby-Friendly hospital or birthing center (Baby-Friendly USA, 2018). The Baby-Friendly Hospital Initiative was launched by the WHO and the United Nations Children’s Fund in 1991 to encourage facilities providing maternity and newborn services to support breastfeeding by implementing ten key clinical practices and complying with the *International Code of Marketing of Breast-Milk Substitutes* (WHO, 1981, 2018a). This initial environment to which the infant and parents are exposed to provide the context of what is appropriate and supported by trusted medical providers when it comes to infant feeding practices. The Baby-Friendly Hospital Initiative has been found to increase rates of breastfeeding initiation, exclusivity and duration in the U.S. (Munn et al., 2016)

Factors at the mother’s workplace also can significantly influence infant feeding practices. The U.S. is one of only two countries without a national paid family leave policy to allow mothers to stay home to care for their infant and recover from childbirth (Isaacs et al., 2017). If a woman’s workplace does not offer maternity leave, she may not have enough time to successfully establish a breastfeeding routine. Maternity leave of 6 weeks or less increases the odds of not establishing breastfeeding by four times compared to maternity leave of 12 weeks (Guendelman et al., 2009; Rollins et al., 2016). In the U.S., only 16% of workers have access to paid family leave (Bureau of Labor Statistics, 2018). When a woman does return to work, even if she is committed to breastfeeding, if her workplace does not have lactation accommodations, she may be unable to continue breastfeeding as intended. Access to a private place to pump, refrigerators to store milk, and supportive supervisors and coworkers are correlated with longer durations of breastfeeding (Bai & Wunderlich, 2013). In addition, availability of resources to support the caregivers in their infant feeding choices can also determine their success, including the availability of lactation counseling and breast pumps either through the hospital or through programs such as WIC (Haughton et al., 2010; Needels, 2019).

Community

At the community level, factors influencing infant feeding practices include the built environment, social norms, and information about and positive portrayals of infant feeding in the media and online. The built environment includes the physical parts of where we live, such as the retailers, open spaces, and public transportation options (CDC, 2015), and can have important influences on infant feeding practices. For example, proximity to lactation support services can promote or hinder a woman's efforts to establish and continue breastfeeding. Researchers have found that women in urban and suburban communities have greater access to Baby-Friendly hospitals, lactation consultants and breastfeeding support groups like La Leche League compared to women in rural and remote communities (Grubesic & Durbin, 2017). In addition, in both rural and urban communities, low-income mothers may lack access to transportation to utilize breastfeeding support resources (Bronner et al., 2001). The built environment also determines what foods are accessible when it is time to introduce complementary foods to the infant's diet. Certain neighborhoods in the U.S., particularly those with greater income inequality and higher levels of racial segregation, have limited access to healthy, affordable foods (Ver Ploeg et al., 2009). Families in these neighborhoods, known as food deserts, may have limited availability of healthy complementary food options, particularly those without access to automobiles to shop for groceries outside of their immediate community (Ver Ploeg et al., 2009).

Another important community-level factor influencing infant feeding practices is social norms, or the behaviors that members within a social network perceive to be normal and acceptable. Particularly for a first-time mother who does not have prior personal experience with infant feeding, the opinions of those in her social network may have a significant impact on her own decisions about what to feed her baby (Carlin et al., 2019). For example, rates of breastfeeding among African American women are consistently lower than rates among white women, and stigma against breastfeeding in public and lack of support from social networks have been identified as key barriers to breastfeeding among African American women (Kim et al., 2017).

A final aspect of the community that may play a role in infant feeding is the information and messaging that is available to community members. This could be in the form of advertisements, or information available online. Targeted marketing of infant formula toward low-income and racial and ethnic minority populations is one factor driving breastfeeding disparities by SES and race/ethnicity in the U.S. (Strader, 2016). An *International Code of Marketing of Breast-milk Substitutes* was adopted by the WHO (1981) to promote breastfeeding and prevent aggressive marketing practices by formula companies that prevent women from meeting their breastfeeding goals. However, while most countries have taken measures to implement the code by adopting legislation or other measures that reflect the code recommendations, the U.S. has not (Soldavini & Taillie, 2017).

Policy

The final level of influence is public policy. There are several laws and policies that influence infant feeding in the United States. One of the most significant is the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC). WIC is a federally administered program that provides nutritious supplemental food, nutrition education, counseling, and referrals to healthcare and other services for low-income pregnant and postpartum women and infants and children up to age 5 years (Thorn et al., 2018). WIC was established in 1972 by an amendment to the Child Nutrition Act of 1966, and currently serves approximately 8.8 million women, infants and children at an annual cost of $6.4 billion (Thorn et al., 2018). In order to be eligible for WIC, household income must be ≤185% of the Federal poverty guidelines (though some states set eligibility to as low as ≤100% of the FPL) and applicants must demonstrate state residency (Food and Nutrition Service, 2019).

The broader policy landscape can also have a significant effect on infant feeding practices. For example, though WIC benefits are available to residents regardless of citizenship status, the WIC program has recently experienced decreased participation rates among immigrants due to worries that participation would affect their immigration status. In 2018, leaked drafts of policy proposals from the administration of President Donald Trump suggested that WIC benefits would be considered in public charge evaluations, which allow federal authorities to deny legal status to individuals with a financial reliance on the government (National WIC Association, 2019). One study among Latinx American immigrants found that having heard the erroneous rumor that use of nutrition safety net programs (WIC or SNAP [i.e., food stamps]) by any person in a household may result in the reporting of undocumented family members to the government decreased the odds of participating in nutrition safety net programs by 85% (OR 0.15, [95% CI, .03, .94]) (Pelto et al., 2019).

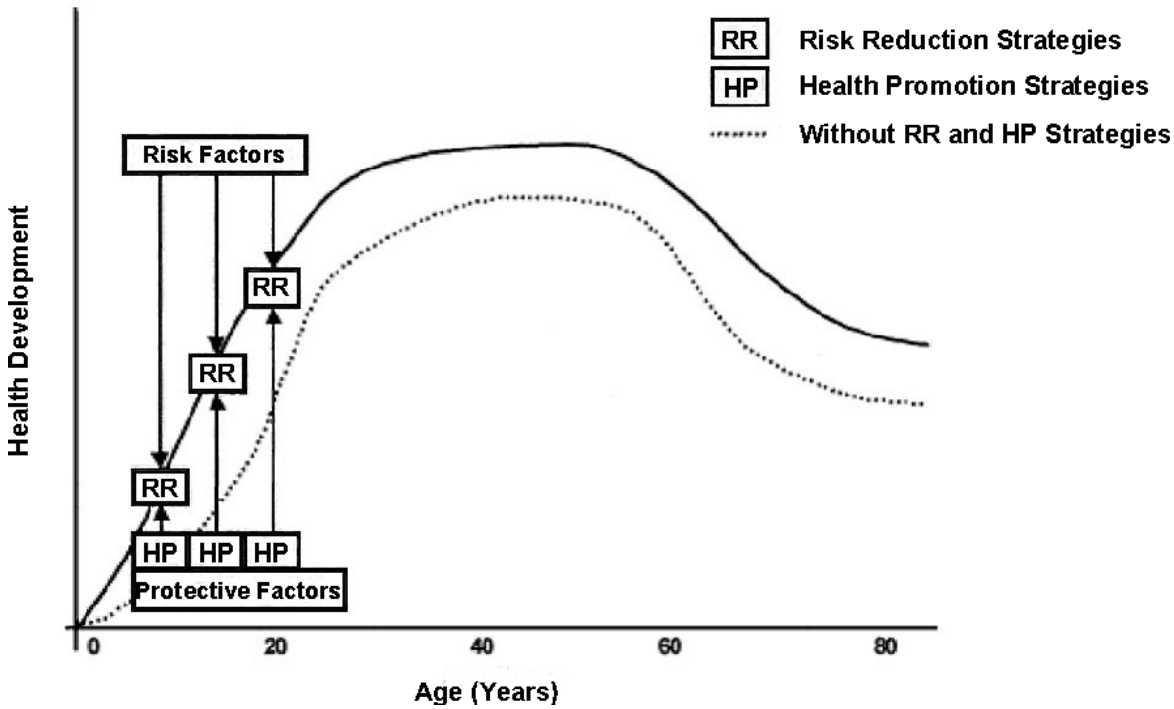
The ACA provided landmark federal legal protections for breastfeeding mothers through the *Break time for Nursing Mothers Law,* including break time and a private space to express milk; however, the law is not comprehensive (Hilliard & Schneidermann, 2019). Millions of working mothers are not covered by the law including those working for small business and independent contractors, and those without access to the benefits tend to be disproportionately of lower SES (Juliano, 2014). Furthermore, while the ACA mandates that insurance plans cover breast pumps, health insurers determine the value of the breast pump benefit which may result in some women receiving lower quality pumps (Kapinos et al., 2018). Research has demonstrated significant heterogeneity across breast pumps in terms of efficiency and volume of milk output, which may affect milk supply and discourage women from pumping (Kapinos et al., 2018; Post et al., 2016).

Life Course Theory

While the social ecological model helps us understand how multiple factors at different levels of influence play a role in determining infant feeding practices, the life course theory helps us understand how nutrition exposures during the first months of life can have lasting impacts on health. The life course theory provides a framework for studying the long-term effects of physical or social exposures at one point in life on health and disease risk later in life (Ben-Shlomo & Kuh, 2002; Kuh et al., 2003). The life course theory offers several key concepts that help us understand how nutrition status in infancy, influenced by breastfeeding and complementary feeding practices, affects growth and weight status in early childhood.

An individual's health status across their lifetime can be understood as trajectory which is shaped by cumulative exposures to risk and protective factors (see Figure 3) (Ben-Shlomo & Kuh, 2002; Halfon & Hochstein, 2002; Halfon et al., 2000). One major concept of the life course theory is that public health promotion strategies can seek to prevent exposures to key risk factors, and thereby establish a more positive health trajectory (Ben-Shlomo & Kuh, 2002). Risks are often interrelated, or clustered, such that some individuals are exposed to multiple biological, physical and social risk factors as a result of their social class (Ben-Shlomo & Kuh, 2002). For example, low-income women are at increased risk of poor nutrition status during pregnancy because they may lack health insurance to access medical care, they may not be able to afford prenatal vitamins or healthy foods, and they may experience more stress which can lead to unhealthy food cravings. In contrast, pregnant women of higher-SES are less likely to experience this cluster of nutrition risk factors.

Figure 3. Influence of Risk and Protective Factors on Health Across the Life Course Trajectory



Source: Halfon et al. (2000)

A key concept in life course theory is that of critical or sensitive periods, which represent specific times during the life course where an exposure has a differential impact. Outside of this time frame, the same exposure would either have a less significant impact (sensitive period) or would have no impact at all (critical period) (Ben-Shlomo & Kuh, 2002). A seminal publication contributing to our understanding of critical periods is Barker's (1995) fetal origins hypothesis, which suggests that undernutrition during middle to late gestation programs the body for coronary heart disease in adulthood. The fetal origins hypothesis proposed that inadequate access to nutrients during critical periods of cell growth in utero can permanently alter organ function and impair physiological processes such us glucose tolerance and lipid metabolism, which increases the risk of coronary heart disease in adulthood (Barker, 1995). Subsequent to the fetal origins hypothesis, the importance of nutrition exposures in utero and during the first year of life have been demonstrated for multiple disease processes across many different populations (Langley-Evans, 2015).

Infancy represents a critical period because several developmental processes are taking place, including physical and cognitive development. The most rapid period of brain growth and the period of highest brain plasticity occurs during the first thousand days (Kolb, 2009). If an infant does not have adequate energy and nutrients to support these processes, there may be permanent and irreversible impacts on growth, development and lifelong health. For example, iron plays a role in the creation and differentiation of brain cells, so iron deficiency during infancy can result in developmental delays that often cannot be reversed even with later iron supplementation (Beard, 2008).

The notion of linked lives is a third key concept from life course theory that is of particular importance to understanding feeding behaviors in infancy. The perspective of linked lives recognizes that lives are lived interdependently, and events or exposures that affect one person also affect others in their social network (Gee et al., 2012). The lives of an infant and its parents, particularly its mother, are inextricably linked. The mother's own dietary choices influence the nutrition status of the baby by determining nutrition exposures in utero (Morrison & Regnault, 2016) and in infancy if the mother is breastfeeding (Bravi et al., 2016). In addition, parents' dietary preferences further influence what foods are purchased and consumed in the household food environment, and therefore likely to be introduced to the infant (Scaglioni et al., 2018).

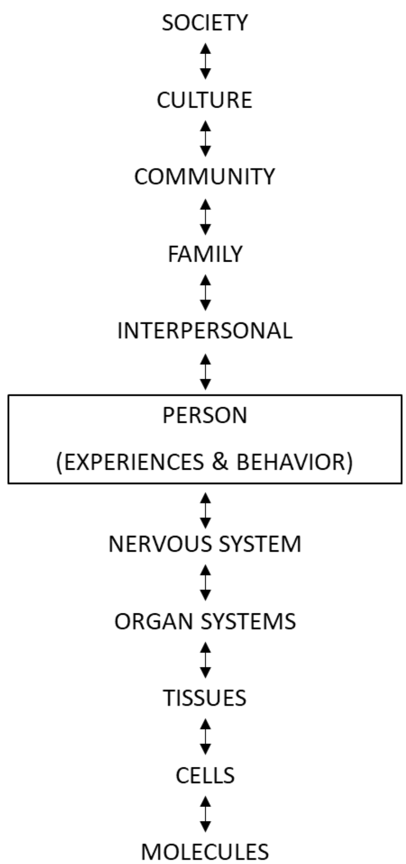
The longitudinal nature of the WIC Infant and Toddler Feeding Practices Study 2 provides a unique opportunity to apply the life course theory to understand how early infant feeding practices influence the risk of overweight and obesity in early childhood.

Biopsychosocial Model

While the social ecological model explains how a person's environment influences health behaviors, the biopsychosocial model helps to understand how environmental exposures get "under the skin" to manifest in physical health problems. The biopsychosocial model was introduced by George Engel, a physician who developed the framework as an alternative to the reductionist biomedical model which failed to recognize the influence of the physical and social environments in which people live when treating disease (Engel, 1980). The biopsychosocial model helps elucidate the underlying mechanisms of health disparities by proposing that environmental stressors – such as poverty and racism – work through biological factors to affect premature onset of disease among disadvantaged populations (Crimmins & Seeman, 2004).

The biopsychosocial model provides a holistic framework for understanding illness, demonstrating how biological, psychological and social processes interact to affect physical health outcomes (Suls & Rothman, 2004). In the biopsychosocial model, Engel (1980) presented a hierarchy of systems from the molecular level to the societal level (Figure 4). He proposed that health reflects harmony within and between each component system, while disturbances to any of these individual systems may result in illness or disease (Engel, 1980). In addition, the biopsychosocial model emphasizes that a single exposure may have a differential impact on two people, depending on their past experiences. For example, while a disturbance to the social environment may have no impact on the health of one individual, it may result in illness for another individual with a different history of experiences and exposures (Engel, 1978). The biopsychosocial model provides a framework for understanding how social determinants of health manifest in physical illness.

Figure 4. Biopsychosocial Model: Hierarchy of Natural Systems



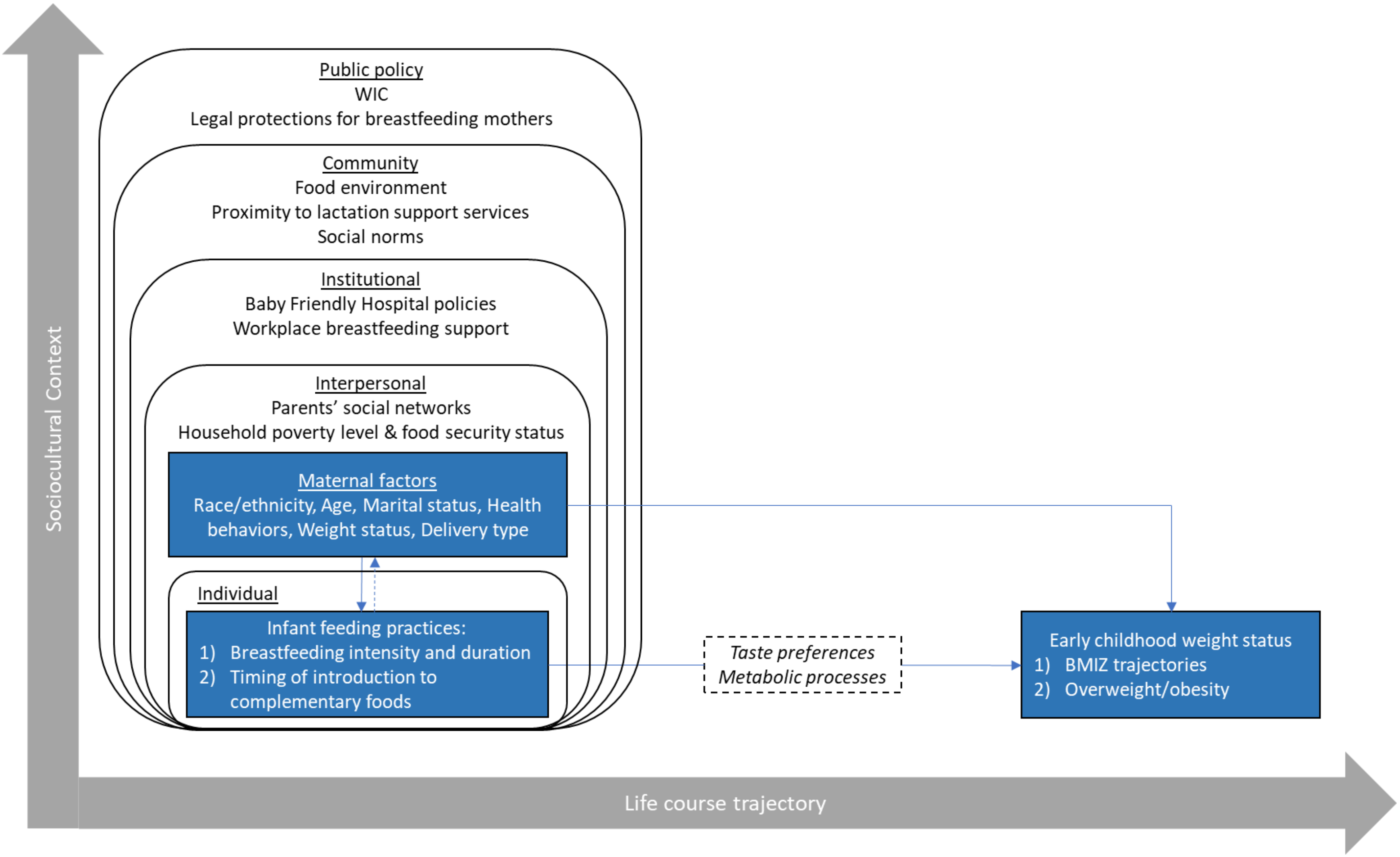
Source: Adapted from Engel (1980)

The biopsychosocial model is complementary to the life course theory in explaining how early life exposures can affect health throughout the lifetime by altering physiologic processes. For example, processes related to sensory development and metabolic function occur during infancy which may program an individual to have an increased risk of obesity as they age. Taste preferences are established early in life, and infants' reactions to flavors are significantly influenced by the flavor compounds they are exposed to in utero and infancy (J. A. Mennella et al., 2001). Therefore, it is plausible that infants with greater or earlier exposure to sweet foods will demonstrate a preference for foods with added sugars, which could predispose them to weight gain. Similarly, it has been suggested that higher protein intake in infancy permanently decreases the body's sensitivity to the hormone insulin (Melnik, 2012). Insulin plays a role in the body's regulation of blood sugar levels and storage of glucose and fat, and insensitivity or resistance to insulin is associated with obesity (Ye, 2013). As infant formula has higher protein content than human breast milk, this may be another possible mechanism linking shorter duration of breastfeeding with higher body weight later in life.

Conceptual Framework

An integrated conceptual framework, drawing on concepts from the social ecological model, the life course theory, and the biopsychosocial model has been utilized in this dissertation to understand the impact of nutrition exposures in infancy on the risk of overweight and obesity in early childhood (Figure 5). Life course theory emphasizes the impact of nutrition exposures during critical and sensitive periods of development in infancy on later health outcomes. In the conceptual model, this is illustrated as the relationship between infant feeding practices and early childhood obesity. Additionally, through the concept of linked lives, life course theory emphasizes the importance of the mother and other caregivers in shaping the nutrition exposures of the infant. The social ecological model highlights the broader contextual factors that shape the environment in which choices are made about infant feeding practices. In the conceptual model, this is illustrated by the factors at the institutional, community, and public policy levels that influence the context in which the mother makes decisions about infant feeding practices. The biopsychosocial model helps explain the biological mechanisms that mediate the relationship between early life exposures and health outcomes in childhood. This is represented by the influence of early infant feeding practices on taste preferences and metabolic processes.

Figure 5. Conceptual Framework



Note: The blue boxes represent the relationships that are explicitly tested by the research questions in this dissertation

Informed by the theoretical perspectives of the Social Ecological Model, Life Course Theory, and Biopsychosocial Model, the studies in this dissertation address gaps in the current literature by examining the influence of early infant feeding practices, including breastfeeding duration and intensity and timing of introduction to complementary foods on the risk early childhood obesity among a longitudinal cohort of low-income children in the U.S. Chapter 3 summarizes the aims of the dissertation, including specific research questions and hypotheses.

CHAPTER 3: RESEARCH AIMS, RESEARCH QUESTIONS & HYPOTHESES

This chapter provides a summary of the aims of the three research studies, including the research questions and hypotheses. I review the data source and analytic strategy used to answer these research questions in Chapter 4.

Primary Research Question: How do infant feeding practices influence the risk of early childhood obesity among low-income children?

The three studies in this dissertation examine the influence of infant feeding practices, including breastfeeding and complementary feeding practices (i.e., timing of introduction of complementary foods and timing of introduction of sugar-sweetened foods and beverages) on weight trajectories and risk of overweight and obesity of low-income infants and children up to age 3 years.

I operationalize the measures in Chapter 4, but briefly define terms used in the research questions and hypotheses here for purposes of clarity. *Exclusive breastfeeding* refers to feeding the infant only breast milk. *Partial breastfeeding* refers to feeding the infant breast milk in combination with other foods and beverages, including formula. *Any breastfeeding* refers to breastfeeding with or without the provision of additional foods and beverages, including formula; therefore, duration of any breastfeeding reflects both exclusive and partial breastfeeding practices. *Timing of introduction of complementary foods* refers to the age at which the child first received food or beverages other than breast milk, formula, or water. *Timing of introduction of sugar-sweetened foods and beverages* refers to the age at which the child first received certain foods high in added sugars, such as soda, cake, or cookies. Of note, duration of breastfeeding and timing of introduction of complementary foods are not perfectly correlated. For example, a mother may terminate breastfeeding and provide formula exclusively to her infant, in which case she is no longer breastfeeding but the infant has not yet been introduced to complementary foods. Similarly, a woman may continue to breastfeed after beginning to introduce complementary foods, in which case she would still be breastfeeding but not exclusively breastfeeding.

Study 1

Study Aim: To understand the influence of **breastfeeding (BF)** on early childhood **weight trajectories** among low-income children. To address this aim, I identified the following research questions and hypotheses:

> **Question 1.1:** What is the relationship between **breastfeeding duration** and early childhood **BMI-for-age z-score (BMIZ) trajectories?**
>
> > **Question 1.1a:** What is the relationship between ***duration of any BF*** and early childhood **BMIZ trajectories?**
> >
> > > **Hypothesis 1.1a:** Greater duration of any BF will be associated with healthier BMIZ trajectories (defined as closer to BMIZ=0 and furthest from the overweight category [BMIZ≥2]).
> >
> > **Question 1.1b:** What is the relationship between ***duration of exclusive BF*** and early childhood **BMIZ trajectories?**
> >
> > > **Hypothesis 1.1b:** Greater duration of exclusive BF will be associated with healthier BMIZ trajectories.
>
> **Question 1.2:** What is the relationship between **breastfeeding duration** and early childhood **overweight/obesity?**

Question 1.2a: What is the relationship between ***duration of any BF*** and early childhood **overweight/obesity?**

Hypothesis 1.2a: Greater duration of any BF will be associated with lower odds of overweight/obesity.

Question 1.2b: What is the relationship between ***duration of exclusive BF*** and early childhood **overweight/obesity?**

Hypothesis 1.2b: Greater duration of exclusive BF will be associated with lower odds of overweight/obesity.

Question 1.3: Is there a dose response relationship between breastfeeding duration and intensity (i.e., exclusive vs. partial) and early childhood overweight/obesity?

Hypothesis 1.3: There will be a dose-response relationship between breastfeeding duration and intensity, such that longer duration of exclusive BF will be associated with lower odds of overweight/obesity compared to longer duration of partial BF.

Study 2

Study Aim: To understand the relationship between **timing of introduction of complementary foods** and early childhood **BMIZ trajectories**, controlling for breastfeeding duration. To address this study aim, I identified the following research questions and hypotheses:

Question 2.1: Controlling for breastfeeding duration, what is the relationship between **timing of introduction of complementary foods** and early childhood **BMIZ trajectories?**

Hypothesis 2.1a: Controlling for breastfeeding duration, introduction of complementary foods at 4-6 months will be associated with healthier BMIZ trajectories compared to introduction before 4 months or after 7 months.

Hypothesis 2.1b: Among those with introduction to complementary foods at 4-6 months, adherence to current recommended feeding practices (around 6 months) will be associated with healthier BMIZ trajectories.

Question 2.2: Controlling for breastfeeding duration, what is the relationship between **timing of introduction of complementary foods** and early childhood **overweight/obesity?**

Hypothesis 2.2: Introduction of complementary foods at 4-6 months will be associated with reduced odds of overweight/obesity compared to introduction before 4 months or after 7 months.

Question 2.3: Does the relationship between **timing of introduction of complementary foods** and **overweight/obesity** depend on **breastfeeding duration?**

Hypothesis 2.3: There will be an interaction between timing of introduction of complementary foods and breastfeeding duration, such that early introduction of complementary foods will be associated with higher odds of overweight/obesity for infants with shorter BF duration but not those with longer BF duration.

Study 3

Study Aim: To understand the relationship between **early introduction of sugar-sweetened foods and beverages (SSFBs)** and early childhood **BMIZ trajectories**, controlling for breastfeeding duration. To address this study aim, I identified the following research questions and hypotheses:

Question 3.1: Controlling for breastfeeding duration, what is the relationship between **early introduction of SSFBs** (before 1 year of age) and early childhood **BMIZ trajectories?**

Hypothesis 3.1: Early introduction of SSFBs will be negatively associated with healthy BMIZ trajectories.

Question 3.2: Controlling for breastfeeding duration, what is the relationship between **early introduction of SSFBs** and early childhood **overweight/obesity?**

Hypothesis 3.2: Early introduction of SSFBs will be associated with increased odds of overweight/obesity.

CHAPTER 4: METHODS

This chapter describes the data source and analytic approaches used for the dissertation.

WIC Infant and Toddler Feeding Practices Study-2

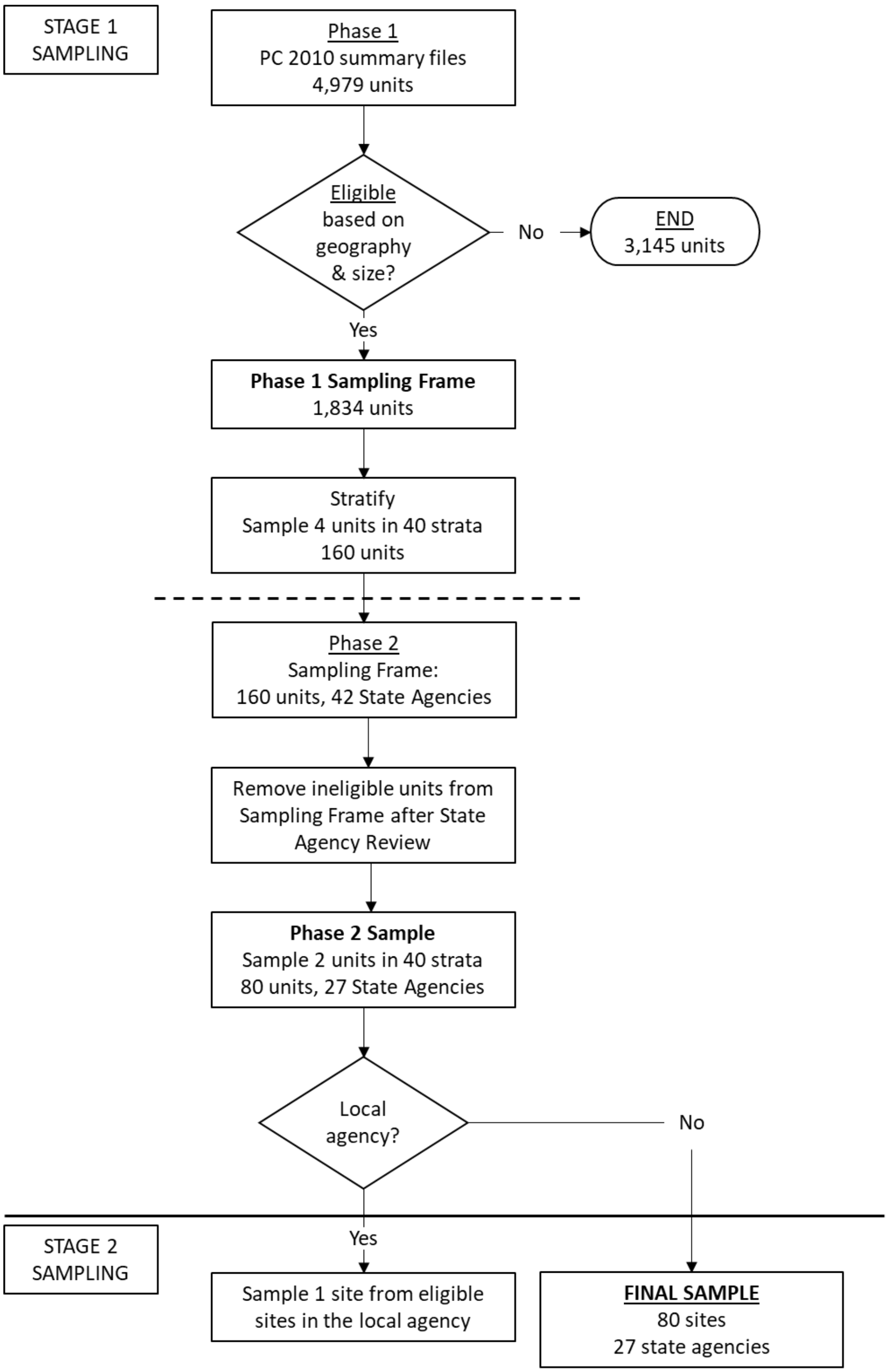
Data for this study were from the WIC Infant and Toddler Feeding Practices Study-2 (WIC ITFPS-2), which captured data on WIC mothers and their children through 6 years of age. WIC ITFPS-2 is a nationally representative, longitudinal study of feeding practices of infants, toddlers and children participating in the WIC program, the first of its nature in over 20 years (Harrison et al., 2014). The publicly available data set that was used for this dissertation included WIC ITFPS-2 data collected through 3 years of age.

Sample

Selection of WIC Sites

Mothers were recruited from 80 WIC sites across 27 states and territories in the U.S. at their time of WIC enrollment during the summer or fall of 2013. WIC sites were selected using a stratified two-stage sampling approach (May et al., 2017), as outlined in Figure 6. The sampling frame was defined as the 2010 WIC Program and Participant Characteristics (PC 2010), a record of each participant being served by WIC in April of 2010, as reported by each State Agency. State agencies had flexibility for reporting service location identifiers in PC 2010, and some reported both the site ID and local agency code, whereas others included only a local agency code. Therefore, a two-stage sampling approach was adopted, where the first stage involved sampling of units for which the tabulation unit was site IDs and the second stage involved sampling of sites where the tabulation unit was the local agency (both tabulation units are referred to as “first-stage sampling units”). The ultimate goal was selection of 80 WIC service sites.

Figure 6. Overview of WIC Service Site Sampling Process



Source: May et al. (2017)

Stage 1 sampling was conducted in two phases. In Phase 1, a probability proportional to size (PPS) sampling method was applied, in which a measure of size (MOS) is calculated for each population unit prior to sampling, and the probability of selecting a unit is proportional to its size (Skinner, 2016). The MOS was the expected number of eligible enrollees, derived from the PC 2010 records (May et al., 2017). Eligibility criteria for Stage 1 included acceptable geographic location and MOS value ≥ 30 (i.e., expectation of ≥ 1.5 enrollees per day, assuming 20 days of enrollment per month). Of the 4,979 units in the Stage 1 sampling frame, 17 were dropped because of geographic location (American Samoa, Guam, Northern Marina Islands, U.S. Virgin Islands) and 3,128 were dropped because of MOS value <30. The final Phase 1 sampling frame contained 1,834 units.

In Phase 2 of Stage 1 sampling, the 1,834 eligible units were stratified. Forty homogenous strata of approximately equal size were formed based on five characteristics (see Table 1). Three characteristics were features of the State WIC Agency Plan, while two were breastfeeding rates and high weight-for-height rates among program participants. Sampling units in a given stratum all had the same State Agency WIC Plan features and had similar fully breastfeeding and high weight-for-height rates. Four units in each of the 40 strata were selected, yielding 160 first-stage sampling units, which could be either WIC service sites or state agencies, as described previously.

Phase 2 of Stage 1 sampling involved contacting state agencies to identify individual service sites (when the first-stage sampling unit was a local agency rather than a WIC service site) and determine eligibility. State agencies were contacted in April 2012 and asked to report their January 2012 enrollment statistics and whether the site was expected to be operational for the next 12 months. Sites that did not meet enrollment criteria or were not expected to continue in operation were designated as ineligible. Two eligible first-stage units were selected from the 40 strata, with equal probability among the eligible units, yielding 80 first-stage units.

Table 1. Characteristics Considered to Form Stage 1 Sampling Strata

Characteristic	Description
Features of State Agency WIC Plan	
Peer Counseling Program	Is there a breastfeeding peer counseling program in place?
Trained Paraprofessionals	Are trained paraprofessionals (as opposed to staff with professional training/credentials) allowed to provide nutrition education?
Policy to Provide Formula	Is policy to allow 1 can of formula for breastfeeding infants during the first 30 days of life?
Participant Characteristics	
Utilization of Fully Breastfeeding Package	% of women who utilized the fully breastfeeding food package during the postpartum period
High Weight-for-Height Rates Among Mothers and Children	% high weight-for-height was calculated for both mothers and children and then averaged

Stage 2 sampling involved only those first-stage units which were local agencies rather than individual service sites. For each selected state agency, eligible service sites were listed, and an MOS that reflected the expected average daily enrollment was calculated using the January 2012 enrollment statistics. One service site was sampled from the eligible local agencies with probabilities proportional to the MOS. The final sample contained 80 WIC service sites in 27 state agencies.

Sampling WIC Enrollees

The WIC ITFPS-2 sample included all prenatal mothers or their babies less than 2.5 months old who enrolled in WIC at one of the 80 sample sites during a pre-specified recruitment window. The length of the recruitment window was determined based on the estimated amount of time required to yield 98 new WIC enrollees per site (the target sample size for each site), such that sites with a low number of monthly enrollees had longer recruitment windows than sites with a high number of enrollees. The total study recruitment period was a 20-week period from July 1st through November 18th, 2013.

Two samples were selected at each site: a core longitudinal and supplemental cross-sectional sample. The core longitudinal sample was designed to be an equal probability sample of all new enrollees, while the supplemental sample was designed to focus on specific subpopulations. The core longitudinal sample is nationally representative.

Imputation

The hot deck imputation method (Kalton & Kasprzyk, 1982) was utilized to impute key socio-demographic variables, including household poverty level and food security status, and maternal age, marital status, and weight status to reduce bias due to item nonresponse (May et al., 2017). Hot deck imputation methods replace missing values from a non-respondent with observed values from a respondent who is similar to the non-respondent in other characteristics (Andridge & Little, 2010).

Data Source

The WIC ITFPS-2 study collected data from multiple sources, beginning in July 2013. Data for this dissertation were derived from screening and enrollment interviews, follow-up interviews conducted through 36 months postpartum, and WIC administrative records or health care provider records. All recruitment activities and interviews were conducted by staff from Westat, the research corporation contracted by the USDA Food and Nutrition Service to conduct the WIC ITFPS-2 study. Screening and enrollment interviews were conducted in-person at the time of enrollment. After WIC staff identified eligible participants (English- or Spanish-speaking, age ≥16 years, enrolling in WIC for the first time for current pregnancy or enrolling a new baby <3 months old), recruiters at the WIC study sites explained the study to the potential participant, completed a computerized screener to verify study eligibility, obtained written informed consent, and conducted a computerized 10-minute enrollment interview. If interested participants were unable to stay on-site to complete enrollment, recruiters followed up to conduct the screener and enrollment interview by telephone.

Participants in the core sample were contacted by phone for follow-up interviews between 11 and 13 times (depending on time of enrollment) between enrollment and approximately the baby's third birthday. Interviews were conducted at intervals based on the child's age. Follow-up phone interviews were conducted in English or Spanish. All participants were contacted when children were approximately 3-months, 5-months, 7-months, 9-months, 11-months, 13-months, 15-months, 18-months, 24-months, 30-months, and 36-months old (11 interviews). Women who enrolled in the study when their infant was <6 weeks old were also contacted for a 1-month phone interview (12 interviews). Women who enrolled prenatally were contacted for a prenatal interview and a 1-month interview (13 interviews).

Access to a publicly available, deidentified dataset was granted for the purpose of this dissertation through USDA's Food and Nutrition Service.

Analytic Sample

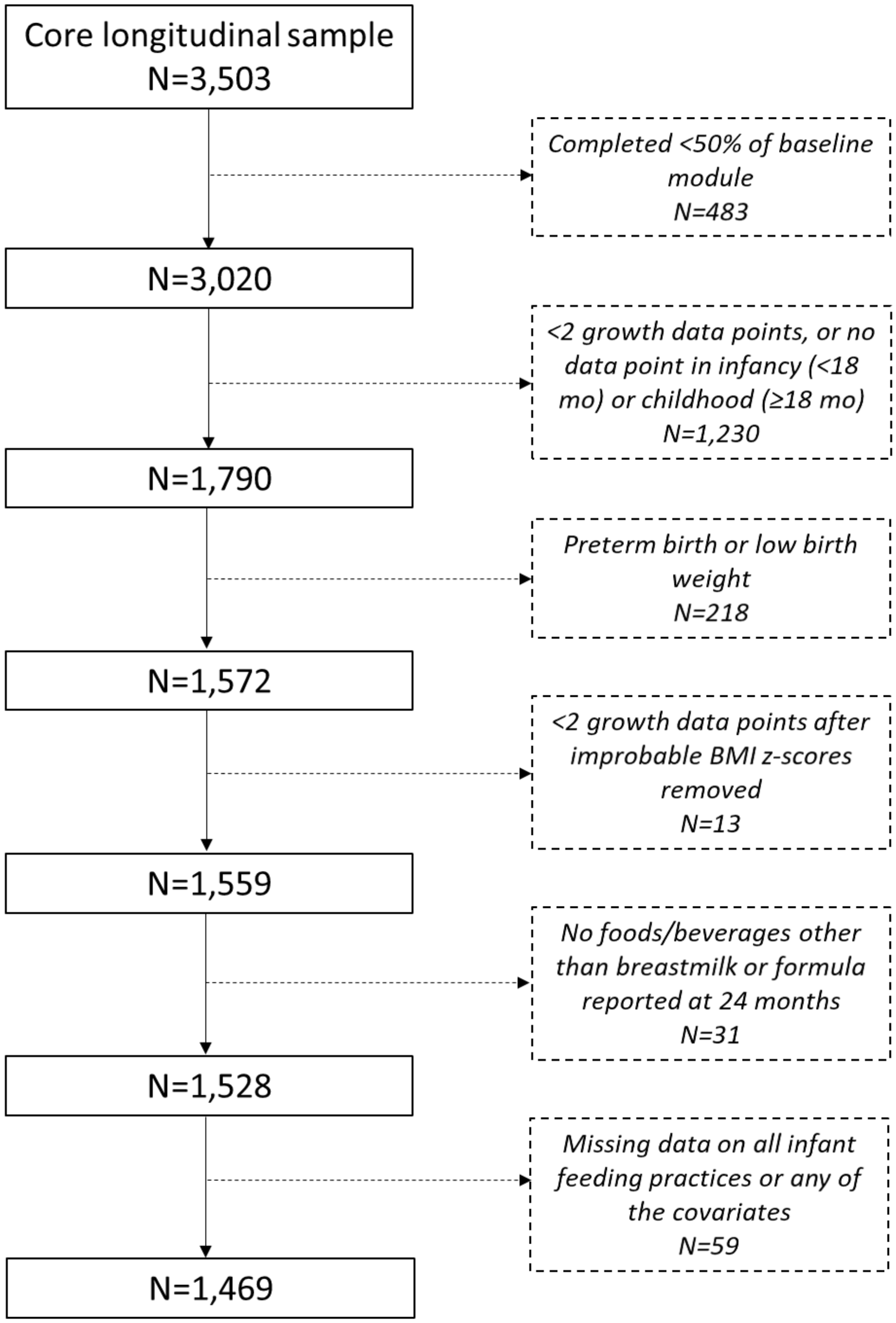
This section describes the steps I took to construct the analytic sample for the studies in this dissertation. The analytic sample (Figure 7) was limited to children in the core longitudinal sample who had at least two growth data points, one of which was during the early infancy period from 0 through <18 months and one of which was during the early childhood period from 18-40 months, to allow modeling of longitudinal weight trajectories.

The core longitudinal sample in the WIC ITFPS-2 study was comprised of 3,503 participants who consented and enrolled in the WIC ITFPS-2 study. Of this sample, 3,020 (86.2%) completed at least 50% of the core baseline module questions and were therefore eligible to continue in the study. Of these 3,020 children, 1,230 were excluded from my analytic sample because they did not have at least two growth data points, one of which was in early infancy (0 to <18 months) and one of which was in early childhood (18 to 40 months). An additional 218 infants were excluded because they were born preterm or low birth weight, and preterm and low birth weight infants have unique weight trajectories.

Next, observations with possibly implausible measurements were identified and examined. Specifically, subjects with extreme BMI-for-age, weight-for-age, length-for-age, or weight-for-length z-scores (as defined by the WHO) or those who had a documented weight or height measurement that was lower than an earlier measurement were visually examined, and clearly implausible measurements were excluded (e.g., length recorded at 36 months was identical to length recorded at 24 months). In the case that measurements were not clearly implausible, an objective method was utilized to determine outliers. Specifically, a series of scores representing the difference between each of the measurements (e.g., [weight-for-age at time 2] – [weight-for-age at time 1]) were calculated and plotted to identify outliers. Seventy-eight subjects were flagged as having potentially implausible measurements; of these, 54 measurements were deemed implausible. After implausible BMI-for-age z-scores were excluded, the majority still had two valid measurements and were retained in the sample. A total of n=13 subjects no longer met the inclusion criteria of having measurements both in early infancy and early childhood, and therefore were excluded from the sample.

Among a small sample of children (n=31), caregivers reported that they had not been given anything besides breast milk or formula at 24 months of age. As this is highly unusual, these observations were removed from the sample as it is likely that either the data were misreported, or the children are not representative of the broader population of children. Finally, subjects who were missing data on all of the infant feeding practices examined in the analyses (n=20) or any of the covariates (n=39) were removed from the analytic sample. Therefore, the final analytic sample for the research questions addressed in this dissertation was 1,469 infants with at least two plausible growth data points who were not born preterm or low birth weight and had been introduced complementary foods before 2 years of age.

Figure 7. Analytic Sample Flow Chart



Differences Between Analytic Sample and Those Excluded

Compared to those excluded, those in the analytic sample were more likely to be Hispanic (48% vs. 39%, $p<.0001$). Compared to mothers of children who were excluded, mothers of children in the analytic sample were older (mean age of 26.3 years vs. 25.7 years, $p<.01$), more likely to be married (33% vs. 29%, $p<.05$) and have greater than a high school education (40% vs. 35%, $p<.01$), and less likely to have smoked during pregnancy (10% vs. 13%, $p=.04$). There were no differences by sex of the child or household poverty level between the sample and those excluded.

Measures

Dependent Variables

Weight: The WIC ITFPS-2 Study aimed to gather children's weight and length/height measurements at the following times between birth and 3 years of age: 6 months, 12 months, 24 months, and 36 months. Weight was operationalized two ways: a continuous BMI-for-age z-score (BMIZ) and a dichotomous overweight/obesity classification. BMI-for-age z-scores were generated using the WHO igrowup SAS package (2007).

1) BMI-for-age z-scores: In order to maintain consistency in assessing the weight trajectory, BMIZ based on WHO growth standard charts were used to assess weight between 6 months and 3 years of age, despite the common practice in U.S. clinical settings of transitioning to CDC growth standards at 2 years of age.

2) Overweight/obesity: BMIZ cut-points of >2.0, and >3.0 are recommended by the WHO to classify children 0-5 years of age as overweight and obese, respectively (WHO, 2008). For analyses, children's weight status was dichotomized into overweight/obese (BMIZ >2) vs not overweight/obese (BMIZ $\leq$2) at ages 2 and 3 years.

Independent Variables

Duration of Any Breastfeeding: At each interview, the caregiver was asked the age at which the baby completely stopped breastfeeding ("How old was {CHILD} when you completely stopped breastfeeding or feeding [HIM/HER] breastmilk from a bottle?"). Breastfeeding duration could be reported in days, weeks, months, or years; all reported values were converted to months for analysis. If children were never breastfed, duration of breastfeeding was assigned a value of 0 months.

Duration of Exclusive Breastfeeding: At each interview, the caregiver was asked to report when the infant started receiving formula every day ("How old was {CHILD} when (he/she) was first fed formula every day?"). Exclusive breastfeeding was considered terminated when a) infants started receiving formula every day, or b) infants were introduced complementary foods, whichever age was earlier. Therefore, duration of exclusive breastfeeding was assigned as the earlier value of either introduction of formula every day or introduction of complementary foods, minus one day. Values could be reported in days, weeks or months and were converted to months for analysis. If children were never breastfed, duration of exclusive breastfeeding was assigned a value of 0 months. Of note, mothers were also asked the age at which the infant first received formula; however, I selected the age at which the infant first started receiving formula every day as the end of exclusive breastfeeding as receiving formula one time or infrequently may have very different impacts on metabolism and growth compared to consumption every day. In addition, with this operationalization, rates of exclusive breastfeeding at 3 months of age were similar to those reported in the WIC Infant and Toddler Feeding Practices Study-2 reports (May et al., 2017).

Timing of Introduction of Complementary Foods: At each interview, caregivers reported whether the infant had received complementary foods or beverages ("Has {CHILD} been given anything to eat or drink besides formula or breastmilk?"). Subsequently, caregivers who responded affirmatively were asked to report the age at which the infant received a series of complementary foods ("For each of the following, please tell me if {CHILD} has been given this food or drink, and if so, how old {CHILD} was when he/she first had that food."). For example, caregivers were asked "Has [HE/SHE] been given soda or soft drinks?; (*IF YES)* How old was {CHILD} when [HE/SHE] was first fed soda or soft drinks?" (see Table 2 for complete list of complementary foods and beverages). Age of introduction was reported in either weeks or months and was be converted to months for analyses.

The timing of introduction of complementary foods was operationalized as the earliest age at which the caregiver reported introduction to any of the foods or beverages, excluding water. The 24-month interview was the last interview at which the complementary foods module was administered. If caregivers reported at 24 months that the child had not been given a food, the timing of introduction of the food was top-coded as 24 months; in other words, timing of introduction of a complementary food was assigned as 24 months if the child was introduced the food *at or after* 24 months (see Appendix Table A1 for the number of children this top-coding was applied to for each food category).

Table 2. List of Complementary Foods and Beverages for Which Age of Introduction was Reported by Caregiver[1]

Food or Beverage	Specifications provided by interviewer
Soda or soft drinks	N/A
Other sweetened beverages	Such as Kool Aid, Hi-C, Fruit Punch, sweetened juice, sweetened or flavored water, Gatorade, or sweet tea.
100% fruit juice	Such as apple juice, orange juice, or other types of 100% juice. Do not include fruit-flavored drinks with added sugar or fruit juice you made at home and added sugar to.
Other drinks and liquids	Including teas and broths.
Cow's milk	Including whole milk, 2%, 1%, or skim. Include milk you add to other foods such as cereal.
Other dairy products	Dairy products other than cow's milk including cheese, yogurt, or goat's milk.
Baby cereal	Either with a spoon, or by adding it to a bottle of breastmilk or formula.
Other cereal	Besides baby cereal.
Eggs	N/A
Fruit	Including baby food or regular fruit.
Vegetables	Including baby food or regular vegetables.
Beans	Such as black beans, pinto beans, or chick peas.
Peanut butter	N/A
Meats	Meats, chicken, or fish, including baby food and baby food combination dinners containing these foods.
Salty snacks	Such as chips, pretzels, crackers, or other snack foods including baby snacks.
Sweets	Such as cake, cookies, candy, or jam.

[1]Excluding water

Timing of Introduction of Sugar-sweetened Foods and Beverages: This variable was operationalized as the earliest age at which caregivers report introduction of soda or soft drinks, other sweetened beverages (such as Kool Aid, Hi-C, Fruit Punch, sweetened juice, sweetened or flavored water, Gatorade, or sweet tea), or sweets (such as cake, cookies, candy, or jam). In addition, a sensitivity analysis was performed by modifying the definition of sugar-sweetened foods and beverages. In addition to soda/soft drinks, other sweetened beverages, and sweets, the “other dairy products” category was included, as research suggests that yogurt contributes 18% of the added sugar to infants’ diets (Herrick et al., 2020).

Covariates

The following variables were included as covariates based on prior research. They represent variables that were measured in the study that have been demonstrated in the literature to be related either to infant feeding practices or to early childhood obesity.

Race/ethnicity: Caregivers were asked at enrollment or at the 1-month interview the infant’s race (“What is {CHILD’S} race? American Indian or Alaska Native; Asian; Black or African American; Native Hawaiian or other Pacific Islander; White; Other”) and ethnicity (“Is {CHILD} Hispanic or Latino?”). For analyses, a combined race/ethnicity variable was created and operationalized as Hispanic (Hispanic ethnicity, of any race), non-Hispanic white (non-Hispanic ethnicity, white race), non-Hispanic Black (non-Hispanic ethnicity, Black race), and other.

Age of mother at childbirth: Maternal age was operationalized as a three-category variable summarizing age at birth as 16-19 years, 20-25 years or ≥26 years.

Mother’s marital status: Caregivers were asked to report their marital status at the first interview (“Are you married, separated, divorced, widowed, or never married?”) In the publicly available data set, marital status was dichotomized into married or not married (including divorced or widowed). This binary variable was used for analyses.

Weight status of mother at screening: At the time of screening, the mother's BMI is calculated and classified as normal or underweight (BMI<25), overweight (BMI 25 to <30) or obese (BMI ≥30).

Household poverty level: Participants were asked to report their household income during screening, and classified according to the 2013 Federal Poverty Level (FPL) as ≤75%, >75 but ≤130% FPL, or >130% FPL. Of note, household income must be ≤185% FPL to qualify for WIC, so the latter category will be described as >130 but ≤185% FPL.

Household food security: Household food security was measured at screening through administration of the USDA Six-Item Food Security Module, which asks if households experienced any of the following symptoms of food insecurity during the past 12 months: 1) " 'The food (I/we) bought just didn't last, and (I/we) didn't have money to get more.' Was that often, sometimes, or never true…"; 2) " '(I/we) couldn't afford to eat balanced meals.' Was that often, sometimes, or never true…"; 3) "…[D]id (you/you or other adults in your household) ever cut the size of your meals or skip meals because there wasn't enough money for food?"; 4) [If yes to 3, ask] "How often did this happen – almost every month, some months but not every month, or in only 1 or 2 months?"; 5) "…[D]id you ever eat less than you felt you should because there wasn't enough money for food?"; 6) "…[W]ere you ever hungry but didn't eat because there wasn't enough money for food?"

Respondents were classified as having high or marginal, low, or very low food security based on the number of affirmative responses. Responses of "often" or "sometimes" on questions 1 and 2, "yes" on questions 3, 5, and 6 and "almost every month" or "some months but not every month" were coded as affirmative. Affirmative responses were summed to create a score. Those with scores of 0-1 were classified as having high or marginal food security; those with scores of

2-4 were classified as having low food security; and those with scores of 5-6 were classified as having very low food security.

Delivery type: Mode of delivery was asked of mothers during the 1-month interview ("How was your baby delivered? Vaginally and not induced; vaginally and induced; a planned caesarean or c-section; or an unplanned or emergency caesarean or c-section.") In the publicly available dataset, delivery type was dichotomized into vaginal or caesarean.

Smoking during pregnancy: At the first follow-up interview, mothers were asked to report their cigarette use during pregnancy ("During your pregnancy with {CHILD}/(*PN [Prenatal interview]:* currently), about how many cigarettes did you smoke/(*PN:* do you smoke) on an average day? Just your best estimate is fine." In the publicly available dataset, cigarette use was a categorical variable (did not smoke, 1-9 cigarettes, or 10-20 cigarettes). For analyses, smoking during pregnancy was dichotomized as yes (smoked ≥1 cigarette per day) or no (did not smoke).

Analytic Strategy

All data were cleaned and analyzed using SAS Version 9.4 (SAS Institute, Inc., Cary, North Carolina). First, univariate distributions of all variables were examined using histograms, frequencies for categorical variables and measures of central tendency and dispersion (e.g., mean and standard deviation) for continuous variables.

For research questions that explored the relationship between infant feeding practices and BMIZ trajectories (questions 1.1, 2.1, and 3.1), linear mixed effects regression models were used. Linear mixed effects models are an extension of linear models that allow for non-independence of observations. In the case of WIC ITFPS-2 data, the non-independence stems from repeated measurements taken on individual subjects. Specifically, the models take into account that the BMIZ observations for each individual child are correlated.

Several additional specifications were made to the models. First, as the analyses used measurements obtained from children starting at approximately 6 months of age, the age variable was centered at 6 months. As such, the intercepts represented predicted BMIZ at age 6 months (and values of zero for other covariates in the model), which a) allowed for meaningful interpretation and b) prevented extrapolation of results to birth (age 0), for which we did not have data to support. Second, models incorporated a random intercept (to allow children to vary in their initial BMI) and random slope (to allow children to vary in their linear trends over time). Third, an age polynomial term was included in the model to reflect the nonlinearity in children's weight trajectories between 6 months and 3 years of age (WHO, 2006). Model fit statistics were used to determine the appropriate order of the polynomial; models with an age^3 term did not significantly improve model fit, so age^2 models were determined to sufficiently reflect the nonlinearity of children's weight trajectories. Fourth, to understand whether weight trajectories varied over time between the infant feeding practice groups, age*infant feeding practice interaction terms were included in the models. Figure 8 provides an example of the model equation and interpretation of regression coefficients.

Two primary sensitivity analyses were conducted for the linear mixed effects models. First, as there is disagreement as to whether BMI or weight-for-length estimates are superior in assessing adiposity and early risk of obesity (Roy et al., 2016), sensitivity analyses were conducted using weight-for-length z-scores rather than BMI-for-age z-scores. Second, model diagnostics were performed by examining residuals to understand whether the model fit the data well over the full age range from six months to 3 years.

*Figure 8. Interpretation of coefficients in example linear mixed effects model with age*infant feeding practice interaction*

$$BMIz = \beta_0 + \beta_1 * BF + \beta_2 * age + \beta_3 * age * BF + \beta_4 * age^2 + \beta_5 * age^2 * BF$$

Notes:
- BF = breastfeeding groups, assume 2 groups: BF <6 months (ref) vs. BF ≥6 months
- Assume age is centered at 6 months

β_0: mean BMIZ at 6 months for children BF <6 months
($\beta_0 + \beta_1$): mean BMIZ at 6 months for children BF ≥6 months
β_2: slope at age 6 months for children BF<6 months, i.e., average monthly increase in BMIZ at age 6 months
($\beta_2 + \beta_3$): slope at age 6 months for children BF ≥6 months
β_4: degree of curvature of the quadratic trend for children BF <6 months
($\beta_4 + \beta_5$): degree of curvature of the quadratic trend for children BF ≥6 months

If β_1 is statistically significant, the mean BMIZ at age 6 months is different between BF groups.
If β_3 is statistically significant, the slope (or average monthly BMIZ increase at age 6 months) is different between BF groups.
If β_5 is statistically significant, the BF groups have different quadratic trends over time.

For research questions that explored the relationship between infant feeding practices and odds of overweight/obesity (questions 1.2, 1.3, 2.2, 2.3, and 3.2), logistic mixed effects regression models with a random intercept for subjects were used. Logistic mixed effects models similarly extend generalized linear models by incorporating correlation among the responses. In other words, the model takes into account that a child who is overweight at age 2 will be more likely to be overweight at age 3 compared to a child who is not overweight at age 2 years.

Sample Characteristics

This section provides a brief overview of the characteristics of the analytic sample. As all analyses are stratified by sex due to variations in growth patterns between boys and girls, the data presented here are also sex stratified.

The demographic characteristics of the analytical sample are summarized in Table 3.

Table 3. Demographic characteristics of the analytic sample, by sex (n=1,469)

	Total (n=1,469) *N (%)*	Male (n=755) *N (%)*	Female (n=714) *N (%)*
Race/ethnicity			
Hispanic	707 (48)	344 (46)	363 (51)
Non-Hispanic White	371 (25)	192 (25)	179 (25)
Non-Hispanic Black	271 (18)	157 (21)	114 (16)
Non-Hispanic Other	120 (8)	62 (8)	58 (8)
Household poverty level[a]			
≤75%	912 (62)	473 (63)	439 (61)
>75 to 130%	412 (28)	198 (26)	214 (30)
>130 to 185%	145 (10)	84 (11)	61 (9)
Household food security			
High or Marginal	777 (53)	404 (54)	373 (52)
Low	460 (31)	240 (32)	220 (31)
Very low	232 (16)	111 (15)	121 (17)
Maternal age at birth (years)			
16-19	144 (10)	74 (10)	70 (10)
20-25	593 (40)	312 (41)	281 (39)
≥26	732 (50)	369 (49)	363 (51)
Maternal marital status			
Married	482 (33)	241 (32)	241 (34)
Not married[b]	987 (67)	514 (68)	473 (66)
Maternal education level			
HS or less	875 (60)	441 (58)	434 (61)
More than HS	594 (40)	314 (42)	280 (39)
Maternal weight[c]			
Normal/underweight	666 (45)	331 (44)	335 (47)
Overweight	354 (24)	180 (24)	174 (24)
Obese	449 (31)	244 (32)	205 (29)
Delivery type			
Vaginal	1009 (69)	512 (68)	497 (70)
Caesarean	460 (31)	243 (32)	217 (30)
Maternal smoking status during pregnancy			
Did not smoke	1315 (90)	679 (90)	636 (89)
Smoked ≥1 cigarette per day	154 (10)	76 (10)	78 (11)

[a] relative to 2013 federal poverty guidelines; [b] including divorced and widowed; [c] weight status at the time of screening

Note: Percentages may not sum to 100 due to rounding

Approximately half of the children were Hispanic (48%), one quarter were non-Hispanic White (25%), and 18% were non-Hispanic Black. Just over half were male (51%). The majority of children (62%) lived in households at or below 75% of the 2013 FPL. Nearly half of the children lived in food insecure households, with 31% of households experiencing low food security and 16% of experiencing very low food security. Half of the mothers were 26 years or older at the time of birth. Approximately two-thirds of the mothers were not married (67%) and the majority had at most a high school education (60%). Approximately one quarter of mothers were overweight (24%), and 31% were obese. Nearly one in three infants were delivered via cesarean section (31%), and one in ten mothers reported smoking during pregnancy (10%). Chi-square tests indicated that there were no differences in demographic characteristics between boys and girls.

Outcome Measures

This section provides a summary of the dependent variables examined in the studies, BMI-for-age z-scores and overweight/obesity.

BMI-for-Age Z-Scores

Table 4 and Figure 9 illustrate the distribution of BMIZ at ages 6 months, 1 year, 2 year, and 3 years of age. Weight and height measurements were available for n=1,149 (78% of the analytic sample) at 6 months of age, n=1,262 (86% of the sample) at 1 year of age, n=1,113 (76% of the sample) at 2 years of age and n=1,128 (77% of the sample) at 3 years of age (Table 4). The distribution of BMIZ were approximately normal for all measurement occasions (Figure 9), with means of 0.68 at 6 months, 1.00 at 1 year, 1.09 at 2 years and 0.82 at 3 years of age (Table 4).

All children in the sample had at least two measurements, one from infancy (6 month or 1-year measurement occasion) and one from early childhood (2-year or 3-year measurement occasion), as described in the inclusion criteria. Approximately 37% of children (n=545) had measurement data at all four measurement occasions from 6 months to 3 years of age, while 42%

(n=624) had data at three measurement occasions and 20% (n=300) had data at two measurement occasions.

Table 4. Mean BMI-for-age z-score at each measurement occasion

Measurement Age[a]	N	BMI-for-age z-score *Mean (SD)*
6 months	1,149	0.68 (1.16)
1 year	1,262	1.00 (1.12)
2 year	1,113	1.09 (1.23)
3 year	1,128	0.82 (1.26)

Measurement Age: 6 month measurements taken <9 months of age; 1 year measurements taken between 9 - <18 months of age; 2 year measurements taken between 18 - <30 months of age; 3 year measurements taken between 30 – 39 months of age.

Overweight/obesity

Table 5 summarizes the proportion of children in the analytic sample who were classified as overweight or obese, indicated by a BMIZ > 2, at ages 2 and 3 years, stratified by sex. At two years of age, approximately one in five children (20% of boys and 22% of girls) were considered overweight or obese. At three years of age, 13% of boys and 17% of girls were classified as overweight or obese.

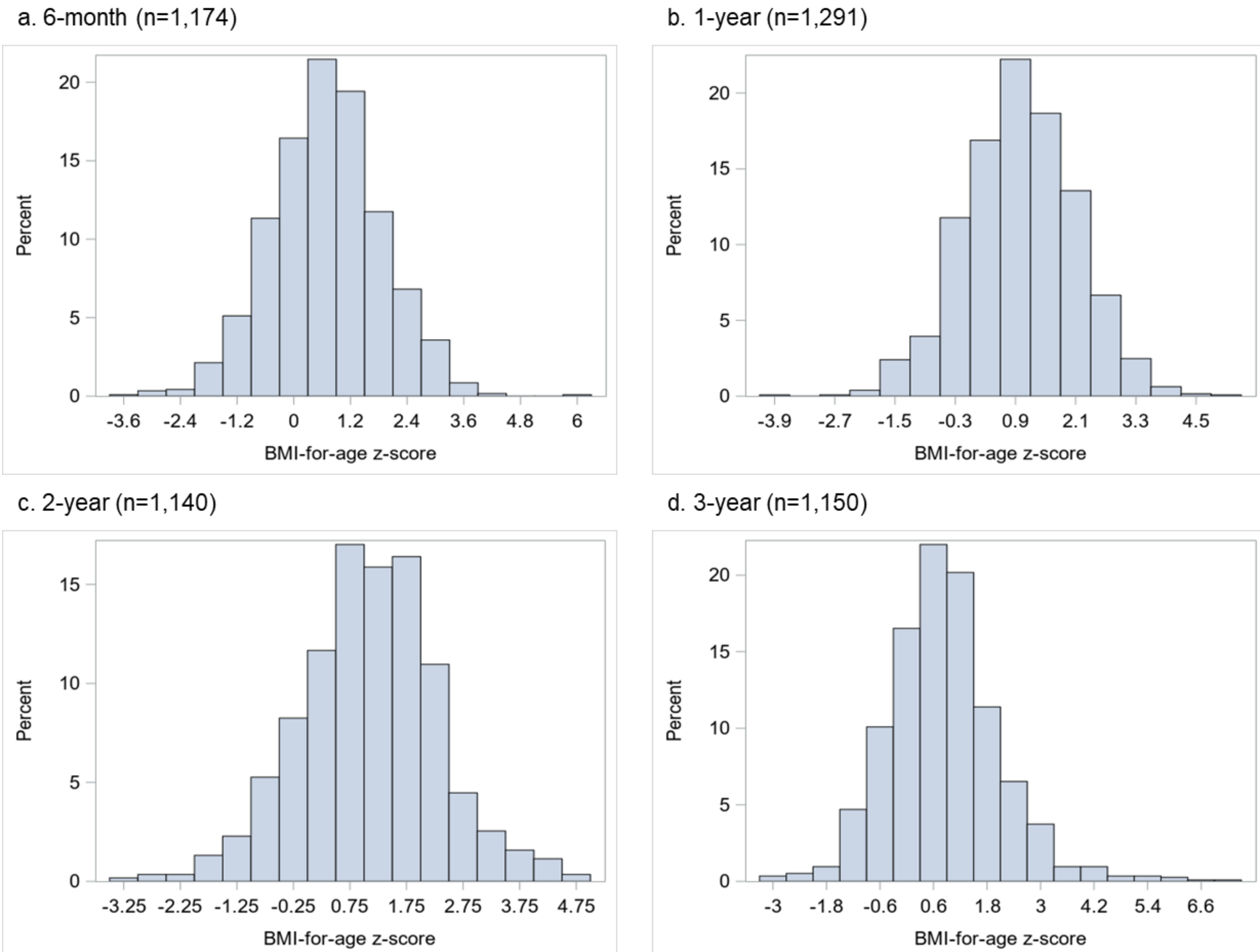
Table 5. Percent of sample overweight/obese at ages 2 and 3 years, stratified by sex

Age[a]	Male (n=776)		Female (n=727)	
	N	*% overweight or obese*[b]	*N*	*% overweight or obese*[b]
2 years	561	20	552	22
3 years	594	13	534	17

[a] 2 years = measurements taken between 18 to <30 mos; 3 years = measurements taken between 30 – 39 mos

[b] BMI-for-age z-score >2

Figure 9. Distribution of BMI-for-age z-scores at 6-month, 1-year, 2-year, and 3-year measurement occasions



CHAPTER 5: STUDY ONE – RESULTS AND DISCUSSION

Overview of Aim, Hypotheses and Methods

The aim of Study 1 was to understand the influence of breastfeeding on weight trajectories in early childhood. First, I examined the relationship between BMIZ trajectories and duration of any breastfeeding (question 1.1a) and duration of exclusive breastfeeding (question 1.1b). Next, I tested the relationship between overweight/obesity at ages 2 to 3 years and duration of any breastfeeding (question 1.2a) and duration of exclusive breastfeeding (question 1.2b). Finally, I tested whether there was a dose response relationship between breastfeeding duration and intensity and overweight/obesity (question 1.3).

I hypothesized that longer durations of both *any breastfeeding* (exclusive or partial) and *exclusive breastfeeding* would be associated with healthier weight trajectories (BMIZ over time closer to 0) and reduced odds of overweight/obesity. In addition, I hypothesized a dose-response relationship between breastfeeding intensity and duration and risk of overweight/obesity, such that longer durations of *exclusive breastfeeding* would be associated with lower odds of overweight/obesity compared to longer durations of *partial breastfeeding.*

Sample Characteristics and Key Variable Distributions

Breastfeeding Duration

To understand the relationship between breastfeeding duration and weight trajectories, both duration of *any breastfeeding* (ABF, breastfeeding with or without formula and/or complementary foods) and duration of *exclusive breastfeeding* (EBF, only breast milk) were explored independently.

Duration of ABF was available for n=1,445 children (98% of the analytic sample). Demographic characteristics of the sample are summarized in Table 6. Compared to boys who were excluded from the sample (n=16), boys retained in the sample were more likely to have mothers who were not married (69% vs. 44%). There were no differences in demographic characteristics between girls who were retained in the sample and those who were excluded (n=8).

Table 6. Demographic characteristics of sample with duration of any breastfeeding data, by sex (n=1,445)

	Male (n=739) *N (%)*	Female (n=706) *N (%)*
Race/ethnicity		
Hispanic	335 (45)	358 (51)
Non-Hispanic White	188 (25)	178 (25)
Non-Hispanic Black	155 (21)	113 (16)
Non-Hispanic Other	61 (8)	57 (8)
Household poverty level[a]		
≤75%	466 (63)	435 (62)
>75 to 130%	192 (26)	211 (30)
>130 to 185%	81 (11)	60 (9)
Household food security		
High or Marginal	394 (53)	368 (52)
Low	236 (32)	217 (31)
Very low	109 (15)	121 (17)
Maternal age at birth (years)		
16-19	73 (10)	69 (10)
20-25	305 (41)	278 (39)
≥26	361 (49)	359 (51)
Maternal marital status		
Married	232 (31)	240 (34)
Not married[b]	507 (69)*	466 (66)
Maternal education level		
HS or less	428 (58)	431 (61)
More than HS	311 (42)	275 (39)
Maternal weight[c]		
Normal/underweight	325 (44)	330 (47)
Overweight	178 (24)	172 (24)
Obese	236 (32)	204 (29)
Delivery type		
Vaginal	502 (68)	489 (69)
Caesarean	237 (32)	217 (31)

Maternal smoking status during pregnancy		
Did not smoke	663 (90)	629 (89)
Smoked ≥1 cigarette per day	76 (10)	77 (11)

* Significantly different compared to those excluded from the sample (chi-square test, $p<0.05$)
[a] relative to 2013 federal poverty guidelines; [b] including divorced and widowed; [c] weight status at the time of screening
Note: Percentages may not sum to 100 due to rounding

Approximately 1 in 6 boys (17%) and 1 in 8 girls (13%) were never breastfed. Among children who were ever breastfed, the mean duration of ABF was 4.7 months for boys and 4.5 months for girls (Figures 10 and 11).

Figure 10. Duration of any breastfeeding among children who were ever breastfed, WIC ITFPS-2 Study (male children, n=611)

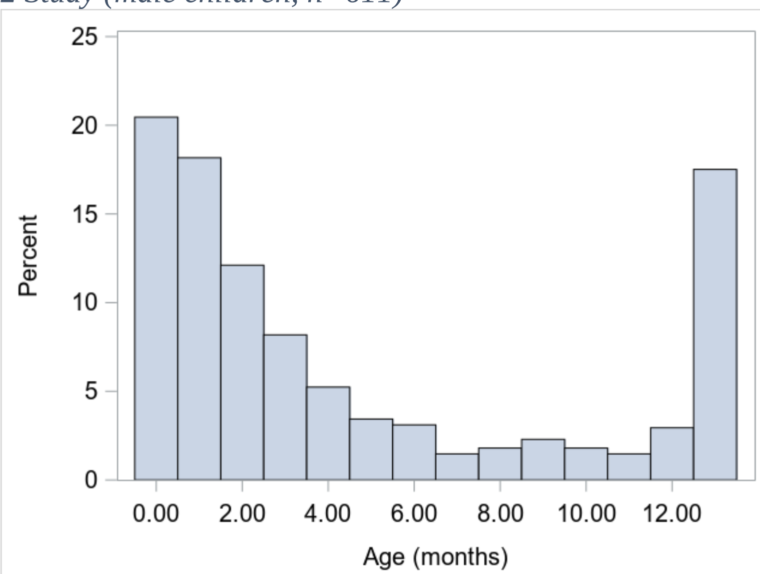
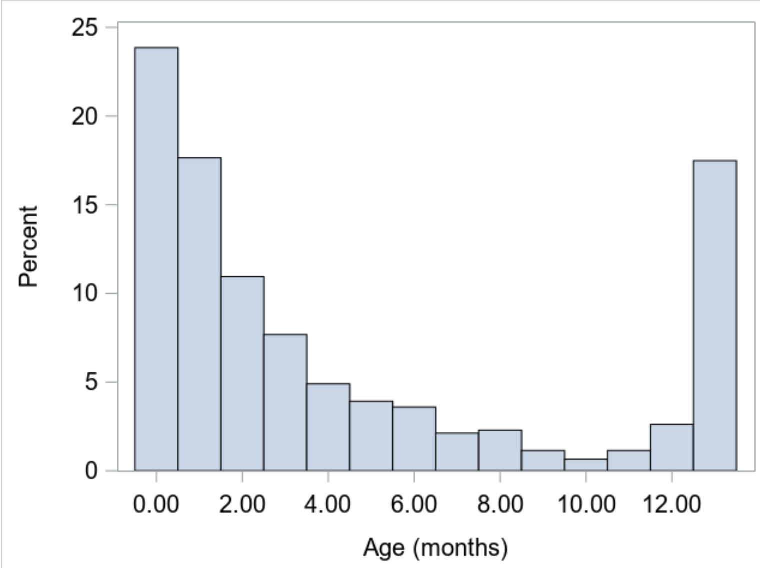


Figure 11. Duration of any breastfeeding among children who were ever breastfed, WIC ITFPS-2 Study (female children, n=612)



For analyses, a 3-category variable was created to indicate whether children were never breastfed, breastfed for less than 6 months, or breastfed for 6 or more months. Table 7 summarizes ABF duration stratified by sex. The majority of children were breastfed, but for a duration of less than 6 months (56% of males and 60% of females). Among both boys and girls, fewer than one third (27%) were breastfed for at least 6 months.

Table 7. Duration of Any Breastfeeding Stratified by Child Sex (N=1,445)

	Male (n=739) *N (%)*	Female (n=706) *N (%)*
Never Breastfed	128 (17)	94 (13)
Breastfed <6 months	413 (56)	423 (60)
Breastfed ≥6 months	198 (27)	189 (27)

Duration of EBF (exclusive breastfeeding) was available for n=1,393 children (95% of the analytic sample). Demographic characteristics of the sample are summarized in Table 8. Compared to boys who were excluded from the sample (n=35), boys retained in the sample were less likely to have mothers who were at least 26 years of age (48% vs. 69%) (Table 8). There were no differences in demographic characteristics between girls who were retained in the sample and those who were excluded (n=41).

Table 8. Demographic characteristics of sample with duration of exclusive breastfeeding data, by sex (n=1,393)

	Male (n=720) *N (%)*	Female (n=673) *N (%)*
Race/ethnicity		
Hispanic	329 (46)	340 (51)
Non-Hispanic White	184 (26)	167 (25)
Non-Hispanic Black	149 (21)	109 (16)
Non-Hispanic Other	58 (8)	57 (8)
Household poverty level[a]		
≤75%	449 (62)	411 (61)
>75 to 130%	189 (26)	205 (30)
>130 to 185%	82 (11)	57 (8)
Household food security		
High or Marginal	386 (54)	352 (52)
Low	232 (32)	206 (31)
Very low	102 (14)	115 (17)
Maternal age at birth (years)		
16-19	70 (10)	67 (10)
20-25	305 (42)	263 (39)
≥26	345 (48)*	343 (51)
Maternal marital status		
Married	229 (32)	222 (33)
Not married[b]	491 (68)	451 (67)
Maternal education level		
HS or less	422 (59)	411 (61)
More than HS	298 (41)	262 (39)
Maternal weight[c]		
Normal/underweight	314 (44)	317 (47)
Overweight	169 (23)	166 (25)
Obese	237 (33)	190 (28)
Delivery type		
Vaginal	492 (68)	473 (70)
Caesarean	228 (32)	200 (30)
Maternal smoking status during pregnancy		
Did not smoke	646 (90)	600 (89)
Smoked ≥1 cigarette per day	74 (10)	73 (11)

* Significantly different compared to those excluded from the sample (chi-square test, p<0.05)
[a] relative to 2013 federal poverty guidelines; [b] including divorced and widowed; [c] weight status at the time of screening
Note: Percentages may not sum to 100 due to rounding

Approximately one in five children were never exclusively breastfed (22% of boys and 20% of girls). Among children who were ever EBF, the mean duration was 1.6 months for boys and 1.4 months for girls. For analyses, a 3-category variable was created to indicate whether children were never EBF, EBF for less than 3 months, or EBF for 3 or more months. Table 9 summarizes EBF duration by sex. Among boys, 61% were EBF for less than three months while 17% were EBF for at least 3 months. Similarly, among girls, 65% were EBF for less than three months while 15% were EBF for 3 months or longer. Fewer than 1% of children (n=6 boys and n=1 girl) were EBF for at least 6 months.

Table 9. Duration of Exclusive Breastfeeding Stratified by Child Sex (N=1,393)

	Male (n=720) *N (%)*	Female (n=673) *N (%)*
Never EBF	160 (22)	136 (20)
EBF <3 months	438 (61)	435 (65)
EBF ≥3 months	122 (17)	102 (15)

EBF: exclusively breastfed

Breastfeeding Duration and Intensity

To understand the relationship between intensity of breastfeeding (i.e., exclusive vs. partial) and weight trajectories (question 1.3), children were classified as never breastfed, breastfed for <3 months (i.e., short duration), partially breastfed for at least 3 months (i.e., longer duration but low intensity), or exclusively breastfed for at least 3 months (i.e., longer duration with higher intensity). Three months was selected as the cutoff for comparison of partial breastfeeding and exclusive breastfeeding because, although the recommendation is to exclusively breastfeed for 6 months, less than 1% of the sample achieved this duration. In addition, the 1993 Family and Medical Leave Act provides up to 3 months (12 weeks) of job-protected leave to eligible employees after the birth of a child (U.S. Department of Labor, 2012), and breastfeeding exclusively through 3 months was an objective in Healthy People 2020, the evidence-based 10-year agenda for improving the health of Americans (HHS, 2010).

The characteristics of the sample with complete data on duration of any breastfeeding and exclusive breastfeeding (n=1,369) is summarized in Table 10. There were no differences in demographic characteristics between children who were retained in the sample and those who were excluded (n=100).

Table 10. Demographic characteristics of sample with duration of any breastfeeding and exclusive breastfeeding data, by sex (n=1,369)

	Male (n=704) *N (%)*	Female (n=665) *N (%)*
Race/ethnicity		
Hispanic	320 (45)	335 (50)
Non-Hispanic White	180 (26)	166 (25)
Non-Hispanic Black	147 (21)	108 (16)
Non-Hispanic Other	57 (8)	56 (8)
Household poverty level[a]		
≤75%	442 (63)	407 (61)
>75 to 130%	183 (26)	202 (30)
>130 to 185%	79 (11)	56 (8)
Household food security		
High or Marginal	376 (53)	347 (52)
Low	228 (32)	203 (31)
Very low	100 (14)	115 (17)
Maternal age at birth (years)		
16-19	69 (10)	66 (10)
20-25	298 (42)	260 (39)
≥26	337 (48)	339 (51)
Maternal marital status		
Married	220 (31)	221 (33)
Not married[b]	484 (69)	444 (67)
Maternal education level		
HS or less	409 (58)	408 (61)
More than HS	295 (42)	257 (39)
Maternal weight[c]		
Normal/underweight	308 (44)	312 (47)
Overweight	167 (24)	164 (25)
Obese	229 (33)	189 (28)
Delivery type		
Vaginal	482 (68)	465 (70)
Caesarean	222 (32)	200 (30)

Maternal smoking status during pregnancy		
Did not smoke	630 (89)	593 (89)
Smoked ≥1 cigarette per day	74 (11)	72 (11)

* Significantly different compared to those excluded from the sample ($p<0.05$)
[a] relative to 2013 federal poverty guidelines; [b] including divorced and widowed; [c] weight status at the time of screening
Note: Percentages may not sum to 100 due to rounding

The distribution of breastfeeding duration/intensity is summarized in Table 11. Among boys, 39% were breastfed for at least three months, with 22% having been partially breastfed and 17% having been exclusively breastfed. Similarly, 39% of girls were breastfed for at least three months, with 24% being partially breastfed and 15% being exclusively breastfed.

Table 11. Duration and intensity of breastfeeding among WIC-ITFPS2 Study sample, by sex (n=1,369)

	Male (n=704)	Female (n=665)
	N (%)	*N (%)*
Never BF	128 (18)	94 (14)
BF<3 months	296 (42)	311 (47)
Partially BF >=3m	158 (22)	160 (24)
Exclusively BF >=3m	122 (17)	100 (15)

BF = breastfed

Results

Breastfeeding Duration and Weight Trajectories

Duration of Any Breastfeeding

Mixed effects linear regression models (Table 12) with age centered at 6 months were used to test the relationship between breastfeeding duration and weight trajectories (repeated BMI z-score measurements from 6 months to 3 years of age). Models incorporate a random intercept (to allow for variation in initial BMIs) and random slope (to allow children to vary in their linear trends over time). In addition, the models incorporate an age^2 term since weight trajectories in early childhood are curvilinear. Finally, an interaction between breastfeeding duration and age was included to test whether BMIZ trajectories varied by breastfeeding duration.

Figures 12 and 13 provide a graphical representation of the regression results for boys and girls, respectively, plotting predicted BMIZ between the ages of 6 months and 3 years by duration of any breastfeeding, calculated at the reference value of all covariates. The corresponding predicted BMIZ were also calculated at the reference value for all covariates. Residual diagnostics indicate that the model provided a good fit of the data across all four measurement times from 6 months to 3 years of age for both boys (Appendix Figure B1.1 a) and girls (Appendix Figure B1.1 b). Age-centered models were used to determine statistical significance of the difference in BMIZ by breastfeeding duration at ages 1, 2 and 3 years by changing the age at which values were centered.

The models suggest that, controlling for race/ethnicity, delivery type, household poverty level and food security status, and maternal age, marital status, education level, and smoking status, there was a significant relationship between breastfeeding duration and BMIZ trajectories during the first three years of life. The significant interactions between age and breastfeeding duration suggest that the trajectories differed for both boys and girls across the categories of breastfeeding duration.

Table 12. Mixed Effects Linear Regression Models: Association Between Duration of Any Breastfeeding and Repeated BMI-for-age z-scores, WIC ITFPS-2 Study (n=1,445)

Coefficients	Male (n=739) β (SE)	Female (n=706) β (SE)
Intercept	0.436 (0.147)**	0.534 (0.147)***
Breastfeeding Duration		
Never BF (ref)	-	-
<6 mo	0.191 (0.122)	0.105 (0.127)
≥6 mo	0.333 (0.141)*	0.145 (0.143)
Age (months)	0.074 (0.014)***	0.089 (0.015)***
Age^2	-0.002 (0.000)***	-0.003 (0.000)***
Age*Breastfeeding Duration		
Age*Never BF (ref)	-	-
Age*<6 mo	-0.017 (0.016)	-0.026 (0.016) †
Age*≥6 mo	-0.055 (0.017)**	-0.068 (0.018)***
Age^2*Breastfeeding Duration		
Age^2*Never BF (ref)	-	-
Age^2*<6 mo	0.000 (0.000)	0.001 (0.001)
Age^2*≥6 mo	0.002 (0.001)**	0.002 (0.001)***
Maternal marital status		
Not married[a] (ref)	-	-
Married	-0.036 (0.086)	0.012 (0.085)
Maternal education level		
HS or less (ref)	-	-
More than HS	-0.025 (0.078)	-0.078 (0.079)
Household poverty level[b]		
≤75% (ref)	-	-
>75 to 130%	0.072 (0.085)	0.279 (0.084)**
>130%	0.006 (0.120)	0.004 (0.137)
Race/ethnicity		
Hispanic (ref)	-	-
NH-Black	-0.195 (0.098)	-0.254 (0.106)*
NH-White	-0.127 (0.094)	-0.181 (0.096)
Other	-0.179 (0.140)	-0.067 (0.140)
Maternal weight[c]		
Normal/Underweight (ref)	-	-
Overweight	0.062 (0.092)	0.125 (0.091)
Obese	0.123 (0.085)	0.203 (0.088)*
Maternal age		
26+ years (ref)	-	-

Coefficients	Male (n=739) β (SE)	Female (n=706) β (SE)
20-25 years	0.049 (0.078)	-0.107 (0.082)
16-19 years	0.136 (0.135)	-0.031 (0.137)
Household food security		
High/Marginal (ref)	-	-
Low	-0.092 (0.080)	0.049 (0.082)
Very Low	0.008 (0.108)	0.029 (0.103)
Delivery Type		
Vaginal (ref)	-	-
Caesarean	0.106 (0.077)	0.037 (0.081)
Smoked during pregnancy		
No (ref)	-	-
Yes	0.415 (0.131)**	0.301 (0.126)*

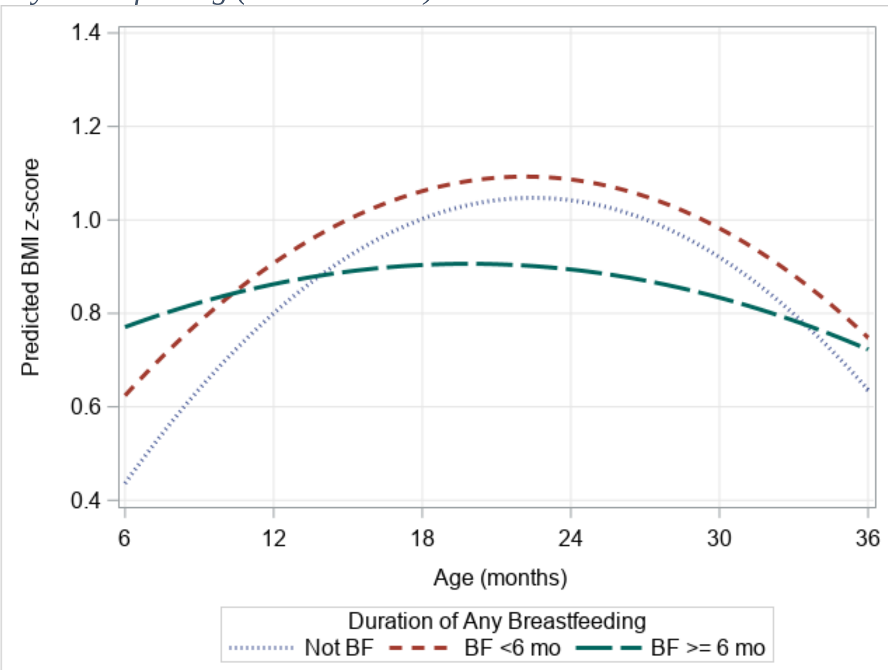
* p < 0.05, ** p < 0.01, *** p < 0.001

Note: age is centered at 6 months; BF=breastfed

[a]including divorced and widowed; [b]relative to 2013 federal poverty guidelines; [c] weight status at the time of screening

Among boys, while those with longer durations of breastfeeding (≥6 months) had higher predicted BMIZ at 6 months of age compared to those who were never breastfed, (β=.33, p=.02), the slope of their weight trajectory at 6 months was flatter by 0.06 z-score units per month (β= -.06, p<.01). As such, by approximately 1.5 years of age, predicted BMIZ were higher for children who were never breastfed and those breastfed <6 months compared to children breastfed for at least 6 months (Figure 12). At two years of age, the predicted BMIZ of males BF for at least six months was .19 z-scores lower compared to those breastfed for <6 months (marginally significant, p=.08) and .15 z-scores lower compared to those never breastfed (not statistically significant). There was no difference in BMIZ trajectories between boys who were never BF and boys with shorter BF durations (<6 months). Similarly, age-centered models revealed no difference in BMIZ at ages 1, 2 or 3 years between boys who were breastfed for <6 months compared to those who were never breastfed.

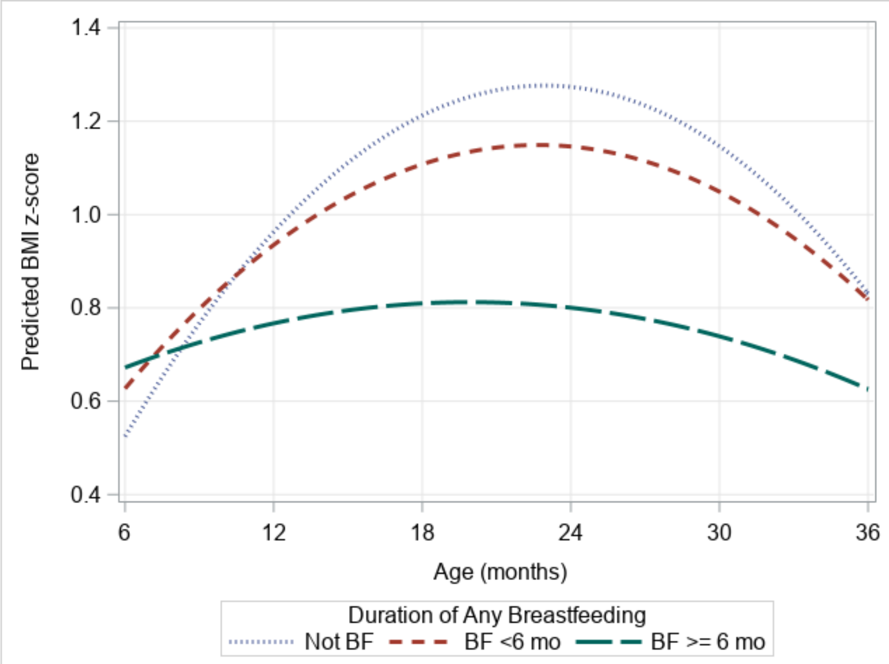
Figure 12. Predicted BMI z-score trajectories from age 6 months to three years by duration of any breastfeeding (male children)



Note: Fit computed at reference categories of all covariates

Among girls, the model suggests no significant difference in BMIZ between breastfeeding duration groups at six months of age (Table 12). However, the slope of the weight trajectory for girls breastfed for six months or more was flatter by 0.07 z-score units per month (β= -.07, p<.001) compared to those never breastfed, meaning that monthly BMIZ increases at 6 months of age were greater for girls who were never breastfed (see Figure 13). Consistent with Figure 13, evaluation of differences in predicted BMIZ using age-centered models indicated no significant difference between girls who were not breastfed and those who were breastfed for <6 months between the ages of 1 to 3 years. However, girls with long durations of breastfeeding (≥6 months) had consistently lower predicted BMIZ over time compared to the other two groups (Figure 13).

Figure 13. Predicted BMI z-score trajectories from age 6 months to three years by duration of any breastfeeding (female children)



Note: Fit computed at reference categories of all covariates

As demonstrated in Figure 13, compared to girls breastfed for <6 months, predicted BMIs of girls breastfed for at least 6 months were 0.17 z-score units lower at one year of age (marginally significant, p=.05), .35 z-score units lower at two years of age (p<.001), and .20 z-score units lower at three years of age (marginally significant, p=.08). Similarly, when compared to girls who were not breastfed, predicted BMIs of girls breastfed for at least 6 months were .20 z-score units lower at 1 year (not statistically significant), .48 z-score units lower at 2 years (p=.001) and .22 z-score units lower at 3 years of age (not statistically significant).

For both boys and girls, similar relationships between duration of breastfeeding and weight trajectories were observed when weight-for-length z-scores were examined instead of BMIZ (Appendix Table B1.1).

Duration of Exclusive Breastfeeding

Mixed effects linear regression models with a random intercept and slope were used to test the association between the duration of EBF and repeated BMIZ measures during the first three years of age (Table 13). Age was centered at 6 months. An interaction between EBF duration and age was included to test whether BMIZ trajectories varied by breastfeeding duration. Figures 14 and 15 provide a graphical representation of the regression results for boys and girls, respectively, plotting predicted BMIZ between the ages of 6 months and 3 years by duration of exclusive breastfeeding, calculated at reference values of all covariates. Predicted BMIZ for between-group comparisons at ages 1, 2, and 3 years were also calculated at covariance reference values. Models with age centered at ages 1, 2, and 3 years were used to determine if between-group differences in predicted BMIZ were statistically significant at these ages. Residual diagnostics indicate that the regression model provided a good fit of the data across all four measurement periods from 6 months to 3 years of age for both boys (Appendix Figure B1.2 a) and girls (Appendix Figure B1.2 b).

Controlling for race/ethnicity, delivery type, household poverty level and food security status, and maternal age, marital status, education level, and smoking status, the models suggest differences in weight trajectories by duration of EBF for both boys and girls (Table 13). Among boys, the model indicated significant differences in weight trajectories between those with long durations of EBF compared to those who were never EBF. At 6 months of age, the slope of the weight trajectory for those EBF for at least 3 months was .07 z-score units lower (β= -.07, $p<.001$) than the slope for children never BF, meaning that BMIZ at 6 months of age were increasing by 0.07 z-score units per month more among children never breastfed compared to those BF for at least 3 months (see Figure 14). Age-centered models revealed significant differences in predicted BMIZ between the breastfeeding duration groups at 2 years of age, but no differences at 1 and 3 years. At 2 years of age, predicted BMIs among the long EBF duration group (≥3 months) were .31 z-score units lower than the short EBF duration group (p=.01) and .32 z-score units lower than the never EBF group (p=.03).

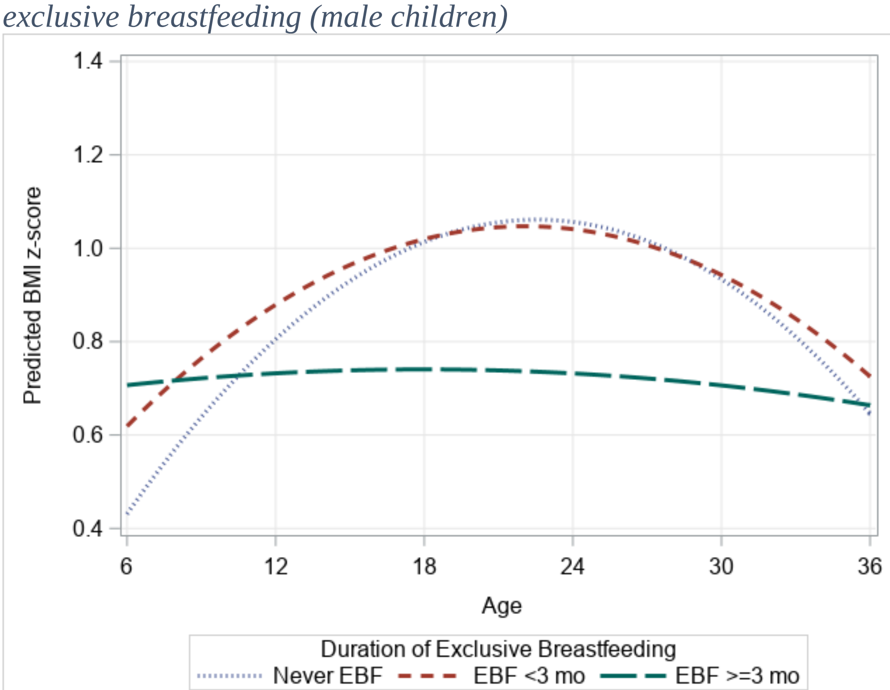
Table 13. Mixed Effects Linear Regression Models: Association Between Duration of Exclusive Breastfeeding and Repeated BMI-for-age z-scores by Sex, WIC ITFPS-2 Study (n=1,393)

Coefficients	Male (n=720) β (SE)	Female (n=673) β (SE)
Intercept	0.433 (0.139)**	0.593 (0.133)***
EBF Duration		
Never EBF (ref)	-	-
EBF <3 mo	0.188 (0.111)†	0.037 (0.110)
EBF ≥3 mo	0.271 (0.146)†	-0.044 (0.149)
Age[d] (months)	0.076 (0.012)***	0.081 (0.012)***
Age^2	-0.002 (0.000)***	-0.002 (0.000)***
Age*EBF Duration		
Age*Never EBF (ref)	-	-
Age*EBF <3 mo	-0.023 (0.014)	-0.027 (0.014)†
Age*≥3 mo	-0.070 (0.018)***	-0.051 (0.018)**
Age^2*EBF Duration		
Age^2*Never EBF (ref)	-	-
Age^2*<3 mo	0.001 (0.000)	0.001 (0.000)†
Age^2*≥3 mo	0.002 (0.001)***	0.001 (0.001)*
Maternal marital status		
Not married[a] (ref)	-	-
Married	-0.011 (0.086)	0.044 (0.088)
Maternal education level		
HS or less (ref)	-	-
More than HS	0.006 (0.079)	-0.081 (0.082)
Household poverty level[b]		
≤75% (ref)	-	
>75 to 130%	0.091 (0.085)	0.242 (0.086)**
>130%	0.026 (0.119)	-0.008 (0.141)
Race/ethnicity		
Hispanic (ref)	-	-
NH-Black	-0.170 (0.099)	-0.257 (0.109)*
NH-White	-0.162 (0.096)	-0.148 (0.099)
Other	-0.230 (0.142)	-0.059 (0.141)
Maternal weight[c]		
Normal or Underweight (ref)	-	-
Overweight	0.051 (0.093)	0.114 (0.093)

Coefficients	Male (n=720) β (SE)	Female (n=673) β (SE)
Obese	0.147 (0.085)	0.217 (0.091)*
Maternal age		
26+ years (ref)	-	-
20-25 years	0.044 (0.079)	-0.089 (0.084)
16-19 years	0.158 (0.138)	-0.009 (0.139)
Household food security		
High/Marginal (ref)	-	-
Low	-0.061 (0.08)	0.08 (0.085)
Very Low	-0.021 (0.11)	0.04 (0.105)
Delivery Type		
Vaginal (ref)	-	-
Caesarean	0.093 (0.077)	0.003 (0.084)
Smoked during pregnancy		
No (ref)	-	-
Yes	0.417 (0.131)**	0.280 (0.131)*

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Note: age is centered at 6 months; EBF=exclusively breastfed
[a]including divorced and widowed; [b]relative to 2013 federal poverty guidelines; [c]weight status at the time of screening

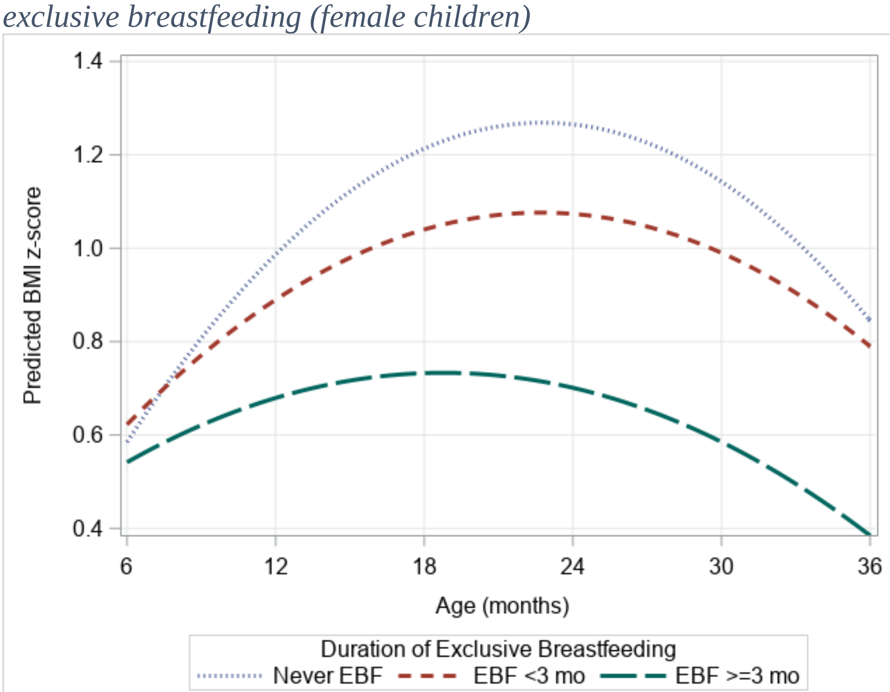
Figure 14. Predicted BMI z-score trajectories from age 6 months to three years by duration of exclusive breastfeeding (male children)



Note: Fit computed at reference categories of all covariates

Among girls, the model similarly suggests that weight trajectories among children exposed to at least 3 months of EBF had flatter slopes at 6 months of age (β= -.05, p=.01), indicating that monthly increases in BMIZ at age 6 months were larger for children who were never EBF. Girls exposed to at least 3 months of EBF had a consistently lower weight trajectory (i.e., closer to 0) compared to those exposed to shorter durations of EBF and those who were never EBF (Figure 15). Compared to BMIZ of females never EBF, BMIZ of those EBF for at least 3 months were .31 z-score units lower at one year (p=.03), .56 z-score units lower at two years (p<.001), and .46 z-score units lower at three years of age (p<.01). In comparing only those who were ever EBF, longer durations of EBF were associated with lower predicted BMIZ at ages one (-.21, p=.07) two (-.36, p<.01) and three (-.39, p<.01) years of age compared to shorter durations of EBF (<3 months).

Figure 15. Predicted BMI z-score trajectories from age 6 months to three years by duration of exclusive breastfeeding (female children)



Note: Fit computed at reference categories of all covariates

For both boys and girls, similar relationships between EBF duration and weight trajectories were observed when weight-for-length z-scores were examined instead of BMIZ (Appendix Table B1.2).

Breastfeeding Duration and Odds of Overweight/Obesity

Sex-stratified mixed effects logistic regression models were used to explore the relationship between duration of any breastfeeding (Table 14) and EBF (Table 15) and odds of overweight/obesity at ages 2 to 3 years, controlling for race/ethnicity, household poverty level and food security status, and maternal marital status, age, weight, education level, delivery type, and smoking during pregnancy. Among boys, the estimates were consistent with a protective effect of breastfeeding, though they only reached marginal statistical significance ($p<0.10$): compared to those who were never breastfed, those breastfed for less than 6 months had 39% lower odds of overweight/obesity (OR=0.61, p=.05) and those who were breastfed for at least 6 months had 42% lower odds of overweight/obesity (OR=.58, p=.08). Among girls, there was a notable dose response relationship between breastfeeding duration and overweight/obesity. Compared to those who were never breastfed, girls who were breastfed for less than 6 months had 45% lower odds of overweight/obesity (OR=0.55, p=.03) and those who were breastfed for at least 6 months had 65% lower odds of overweight/obesity (OR=0.35, p=.002).

Table 14. Mixed effects logistic regression models: association between duration of any breastfeeding and overweight/obesity at ages 2-3 years, WIC ITFPS-2 Study (n=1,445)

	Male (n=739)	Female (n=706)
Effect	OR (95% CI)	OR (95% CI)
Duration of any breastfeeding		
Never BF (ref)	-	-
BF <6 months	0.61 (0.37, 1.01)†	0.55 (0.32, 0.95)*
BF ≥6 months	0.58 (0.32, 1.07)†	0.35 (0.18, 0.67)**
Maternal marital status		
Not married[a] (ref)	-	-
Married	0.90 (0.57, 1.42)	0.81 (0.51, 1.27)
Maternal education level		
HS or less (ref)	-	-
More than HS	1.22 (0.81, 1.84)	0.77 (0.50, 1.17)
Household poverty level[b]		
≤75% (ref)	-	-
>75 to 130%	1.10 (0.71, 1.70)	0.88 (0.56, 1.37)
>130%	0.92 (0.48, 1.76)	1.16 (0.57, 2.38)
Race/ethnicity		
Hispanic (ref)	-	-
NH-Black	0.69 (0.41, 1.16)	0.54 (0.30, 0.95)*
NH-White	0.84 (0.51, 1.38)	0.57 (0.33, 0.97)*
Other	0.72 (0.33, 1.56)	0.62 (0.29, 1.32)
Maternal weight[c]		
Normal or Underweight (ref)	-	-
Overweight	1.37 (0.85, 2.22)	1.31 (0.81, 2.14)
Obese	1.48 (0.95, 2.30)	1.88 (1.19, 2.97)**
Maternal age		
26+ years (ref)	-	-
20-25 years	1.25 (0.83, 1.88)	0.61 (0.39, 0.94)*
16-19 years	1.65 (0.82, 3.31)	1.15 (0.58, 2.27)
Household food security		
High/Marginal (ref)	-	-
Low	0.71 (0.46, 1.09)	1.37 (0.89, 2.11)
Very Low	1.53 (0.91, 2.57)	1.41 (0.84, 2.39)
Delivery Type		
Vaginal (ref)	-	-
Caesarean	1.18 (0.80, 1.76)	0.85 (0.56, 1.30)
Smoked during pregnancy		
No (ref)	-	-
Yes	1.65 (0.87, 3.13)	1.71 (0.92, 3.19)

*p<.05; **p<.01; †Marginally significant at p<.10 (marginal significance only noted for primary independent variables)

Note: BF= breastfed

[a]including divorced and widowed; [b]relative to 2013 federal poverty guidelines; [c] weight status at the time of screening

Likewise, a dose-response relationship was observed between duration of EBF and overweight/obesity among girls (Table 15). Compared to those who were never EBF, those EBF for less than 3 months had 46% lower odds of overweight/obesity (OR=0.54, p=.01) and those EBF for 3 months or longer had 88% lower odds of overweight/obesity (OR=0.22, p<.001) between 2 to 3 years of age. Among boys, the model estimates similarly suggest a potential dose response relationship, though estimates were only marginally statistically significant: compared to boys who were never EBF, those EBF for less than 3 months had 33% lower odds of overweight/obesity (OR=0.67, p=.099), while those EBF for 3 months or longer had 44% lower odds of overweight/obesity (OR=0.56, p=.08).

Table 15. Mixed effects logistic regression models: association between duration of exclusive breastfeeding and overweight/obesity at ages 2-3 years, WIC ITFPS-2 Study (n=1,393)

	Male (n=720)	Female (n=673)
Effect	OR (95% CI)	OR (95% CI)
Duration of exclusive breastfeeding		
Never EBF (ref)	-	-
EBF <3 months	0.67 (0.42, 1.08)†	0.54 (0.33, 0.86)*
EBF ≥3 months	0.56 (0.29, 1.07)†	0.22 (0.10, 0.47)***
Maternal marital status[a]		
Not married (ref)	-	-
Married	0.90 (0.57, 1.43)	0.88 (0.55, 1.40)
Maternal education level		
HS or less (ref)	-	-
More than HS	1.28 (0.84, 1.95)	0.72 (0.46, 1.12)
Household poverty level[b]		
≤75% (ref)	-	-
>75 to 130%	1.10 (0.71, 1.72)	0.90 (0.57, 1.43)
>130%	0.80 (0.41, 1.56)	1.33 (0.63, 2.82)
Race/ethnicity		
Hispanic (ref)	-	-
NH-Black	0.70 (0.41, 1.19)	0.54 (0.30, 0.98)*
NH-White	0.81 (0.48, 1.35)	0.58 (0.33, 1.00)
Other	0.63 (0.28, 1.43)	0.62 (0.29, 1.33)
Maternal weight[c]		
Normal or Underweight (ref)	-	-
Overweight	1.27 (0.77, 2.08)	1.13 (0.68, 1.87)
Obese	1.49 (0.95, 2.33)	1.73 (1.08, 2.77)*
Maternal age		

	Male (n=720)	Female (n=673)
Effect	OR (95% CI)	OR (95% CI)
26+ years (ref)	-	-
20-25 years	1.23 (0.81, 1.87)	0.71 (0.45, 1.11)
16-19 years	1.75 (0.86, 3.56)	1.50 (0.75, 3.00)
Household food security		
High/Marginal (ref)	-	-
Low	0.71 (0.46, 1.10)	1.39 (0.89, 2.17)
Very Low	1.45 (0.85, 2.49)	1.42 (0.82, 2.44)
Delivery Type		
Vaginal (ref)	-	-
Caesarean	1.15 (0.77, 1.72)	0.81 (0.52, 1.27)
Smoked during pregnancy		
No (ref)	-	-
Yes	1.65 (0.86, 3.17)	1.72 (0.90, 3.31)

*p<.05; ***p<.001; †Marginally significant at p<.10 (marginal significance only noted for primary independent variables)

EBF = exclusively breastfed

[a]including divorced and widowed; [b]relative to 2013 federal poverty guidelines; [c] weight status at the time of screening

Breastfeeding Duration and Intensity and Risk of Overweight and Obesity

Next, to understand whether longer durations of exclusive breastfeeding conferred greater protection against overweight/obesity compared to partial breastfeeding (question 1.3), children were classified as never breastfed, breastfed for <3 months (i.e., short duration), partially breastfed for at least 3 months (i.e., longer duration but low intensity), or EBF for at least 3 months (i.e., longer duration with higher intensity). Mixed effects logistic regression models with random intercepts (Table 16) were used to explore the association between breastfeeding duration and intensity and odds of overweight/obesity at 2 to 3 years of age. Figures 16 and 17 provide a graphical representation of the regression results for boys and girls, respectively, plotting the predicted probabilities of overweight/obesity by breastfeeding duration/intensity group calculated at the reference value of each of the covariates. All stated predicted probabilities were calculated at the reference value of each of the covariates.

Table 16. Mixed effects logistic regression models: association between duration and intensity of breastfeeding and overweight/obesity at ages 2-3 years, WIC ITFPS-2 Study (n=1,369)

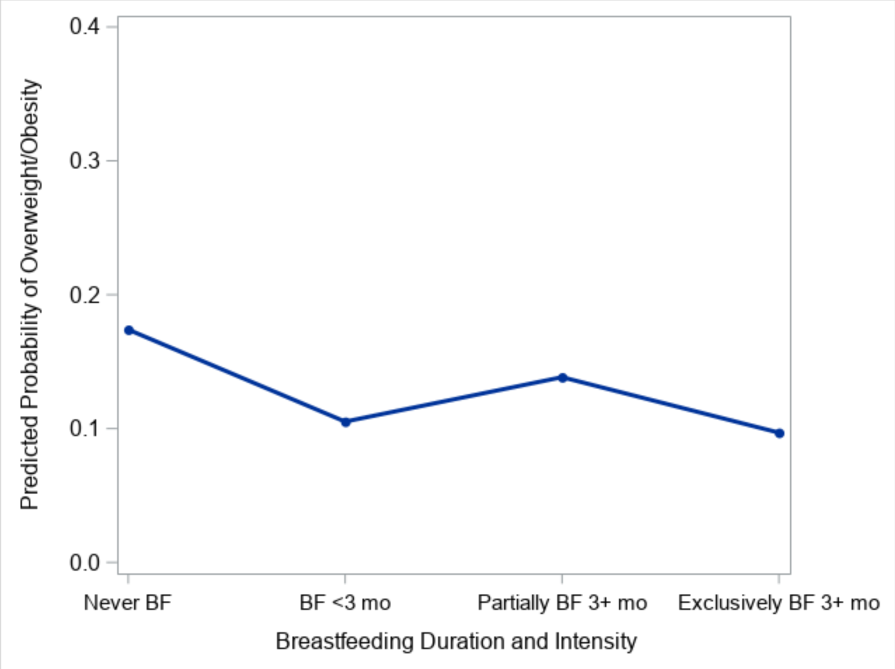
	Male (n=704)	Female (n=665)
Effect	OR (95% CI)	OR (95% CI)
Breastfeeding Duration/Intensity		
Never BF (ref)		
BF <3 mo	0.56 (0.33, 0.95)*	0.61 (0.35, 1.08)†
Partially BF ≥3 mo	0.76 (0.42, 1.39)	0.45 (0.23, 0.87)*
Exclusively BF ≥3 mo	0.51 (0.26, 1.00)†	0.21 (0.09, 0.48)***
Maternal marital status		
Not married[a] (ref)		
Married	0.87 (0.54, 1.39)	0.89 (0.56, 1.44)
Maternal education level		
HS or less (ref)		
More than HS	1.26 (0.83, 1.92)	0.73 (0.47, 1.15)
Household poverty level[b]		
≤75% (ref)		
>75 to 130%	1.06 (0.68, 1.67)	0.92 (0.58, 1.46)
>130%	0.82 (0.41, 1.6)	1.32 (0.62, 2.82)
Race/ethnicity		
Hispanic (ref)		
NH-Black	0.72 (0.42, 1.22)	0.53 (0.29, 0.97)*
NH-White	0.86 (0.51, 1.44)	0.57 (0.32, 0.99)*
Other	0.65 (0.29, 1.48)	0.63 (0.29, 1.35)
Maternal weight[c]		
Normal or Underweight (ref)		
Overweight	1.26 (0.77, 2.08)	1.13 (0.68, 1.87)
Obese	1.48 (0.94, 2.32)	1.72 (1.07, 2.76)*
Maternal age		
26+ years (ref)		
20-25 years	1.21 (0.79, 1.84)	0.67 (0.42, 1.05)
16-19 years	1.73 (0.85, 3.54)	1.30 (0.64, 2.61)
Household food security		
High/Marginal (ref)		
Low	0.66 (0.43, 1.04)	1.43 (0.91, 2.25)
Very Low	1.43 (0.83, 2.44)	1.42 (0.82, 2.45)
Delivery Type		
Vaginal (ref)		
Caesarean	1.14 (0.76, 1.72)	0.77 (0.49, 1.21)
Smoked during pregnancy		
No (ref)		
Yes	1.54 (0.80, 2.98)	1.70 (0.88, 3.27)

*p<.05; ***p<.001; †Marginally significant at p<.10 (marginal significance only noted for primary independent variables)
BF = breastfed

[a]including divorced and widowed; [b]relative to 2013 federal poverty guidelines; [c] weight status at the time of screening

Among boys, there was no evidence of a dose response relationship between increasing duration and intensity of breastfeeding and overweight/obesity. The only statistically significant association was found with short breastfeeding duration: boys who were breastfed for <3 months had 44% lower odds of overweight/obesity compared to boys who were never breastfed (OR=0.56, p=0.03). In contrast, there was no difference in odds of overweight/obesity between boys who were partially breastfed for at least three months (longer duration, lower intensity), and while the model suggests that boys EBF for at least three months (longer duration, higher intensity) had about half the odds of obesity compared to those never breastfed (OR=0.51), the estimate only reached marginal statistical significance (p=0.05). The predicted probability of overweight/obesity for a male child who was never breastfed was 17% (Figure 16). In comparison, the predicted probability of overweight/obesity was 11% for a boys breastfed for <3 months, 14% for boys partially BF at least 3 months and 10% for those exclusively BF for at least 3 months.

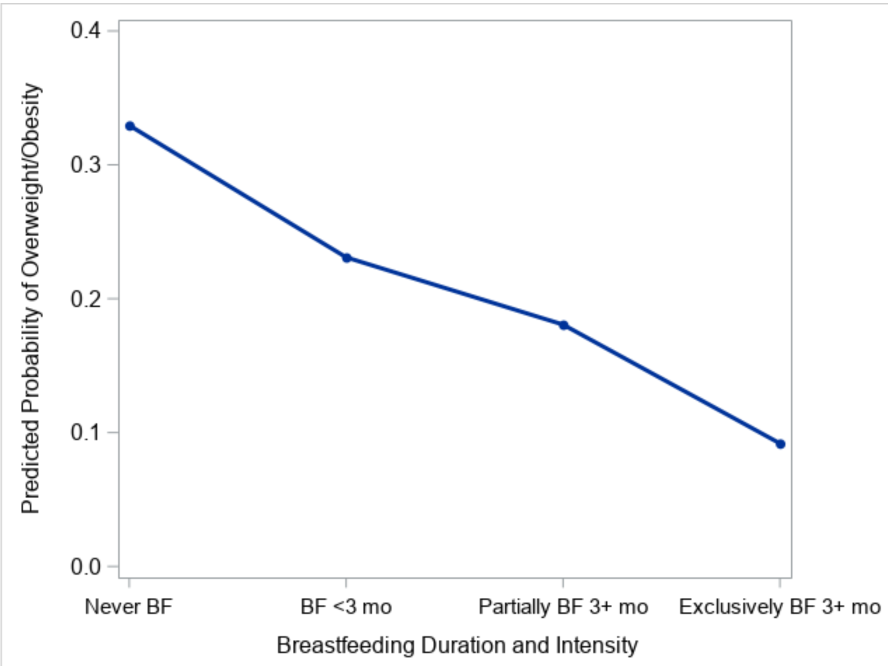
Figure 16. Predicted probabilities of overweight/obesity at 2-3 years of age by breastfeeding duration and intensity (male children)



Note: Fit computed at reference categories of all covariates

Among girls, the point estimates are consistent with an ordered relationship between breastfeeding intensity and overweight/obesity, such that exclusive BF may confer more protection against childhood obesity compared to partial BF (Table 16). Compared to girls who were never BF, those partially BF for at least three months had 55% lower odds of overweight/obesity (OR=.45, p=.017) while those EBF had 79% lower odds of overweight/obesity (OR=.21, p<.001). Partially BF girls had approximately two times the odds of overweight/obesity (model not shown, OR=2.18) compared to EBF girls, though this difference was only marginally statistically significant (p=.05). Figure 17 demonstrates the protective effect of breastfeeding duration and intensity on the probability of overweight/obesity. The predicted probability of overweight/obesity decreased with increasing frequency and intensity, from 33% among girls who were never BF, to 23% among those BF for <3 months, 18% among those partially BF for at least 3 months, and 9% among those EBF for at least 3 months.

Figure 17. Predicted probabilities of overweight/obesity at 2-3 years of age by breastfeeding duration and intensity (female children)



Note: Fit computed at reference categories of all covariates

Discussion

Primary Findings

Overall, this study found evidence that breastfeeding may promote healthier weight trajectories and reduce the risk of early childhood overweight/obesity. Weight trajectories were assessed using repeated BMIZ measures calculated from WHO Growth Reference Standards, which were developed to reflect normal child growth under optimal environmental conditions. Each child in the study sample had at least two measurements and up to four measurements taken between approximately 6 months and 3 years of age. Mixed effects regression models were used to model the BMIZ trajectories, taking into account the correlation between measurements obtained on individual subjects. For the purpose of understanding whether breastfeeding practices may be protective of childhood overweight/obesity, "healthier weight trajectories" were defined as trajectories where BMIZ were lower, indicating they were further away from the overweight classification (BMIZ >2).

Hypothesis 1.1a: Greater duration of any BF will be associated with healthier BMIZ trajectories.

First, the relationship between duration of any breastfeeding (exclusive or partial) and weight trajectories was assessed. Among the study sample, approximately one in six boys and one in eight girls were never breastfed, while just over one quarter of both boys and girls were breastfed for at least 6 months. Breastfeeding for at least 6 months was associated with healthier weight trajectories compared to never breastfeeding. Among both boys and girls, those who were breastfed for at least six months had significantly "flatter" trajectories, characterized by smaller monthly increases in BMI-for-age at 6 months (i.e., less steep slope) and less pronounced changes in the slope of the trajectory over time (i.e., lower degree of curvature in the trajectory).

These differences translated to significantly higher predicted BMIZ at age 2 years for girls who were never breastfed compared to those who were breastfed for at least 6 months, but no statistically significant differences in BMIZ at ages 1, 2, or 3 years among boys. Notably, the study did not detect a protective effect of shorter durations of breastfeeding. For both boys and girls, there was no significant difference in weight trajectories between children breastfed for less than 6 months compared to those who were not breastfed at all.

Hypothesis 1.1b. Greater duration of EBF will be associated with healthier BMIZ trajectories.

Next, the relationship between duration of exclusive breastfeeding and weight trajectories was examined. Although health organizations and care providers, including WIC, encourage breastfeeding exclusively until 6 months of age, very few infants in the sample were exclusively breastfed (EBF) for this duration. As such, the analyses compared children who were never EBF to those who were EBF for <3 months and those who were EBF for at least 3 months. Approximately 20% of both boys and girls in the sample were never EBF, while approximately one in six boys and one in seven girls were EBF for at least 3 months. Among both boys and girls, those who were EBF for at least 3 months had healthier weight trajectories compared to those who were never EBF. Compared to those never EBF, the weight trajectories of those EBF for 3 or more months were flatter, characterized by lower monthly increases in BMIZ at age 6 months and less variation in BMIZ as children aged. Among both boys and girls, the age-centered models suggested that BMIZ were significantly lower for children breastfed exclusively for at least 3 months compared to those never EBF. For boys, the difference was significant at age 2 years, while for girls the difference was significant at ages 1, 2 and 3 years. Of note, for both boys and girls, the models indicated that those with longer durations of EBF (≥3 months) had lower predicted BMIZ at age 2 compared to those with shorter durations of EBF (<3 months), suggesting that there may be a dose-response effect of EBF.

Hypothesis 1.2. Greater duration of any BF (1.2a) and EBF (1.2b) will be associated with lower odds of overweight/obesity.

Finally, the study sought to understand whether breastfeeding was associated with reduced odds of overweight and obesity in early childhood, and specifically, if exclusive breastfeeding conferred greater protection than partial breastfeeding. Among girls, there was a notable dose-response relationship between duration of any breastfeeding and obesity. Compared to girls who were never breastfed, those who were breastfed less than 6 months had 45% lower odds of overweight/obesity, while those breastfed for 6 months or longer had 65% lower odds of overweight/obesity. A similar dose-response effect was observed among girls by duration of EBF. Compared to girls who were never EBF, those EBF for less than 3 months had 46% lower odds of overweight/obesity while those EBF for 3 months or longer had 78% lower odds of overweight/obesity between 2 to 3 years of age. Among boys, the findings suggested that both duration of any breastfeeding and duration of EBF were associated with reduced odds of overweight/obesity, but the estimates were only marginally statistically significant.

Hypothesis 1.3. There will be a dose-response relationship between breastfeeding duration and intensity, such that longer duration of exclusive BF will be associated with lower odds of overweight/obesity compared to longer duration of partial BF.

Next, to understand whether exclusive breastfeeding provides greater protection against overweight/obesity compared to partial/mixed breastfeeding, children were classified according to both duration and intensity (partial vs. exclusive) of breastfeeding. Among boys, contrary to the hypothesis, there was no evidence of a dose-response relationship between breastfeeding duration and intensity and overweight/obesity. Boys who were breastfed for a short duration (<3 months) had 44% lower odds of overweight/obesity compared to those who were never breastfed. Among those with longer durations of breastfeeding (≥3 months), there was no difference in overweight/obesity among those who were partially breastfed for at least 3 months (longer duration, low intensity) and those who were never breastfed, and while the model suggested that boys who were exclusively breastfed for at least 3 months (longer duration, higher intensity) had approximately half the odds of overweight/obesity compared to those who were never breastfed, the estimates did not reach statistical significance at $p<0.05$ ($p=0.05$).

In contrast, among girls, both partial and exclusive BF for at least 3 months were associated with reduced odds of overweight/obesity. In addition, the point estimates were consistent with the hypothesized dose-response relationship between breastfeeding duration and intensity and overweight/obesity. Compared to girls never breastfed, those breastfed for less than 3 months had 39% lower odds of overweight/obesity, those partially breastfed for at least 3 months had 55% reduced odds of overweight/obesity, and those EBF for at least 3 months had 79% lower odds of overweight/obesity.

Comparison with other studies and implications

The following discussion will summarize how these findings fit within and expand the current literature. Few prospective cohort studies of infants and caregivers in the U.S. have explored the relationship between breastfeeding and weight outcomes in early childhood. This review focuses on studies in the U.S. because social and cultural contexts which influence infant feeding practices and risk for overweight differ significantly across countries.

Researchers analyzing data from Project Viva, an observational cohort study of mother infant pairs in Massachusetts, found that each additional 3 months of BF was associated with a reduction of .045 BMI z-score units at 3 years of age, though breastfeeding duration was not associated with obesity at 3 years of age (Taveras et al., 2006). The results from this dissertation make an important contribution by extending these findings to a more ethnically diverse and socioeconomically disadvantaged population which is disproportionately affected by overweight and obesity. Project Viva participants were of relatively high SES, with most mothers White (77%) and college educated (74%) (Taveras et al., 2006). In contrast, in the current sample, the infants were largely Hispanic (48%), and most mothers had at most a high school education (60%).

Grummer-Strawn and Mei (2004) examined breastfeeding duration and risk of overweight at age 4 years among a large sample of low-income children born between 1988 and 1992 using data from the CDC Pediatric Nutrition Surveillance System. The researchers found that, controlling for the child's gender, race/ethnicity, and birth weight, breastfeeding was associated with reduced odds of overweight at 4 years of age. However, after controlling for maternal factors, including age, education, pre-pregnancy BMI, gestational weight gain, and smoking, breastfeeding was protective against overweight/obesity only for non-Hispanic white children, but not Hispanic or non-Hispanic Black children. In contrast, the current study found support for protective effects of breastfeeding on overweight/obesity regardless of the race/ethnicity of the baby, controlling for many of the same maternal factors. One possible explanation for the incongruent findings is the significant shift in infant feeding practices that have occurred in the past several decades. While Grummer-Strawn and Mei (2004) found that fewer than 30% of children were ever BF and only 6% were breastfed for 6 months or more, over a quarter of the sample of children in our study were breastfed for at least 6 months. The authors also proposed that racial/ethnic differences in lifestyle factors, such as dietary and physical activity patterns, may explain the differences (Grummer-Strawn & Mei, 2004). Thus, policy, systems and environmental changes that have occurred may have reduced some of these disparities. For example, changes to the WIC food packages in 2009 resulted in increased availability of healthy foods in low-income Black and Hispanic neighborhoods (Hillier et al., 2012), and improved diet quality among children in low-income neighborhoods (Kong et al., 2014), which may have reduced racial/ethnic disparities in dietary practices. The findings from this dissertation among a largely Hispanic population are consistent with results from a study exclusively of Hispanic mothers and children which found that breastfeeding through 1 year of age was associated with reduced odds of obesity at 3 years of age (Verstraete et al., 2014).

Few studies have explored the relationship between breastfeeding and early childhood overweight/obesity specifically among children in the WIC program, and those that have were largely limited to specific geographic regions or service areas and had somewhat conflicting findings. Davis et al., (2014) analyzed data from 2-4 year old children enrolled in the Los Angeles County (LAC) WIC program and found that children breastfed for at least 1 year had approximately half the odds of obesity (OR=0.53), compared to those who were never breastfed. However, children breastfed for 6 months to less than 1 year did not have significantly lower odds of overweight or obesity compared to those never breastfed (Davis et al., 2014). In contrast, using data from the Hawai'i WIC program, Anderson et al., (2014) found that breastfeeding for 6 months or more was protective of overweight/obesity at age 2 years. In their study, the prevalence of overweight/obesity at 2 years of age was 18% lower for children breastfed for at least six months compared to children who were never breastfed (prevalence ratio=0.82) (Anderson et al., 2014). Study 1 of this dissertation similarly found that breastfeeding for at least 6 months was associated with lower odds of overweight/obesity between 2 to 3 years of age

(65% lower odds for girls), and while this study did not examine separately children who were breastfed for 12 months or more, approximately 40% of the children who were breastfed for 6 months or more had a breastfeeding duration of less than 1 year. A strength of this study is the use of data from a national sample of WIC participants, which makes the findings more generalizable.

One significant strength of the current study was the ability to explore the impact of intensity of breastfeeding by differentiating children who were exclusively breastfed compared to those who were breastfed but also had regular intake of infant formula or complementary foods and beverages. Most studies do not capture exclusivity of breastfeeding, and this has been cited as a major limitation of the current literature (Victora et al., 2015). In one recent study of WIC participants, researchers used the duration of receipt of the fully breastfeeding infant package – the food package provided by the WIC program when mothers report exclusively breastfeeding – as a proxy for EBF and found that longer durations of EBF were associated with significantly lower mean weight-for-height z-scores by ages 1 to 2 years, and significantly lower risk of obesity at age 4 years (Anderson et al., 2020). Findings from this dissertation similarly suggested that longer durations of exclusive breastfeeding were associated with lower BMIZ between the ages of 1 and 3 years of age, and lower odds of obesity between 2 to 3 years of age among girls. The current study provides an important contribution by not only extending the generalizability of the findings, as data were derived from WIC participants across the U.S., but also by using a more direct measure of duration of exclusive breastfeeding rather than using a proxy.

Of note, Davis et al., (2014) also examined duration of EBF and found no association between EBF for 6 months or more and odds of overweight or obesity among children aged 2 to

4 years in the LAC WIC Program. One limitation of that study which may help explain differences in findings is retrospective reporting of the duration of exclusive breastfeeding. Caregivers were contacted when their child was between the ages of 2 and 4 years and asked to report breastfeeding practices. While less than one percent of mothers in the current sample reported exclusively breastfeeding for 6 months when breastfeeding data were assessed frequently during infancy, 7.5% of mothers retrospectively reported exclusively breastfeeding for at least 6 months when asked 2 to 4 years later (Davis et al., 2014). Studies have found that while recall of breastfeeding duration is highly accurate, particularly with recall periods less than 3 years, recall of age of introduction of foods and fluids other than breast milk is less accurate (Li et al., 2005), which may influence the validity of retrospective report of duration of exclusive breastfeeding.

Another strength of the current study is the evaluation of trajectories of weight over time to add context to the body of literature demonstrating associations between breastfeeding and reduced risk of childhood obesity. Among boys, this study showed that breastfed children actually weighed more than non-breastfed children at around six months of age, but their trajectories were flatter, such that by about 1.5 years of age, they weighed less than their non-breastfed counterparts. This is consistent with another examination of weight trajectories among WIC participants, which found that breastfed children had faster rates of growth compared to children who were never BF between birth and 6 months of age, but this period of accelerated growth was followed by a period of more rapid decline in weight, such that, while breastfed children weighed more than non-breastfed children around 6 months, they weighed less by 1 – 2 years of age (Anderson et al., 2020). Understanding differences in weight trajectories between breastfed and non-breastfed infants are important for providing appropriate counseling and guidance to mothers and families.

One surprising finding was the notable sex differences in associations between breastfeeding and risk of overweight/obesity. Among girls, breastfeeding was consistently associated with reduced odds of overweight/obesity, and there was a clear dose response relationship with increasing durations of breastfeeding. In contrast, while the results were suggestive of a protective effect of breastfeeding on overweight/obesity among boys, the estimates were only marginally statistically significant. Anderson et al. (2020) similarly found sex-differences in the association between EBF and obesity at 4 years of age, with a stronger association for girls than boys. One potential mechanism could be differences in breast milk composition by infant sex. A recent study found higher concentrations of insulin in breast milk of obese mothers of female infants compared to obese mothers of male infants (Fields et al., 2017) and breast milk insulin concentrations have been associated with lower infant weight (Mazzocchi et al., 2019). Additionally, research has suggested that the energy content of breast milk from mothers of male infants may be higher than the energy content of breast milk from mothers of female infants (Powe et al., 2010). Since neither infant formula composition nor formula feeding recommendations are sex-specific, this could help explain the stronger protective effect of breastfeeding for girls as opposed to boys.

Potential Mechanisms

There are several proposed mechanisms by which exposure to breastfeeding, and breast milk itself, may be related to healthier weight outcomes. Research has indicated that differences in composition of infant formula compared to breast milk may play a role in weight gain among formula-fed infants (Weber et al., 2014). Specifically, the high protein content in infant formula has been shown to upregulate specific metabolic systems responsible for the formation of fat cells which may result in weight gain (Melnik, 2012). In contrast, breast milk contains hormones, such as leptin and ghrelin, which help regulate appetite and energy balance (Savino et al., 2009). Furthermore, by virtue of not observing the volume of intake, mothers who breastfeed may allow children to learn to self-regulate their intake; in contrast, a caregiver who is formula feeding can easily see the volume the infant has consumed and may be inclined to encourage the infant to finish the bottle (Birch & Fisher, 1998). In this way, breastfeeding may help children learn to listen and respond to hunger and satiety cues.

Other bioactive components of breast milk which are not present in infant formula may play an important role in weight regulation and obesity prevention. For example, human milk oligosaccharides – specific sugars present in human milk – encourage growth of beneficial bacteria in the human gut (Maessen et al., 2020), and there is evidence that early composition of the gut microbiome predicts obesity in childhood (Stanislawski et al., 2018). Notably, the composition of human milk changes in response to several factors, including the infant's age and maternal diet and other exposures (Wu et al., 2018), so infant formula can never precisely replicate breast milk.

Another potential mechanism could be greater acceptance of healthy foods in infancy and early childhood as a result of transmission of flavor compounds through breast milk (Désage et al., 1996; Mennella et al., 2001; Mennella & Beauchamp, 1996). Mennella et al. (2001) found that infants who were exposed to carrot flavor compounds via breast milk were more accepting of infant cereal with carrot juice than those who had previously not been exposed to carrot flavor compounds. Thus, breastfed infants who are exposed to a greater variety of flavor compounds from healthy foods compared to infants who consume exclusively or primarily formula may be more willing to consume healthy foods at the time of weaning and into early childhood. This has long term implications for weight and health, as dietary intake at 9 months has been shown to predict dietary intake at age 6 years (Rose et al., 2017).

Implications for Policy and Practice

The results from Study 1 suggest that increasing the duration of breastfeeding among low-income women participating in the WIC program may decrease rates of early childhood obesity. Breastfeeding rates among mothers in the WIC program are lower than rates among non-participating mothers in the U.S. (Carlson & Neuberger, 2017; Ryan & Zhou, 2006). While 84% of all children in the U.S. are breastfed, 72% of children in the WIC program are breastfed (CDC, 2020a; Kline et al., 2020). However, these gaps have been narrowing as a result of substantial rises in breastfeeding rates among WIC participants. Between 2002 and 2018, the percentage of infants participating in WIC who were breastfed increased by 49% (Carlson & Neuberger, 2017; Kline et al., 2020).

Changes to the WIC food packages and WIC breastfeeding promotion efforts are two factors contributing to improvements in breastfeeding rates. One goal of the 2009 revisions to the WIC food packages was to provide stronger incentives to breastfeed. With the new food packages, fully breastfeeding mothers receive a greater quantity and variety of foods compared to mothers who partially breastfeed or exclusively formula feed, and mothers who breastfeed at all (full or partial) receive food packages for a full year rather than six months (Cole et al., 2011). One study of WIC participants in LA County found that mothers had over twice the odds of ever breastfeeding and three times the odds of exclusive breastfeeding at six months after the new food packages were implemented compared to before the revisions (Langellier et al., 2014).

However, other studies have not demonstrated this pronounced of an effect on breastfeeding rates following the 2009 policy changes. An evaluation study conducted by the USDA found no difference in breastfeeding initiation rates before and after implementation of the new food packages among a sample of WIC mothers from 17 Local WIC Agencies across the U.S. (Wilde et al., 2011). One possible factor contributing to the differences observed in breastfeeding rates among LA County WIC participants compared to national WIC participants after the revised food package implementation is targeted staff training and WIC participant education efforts that were simultaneously implemented in LA County (Whaley et al., 2012). In the six months leading up to the food package changes, the Local WIC Agency serving LA County provided focused breastfeeding promotion training to staff and educated pregnant WIC participants about the food package changes and the incentives for breastfeeding (Whaley et al., 2012).

These training and education efforts had an independent effect on breastfeeding rates, with fully breastfeeding food package issuance rates increasing by 34% during the training and education period but before the new food packages were introduced (Whaley et al., 2012). This finding demonstrates the significant impact of the front-line WIC staff on breastfeeding practices. Therefore, widespread adoption of evidence-based staff training and participant education interventions by Local WIC Agencies across the U.S., particularly those with low breastfeeding initiation rates among their participants, may improve breastfeeding initiation and duration.

In addition to policy and education efforts within the WIC program, changes to the broader healthcare and policy landscape in the U.S. could have a substantial impact on breastfeeding rates. A recent analysis conducted by the U.S. Department of Health and Human

Services identified key policy solutions to help communities increase breastfeeding rates, including increasing the proportion of U.S. hospitals designated Baby Friendly, expanding paid family leave policies, and protecting and supporting breastfeeding in the workplace (Barraza et al., 2020). Baby Friendly hospitals adopt 10 evidence-based practices that have been shown to increase breastfeeding initiation and duration, including hospital policies, health care provider training, prenatal breastfeeding education, support with breastfeeding initiation within one-hour after birth, and referral to breastfeeding support groups at hospital discharge (WHO, 2018a). A national survey of hospitals in the U.S. found that rates of breastfeeding initiation were 21% higher at hospitals with Baby Friendly designations compared to those without (Merewood et al., 2005). Currently, only one in four babies in the U.S. are born in Baby Friendly hospitals, so efforts to increase the proportion of hospitals designated Baby Friendly could have a significant impact on improving breastfeeding rates (Baby-Friendly USA, 2018).

The second key policy that is critical to increasing breastfeeding initiation and duration is paid family leave. Current national legislation provides for up to 12 weeks of family leave after the birth of a child, but approximately 40% of the U.S. workforce is not eligible for this benefit and the benefit guarantees only unpaid leave which many families cannot afford to use (Barraza et al., 2020; Han et al., 2009; U.S. Department of Labor, 2012). Nine states have enacted paid family leave laws, and these policies are demonstrating improved breastfeeding outcomes. For example, California enacted a 6-week paid family leave law in 2009 which resulted in a doubling of the median duration of breastfeeding among new mothers who used the benefit and a 10-20% increase in rates of breastfeeding at 3, 6, and 9 months postpartum (Appelbaum & Milkman, 2011; Huang & Yang, 2015). Given the benefit demonstrated in this study of at least 3 months of exclusive breastfeeding, paid family leave laws ideally should provide a minimum of 3 months

(12 weeks) of paid family leave. Four states have recently enacted laws that will provide 12 weeks of paid family leave: Washington, Massachusetts, Connecticut, and Oregon (Barraza et al., 2020). The family leave programs in these four states go into effect between 2020 and 2023, so there is not yet evidence of the impact of these policies on breastfeeding rates.

Finally, policies that protect and support breastfeeding in workplaces can have a significant impact on breastfeeding duration. Even with the most supportive paid family leave laws providing 12 weeks of family leave, there is still a gap of an additional 12 weeks during which mothers are encouraged to exclusively breastfeed, and during which any breastfeeding was demonstrated in this study to provide significant protection against early childhood obesity. Mothers who wish to continue exclusively breastfeeding need to express (i.e., pump) milk at the same frequency they would normally breastfeed their baby in order to maintain a sufficient milk supply, which averages 8 times per day during the first six months (Kent et al., 2012). The ACA enacted the first national law supporting breastfeeding in the workplace by amending the Fair Labor Standards Act to include the Break Time for Nursing Mothers provision, which requires employers to provide break time and a private space to express milk (Barreza et al., 2020; U.S. Department of Labor, 2018). However, there are significant gaps in coverage, with the law only providing protection for non-exempt employees and employees in companies with more than 50 employees, leaving millions of women without federal breastfeeding protections (Dinour & Bai, 2016). Low-income women are significantly less likely than higher-income women to have workplace lactation accommodations, which may perpetuate SES disparities in breastfeeding rates (Dinour & Bai, 2016; Juliano, 2014). Therefore, workplace lactation protection laws should be extended to cover all working women.

CHAPTER 6: STUDY TWO – RESULTS AND DISCUSSION

Overview of Aim, Hypotheses and Methods

The overall aim of Study 2 was to examine the relationship between timing of introduction of complementary foods (CF) and weight trajectories and risk of overweight/obesity in early childhood, controlling for the influence of breastfeeding. The study sought to understand the relationship between timing of CF introduction and weight trajectories (research question 2.1) and early childhood overweight/obesity (research question 2.2). The final objective was to understand whether the effect of timing of CF introduction on overweight/obesity varied by duration of breastfeeding (research question 2.3).

I hypothesized that CF introduction at 4 to 6 months would be associated with healthier weight trajectories (i.e., BMIZ trajectories closer to 0) (Hypothesis 2.1a) and reduced risk of overweight and obesity (Hypothesis 2.2) compared to introduction before 4 months or after 7 months. I further hypothesized that within the broad recommended time frame of 4-6 months, CF introduction around 6 months, according to current infant feeding recommendations (operationalized as 5.5-<7 months) would be associated with healthier weight trajectories compared to introduction between 4-<5.5 months (Hypothesis 2.1b). Finally, I hypothesized that there would be an interaction between timing of CF introduction and duration of breastfeeding, such that early introduction of complementary foods would be associated with higher odds of overweight/obesity for infants with shorter BF duration compared to those with longer BF duration (Hypothesis 2.3).

Sample Characteristics and Key Variable Distributions

Both timing of CF introduction and duration of breastfeeding was available for n=1,410 subjects (96% of the analytic sample). Demographic characteristics of the sample for Study 2 are summarized in Table 17. Compared to boys excluded from the sample (n=28), boys retained in the sample were more likely to have mothers with more than a high school education (43% vs. 18%). There were no differences in demographic characteristics of girls retained in the sample and those excluded (n=31).

Table 17. Demographic characteristics of Study 2 sample, by sex (n=1,410)

	Male (n=727) *N (%)*	Female (n=683) *N (%)*
Race/ethnicity		
Hispanic	328 (45)	345 (51)
Non-Hispanic White	187 (26)	172 (25)
Non-Hispanic Black	153 (21)	110 (16)
Non-Hispanic Other	59 (8)	56 (8)
Household poverty level[a]		
≤75%	458 (63)	415 (61)
>75 to 130%	189 (26)	209 (31)
>130 to 185%	80 (11)	59 (9)
Household food security		
High or Marginal	388 (53)	359 (53)
Low	233 (32)	206 (30)
Very low	106 (15)	118 (17)
Maternal age at birth (years)		
16-19	70 (10)	65 (10)
20-25	303 (42)	268 (39)
≥26	354 (49)	350 (51)
Maternal marital status		
Married	229 (32)	231 (34)
Not married[b]	498 (69)	452 (66)
Maternal education level		
HS or less	418 (58)	415 (61)
More than HS	309 (43)*	268 (39)
Maternal weight[c]		
Normal/underweight	322 (44)	319 (47)
Overweight	172 (24)	169 (25)
Obese	233 (32)	195 (29)
Delivery type		

Vaginal	196 (68)	475 (70)
Caesarean	231 (32)	208 (30)
Maternal smoking status during pregnancy		
Did not smoke	653 (90)	609 (89)
Smoked ≥1 cigarette per day	74 (10)	74 (11)

* Significantly different compared to those excluded from the sample ($p<0.05$)
[a] relative to 2013 federal poverty guidelines; [b] including divorced and widowed; [c] weight status at the time of screening
Note: Percentages may not sum to 100 due to rounding

The distribution of timing of CF introduction is presented in Figure 18 for boys and Figure 19 for girls. The mean age at which children were first given complementary foods was 4.5 and 4.4 months for boys and girls, respectively.

Figure 18. Distribution of Timing of Introduction of Complementary Foods Among Male Children (n=727)

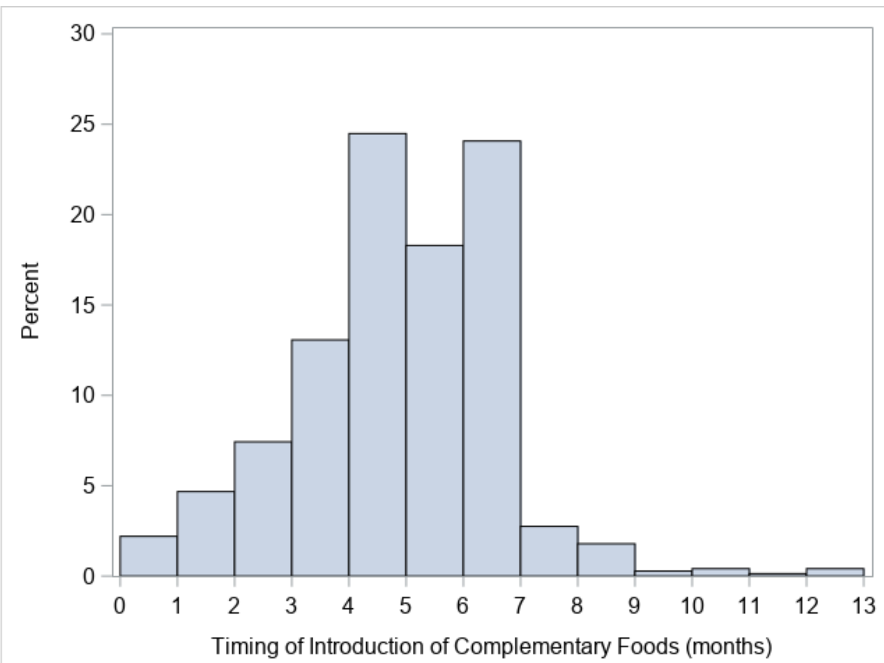
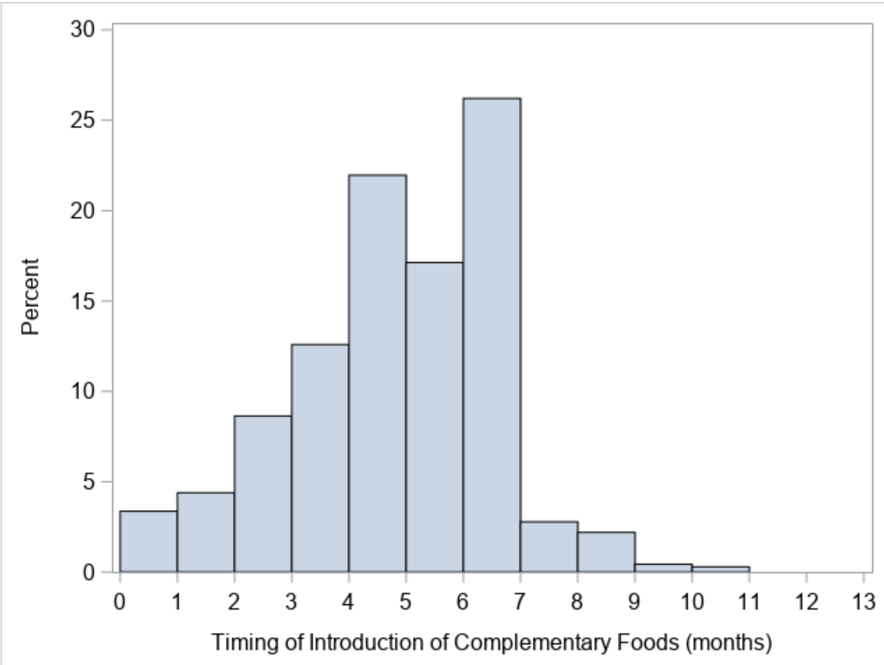


Figure 19. Distribution of Timing of Introduction of Complementary Foods Among Female Children (n=683)



For analyses, a 3-category timing of introduction of complementary foods variable was created which classified timing of introduction as before 4 months (early), at 4-6 months (inclusive of 6 months), or at or after 7 months (late). Table 18 summarizes timing of CF introduction by sex. The majority of children (67% of males and 65% of females) were first introduced to complementary foods at 4-6 months of age. However, approximately one quarter of children (27% of boys and 29% of girls) had early CF introduction (before 4 months of age). Fewer than one in ten children (6% of both boys and girls) had late CF introduction (at or after 7 months of age).

Table 18. Timing of Introduction of Complementary Foods (n=1,410)

	Male (n=727) *N (%)*	Female (n=683) *N (%)*
Before 4 months	199 (27)	198 (29)
4 to 6 months	486 (67)	446 (65)
7 months or later	42 (6)	39 (6)

Next, a sub-analysis was conducted on the sample of children with CF introduction at 4-6 months (n=932) to understand whether introduction closer to 6 months, consistent with current guidelines, was associated with healthier weight trajectories compared to introduction closer to 4 months. For these analyses, timing of CF introduction was dichotomized into around six months (5.5 to <7 months) vs not (4 to <5.5 months). Approximately two in five children (38% of boys and 41% of girls) were introduced to CF during the period around 6 months of age (Table 19).

Table 19. Introduction of Complementary Foods According to Current Recommendations Among Subsample of Children who Received Complementary Foods Between 4-<7 months (n=932)

	Male (n=486) *N (%)*	Female (n=446) *N (%)*
4 to <5.5 months	187 (38)	185 (41)
5.5 to <7 months	299 (62)	261 (59)

Results

Timing of Introduction of Complementary Foods and Weight Trajectories

Mixed effects linear regression models (Table 20) with age centered at 6 months were used to test the relationship between timing of CF introduction and weight trajectories (repeated BMIZ measures from age 6 months to 3 years). Models incorporate a random intercept (to allow children to vary in their initial BMI) and random slope (to allow children to vary in their linear trends over time). In addition, the models included an age^2 term since growth trajectories in early childhood are curvilinear. An interaction between timing of CF introduction and age was used to test whether weight trajectories varied by complementary feeding practices. Models controlled for breastfeeding duration to understand if complementary feeding practices influence children's weight trajectories independent of breastfeeding practices. Figures 20 and 21 provide graphical representations of the regression results, plotting predicted BMIZ trajectories for boys and girls, respectively, with all covariates set to reference values. Corresponding predicted BMIZ were also calculated with covariates set to reference values. Age-centered models at 1, 2, and 3 years of age were used to evaluate whether predicted BMIs were significantly different between the complementary feeding groups at these specific ages. Residual diagnostics indicate that the model provided a good fit of the data across all four measurement times from 6 months to 3 years of age for both boys (Appendix Figure B2.1 a) and girls (Appendix Figure B2.1 b).

Table 20. Mixed Effects Linear Regression Models: Association Between Timing of Introduction of Complementary Foods and Repeated BMI-for-age z-scores by Sex, WIC ITFPS-2 Study (n=1,410)

Effect	Male (n=727) β (SE)	Female (n=683) β (SE)
Intercept	0.623 (0.117)***	0.665 (0.119)***
Timing of CF Introduction		
4 to <7 mo (ref)	-	-
<4 mo	-0.046 (0.101)	0.044 (0.098)
≥7 mo	0.518 (0.191)**	-0.234 (0.185)
Age (months)	0.050 (0.007)***	0.047 (0.007)***
Age^2	-0.002 (0.000)***	-0.002 (0.000)***
Age*CF Introduction		
Age*4 to <7 mo (ref)	-	-
Age*<4 mo	0.002 (0.013)	0.018 (0.012)
Age*≥7 mo	-0.026 (0.024)	0.034 (0.022)
Age^2*CF Introduction		
Age^2*4 to <7 mo (ref)	-	-
Age^2*<4 mo	0.000 (0.000)	0.000 (0.000)
Age^2*≥7 mo	0.000 (0.001)	-0.001 (0.001)
Breastfeeding Duration		
<6 months (ref)	-	-
Not BF	-0.104 (0.103)	0.027 (0.116)
≥6 months	-0.018 (0.090)	-0.103 (0.09)
Maternal marital status		
Not married[a] (ref)	-	-
Married	-0.031 (0.087)	0.041 (0.088)
Maternal education level		
HS or less (ref)	-	-
More than HS	-0.006 (0.078)	-0.099 (0.081)
Household poverty level[b]		
≤75% (ref)	-	-
>75 to 130%	0.078 (0.086)	0.284 (0.086)**
>130%	0.007 (0.121)	-0.005 (0.14)
Race/ethnicity		
Hispanic (ref)	-	-
NH-Black	-0.179 (0.099)	-0.250 (0.109)*

Effect	Male (n=727) β (SE)	Female (n=683) β (SE)
NH-White	-0.111 (0.095)	-0.200 (0.100)
Other	-0.206 (0.142)	-0.065 (0.143)
Maternal weight[c]		
Normal or Underweight (ref)	-	-
Overweight	0.028 (0.093)	0.118 (0.093)
Obese	0.129 (0.086)	0.209 (0.091)*
Maternal age		
26+ years (ref)	-	-
20-25 years	0.060 (0.079)	-0.106 (0.084)
16-19 years	0.198 (0.139)	-0.048 (0.143)
Household food security		
High/Marginal (ref)	-	-
Low	-0.081 (0.081)	0.057 (0.085)
Very Low	0.013 (0.109)	0.019 (0.105)
Delivery Type		
Vaginal (ref)	-	-
Caesarean	0.064 (0.078)	0.030 (0.083)
Smoked during pregnancy		
No (ref)	-	-
Yes	0.431 (0.132)	0.290 (0.131)*

* p < 0.05, ** p < 0.01, *** p < 0.001

Note: age is centered at 6 months

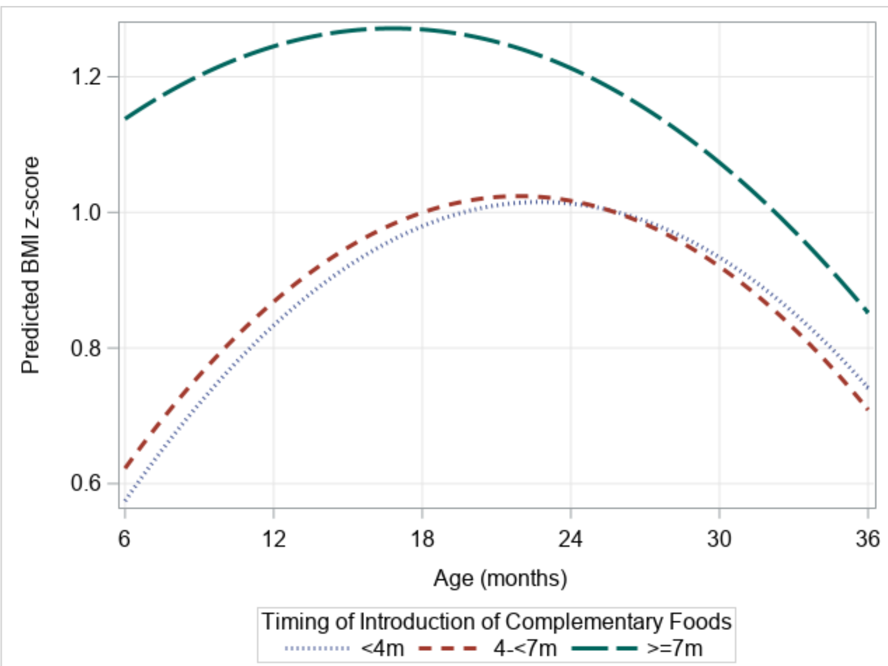
CF = complementary foods; BF = breastfed; HS = high school; NH = non-Hispanic

[a]including divorced and widowed; [b]relative to 2013 federal poverty guidelines; [c] weight status at the time of screening

Among boys, the model suggests differences in weight trajectories between those with late CF introduction (≥7 months) compared to those with CF introduction at 4-6 months, but no difference between those with early CF introduction (<4 months) compared to those with CF introduction at 4-6 months. BMIZ at 6 months of age were 0.52 z-score units higher for those with late CF introduction (β=.52, p=.01) compared to those with CF introduction at 4 to 6 months of age. There were no significant differences in the slope at age 6 months (age*CF) or the changes in slope over time (age^2*CF) between children by timing of introduction of complementary foods, though Figure 20 suggests that the difference in BMIZ between the late introduction and the recommended introduction groups seen at 6 months decreased over time.

This was reflected in age-centered models, where predicted BMIZ of males with late CF introduction were 0.38 z-score units higher at 1 year of age (p=.02), 0.20 z-score units higher at 2 years of age (not statistically significant) and 0.14 z-score units higher at three years of age (not statistically significant) compared to those with introduction at 4-6 months. Consistent with the model and with Figure 20, age-centered models revealed no significant difference in BMIZ at ages 1, 2, or 3 years of age between boys with early introduction of complementary foods (<4 months) and those introduced complementary foods between 4 and 6 months of age.

Figure 20. Predicted BMI-for-age z-score trajectories from age six months to three years by timing of introduction of complementary foods (male children)

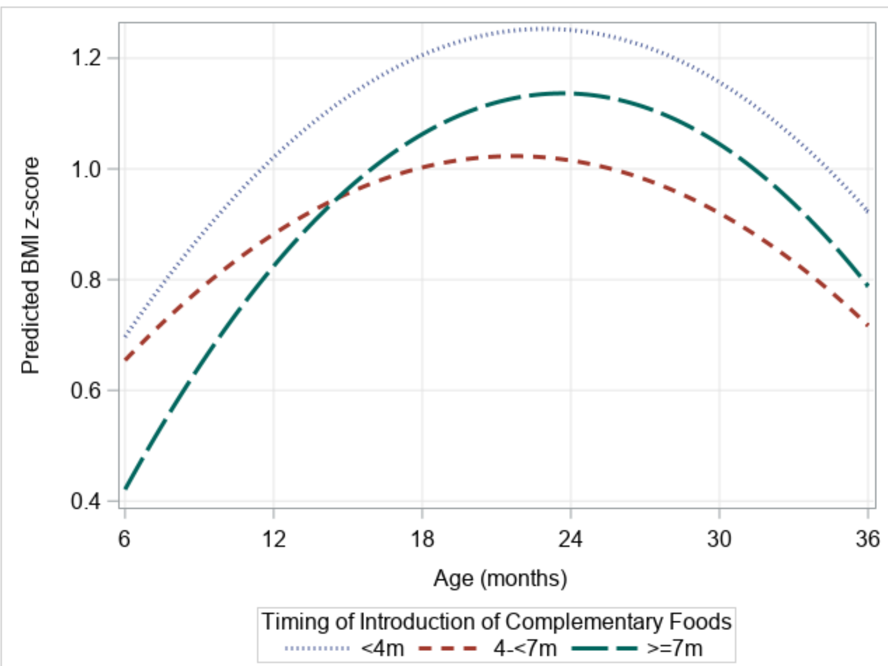


Note: Fit computed at reference categories of all covariates

Among girls, the model suggests no significant difference in BMIZ at 6 months of age, and no significant difference in the initial slope of the weight trajectories at 6 months or the change in slope of the weight trajectories over time based on timing of CF introduction (Table 20). Though it did not reach statistical significance, the slope of the weight trajectory of children with early CF introduction (<4 months) was slightly steeper compared to children introduced to

CF between 4 to 6 months (β=.02). This difference is reflected in Figure 21, where predicted BMIZ increase more quickly at 6 months of age for the early CF introduction group compared to the group with CF introduction at 4-6 months. Age-centered models suggested that, though statistically insignificant, these small differences in trajectories may result in significant differences in weight as girls age: predicted BMIs were higher for the early introduction group at 2 years (.23 z-score units, p=.03) and 3 years (.20 z-score units, marginally significant at p=.08) of age compared to those introduced CF at 4 to 6 months of age.

Figure 21. Predicted BMI-for-age z-score trajectories from age six months to three years by timing of introduction of complementary foods (female children)



Note: Fit computed at reference categories of all covariates

For both boys and girls, similar relationships between timing of CF introduction and weight trajectories were observed when weight-for-length z-scores were examined instead of BMIZ (Appendix Table B2.1).

To understand if, within the broad historically recommended period for CF introduction at 4 to 6 months of age, introduction of CF according to current recommendations of approximately 6 months of age was associated with healthier growth trajectories (Hypothesis 2.1b), mixed effects linear regression models were used to compare growth trajectories of those with CF introduction between 5.5 to <7 months compared to 4 to <5.5 months (Table 21). Models were fit with a random intercept and slope and age was centered at 6 months. Residual diagnostics indicate that the model provided a good fit of the data across all four measurement times from 6 months to 3 years of age for both boys (Appendix Figure B2.2 a) and girls (Appendix Figure B2.2 b).

Table 21. Mixed effects linear regression models: association between timing of introduction of complementary foods and repeated BMI-for-age z-scores among subsample of children with complementary food introduction between 4 to 6 months, WIC ITFPS-2 Study (n=932)

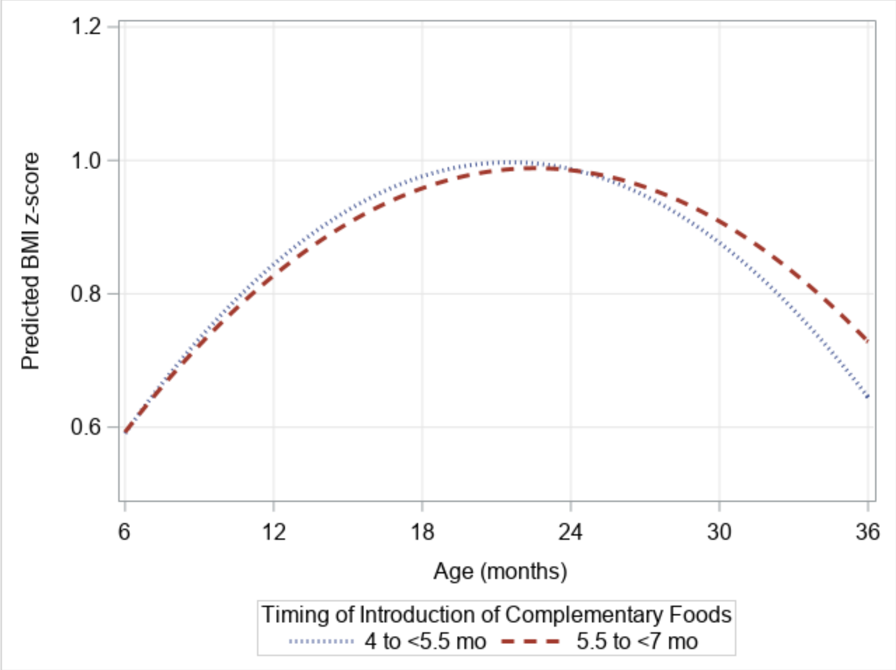
Coefficients	Male (n=486) β (SE)	Female (n=446) β (SE)
Intercept	0.589 (0.15)***	0.771 (0.159)***
Timing of CF Introduction		
5.5 - <7 mo (ref)	-	
4 - <5.5 mo	0.001 (0.109)	-0.230 (0.108)*
Age (months)	0.048 (0.011)***	0.047 (0.010)***
Age^2	-0.001 (0.000)***	-0.002 (0.000)***
Age*CF Introduction		
Age*5.5 - <7 mo (ref)	-	
Age*4 - <5.5 mo	0.005 (0.014)	0.000 (0.013)
Age^2*CF Introduction		
Age^2*5.5 - <7 mo (ref)	-	
Age^2*4 - <5.5 mo	0.000 (0.000)	0.000 (0.000)
Breastfeeding Duration		
<6 months (ref)	-	
Not BF	-0.088 (0.13)	-0.036 (0.156)
≥6 months	0.00 (0.105)	-0.125 (0.103)
Maternal marital status		
Not married[a] (ref)	-	
Married	-0.069 (0.103)	0.061 (0.106)
Maternal education level		
HS or less (ref)	-	
More than HS	-0.009 (0.095)	-0.114 (0.100)
Household poverty level[b]		
≤75% (ref)	-	
>75 to 130%	0.132 (0.105)	0.322 (0.104)**
>130%	0.165 (0.136)	0.015 (0.169)
Race/ethnicity		

Coefficients	Male (n=486) β (SE)	Female (n=446) β (SE)
Hispanic (ref)	-	
NH-Black	-0.211 (0.121)	-0.164 (0.140)
NH-White	-0.110 (0.116)	-0.109 (0.124)
Other	-0.164 (0.178)	-0.132 (0.172)
Maternal weight[c]		
Normal or Underweight (ref)	-	
Overweight	0.061 (0.113)	0.139 (0.118)
Obese	0.126 (0.103)	0.250 (0.112)*
Maternal age		
26+ years (ref)	-	
20-25 years	0.057 (0.095)	-0.142 (0.105)
16-19 years	0.194 (0.163)	-0.039 (0.197)
Household food security		
High/Marginal (ref)	-	
Low	-0.074 (0.099)	0.088 (0.105)
Very Low	-0.006 (0.132)	-0.108 (0.133)
Delivery Type		
Vaginal (ref)	-	
Caesarean	0.077 (0.093)	0.034 (0.101)
Smoked during pregnancy		
No (ref)	-	
Yes	0.415 (0.169)*	0.364 (0.179)*

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Note: age is centered at 6 months
CF=complementary foods; BF=breastfed; HS = high school; NH = non-Hispanic
[a]including divorced and widowed; [b]relative to 2013 federal poverty guidelines; [c] weight status at the time of screening

Among boys, weight trajectories were similar between the two groups, with no significant differences in BMIZ at 6 months of age, no difference in the slope of their BMIZ trajectories at six months, and no significant difference in the change in the quadratic trends of the BMIZ trajectories between 6 months to 3 years of age (Table 21). Consistent with Figure 22, age-centered models similarly indicated no significant difference between the groups in BMIZ at ages 1, 2, or 3 years of age.

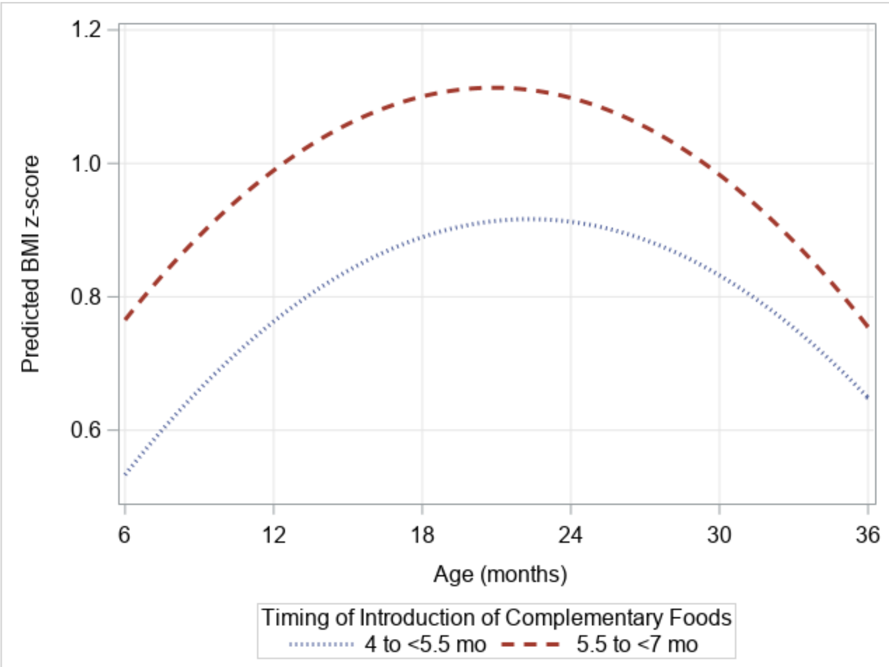
Figure 22. Predicted BMI z-score trajectories from age 6 months to 3 years by timing of introduction of complementary foods (male children)



Note: Fit computed at reference categories of all covariates

Among girls, contrary to the hypothesis, BMIZ were consistently lower for those introduced complementary foods between 4 to <5.5 months compared to those introduced complementary foods during the recommended 5.5 to <7 months (Figure 23). At 6 months of age predicted BMIs were 0.23 z-score units lower (p=.03) for children with earlier introduction of CF compared to introduction around six months (Table 21). Age-centered models suggest this difference persisted through 2 years of age. Compared to children with CF introduction at 5.5 to <7 months, BMIs of children with earlier introduction were 0.22 z-score units lower at 1 year of age (p=.02) and 0.18 z-score units lower at 2 years of age (marginally significant at p=0.099).

Figure 23. Predicted BMI z-score trajectories from age 6 months to 3 years by timing of introduction of complementary foods (female children)



Note: Fit computed at reference categories of all covariates

For both boys and girls, similar relationships between timing of CF introduction and weight trajectories were observed when weight-for-length z-scores were examined instead of BMIZ (Appendix Table B2.2).

Timing of Introduction of Complementary Foods and Odds of Overweight and Obesity

Mixed effects logistic regression models with random intercepts (Table 22) were used to explore the relationship between timing of CF introduction and odds of overweight/obesity at 2 to 3 years of age (research question 2.2). Figures 24 and 25 provide a graphical representation of the regression results for boys and girls, respectively, plotting the predicted probabilities of overweight/obesity by CF introduction group calculated at the reference value of each of the covariates. All stated predicted probabilities were also calculated at the reference values of each of the covariates.

Table 22. Mixed effects logistic regression models: association between timing of introduction of complementary foods and overweight/obesity at ages 2-3 years, WIC ITFPS-2 Study (n=1,410)

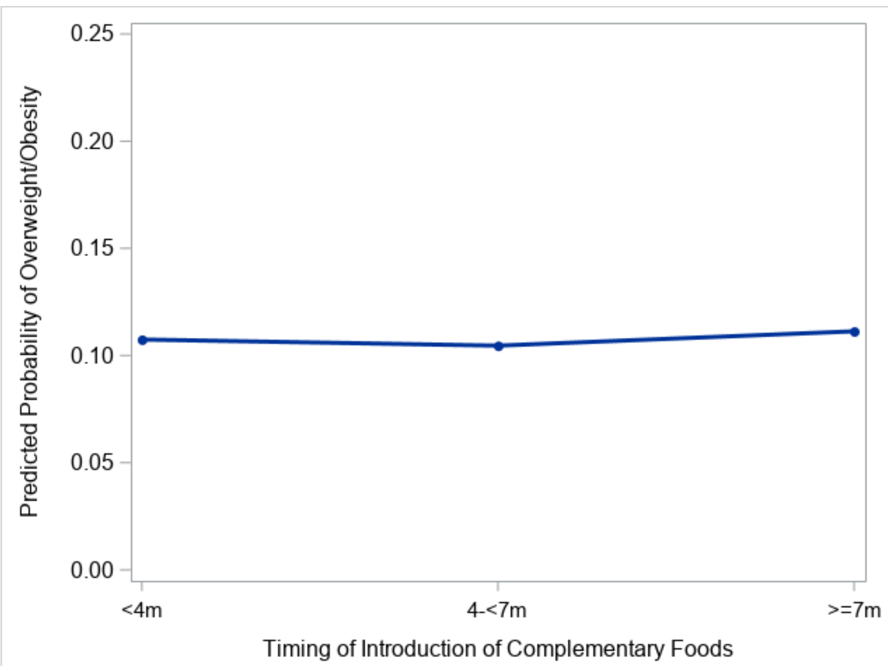
Effect	Male (n=727) OR (95% CI)	Female (n=683) OR (95% CI)
Timing of CF Introduction		
4 to <7 mo (ref)	-	-
<4 mo	1.03 (0.67, 1.60)	1.13 (0.73, 1.77)
≥7 mo	1.07 (0.47, 2.47)	1.06 (0.46, 2.45)
Breastfeeding Duration		
<6 months (ref)	-	-
Not BF	1.74 (1.05, 2.89)*	1.83 (1.04, 3.20)*
≥6 months	1.02 (0.63, 1.66)	0.63 (0.38, 1.03)
Maternal marital status		
Not married[a] (ref)	-	-
Married	0.89 (0.56, 1.42)	0.87 (0.54, 1.38)
Maternal education level		
HS or less (ref)	-	-
More than HS	1.25 (0.82, 1.89)	0.76 (0.49, 1.17)
Household poverty level[b]		
≤75% (ref)	-	-
>75 to 130%	1.04 (0.67, 1.63)	0.88 (0.56, 1.39)
>130%	0.82 (0.42, 1.6)	1.10 (0.53, 2.30)
Race/ethnicity		
Hispanic (ref)	-	-
NH-Black	0.71 (0.42, 1.21)	0.58 (0.32, 1.04)
NH-White	0.88 (0.53, 1.46)	0.58 (0.34, 1.00)
Other	0.65 (0.29, 1.47)	0.66 (0.31, 1.42)
Maternal weight[c]		
Normal or Underweight (ref)	-	-
Overweight	1.30 (0.79, 2.12)	1.18 (0.72, 1.93)
Obese	1.52 (0.97, 2.38)	1.71 (1.07, 2.73)*
Maternal age		
26+ years (ref)	-	-
20-25 years	1.26 (0.83, 1.90)	0.65 (0.41, 1.01)
16-19 years	1.79 (0.88, 3.66)	1.30 (0.65, 2.63)
Household food security		
High/Marginal (ref)	-	-
Low	0.69 (0.44, 1.07)	1.42 (0.91, 2.21)
Very Low	1.44 (0.85, 2.45)	1.43 (0.84, 2.45)
Delivery Type		
Vaginal (ref)	-	-
Caesarean	1.08 (0.72, 1.63)	0.87 (0.57, 1.35)
Smoked during pregnancy		
No (ref)	-	-
Yes	1.46 (0.76, 2.83)	1.68 (0.88, 3.19)

*p<.05

CF = complementary foods; BF = breastfed; HS = high school; NH = non-Hispanic
[a]including divorced and widowed; [b]relative to 2013 federal poverty guidelines; [c] weight status at the time of screening

Among boys, there was no difference in odds of overweight/obesity by timing of introduction of complementary foods. Figure 24 illustrates that the predicted probabilities of overweight/obesity at ages 2-3 years were virtually the same regardless of timing of CF introduction: 10.7% among those with early introduction, 10.5% among those with introduction between 4 to <7 months, and 11.1% among those with late introduction.

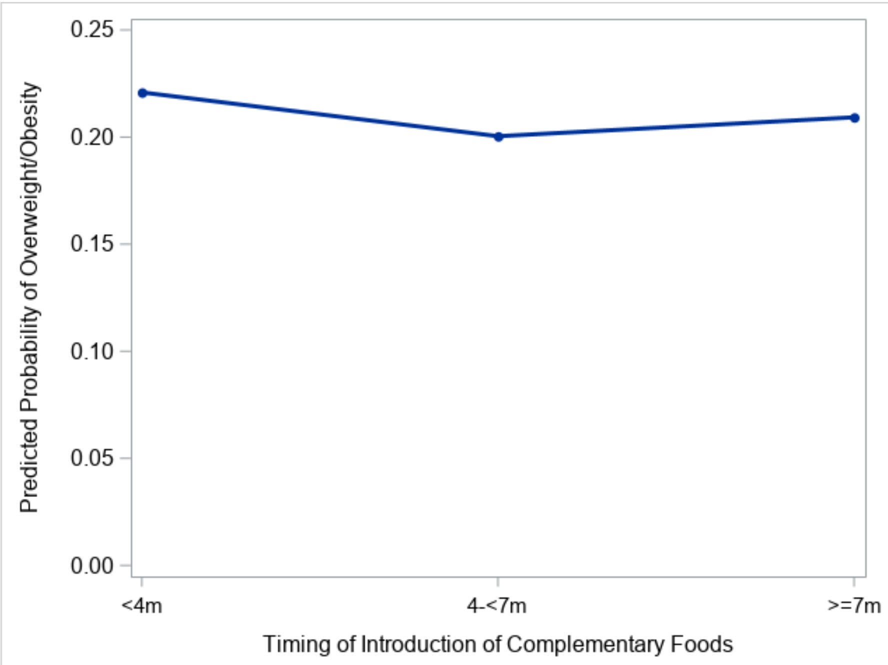
Figure 24. Predicted probabilities of overweight/obesity at 2-3 years of age by timing of introduction of complementary foods (male children)



Note: predicted probabilities calculated at reference values of all covariates

Similarly, there was no significant difference in odds of overweight/obesity among girls by timing of CF introduction (Table 22). This is reflected in the similarity of predicted probabilities of overweight/obesity at 2-3 years of age (Figure 25). The predicted probabilities of overweight/obesity were 22.1% among those with early introduction, 20.0% among those with introduction between 4-6 months, and 20.9% among those with late introduction.

Figure 25. Predicted probabilities of overweight/obesity at 2-3 years of age by timing of introduction of complementary foods (female children)



Note: predicted probabilities calculated at reference values of all covariates

Testing Interaction Between Timing of Introduction of Complementary Foods and Duration of Breastfeeding

To explore whether the effect of timing of CF introduction depended on how long the child was breastfed (question 2.3), an interaction between CF introduction and BF duration was included in mixed effects logistic regression models. In these analyses, both timing of CF introduction and BF duration were dichotomized because of small cell sizes. For example, there were no girls who were breastfed for at least six months with late CF introduction (≥7 months) who had the outcome of interest (overweight/obesity at age 2 or 3 years). BF duration was dichotomized as <6 months vs ≥6 months, and timing of CF introduction was dichotomized as <4 months vs ≥4 months. The distribution of the dichotomized variables by sex are summarized in Tables 23 and 24.

Table 23. Dichotomous breastfeeding duration by sex, WIC ITFPS-2 Study (n=1,410)

Duration of Any Breastfeeding	Male (n=727) N (%)	Female (n=683) N (%)
<6 months	530 (73)	496 (73)
≥6 months	197 (27)	187 (27)

Table 24. Dichotomous timing of introduction of complementary foods by sex, WIC ITFPS-2 Study (n=1,410)

Timing of Introduction of Complementary Foods	Male (n=727) N (%)	Female (n=683) N (%)
<4 months	199 (27)	198 (29)
≥4 months	528 (73)	485 (71)

The models did not support the hypothesis that the relationship between timing of CF introduction and overweight/obesity would vary by duration of breastfeeding. The interaction between CF introduction and BF duration was not statistically significant for either boys or girls (Table 25). Among boys who were breastfed for <6 months, those who were introduced to CF after 4 months had slightly higher log odds of overweight/obesity compared to those who were introduced to CF before 4 months (β=.07), though this difference was not statistically significant. Among boys who were breastfed for at least 6 months, those with later introduction to CF had lower log odds of overweight/obesity compared to those with early introduction (β = -.41 [.07+(-.48)]) but this difference was also not statistically significant.

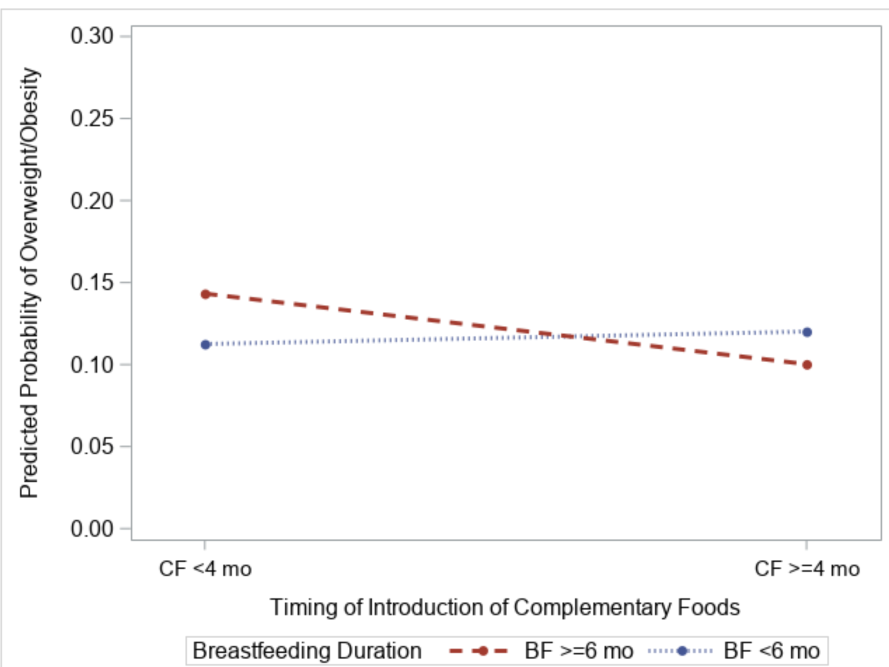
Table 25. Mixed effects logistic regression models: testing interaction between timing of introduction of complementary foods and breastfeeding duration, WIC ITFPS-2 Study (n=1,410)

Coefficient	Male (n=727) β (SE)	Female (n=683) β (SE)
Intercept	-2.07 (0.34)**	-1.17 (0.34)**
Timing of CF Introduction		
<4 mo (ref)	-	-
≥4 mo	0.07 (0.25)	-0.04 (0.25)
BF Duration		
<6 mo (ref)	-	-
≥6 mo	0.28 (0.49)	-0.24 (0.51)
CF Introduction * BF Duration		
CF ≥4 mo * BF ≥6 mo	-0.48 (0.55)	-0.41 (0.58)
Maternal marital status		
Not married[a] (ref)	-	-
Married	-0.12 (0.24)	-0.17 (0.24)
Maternal education level		
HS or less (ref)	-	-
More than HS	0.17 (0.21)	-0.31 (0.22)
Household poverty level[b]		
≤75% (ref)	-	-
>75 to 130%	0.02 (0.23)	-0.14 (0.23)
>130%	-0.22 (0.34)	0.07 (0.37)
Race/ethnicity		
Hispanic (ref)	-	-
NH-Black	-0.26 (0.27)	-0.48 (0.29)
NH-White	-0.06 (0.26)	-0.45 (0.27)
Other	-0.34 (0.41)	-0.32 (0.38)
Maternal weight[c]		
Normal or Underweight (ref)	-	-
Overweight	0.25 (0.25)	0.12 (0.25)
Obese	0.43 (0.23)	0.47 (0.24)*
Maternal age		
26+ years (ref)	-	-
20-25 years	0.22 (0.21)	-0.44 (0.23)
16-19 years	0.53 (0.36)	0.21 (0.36)
Household food security		
High/Marginal (ref)	-	-
Low	-0.38 (0.22)	0.32 (0.22)
Very Low	0.37 (0.27)	0.34 (0.27)
Delivery Type		
Vaginal (ref)	-	-
Caesarean	0.11 (0.21)	-0.15 (0.22)
Smoked during pregnancy		
No (ref)	-	-
Yes	0.50 (0.33)	0.58 (0.32)

* <0.05 ** < 0.001
CF = complementary foods; BF = breastfeeding; HS = high school; NH = non-Hispanic
[a]including divorced and widowed; [b]relative to 2013 federal poverty guidelines; [c]weight status at the time of screening

Figure 26 provides a graphical representation of the model for boys, plotting predicted probabilities of overweight/obesity by timing of introduction of CF and BF duration calculated at the reference value of each of the covariates. Among boys breastfed for less than 6 months, the predicted probability of overweight/obesity for a child with early introduction to CF was 11.3% while the probability for a child introduced to CF at or after 4 months was 12.0%. Among boys breastfed for at least six months, the predicted probability of overweight/obesity for a child with early introduction to CF was 14.3% while the probability for a child introduced to CF at or after 4 months was 10%.

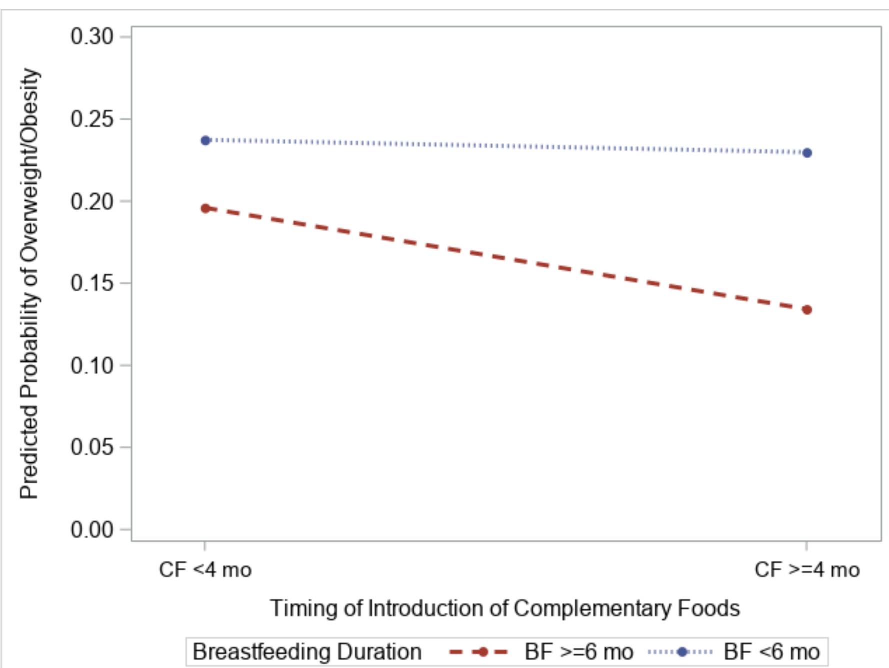
Figure 26. Predicted probabilities of overweight/obesity at 2-3 years of age by timing of introduction of complementary foods and breastfeeding duration (male children)



Note: Fit computed at reference categories of all covariates

Among girls breastfed for less than 6 months, log odds of obesity were slightly lower for those with introduction to CF at or after 4 months compared to those with early CF introduction (β = -.04), but the difference was not statistically significant (Table 25). This is reflected in Figure 27, where the predicted probability (calculated at reference categories of all covariates) of overweight/obesity among children breastfed for <6 months was 23.7% for those with early introduction to CF and 23% for those with CF introduction at or after 4 months. Among girls breastfed for at least six months, log odds of obesity were lower for those with CF introduction at or after 4 months (β = -.45 [-.04 + (-.41)]) compared to those with early CF introduction, but this difference again was not statistically significant. Figure 27 demonstrates that the predicted probability of overweight/obesity among girls breastfed for at least six months was 19.6% for those with early CF introduction and 13.4% for those with introduction at or after 4 months.

Figure 27. Predicted probabilities of overweight/obesity at 2-3 years of age by timing of introduction of complementary foods and breastfeeding duration (female children)



Note: Fit computed at reference categories of all covariates

Discussion

Primary Findings

Hypothesis 2.1: Controlling for breastfeeding duration, CF introduction at 4-6 months will be associated with healthier BMIZ trajectories compared to introduction before 4 months or after 7 months.

The results of this study provide limited evidence to support this hypothesis, and relationships varied by the child's sex. Among boys, those with late CF introduction had significantly higher BMIZ at 6 months of age compared to those with introduction at 4-6 months. Age-centered models indicated that this difference persisted at 1 year of age, but not at ages 2 and 3 years. Among girls, while the model indicated no statistically significant differences in BMIZ trajectories by timing of CF introduction, those with early CF introduction (<4 months) had slightly higher BMIZ at 6 months of age, and slightly greater monthly increases in BMI at 6 months of age. Age-centered models suggested that these small differences resulted in significantly higher BMIZ among girls with early CF introduction at 2 and 3 years of age compared to girls with CF introduction at 4 to 6 months.

Hypothesis 2.1a: Among those with introduction at 4-6 months, adherence to current recommended feeding practices (around 6 months) will be associated with healthier BMIZ trajectories.

This study again revealed sex differences in the relationship between complementary feeding practices and weight status. Among boys, there was no difference in BMIZ trajectories between the two groups. Among girls, contrary to the hypothesis, those with introduction between 5.5 to <7 months had significantly higher BMIZ at 6 months of age, and age-centered models suggested that these differences persisted through 2 years of age.

Hypothesis 2.2: Controlling for breastfeeding duration, CF introduction at 4-6 months will be associated with reduced odds of overweight/obesity at ages 2-3 years compared to introduction before 4 months or after 7 months.

In contrast to the hypothesis, there were no significant differences in odds of overweight/obesity by timing of CF introduction among boys or girls.

Hypothesis 2.3: There will be an interaction between timing of CF introduction and breastfeeding duration, such that early introduction of complementary foods will be associated with higher odds of overweight/obesity for infants with shorter breastfeeding duration but not those with longer breastfeeding duration.

In contrast to the hypothesis, there was no interaction between duration of breastfeeding and timing of CF introduction, suggesting that duration of breastfeeding did not affect the relationship between timing of CF introduction and weight status in early childhood.

Comparison with other studies and implications

A recent literature review conducted by the USDA Evidence Systematic Review to inform the Pregnancy and Birth to 24 Months Project (English et al., 2019) identified 10 articles published since 1990 using data from children in the U.S. to explore the relationship between timing of introduction of complementary foods and weight status in childhood (Agras et al., 1990; Barrera et al., 2016; Burdette et al., 2006; Flores & Lin, 2013a, 2013b; Gibbs & Forste, 2014; Gungor et al., 2010; M J Heinig et al., 1993; Huh et al., 2011; Moss & Yeaton, 2014). Of these studies, approximately half (six of 10) found a significant association between complementary feeding practices and risk of overweight/obesity (Flores & Lin, 2013b; Gibbs & Forste, 2014; Gungor et al., 2010; Huh et al., 2011; Moss & Yeaton, 2014) and/or BMI (Agras et al., 1990; Huh et al., 2011). The review concluded there is limited evidence that CF introduction before 4 months may be associated with higher odds of overweight/obesity (English et al., 2019).

In contrast, we found no association between early CF introduction (<4 months) and odds of overweight/obesity. One important consideration of the current evidence supporting the relationship between complementary feeding practices and weight status in early childhood is that most of the studies which found significant associations examine data from only two longitudinal cohort studies. Of the six studies previously mentioned which found timing of CF introduction to be associated with childhood weight, four used data from either the Early Childhood Longitudinal Study-Birth Cohort (ECLS-B) (Flores & Lin, 2013b; Gibbs & Forste, 2014; Moss & Yeaton, 2014) or Project Viva (Huh et al., 2011).

Among children in the ECLS-B, a nationally representative prospective cohort of U.S. children born in 2001, those with CF introduction before 4 months of age had higher odds of obesity at 2 years of age compared to those with later introduction (Gibbs & Forste, 2014; Moss & Yeaton, 2014), though by 4 years of age there was no difference in odds of obesity between those with introduction before 4 months of age and introduction at or after 6 months of age (Moss & Yeaton, 2014). Of note, Moss & Yeaton (2014) found no difference in odds of overweight at 2 or 4 years of age by timing of introduction of CF. This may help explain the lack of significance of our findings, as we explored the association between CF introduction and odds of overweight *or* obesity between 2 to 3 years. It is possible that we may have found an association had we looked specifically at the odds of obesity between 2 to 3 years. Unmeasured confounding variables may also be responsible for differences in the study findings, as the populations were significantly different. While the ECLS-B followed a nationally representative sample of children, children in the WIC ITFPS-2 Study were more racially and ethnically diverse and of lower socioeconomic status.

Huh et al. (2011) analyzed data from Project Viva, a prospective cohort study of children born between 1999 and 2002 in eastern Massachusetts and similarly found that CF introduction before 4 months of age was associated with increased odds of obesity at 3 years of age among children who were never breastfed or those who stopped breastfeeding before 4 months of age. There was no association between timing of CF introduction and obesity among children breastfed for at least 4 months. Another recent examination of data from Project Viva found that these differences persisted into mid-childhood (Gingras et al., 2019). However, Project Viva has notable limitations that limit the generalizability of the findings. First, the sample was primarily White (70%) and of higher socioeconomic status (e.g., 75% of moms were college graduates and 90% lived in households with annual incomes ≥$40,000) (Huh et al., 2011). In addition, the analyses relied on relatively small cell sizes, so the results could be due to chance. For example, among children breastfed for at least 4 months, only n=23 of those with early introduction to solids were obese; similarly among children who stopped breastfeeding before 4 months, only n=8 of those who had CF introduction between 4-5 months (the reference group) were obese (Huh et al., 2011).

Another important consideration is that some of the studies with positive associations were examining specific subgroups of children based on characteristics that may influence their underlying risk for overweight/obesity. In a retrospective cohort study, Gungor (2010) examined children who were at risk for overweight based on rapid weight gain during the first two years of age and found that those who become overweight between 6-8 years had earlier mean complementary food introduction (5.1 months) compared to those who did not become overweight (6.5 months). In another study, Flores et al. (2013), using data from the ECLS-B found that timing of introduction of CF may be an important factor only for children whose mothers did not have diabetes during pregnancy (GDM). Among children of mothers without GDM, 58% of those with introduction to solid foods at <3.5 months were overweight in kindergarten compared to 26% of children with introduction at or after 3.5 months (Flores et al., 2013).

Though this study did not find timing of CF introduction to be associated with odds of overweight/obesity at ages 2 to 3 years, there were significant differences in BMIZ trajectories between the ages of 6 months to 3 years. Among boys, late introduction (7 months or later) was associated with higher BMIZ at 6 months of age which persisted at 1 year of age. Few studies have examined the influence of late CF introduction on weight status. One large prospective cohort study of children from eight European countries found that introduction of solid foods between 7-12 months was associated with 19% higher odds of overweight/obesity compared to introduction between 4-6 months, though the association was not statistically significant after controlling for parental factors including weight and highest level of education (Papoutsou et al., 2018). Among girls in our study, age-centered models suggested that those with CF introduction before 4 months had higher BMIZ at 2 and 3 years of age compared to those with CF introduction between 4-6 months. These results are consistent with those from Agras et al., (1990) who found that timing of CF introduction was positively associated with BMI at ages 1, 2, and 3 years, and from Huh et al., (2011) who found that CF introduction before 4 months was associated with higher BMIZ at age 3 compared to introduction between 4-5 months (though only among formula fed infants). However, other studies in the U.S. have found no association between timing of CF introduction and weight-to-height indices, including BMIZ and weight-for-length z-scores (Burdette et al., 2006; Heinig et al., 1993; Huh et al., 2011). One advantage of our study was the stratification of analyses by sex, as different relationships between complementary feeding practices and weight trajectories were revealed.

Few studies have explored the relationship between complementary feeding practices and early childhood weight specifically among children participating in the WIC program. An observational cohort study of 217 African-American mother-infant dyads recruited from WIC clinics in North Carolina (the U.S. Infant Care and Risk of Obesity Study) found that inappropriate feeding practices, including receipt of foods and beverages other than breast milk or formula at age 3 months, was associated with higher odds of high weight-for-length between 3 to 18 months of age (Thompson & Bentley, 2013). In this study, 78% of infants had been given complementary foods at 3 months of age, most often infant cereal (Thompson & Bently, 2013). Of note, complementary feeding practices were markedly different in the sample of WIC children in this dissertation study, with fewer than 30% of children receiving complementary foods before 4 months of age. Nationally representative data from NHANES from 2009-2014 found that 23.7% of non-Hispanic Black children were introduced complementary foods before 5 months of age (Barrera et al., 2018). These notable differences in infant feeding practices between participants in the U.S. Infant Care and Risk of Obesity Study and other populations, as well as the relatively small sample size, may limit the generalizability of their findings.

Study 2 findings were consistent with a cross-sectional study of complementary feeding practices and weight status of Hispanic infants and toddlers participating in the WIC program in Puerto Rico (n=189) (Sinigaglia et al., 2016). In this sample, approximately 23% of children were classified as having excessive weight (defined as $\geq 90^{th}$ percentile weight-for-length, using WHO growth charts) between 9 to 18 months of age. There was no relationship between timing of introduction of foods (solid foods, juice, or cow's milk) and odds of excessive weight, either in unadjusted analyses, or analyses adjusted for infant's sex and age and parent's age and education (Sinigaglia et al., 2016).

Some prior research has suggested that the effect of timing of introduction of CF may be conditional on breastfeeding duration, though this study did not support this hypothesis. Data from Project Viva found that early CF introduction (before 4 months) was associated with a sixfold increase in the odds of obesity at 3 years of age among infants who were never breastfed or who stopped breastfeeding before 4 months of age, while there was no association between timing of CF introduction and obesity among children breastfed for at least 4 months. However, as discussed previously, limitations of the Project Viva study include a primarily White higher-SES sample and small cell sizes which may result in unstable and imprecise estimates. Data from ECLS-B found that, at each category of timing of introduction of complementary foods (<4 months, 4-5 months, ≥6 months), children who were ever breastfed had significantly lower odds of obesity at 2 and 4 years of age compared to those who were never breastfed (Moss & Yeaton, 2014). Of note, Moss & Yeaton (2014) observed no difference in odds of overweight between breastfed vs. non-breastfed children across the groups of CF introduction at 2 or 4 years of age. This may have contributed to our null findings, as we did not separately examine the odds of obesity. In contrast to these two studies, our study found no significant interaction between timing of CF introduction and duration of breastfeeding, suggesting that there was no association between timing of CF introduction and odds of overweight/obesity at 2-3 years of age regardless of whether children were breastfed for at least six months or not.

Implications for Policy and Practice

In this sample of WIC infants and children from across the U.S., fewer than half were introduced to complementary foods according to current recommendations. Currently, the APA recommends complementary feeding begin around six months of age. Only 41% of boys and 38% of girls in this sample were first given complementary foods at this age. More than 1 in 4 children (27% of boys and 29% of girls) had early CF introduction (<4 months). These rates of early CF introduction are higher than national averages. Nationally-representative data from NHANES indicate that 17.3% of all infants and 16% of Hispanic infants in the U.S. receive CF before 4 months of age (Barrera et al., 2018). Notably, analyses of NHANES data have also indicated lower rates of early CF introduction among WIC recipients compared to our study findings, with 18% reporting CF introduction before 4 months. However, NHANES asked caregivers of children ages 0 to 6 years to retrospectively report complementary feeding practices, and studies have documented limited validity of retrospective recall of foods and fluids other than breast milk (Li et al., 2005). Thus, it is possible that the higher prevalence of early CF introduction in this sample may be a more accurate reflection of infant feeding practices among WIC families.

Though timing of CF introduction was not associated with odds of overweight/obesity in early childhood in this sample, encouraging moms to delay CF introduction may result in longer durations of breastfeeding, which was found in Study 1 to be associated with healthier weight outcomes. There is some evidence that earlier CF introduction is associated with shorter overall breastfeeding duration, potentially due to a reduction in breast milk supply in response to fewer feedings (Lessa et al., 2020).

Among mothers participating in the WIC program, several qualitative studies have explored reasons for early CF introduction. Baughcum et al., (1998) found that two common reasons that mothers introduced complementary foods early was a) because they perceived that their infants were not receiving enough nourishment from breast milk or formula alone, and b) because infant cereal helped the baby sleep through the night, rather than waking up frequently to feed. Similarly, Heinig et al., (2006) found that WIC mothers introduced complementary foods early because of perceptions that the infants were too thin, or because mothers were worried that they were not producing enough milk and complementary foods allowed them to visually observe the quantity of food the infant was receiving. This suggests two important areas of focus for counseling in the WIC setting to help promote complementary feeding practices in accordance with recommendations: first, around the practice of adding infant cereal to bottles, and second, around the nutritional adequacy of breast milk.

Researchers have found the practice of adding infant cereal to bottles to be common among WIC participants. In a study of low-income Hispanic mothers, 91% of whom were WIC participants, Lucas et al., (2017) found that by 6 months of age, 27% of mothers added cereal to bottles, either so their infant would sleep longer at night or stay full longer. In another study of WIC mothers, Savage & Birch (2017) found that by the time children were 2 years of age, 68% of mothers reported adding cereal to bottles. In the current sample of WIC participants, though the practice of adding cereal to bottles was not specifically examined, approximately 20% of mothers reported giving infant cereal by 4 months, either with a spoon or by adding it to a bottle (see Appendix Figure A1). Despite the common belief that adding infant cereal to the bottle will help the baby sleep longer, there is no evidence that this practice improves sleep (Perez-Escamilla et al., 2017). Therefore, targeted nutrition education interventions that debunk this myth and provide evidence-based strategies to improve infant sleep may help delay CF introduction.

In addition, interventions to shift attitudes and perceptions around infant sleep patterns may be helpful. In the first few months of life, though it is normal and biologically appropriate for infants to need to feed on average every 2 to 4 hours due to the small size of their stomachs (CDC, 2018c), parents have strong beliefs that infants should be sleeping through the night and view frequent wakings as a sign of poor parenting (Brown & Harries, 2015). Thus, normalizing frequent feedings and night wakings may reduce reliance on complementary foods and/or formula to try to help infants sleep through the night.

A second key area of focus for WIC nutrition education and counseling efforts is the nutritional adequacy of breast milk. The perception of an insufficient breast milk supply is one of the key drivers of early breastfeeding cessation (Gatti, 2008; Hurley et al., 2008; McCarter-Spaulding & Kearney, 2001). Among WIC participants, Hurley et al., (2008) found that "not having enough milk" was the most common reason for stopping breastfeeding, reported by nearly one quarter of the mothers in the study. Notably, the perception of insufficient milk supply was higher among Hispanic mothers (41%) compared to African American (20%) or White (18%) mothers (Hurley et al., 2008). As maternal self-efficacy has been found to be correlated with perceptions of sufficient milk supply (Galipeau et al., 2018; McCarter-Spaulding & Kearney, 2001), counseling in the WIC setting focused on improving breastfeeding self-efficacy may help decrease the prevalence of early CF introduction as a result of early BF cessation.

CHAPTER 7: STUDY THREE – RESULTS AND DISCUSSION

Overview of Aim, Hypotheses and Methods

The overall aim of Study 3 was to examine the relationship between early introduction of sugar-sweetened foods and beverages (SSFBs) and BMIZ trajectories (research question 3.1) and odds of early childhood overweight and obesity (research question 3.2), controlling for the influence of breastfeeding. I hypothesized that early introduction (before 1 year of age) to SSFBs – defined as soda, other sugar-sweetened beverages such as Kool-Aid and sweetened juices, and sweet foods such as cakes and cookies – would be negatively associated with healthy BMIZ trajectories and associated with increased odds of overweight/obesity at ages 2 to 3 years.

In addition, a sensitivity analysis was conducted in which age of introduction to "other dairy" products, defined as dairy products other than cow's milk, including yogurt and cheese, was considered in the definition of timing of introduction of SSFBs. Recent research has suggested that yogurt contributes nearly 1/5th of the added sugar in infants' diets, and though the "other dairy" category does not reflect yogurt exclusively and not all yogurts are sweetened, given that yogurt is a top contributor of added sugars it was pertinent to examine whether relationships changed when it was included in the analysis.

Sample Characteristics and Key Variable Distributions

The sample for Study 3 was 1,324 children (90% of the analytic sample) who had data on timing of introduction of SSFBs and breastfeeding duration. Demographic characteristics of the sample are summarized in Table 26. Compared to boys excluded from the sample (n=73), boys retained in the sample were more likely to have mothers with more than a high school education (43% vs. 29%). Compared to girls excluded from the sample (n=72), those retained in the sample were less likely to live in households at or below 75% FPL (60% vs. 76%).

Table 26. Demographic characteristics of sample for Study 3 analyses (n=1,324)

	Male (n=682) *N (%)*	Female (n=642) *N (%)*
Race/ethnicity		
Hispanic	303 (44)	318 (50)
Non-Hispanic White	174 (26)	164 (26)
Non-Hispanic Black	149 (22)	107 (17)
Non-Hispanic Other	56 (8)	53 (8)
Household poverty level[a]		
≤75%	429 (63)	384 (60)
>75 to 130%	177 (26)	200 (31)
>130 to 185%	76 (11)	58 (9)*
Household food security		
High or Marginal	362 (53)	336 (52)
Low	221 (32)	198 (31)
Very low	99 (15)	108 (17)
Maternal age at birth (years)		
16-19	66 (10)	59 (9)
20-25	281 (41)	253 (39)
≥26	335 (49)	330 (51)
Maternal marital status		
Married	218 (32)	219 (34)
Not married[b]	464 (68)	423 (66)
Maternal education level		
HS or less	389 (57)	385 (60)
More than HS	293 (43)*	257 (40)
Maternal weight[c]		
Normal/underweight	295 (43)	302 (47)
Overweight	162 (24)	158 (25)
Obese	225 (33)	182 (28)
Delivery type		
Vaginal	469 (67)	451 (70)
Caesarean	213 (31)	191 (30)
Maternal smoking status during pregnancy		
Did not smoke	613 (90)	571 (89)
Smoked ≥1 cigarette per day	69 (10)	71 (11)

* Significantly different compared to those excluded from the sample (chi-square test, p<0.05)
[a] relative to 2013 federal poverty guidelines; [b] including divorced and widowed; [c] weight status at the time of screening
Note: Percentages may not sum to 100 due to rounding

At two years of age, 3.5% of boys (n=24) and 5% of girls (n=32) had not been fed SSFBs. Among children who had received SSFBs by age two years, the distribution of timing of introduction for boys and girls are displayed in Figures 28 and 29, respectively. The mean age of introduction to SSFBs was 9.5 months for boys and 9.3 months for girls.

Figure 28. Timing of introduction of sugar-sweetened foods and beverages among children who had been fed sugar-sweetened foods and beverages by 2 years of age (male children, n=658)

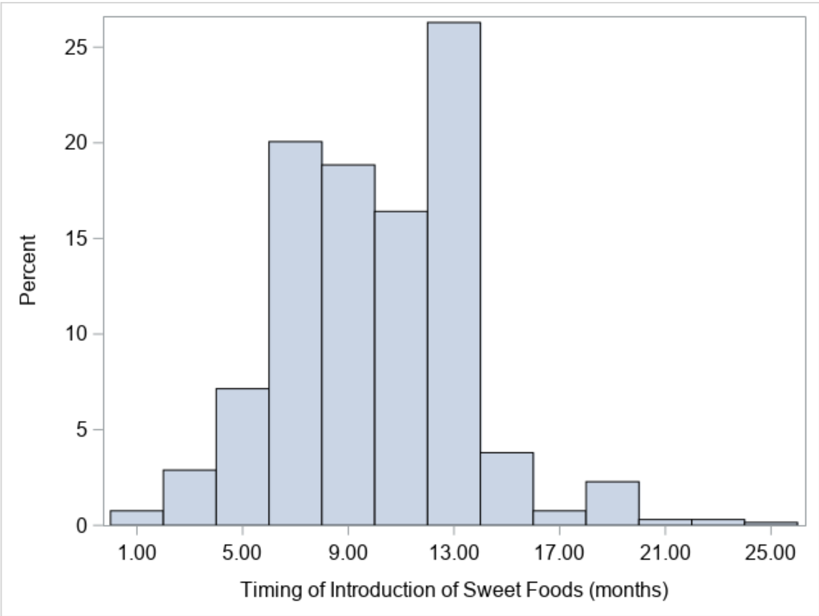
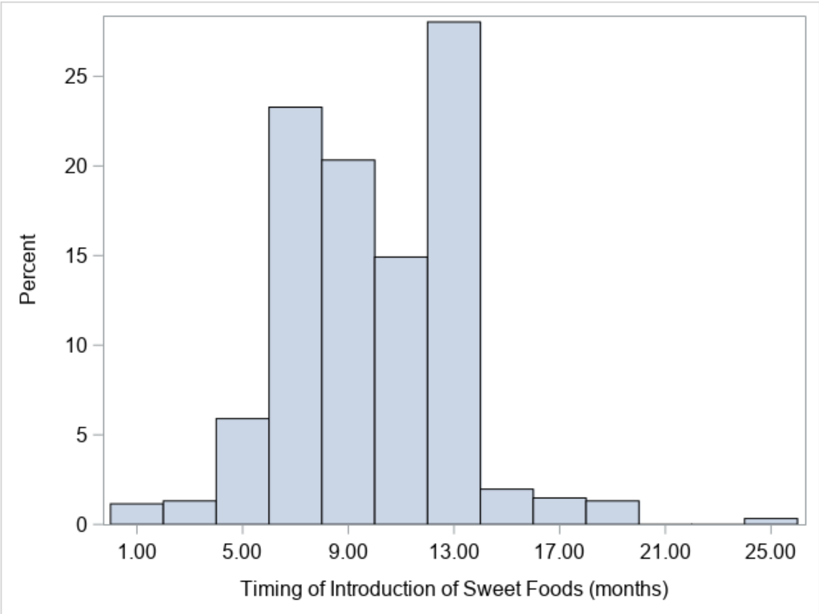


Figure 29. Timing of introduction of sugar-sweetened foods and beverages among children who had been fed sugar-sweetened foods and beverages by 2 years of age (female, n=610)



In order to answer the research questions, a binary variable was created to indicate whether children first received SSFBs before one year of age (early introduction) or at or after one year of age. Nearly two thirds of children (64% of both boys and girls) were first fed SSFBs before one year of age (Table 27).

Table 27. Early introduction to sugar-sweetened foods and beverages by sex, WIC ITFPS-2 Study (n=1,324)

Timing of Introduction to SSFBs	Male (n=682) *N (%)*	Female (n=642) *N (%)*
Before 1 year of age	435 (64)	408 (64)
At or after 1 year of age	247 (36)	234 (36)

SSFBs = sugar-sweetened foods and beverages

Results

Early Introduction to Sugar-Sweetened Foods and Beverages and Weight Trajectories From 6 Months to 3 Years of Age

Mixed effects linear regression models (Table 28) with age centered at 6 months were used to test the relationship between early introduction to SSFBs and weight trajectories (repeated BMIZ measures during the first three years of age). Models incorporate a random intercept (to allow children's initial weights to vary) and random slope (to allow children to vary in their linear trends over time). In addition, the models incorporate an age^2 term since growth trajectories in early childhood are curvilinear. Models control for breastfeeding duration to understand if complementary feeding practices influence children's weight trajectories independent of breastfeeding practices. Figures 30 and 31 provide graphical representations of the regression results, plotting predicted BMIZ trajectories for boys and girls, respectively, calculated at the reference value of each of the covariates. The corresponding predicted probabilities were also calculated at the reference value for all covariates. Models with age centered at 1, 2, and 3 years were used to evaluate whether predicted BMIs were significantly different between the children based on their timing of introduction to sweets at these specific ages. Residual diagnostics indicate that the regression models provided a good fit of the data across all four measurement times from 6 months to 3 years of age for both boys (Appendix Figure B3.1 a) and girls (Appendix Figure B3.1 b).

Table 28. Mixed Effects Linear Regression Models: Association Between Early Introduction to Sugar-Sweetened Foods and Beverages and Repeated BMI-for-age z-scores by Sex, WIC ITFPS-2 Study (n=1,324)

Coefficient	Male (n=682) β (SE)	Female (n=642) β (SE)
Intercept	0.642 (0.131)***	0.707 (0.131)***
Early Introduction[a] to SSFBs		
No (ref)	-	-
Yes	-0.036 (0.095)	-0.011 (0.092)
Age (months)	0.054 (0.010)***	0.050 (0.009)***
Age^2	-0.002 (0.000)***	-0.002 (0.000)***
Age*Early Introduction to SSFBs		
Age*No (ref)	-	-
Age*Yes	-0.006 (0.012)	0.003 (0.011)
Age^2*Early Introduction to SSFBs		
Age^2*No (ref)	-	-
Age^2*Yes	0.000 (0.000)	0.000 (0.000)
Breastfeeding Duration		
<6 months (ref)	-	
Not BF	-0.069 (0.109)	-0.006 (0.123)
≥6 months	-0.008 (0.093)	-0.137 (0.091)
Maternal marital status		
Not married[b] (ref)	-	-
Married	-0.017 (0.091)	0.025 (0.091)
Maternal education level		
HS or less (ref)	-	-
More than HS	-0.011 (0.082)	-0.122 (0.083)
Household poverty level[c]		
≤75% (ref)	-	-
>75 to 130%	0.064 (0.090)	0.302 (0.088)***
>130%	0.000 (0.126)	-0.014 (0.142)
Race/ethnicity		
Hispanic (ref)	-	-
NH-Black	-0.184 (0.103)	-0.242 (0.111)*
NH-White	-0.134 (0.101)	-0.203 (0.102)*
Other	-0.226 (0.148)	-0.125 (0.148)

Coefficient	Male (n=682) β (SE)	Female (n=642) β (SE)
Maternal weight[d]		
Normal or Underweight (ref)	-	-
Overweight	0.052 (0.098)	0.128 (0.096)
Obese	0.147 (0.090)	0.216 (0.094)*
Maternal age		
26+ years (ref)	-	-
20-25 years	0.041 (0.083)	-0.123 (0.087)
16-19 years	0.158 (0.145)	-0.093 (0.150)
Household food security		
High/Marginal (ref)	-	-
Low	-0.061 (0.085)	0.067 (0.087)
Very Low	0.026 (0.115)	0.053 (0.109)
Delivery Type		
Vaginal (ref)	-	-
Caesarean	0.061 (0.082)	0.027 (0.086)
Smoked during pregnancy		
No (ref)	-	-
Yes	0.426 (0.14)**	0.300 (0.134)*

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

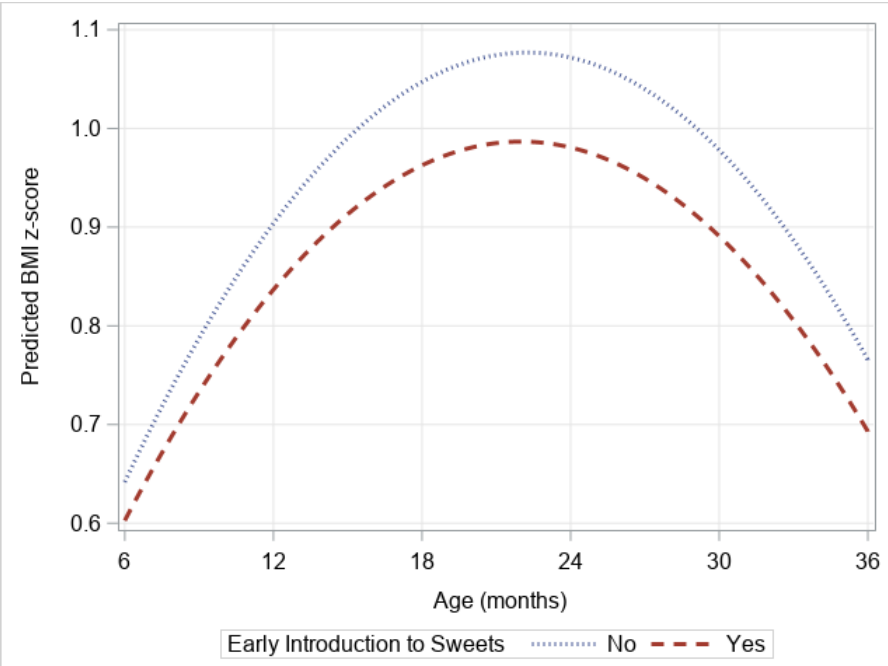
Note: models are age centered at 6 months of age

SSFB = sugar-sweetened foods and beverages; BF = breastfed; HS = high school; NH = non-Hispanic

[a]Early introduction defined as before 12 months of age; [b]including divorced and widowed; [c]relative to 2013 federal poverty guidelines; [d] weight status at the time of screening

The models suggest no difference in weight trajectories between 6 months and 3 years of age for either boys or girls by timing of introduction to sweets. Among boys, the mean BMIZ at age 6 months was slightly lower for those with early introduction to sweets (β= -.04), though the difference was not statistically significant. There was also no significant difference in the slope of the weight trajectories at age 6 months, or the degree of curvature of the trajectories. In contrast to the hypothesis, boys with early introduction to sweets had slightly lower predicted BMIZ between the ages of 6 months and 3 years (Figure 30), though age-centered models indicated that the differences were not statistically significant at ages 1, 2, or 3 years of age.

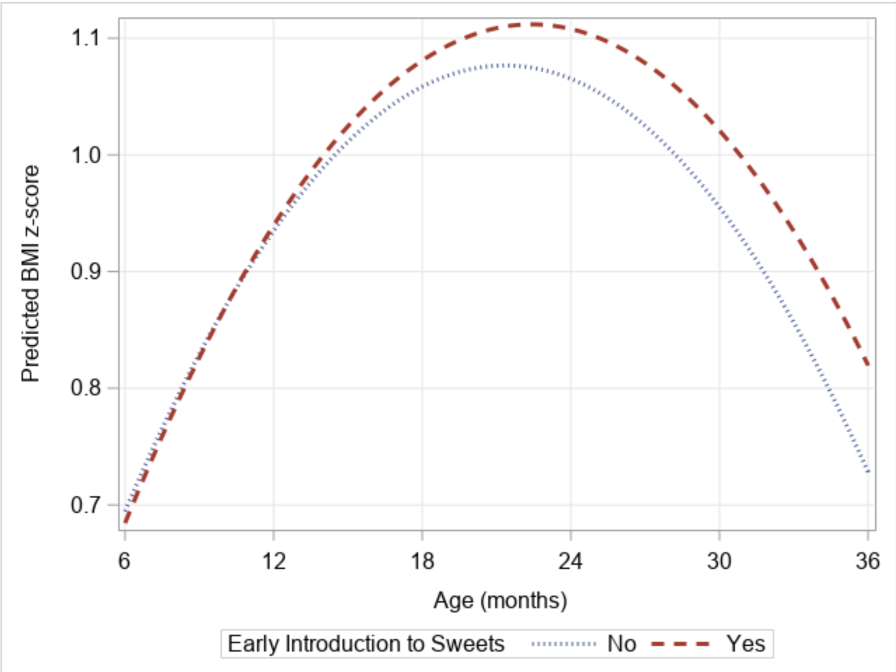
Figure 30. Predicted BMI-for-age z-score trajectories from age six months to three years by timing of introduction to sugar-sweetened foods and beverages (male children, n=682)



Note: Fit computed at reference categories of all covariates

Among girls, there was similarly no significant difference in mean BMIZ at age 6 months, and no difference in the slope at six months or the degree of curvature in the weight trajectories (Table 28). Though the trends demonstrated in Figure 31 are consistent with the hypothesis, such that girls with early introduction to sweets had higher predicted BMIZ between approximately 18 months and 3 years of age, the differences were small (0.04 z-score units at 2 years and 0.09 z-score units at 3 years of age) and were not statistically significant.

Figure 31. Predicted BMI-for-age z-score trajectories from age six months to three years by timing of introduction to sugar-sweetened foods and beverages (female children, n=642)



Note: Fit computed at reference categories of all covariates

For both boys and girls, similar relationships between timing of introduction to SSFBs and weight trajectories were observed when weight-for-length z-scores were examined instead of BMIZ (Appendix Table B3.1).

Early Introduction to Sugar-Sweetened Foods and Beverages and Odds of Overweight and Obesity at Ages 2 to 3 Years

Mixed effects logistic regression models with random intercepts (Table 29) were used to explore the association between early introduction to SSFBs and odds of overweight/obesity at two to three years of age (research question 3.2). For comparison, predicted probabilities of overweight/obesity were calculated, with all covariates set to reference values.

Table 29. Mixed effects logistic regression models: association between early introduction of sugar-sweetened foods and beverages and overweight/obesity at ages 2-3 years, WIC ITFPS-2 Study (n=1,324)

Coefficient	Male (n=682) OR (95% CI)	Female (n=642) OR (95% CI)
Early Introduction to SSFBs		
No (ref)	-	-
Yes	0.96 (0.64, 1.45)	1.02 (0.66, 1.56)
Breastfeeding Duration		
<6 months (ref)	-	-
Not BF	1.78 (1.05, 3.01)*	1.60 (0.88, 2.93)
≥6 months	1.07 (0.65, 1.75)	0.57 (0.34, 0.95)*
Maternal marital status		
Not married[a] (ref)	-	-
Married	1.00 (0.62, 1.61)	0.83 (0.51, 1.35)
Maternal education level		
HS or less (ref)	-	-
More than HS	1.16 (0.76, 1.78)	0.73 (0.46, 1.14)
Household poverty level[b]		
≤75% (ref)	-	-
>75 to 130%	1.02 (0.64, 1.63)	0.93 (0.59, 1.49)
>130%	0.87 (0.44, 1.71)	1.10 (0.52, 2.34)
Race/ethnicity		
Hispanic (ref)	-	-
NH-Black	0.76 (0.44, 1.31)	0.63 (0.35, 1.14)
NH-White	0.90 (0.53, 1.52)	0.59 (0.34, 1.03)
Other	0.69 (0.30, 1.58)	0.56 (0.25, 1.27)
Maternal weight[c]		
Normal or Underweight (ref)	-	-
Overweight	1.35 (0.81, 2.26)	1.16 (0.69, 1.94)
Obese	1.63 (1.02, 2.60)*	1.67 (1.03, 2.71)*
Maternal age		
26+ years (ref)	-	-
20-25 years	1.22 (0.80, 1.87)	0.56 (0.35, 0.89)*
16-19 years	1.82 (0.88, 3.79)	1.19 (0.57, 2.47)
Household food security		
High/Marginal (ref)	-	-
Low	0.70 (0.44, 1.11)	1.56 (0.99, 2.47)
Very Low	1.57 (0.91, 2.71)	1.70 (0.98, 2.96)
Delivery Type		
Vaginal (ref)	-	-
Caesarean	1.01 (0.66, 1.55)	0.87 (0.55, 1.36)
Smoked during pregnancy		
No (ref)	-	-
Yes	1.60 (0.81, 3.17)	1.66 (0.86, 3.21)

*p<.05

SSFBs = sugar-sweetened foods and beverages; BF = breastfed; HS = high school; NH = non-Hispanic
[a]including divorced and widowed; [b]relative to 2013 federal poverty guidelines; [c] weight status at the time of screening

Contrary to the hypothesis, the models revealed no significant association between early introduction to SSFBs and odds of overweight/obesity for boys (OR=0.96, [95% CI: 0.64- 1.45]) or girls (OR=1.02, [95% CI: 0.66-1.56]). This finding was reflected in the similar estimates of predicted probability of overweight/obesity by timing of introduction to SSFBs. Among boys, the predicted probability of overweight/obesity was 9.7% for those with early SSFB introduction and 10.0% for those without early introduction. Among girls, the predicted probability of overweight/obesity was 21.2% for those with early SSFB introduction and 20.9% for those with SSFB introduction at or after 1 year of age.

Sensitivity Analyses: Testing the Effect of Including Other Dairy Products in Operationalization of Timing of Introduction to Sugar-Sweetened Foods and Beverages

As recent research has revealed that yogurt contributes 18% of the added sugar to infants' diets (Herrick et al., 2020), a sensitivity analysis was conducted in which the assessment of early introduction to SSFBs included the earliest reported age at which infants received "other dairy products" (dairy products other than cow's milk, including yogurt and cheese) in addition to soda, SSBs and sweet foods.

There were 10 children (n=3 boys and n=7 girls) who had not received soda, other SSBs, sweet foods, or other dairy products by 24 months of age. Among those who did have reported intake of SSFBs by 24 months, the distribution of timing of introduction is displayed in Figures 32 and 33 for males and females, respectively. Using this revised operationalization, the mean age of introduction to SSFBs was approximately one month earlier for both boys (8.5 months vs. to 9.5 months) and girls (8.3 months vs. to 9.3 months), compared to when only soda, other SSBs and sweet foods were considered. Approximately 80% of children (79% of boys and 81% of girls) were first fed SSFBs before one year of age (Table 30), in comparison to approximately two thirds of children with the initial operationalization.

Figure 32. Distribution of timing of introduction of sugar-sweetened foods and beverages (including other dairy) (males, n=679)

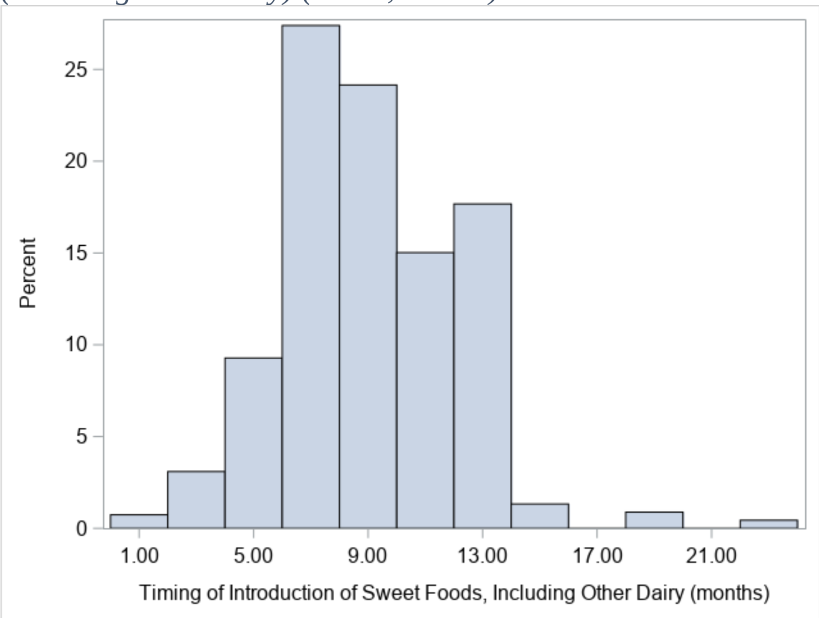


Figure 33. Distribution of timing of introduction of sweets (including other dairy) (females, n=635)

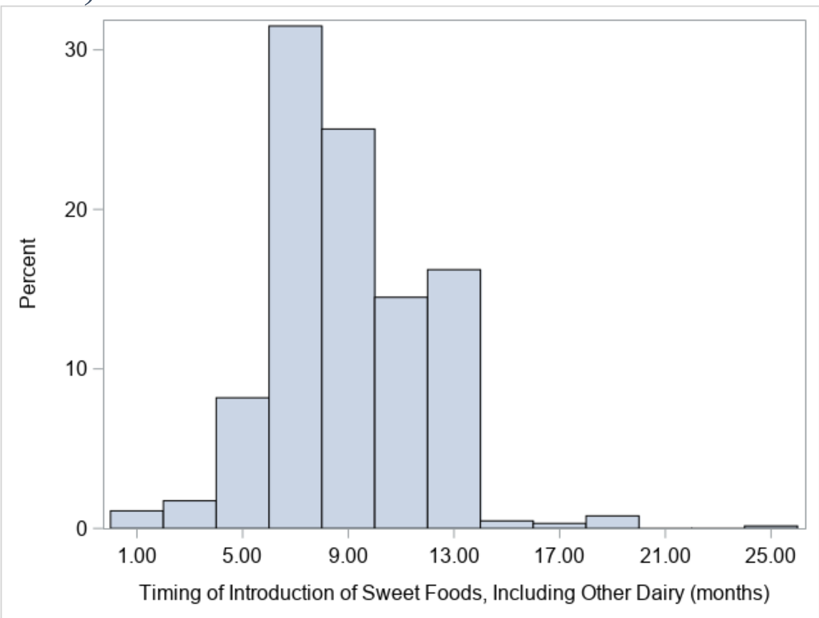


Table 30. Early introduction to sugar-sweetened foods and beverages (including other dairy) by sex, WIC ITFPS-2 Study (n=1,324)

Early Introduction[a] to SSFBs (including "other dairy" products)	Male (n=682) *N (%)*	Female (n=642) *N (%)*
Yes	541 (79)	521 (81)
No	141 (21)	121 (19)

SSFBs = sugar-sweetened foods and beverages

[a]Early introduction defined as before 1 year of age

Table 31 presents the results of sex-stratified mixed effects regression models with random intercepts and slopes examining the relationship between early introduction to SSFBs (including other dairy products) and repeated BMIZ measurements between the ages of 6 months and 3 years. Age is centered at 6 months. An interaction between age and timing of introduction to SSFBs was used to test whether weight trajectories varied between children who first received SSFBs before one year of age and those who did not.

Table 31. Mixed Effects Linear Regression Models: Association Between Early Introduction to Sugar-Sweetened Foods and Beverages (Including Other Dairy) and Repeated BMI-for-age z-scores by Sex, WIC ITFPS-2 Study (n=1,324)

Effect	Male (n=682) β (SE)	Female (n=642) β (SE)
Intercept	0.634 (0.143)	0.659 (0.148)
Early Introduction[a] to SSFBs		
No (ref)	-	-
Yes	-0.019 (0.114)	0.051 (0.112)
Age (months)	0.055 (0.013)	0.057 (0.012)
Age^2	-0.002 (0.000)***	-0.002 (0.000)***
Age*Early Introduction to SSFBs		
Age*No (ref)	-	-
Age*Yes	-0.007 (0.014)	-0.007 (0.014)
Age^2*Early Introduction to SSFBs		
Age^2*No (ref)	-	-
Age^2*Yes	0.000 (0.000)	0.000 (0.000)
Breastfeeding Duration		
<6 months (ref)	-	
Not BF	-0.071 (0.109)	-0.005 (0.123)
≥6 months	-0.006 (0.093)	-0.138 (0.091)
Maternal marital status		
Not married[b] (ref)	-	-
Married	-0.018 (0.091)	0.024 (0.091)
Maternal education level		

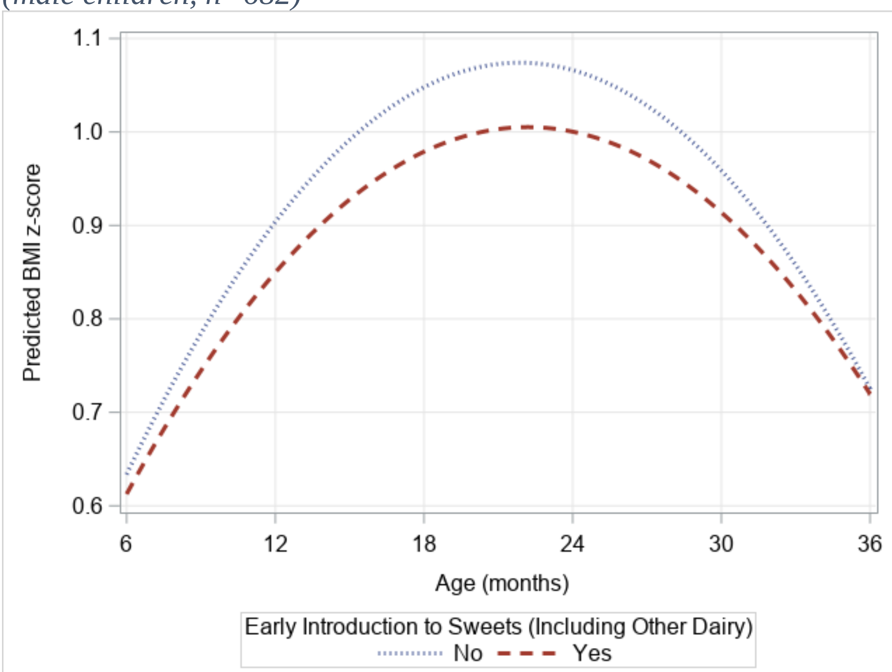
Effect	Male (n=682) β (SE)	Female (n=642) β (SE)
HS or less (ref)	-	-
More than HS	-0.010 (0.082)	-0.122 (0.083)
Household poverty level[c]		
≤75% (ref)	-	-
>75 to 130%	0.065 (0.090)	0.301 (0.088)***
>130%	0.005 (0.126)	-0.016 (0.142)
Race/ethnicity		
Hispanic (ref)	-	-
NH-Black	-0.183 (0.103)	-0.242 (0.111)*
NH-White	-0.133 (0.101)	-0.205 (0.102)
Other	-0.226 (0.149)	-0.125 (0.148)
Maternal weight[d]		
Normal or Underweight (ref)	-	-
Overweight	0.054 (0.098)	0.129 (0.096)
Obese	0.143 (0.090)	0.217 (0.094)*
Maternal age		
26+ years (ref)	-	-
20-25 years	0.040 (0.083)	-0.122 (0.086)
16-19 years	0.155 (0.145)	-0.092 (0.149)
Household food security		
High/Marginal (ref)	-	-
Low	-0.063 (0.085)	0.066 (0.087)
Very Low	0.022 (0.115)	0.054 (0.109)
Delivery Type		
Vaginal (ref)	-	-
Caesarean	0.063 (0.082)	0.029 (0.086)
Smoked during pregnancy		
No (ref)	-	-
Yes	0.423 (0.140)**	0.298 (0.134)*

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Note: models are age centered at 6 months of age
SSFBs = sugar-sweetened foods and beverages; BF = breastfed; HS = high school; NH = non-Hispanic
[a]Early introduction defined as before 12 months of age; [b]including divorced and widowed; [c]relative to 2013 federal poverty guidelines; [d]weight status at the time of screening

Results from the sensitivity analysis are consistent with findings from the initial analysis. When "other dairy products" were included in the definition of SSFBs, though the average age of introduction to SSFBs was approximately 1.5 months earlier, the models revealed no significant association between early introduction to SSFBs and weight trajectories. For both boys and girls, there were no differences in predicted BMIZ at 6 months of age, no differences in the monthly change in BMIZ at age 6 months (slope) and no differences in quadratic trends of the BMIZ trajectories over time between groups by timing of introduction of SSFBs.

Figures 34 and 35 help put the model findings into context, plotting predicted BMIZ for boys and girls, respectively, by their timing of SSFB introduction. Trajectories and the corresponding predicted BMIZ were estimated at the reference values for all covariates. Among boys (Figure 34), consistent with the original model, those with early introduction to SSFBs actually had slightly lower predicted BMIs (by 0.05 z-score units at 1 year, 0.06 z-score units at 2 years, and 0.01 z-score units at 3 years of age) compared to those who did not receive SSFBs until one year of age or later. Age-centered models revealed that these differences were not statistically significant.

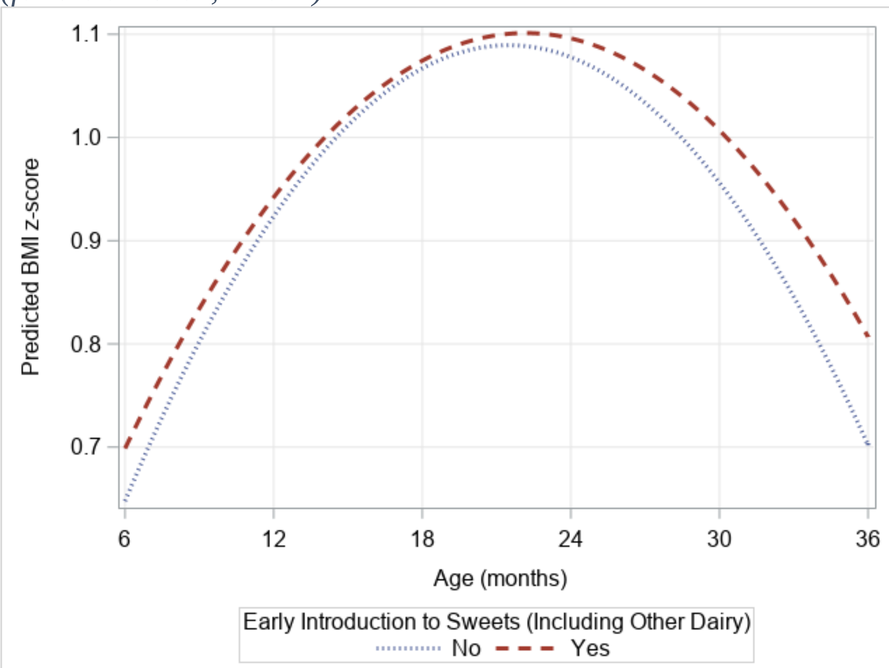
Figure 34. Predicted BMI-for-age z-score trajectories from age six months to three years by timing of introduction to sugar-sweetened foods and beverages, including other dairy products (male children, n=682)



Note: Fit computed at reference categories of all covariates

Among girls (Figure 35), consistent with findings from the initial model, those with early introduction to SSFBs had slightly lower predicted BMIZ (by .02 z-score units at 1 and 2 years of age, and 0.1 z-score units at 3 years of age). Though these trends were consistent with the hypothesis, age-centered models revealed that differences in BMIs were not statistically significant at ages 1, 2, or 3 years.

Figure 35. Predicted BMI-for-age z-score trajectories from age six months to three years by timing of introduction to sugar-sweetened foods and beverages, including other dairy products (female children, n=642)



Note: Fit computed at reference categories of all covariates

Table 32 presents results of the sensitivity analysis exploring the relationship between early introduction to SSFBs and odds of overweight/obesity when "other dairy" products were considered in the definition of SSFBs to capture yogurt intake. The results similarly suggest no significant association between early introduction to SSFBs and overweight/obesity at ages 2-3 years among boys (OR=1.20, [95% CI: 0.73, 1.99]) or girls (OR=1.03, [95% CI: 0.62, 1.73]).

Table 32. Mixed effects logistic regression models: association between early introduction of sugar-sweetened foods and beverages (including other dairy) and overweight/obesity at ages 2-3 years, WIC ITFPS-2 Study (n=1,324)

	Male (n=682)	Female (n=642)
Effect	OR (95% CI)	OR (95% CI)
Early Introduction to SSFBs[a]		
No (ref)	-	-
Yes	1.20 (0.73, 1.99)	1.03 (0.62, 1.73)
Breastfeeding Duration		
<6 months (ref)	-	-
Not BF	1.76 (1.04, 2.98)*	1.60 (0.88, 2.92)
≥6 months	1.06 (0.64, 1.73)	0.57 (0.34, 0.95)*
Maternal marital status		
Not married[b] (ref)	-	-
Married	0.99 (0.62, 1.60)	0.83 (0.51, 1.35)
Maternal education level		
HS or less (ref)	-	-
More than HS	1.15 (0.75, 1.77)	0.73 (0.46, 1.14)
Household poverty level[c]		
≤75% (ref)	-	-
>75 to 130%	1.02 (0.64, 1.63)	0.93 (0.59, 1.48)
>130%	0.86 (0.44, 1.70)	1.10 (0.52, 2.33)
Race/ethnicity		
Hispanic (ref)	-	-
NH-Black	0.75 (0.44, 1.30)	0.63 (0.35, 1.14)
NH-White	0.89 (0.53, 1.50)	0.59 (0.34, 1.03)
Other	0.71 (0.31, 1.62)	0.56 (0.25, 1.27)
Maternal weight[d]		
Normal or Underweight (ref)	-	-
Overweight	1.35 (0.81, 2.25)	1.16 (0.69, 1.94)
Obese	1.61 (1.01, 2.57)*	1.67 (1.03, 2.70)*
Maternal age		
26+ years (ref)	-	-
20-25 years	1.21 (0.79, 1.85)	0.56 (0.35, 0.89)*
16-19 years	1.79 (0.86, 3.72)	1.19 (0.57, 2.47)
Household food security		
High/Marginal (ref)	-	-
Low	0.69 (0.44, 1.09)	1.56 (0.99, 2.47)
Very Low	1.55 (0.90, 2.67)	1.70 (0.98, 2.96)
Delivery Type		
Vaginal (ref)	-	-
Caesarean	1.02 (0.67, 1.56)	0.87 (0.55, 1.36)
Smoked during pregnancy		
No (ref)	-	-
Yes	1.56 (0.79, 3.09)	1.66 (0.86, 3.20)

* p<0.05

SSFBs = sugar-sweetened foods and beverages; BF = breastfed; HS = high school; NH = non-Hispanic

[a]before 1 year of age; [b]including divorced and widowed; [c]relative to 2013 federal poverty guidelines; [d]weight status at the time of screening

Discussion

Primary Findings

This study found no significant difference in weight trajectories between the ages of 6 months to 3 years or in the odds of overweight/obesity at ages 2 to 3 years by timing of introduction of SSFBs. Contrary to the hypotheses, children who received soda, other sugar-sweetened beverages, or sweets such as cakes or cookies before 1 year of age did not have less healthy BMIZ trajectories or higher odds of overweight/obesity compared to children who did not receive SSFBs until 1 year of age or later. Similar null findings were observed when yogurt was considered in timing of introduction of SSFBs. However, this study did reveal that early introduction of SSFBs was common among the sample of WIC participants, with two-thirds of children receiving SSFBs before 1 year of age.

Comparison with other studies and implications

Few studies have explored the impact of early introduction to SSFBs on early childhood weight status. Most either focus specifically on intake of sugar-sweetened beverages (SSBs) or examine intake of energy-dense foods more broadly. For example, using data from the Infant Feeding Practices Study II, Rose et al., (2016) found that infants with dietary patterns characterized by frequent intake of energy-dense foods, including sweet foods and french fries, had a higher prevalence of overweight at 1 year of age compared to infants with other dietary patterns. Similarly, using data from the Nurture Study, an observational cohort study of mother-infant dyads in North Carolina, Vadiveloo et al., (2019) found that the frequency of unhealthy food intake in the first year, including sweets, ice cream, french fries and snacks, was associated with higher weight-for-length z-scores at 1 year of age. One key difference between these studies and the current study is that frequency of intake was not examined in this study. Within the group of children with early introduction to SSFBs, there is likely a large amount of variation in frequency of intake, which may help explain the null findings.

One small prospective study of 94 Latina mother and child pairs participating in the WIC program found that children with high added sugar intake at baseline (age 12-24 months) had greater increases in weight-for-age z-scores at 6-month follow up compared to children with low added sugar intake, though the difference was only marginally statistically significant ($p=.07$) (Chaidez et al., 2014). In comparison, children in the study with high sweetened beverage intake had significantly greater increases in weight-for-height z-scores ($p<.05$) (Chaidez et al., 2014). One reason that SSBs may have a stronger association with weight gain is the possibility that SSBs do not trigger the same physiological satiety mechanisms as foods with added sugars. There is some evidence that calories consumed in liquid form may not be compensated for (i.e., with lower calorie intake in later meals) in the same way that calories from solid foods are, leading to increased energy intake and potentially weight gain (DiMeglio & Mattes, 2000).

This is consistent with a growing body of evidence suggesting that SSB intake may be a major contributor to childhood obesity. A meta-analysis of studies published through 2013 found that over the course of one year, each additional daily 12 oz. portion of SSBs is associated with a 0.06-unit increase in BMI among children and adolescents (Malik et al., 2013), and a review of studies published between 2013-2015 found that 94% of prospective cohort studies among children found a positive association between SSB intake and body weight measures (Luger et al., 2017). While a majority of the studies focus on dietary intake and weight status in later childhood or adolescence, some have explored the relationship in infancy and early childhood.

Data from two separate surveys of children participating in the LA County WIC program found that 2-4 year old children who did not consume SSBs had 28-31% lower odds of obesity compared to those who consumed 2 or more servings per day (Davis et al., 2012, 2014). Of note, while SSB consumption was associated with increased odds of obesity, it was not associated with increased odds of overweight at 2-4 years (Davis et al., 2014). Therefore, it is possible that there may have been an association with SSFB intake and obesity had overweight and obesity been separately examined in the analyses.

However, studies examining the relationship between SSBs and weight in infancy and early childhood have not universally found positive associations. In a retrospective cohort study of over 10,000 children enrolled in the Missouri WIC program, Welsh et al., (2005) found that SSB intake at 2-3 years of age was associated with higher odds of obesity at ages 3-4 years only for those who were already overweight or at-risk for overweight at baseline. For children who were under- or normal weight at age 2-3 years, consumption of 3 or more SSBs per day was not associated with higher odds of overweight at age 3-4 years; however, among those who were at risk for overweight at age 2-3 years (85^{th}-<95^{th} BMI-percentile), consuming even 1-<2 servings of sweet beverages was associated with twice the odds of overweight one year later (Welsh et al., 2005). This relationship suggests that SSB intake may have a particularly strong impact on weight outcomes for children with other underlying predispositions for overweight/obesity.

Another large prospective cohort study that examined SSB intake and weight of children at ages 2, 4, and 5 years found that while SSB intake was associated with significantly higher odds of obesity at 4 and 5 years of age, there was no association at age 2 years (De Boer et al., 2013). This finding suggests the possibility that the effects of early intake of sweet foods may not be reflected in weight status until later in childhood. One mechanism by which early introduction to SSFBs may result in weight gain is through shaping taste preferences for sweet foods, which would influence dietary practices in later childhood. There is evidence that early flavor experiences are imprinted, with 4- to 5-year old children responding more favorably to flavors they were exposed to in infancy compared to children not exposed to those flavors (Beauchamp & Mennella, 2009). Consistent with this evidence, researchers have found that if children have high intake of energy-dense foods, including sweets, at 9 months of age, they have higher intake of SSBs and dessert foods at 6 years of age and a greater incidence of obesity at 6 years of age (Rose et al., 2017). As the WIC ITFPS-2 study continued to follow children until 6 years of age, future research can explore whether early introduction to SSFBs may be associated with increased odds of overweight/obesity in later childhood.

Implications for Policy and Practice

Although this study did not find a relationship between early introduction to sweets and weight trajectories, it did reveal that very early introduction to sweets is relatively common among children participating in the WIC program. The American Academy of Pediatrics and the American Heart Association recommend children under 2 years of age avoid foods with added sugars (Korioth, 2020; Vos et al., 2017). In the current sample, 96% of children had received SSFBs before 2 years of age, and 64% had been fed SSFBs before 1 year of age. This is consistent with nationally representative data which found that 61% of infants aged 6-11 months consumed added sugars on a given day (Herrick et al., 2020). On average, children in this study sample were introduced to sweet foods, such as cake, cookies or candy at 10.3 months of age, soda at 12.9 months of age, and other SSBs such as Kool Aid, sweetened juices, Fruit Punch or sweet tea at 10.6 months of age (Appendix Table A1).

The early and widespread introduction of SSFBs suggests that interventions in the WIC setting to encourage caregivers to delay introduction to SSFBs may be warranted to improve the nutrition and health status of low-income children in the U.S. Nutrition education is a core service of the WIC program, and tailored nutrition education interventions have been shown to impact dietary practices of participants. The Massachusetts Childhood Obesity Research Demonstration (MA-CORD) study found that training WIC providers in best practices of health behavior counseling, providing nutrition education materials, and linking WIC providers to clinical and community obesity prevention efforts significantly reduced intake of SSBs (Woo Baidal et al., 2017). At 2-year follow-up, children in MA-CORD intervention WIC sites had three times the odds of eliminating SSBs compared to children in control sites (Woo Baidal et al., 2017). Other WIC-based nutrition intervention studies have demonstrated positive shifts in dietary intake, including decreased juice intake (Cloutier et al., 2015) and increased fruit and vegetable consumption (Whaley et al., 2010).

While many interventions to decrease added sugar intake focus on reducing consumption of SSBs (Vercammen et al., 2018), results of this study suggest that sweets and yogurt are also important targets for nutrition education efforts. In this sample, the mean timing of introduction to sweet foods (e.g., cakes, cookies) and other dairy products (e.g., yogurt) was earlier than the mean timing of introduction to SSBs (sodas or other SSBs). Furthermore, yogurt, baby snacks and sweets, and sweet bakery products are the top three sources of added sugars in the diet of U.S. infants, accounting for 40% of the total added sugars consumed (Herrick et al., 2020). Understanding these dietary practices can help tailor appropriate nutrition education materials for WIC mothers.

Another key public policy that may help improve diet quality and decrease health disparities among low-income infants and children include nutrition standards for foods purchased through the Supplemental Nutrition Assistance Program (SNAP). SNAP is the only nutrition assistance program that does not have nutrition standards, and researchers have found that 20% of food dollars are spent on junk food and SSBs (Seligman & Basu, 2018). Nearly half of SNAP households include children (Cronquis, 2019), and low income families with children may concurrently receive both WIC and SNAP benefits, so revisions to the SNAP program could have a considerable impact on children's diet quality. Though there is substantial concern that restrictions on SNAP purchases may increase stigma and decrease program participation, surveys of SNAP participants have found that over half support removing SSBs from products allowed for purchase (Leung et al., 2017). Alternatively, strategies that incentivize healthy food purchases (e.g., by doubling SNAP dollars spent on healthy foods such as fruits and vegetables) rather than restricting food purchases may also improve the quality of foods purchased with SNAP benefits, and are more widely supported by SNAP participants (Bartlett et al., 2014; Leung et al., 2017).

CHAPTER 8: CONCLUSION

Integrated Findings and Recommendations

This dissertation sought to understand how infant feeding practices during the first year of life may influence weight trajectories and odds of overweight/obesity in early childhood. Table 33 summarizes the primary findings of the three studies in this dissertation.

Table 33. Summary of primary research results from studies 1, 2, and 3

	Boys		Girls	
	Healthier BMIZ trajectories	Odds of overweight/ obesity	Healthier BMIZ trajectories	Odds of overweight/ obesity
BREASTFEEDING				
Duration of **any breastfeeding** (ref: never breastfed)				
<6 months	N/A	N/A	N/A	↓
≥6 months	+	N/A	+	↓
Duration of **exclusive breastfeeding** (ref: never exclusively breastfed)				
<3 months	N/A	N/A	N/A	↓
≥3 months	+	N/A	+	↓
Breastfeeding **duration and intensity**				
<3 months	N/A	N/A	↓	N/A
≥3 months (partial)	N/A	N/A	N/A	↓
≥3 months (exclusive)	N/A	N/A	N/A	↓
COMPLEMENTARY FOOD INTRODUCTION				
Timing of complementary food introduction (ref: 4-6 months)				
Early (<4 months)	N/A	N/A	-	N/A
Late (≥7 months)	-	N/A	N/A	N/A
INTRODUCTION TO SUGAR-SWEETENED FOODS AND BEVERAGES				
Early introduction to sugar-sweetened foods and beverages (before 1 year of age)	N/A	N/A	N/A	N/A

+: positive association, -: negative association, ↓: lower odds, N/A: no association

The results of this research suggest that breastfeeding may play a substantial role in promoting healthy weight trajectories and preventing overweight and obesity in early childhood. Girls who were breastfed (partially or exclusively) for at least 6 months had healthier weight trajectories between 6 months and 3 years of age and 65% lower odds of overweight/obesity at 2-3 years of age compared to those who were never breastfed. Though boys who were breastfed for at least 6 months had healthier weight trajectories compared to those who were not breastfed, this did not translate into differences in odds of overweight/obesity in early childhood.

Exclusively breastfeeding for at least three months was associated with healthier weight trajectories between 6 months and 3 years of age among both boys and girls. A dose-response relationship between exclusive breastfeeding and overweight/obesity was observed among girls, where those who were exclusively breastfed for less than three months had 46% lower odds of overweight/obesity while those breastfed for at least three months had 78% lower odds of overweight/obesity at 2-3 years of age. While the analyses suggested similar trends among boys, the estimates were only marginally statistically significant ($p<.10$).

There was some evidence that exclusive breastfeeding may confer greater protection against overweight/obesity than partial or mixed breastfeeding. This was reflected by a dose-response relationship between increasing levels of duration and intensity observed among girls. Compared to girls who were never breastfed, the odds of overweight/obesity were 39% lower for those breastfed for less than three months (short duration, low intensity), 55% lower for those partially breastfed for three months or longer (longer duration, low intensity), and 79% lower for those exclusively breastfed for three months or longer (longer duration, higher intensity). Among boys, this same dose-response relationship was not observed.

There was limited evidence that timing of introduction of complementary foods may be associated with weight trajectories, though the relationships varied by sex. Among boys, late introduction to complementary foods (at or after 7 months) was associated with less healthy weight trajectories compared to introduction at 4 to 6 months. However, boys with late introduction to complementary foods did not have higher odds of overweight/obesity at 2-3 years of age. Among girls, early complementary food introduction (before 4 months) was associated with greater monthly increases in BMIZ, which, although statistically insignificant in the mixed effects regression model, resulted in significantly higher BMIZ at ages 2 and 3 years compared to girls with complementary food introduction at 4 to 6 months. However, girls with early introduction to complementary foods did not have higher odds of overweight/obesity at 2-3 years of age compared to those with recommended timing of introduction. Duration of breastfeeding did not modify the relationship between timing of introduction of complementary foods and overweight/obesity.

There was no evidence of a relationship between timing of introduction of sugar-sweetened foods and beverages and early childhood weight trajectories. Children who were first fed soda, other SSBs, and/or sweet foods before one year of age did not have significantly different weight trajectories or odds of early childhood overweight/obesity compared to those who were introduced these sweet foods and beverages at or after one year of age. The lack of association persisted when yogurt was considered in analyses as an important contributor of added sugars.

This study revealed significant disparities between recommended infant feeding practices and actual practices among WIC participants. While current guidelines suggest exclusive breastfeeding through six months of age, less than 1% of infants were exclusively breastfed for this duration and less than one third were even partially breastfed for six months or more. Similarly, only 41% of boys and 38% of girls were introduced to complementary foods around six months of age (5.5 to <7 months), the current recommendation from the AAP. Finally, though several health organizations discourage any added sugar consumption before the age of two years, 96% of children had been given sugar-sweetened foods and beverages before two years of age, and 64% had received these sweet foods and beverages before one year of age.

Taken together, these findings have several implications for policy and practice. First, given the association between breastfeeding and healthy weight outcomes in early childhood and the fact that the majority of mothers do not breastfeed for the recommended duration, efforts should focus on increasing breastfeeding duration, particularly exclusive breastfeeding duration, among low-income mothers. Several targets for policy, systems, and environmental change strategies to improve breastfeeding initiation and duration have been identified throughout this dissertation, including a) adoption by Local WIC Agencies across the U.S. of evidence-based staff training and participant education focused on breastfeeding promotion; b) an increase in the proportion of hospitals with Baby Friendly designation; c) paid family leave for 12 weeks following the birth of a child; and d) expansion of workplace lactation accommodation policies to cover all mothers in the workplace.

Second, though complementary feeding practices were not found to be independently associated with weight outcomes in early childhood, efforts to delay complementary food introduction may increase the duration of breastfeeding, which was found to protect against overweight/obesity. Two of the primary reasons for early complementary food introduction among WIC mothers is a concern that infants are not receiving enough nourishment from breast milk, and a misconception that adding infant cereal to bottles will help the baby sleep through the night (Baughcum et al., 1998; Heinig et al., 2006). Therefore, evidence-based WIC nutrition education interventions that address these two common concerns may help delay complementary food introduction and potentially increase breastfeeding duration. Recommendations for nutrition education include a) educating parents that there is no evidence that adding infant cereal to bottles helps the baby sleep longer; b) reinforcing that frequent feedings and night wakings in infancy are normal and not a sign of poor parenting; and c) improving breastfeeding self-efficacy to foster perceptions of sufficient milk supply.

Finally, though early introduction of sugar-sweetened foods and beverages were similarly not associated with early childhood overweight/obesity, this study did reveal that early introduction to sweets was very common among children participating in WIC, with only 4% of children in the sample meeting national recommendation to avoid consumption of foods and beverages with added sugars before 2 years of age. The energy intake from foods and beverages with added sugars may displace energy from healthy, nutrient-dense foods and likely have longer-term implications for nutritional adequacy and health (Vos et al., 2017). Policy, systems, and environmental change strategies to delay early introduction of sweets among children in low-income families to help improve dietary intake and reduce health disparities include a) evidence-based WIC nutrition education interventions; and b) policy changes to the SNAP program (i.e., food stamps) to align food purchases with nutrition recommendations across federal nutrition assistance programs, such as nutrition standards for foods purchased and/or incentives for purchasing healthy foods.

These findings highlight several opportunities for future research. First, there were notable sex differences in the relationship between breastfeeding and overweight/obesity. Future research should examine whether these differences are observed consistently in this and other populations, as well as explore potential mechanisms for these differences. Most studies of childhood obesity control for sex (e.g., by including sex as a covariate in regression models), rather than stratifying to understand if there are sex differences (Shah et al., 2020). However, one recent study similarly observed a stronger association between exclusive breastfeeding and obesity among girls compared to boys (Anderson et al., 2020). Boys and girls differ not only in their body composition and growth patterns, but also in their response to social, genetic, and environmental factors (Wisniewski & Chernausek, 2009). These results, therefore, could potentially reflect sex differences in the exposure to breast milk or the social experience of breastfeeding. There were no differences in demographic characteristics between boys and girls in the analytic sample, including race/ethnicity, household poverty level and food security, and maternal age, marital status, education level, and weight. More research is needed to confirm these sex differences in the relationship between breastfeeding and early childhood obesity and understand the mediating factors.

Second, it is possible that 2-3 years of age may be too early to observe the influence of complementary feeding practices on overweight/obesity, so future studies should explore whether early introduction of complementary foods is associated with overweight/obesity at later ages. This is plausible particularly for early introduction of sugar-sweetened foods and beverages given the evidence that early flavor exposures may shape long-term taste preferences and dietary intake. At 2-3 years old, children have limited autonomy in their food choices. Therefore, the effect of complementary feeding practices may not be seen until children have more control over their food choices and dietary intake. Similarly, preferences for less healthy foods can only translate into consumption if the foods are available to the child, so timing of introduction of sweet foods should be evaluated in conjunction with frequency of consumption.

Third, this study was largely unable to examine the influence of adherence to infant feeding recommendations given the low proportion of children who were fed according to guidelines, particularly for breastfeeding duration and timing of introduction of sweet foods and beverages. Therefore, future studies should examine whether adherence to recommended infant feeding practices are associated with early childhood weight status. This is particularly important given the new mandate to include dietary guidance for infants and children up to age 2 years in the Dietary Guidelines for Americans.

Strengths and Limitations

This dissertation addresses the important public health issue of childhood obesity by investigating the influence of infant feeding practices on early childhood weight status. Moreover, the sample was low-income and largely Hispanic, populations which are disproportionately affected by childhood obesity and underrepresented in the literature. The data were derived from a relatively large sample of WIC mother-infant pairs from across the U.S., which helps make the findings generalizable.

One major strength of the research is the use of longitudinal data which establishes temporality and can infer causal relationships between the variables of interest. Participants had multiple height and weight measurements collected between approximately six months and three years of age, allowing for the examination of weight trajectories over time. Anthropometric data were obtained directly from health care providers or WIC clinics, which have been demonstrated to have high validity (Crespi et al., 2012). In addition, data on breastfeeding and children's dietary intake were collected from mothers frequently (every two months through age 1 year and every two to six months through age 2 years) which helps reduce the potential for significant recall bias. Another significant strength of the study is the ability to differentiate exclusive breastfeeding from partial or mixed breastfeeding through the collection of detailed data on breastfeeding and complementary feeding practices. Few studies in high income countries report on exclusivity of breastfeeding (Victora et al., 2015).

Additionally, a major strength of these studies was the ability to adjust for several factors which have been shown in the literature to be associated with infant feeding practices or early childhood weight status. Longitudinal cohort studies examining early childhood obesity have been criticized because of failure to adjust for or inadequate measure of SES, maternal obesity and smoking status (Smithers et al., 2015), and systematic reviews examining the association between infant feeding practices and childhood obesity suffer from potential confounding by SES (Victora et al., 2015). By nature of the study sample being derived exclusively from a low-income population of mothers and children, the results are not confounded by SES. In addition, the analyses controlled for maternal weight status and smoking status, along with several other important confounders including household food security status, maternal age, education level and marital status, and delivery type.

As with all research, there are also limitations. Though the WIC ITFPS-2 study included a nationally representative sample of 3,503 mother-infant dyads, the inclusion criteria for the studies in this dissertation limited the sample to 1,469. Most children were excluded because they did not have at least two weight and height measurements. The children retained in the sample were more likely to be Hispanic, and mothers were more likely to be older, married and more highly educated compared to those who were excluded, which limits the generalizability of the findings to some extent. Breastfeeding and complementary feeding practices were self-reported by caregivers, making them subject to social desirability bias.

There were several factors that were not controlled for in the analyses, so there is potential that associations were due to other unmeasured variables. Analyses did not control for total energy intake or expenditure, gestational diabetes mellitus, and postpartum depression, which are important confounders. In addition, these studies did control for the region of the country in which the participants lived, or neighborhood factors such as access to Baby Friendly Hospitals or healthy food retailers, all of which can have significant impacts on breastfeeding, food intake and weight status. Both obesity prevalence and infant feeding practices vary significantly across the U.S., with state-specific rates of obesity among 2- to 4-year old WIC participants ranging from approximately 8% to nearly 20% (Pan et al., 2019a). Similarly, the proportion of mothers breastfeeding at six months of age varies across states from 41% to 79% (CDC, 2020b). Furthermore, we were unable to explore the proposed pathways by which relationships between infant feeding practices and overweight may operate, such as the influence on taste preferences and later dietary intake.

Conclusion

Obesity disparities begin early in life, with a disproportionate number of racial and ethnic minority children and children from lower SES households experiencing excessive weight gain compared to their White and higher SES peers (Fradkin et al., 2015; Ogden et al., 2010; Taveras et al., 2013). Though rates have declined in recent years, currently one in seven low-income children aged 2-4 years enrolled in the WIC program are obese (Pan et al., 2019b). Children who are overweight/obese are more likely to experience problems with their physical and mental health, and they are more likely to grow into overweight/obese adults. As such, understanding how to prevent excessive weight gain in infancy and early childhood is imperative to reducing health disparities across the life course.

Results from this dissertation provide a meaningful contribution to understanding the role of infant feeding practices in preventing childhood obesity. These findings suggest that longer durations of breastfeeding may be particularly beneficial in establishing healthy weight trajectories and preventing overweight/obesity in early childhood. Among girls in the study, at least three months of exclusive breastfeeding and at least six months of partial breastfeeding were associated with reduced odds of overweight/obesity at 2-3 years of age. Notably, substantial benefits were seen with durations shorter than current recommendations (6 months of exclusive breastfeeding and 12 months of partial breastfeeding), which is encouraging given that many low-income mothers are unable to achieve recommended breastfeeding durations. Ultimately, public health efforts to increase breastfeeding duration may have significant impacts on reducing the burden of obesity on low-income populations.

Current public health events are magnifying the importance of obesity prevention. During the coronavirus disease 2019 (COVID-19) pandemic, obesity has emerged as a significant risk factor for hospitalization and death, likely in part because obesity is associated with compromised pulmonary function and chronic inflammation (Dietz & Santos-Burgoa, 2020; Tartof et al., 2020). Obesity may be one factor driving the substantial COVID-19 disparities, as populations disproportionately affected by obesity are also experiencing disproportionate burdens of infections, hospitalizations and deaths from COVID-19 (Belanger et al., 2020). This intersection between communicable and non-communicable diseases should spark a renewed commitment to addressing social determinants of health in U.S. policies and systems.

At the same time, the COVID-19 pandemic has exposed the importance and fragility of nutrition support systems for mothers and infants. With physical distancing restrictions, new mothers may have lost access to critical in-person breastfeeding support resources, such as hospital lactation consultants, well-newborn visits, and WIC nutrition educators (Caron, 2020; Demirci, 2020). Though care providers have adapted quickly by shifting to web-based options, access to these telemedicine services is not universal. A growing digital divide in the U.S. leaves many patients with limited access to internet and computers, particularly racial/ethnic minorities, patients in rural areas, and those with low incomes (Ortega et al., 2020). There is some evidence that pandemic-caused disruptions in lactation support systems have had a negative impact on breastfeeding rates, with some mothers – particularly those experiencing challenges with breastfeeding – stopping earlier than they had intended (Brown & Shenker, 2020; Caron, 2020). The findings from this dissertation suggest that this may have long-term impacts on childhood obesity. It is imperative that the health system continue to adapt quickly to provide comprehensive lactation support to new mothers with a focus on health equity so that already stark disparities in breastfeeding and childhood obesity do not widen as a result of the pandemic.

APPENDICES

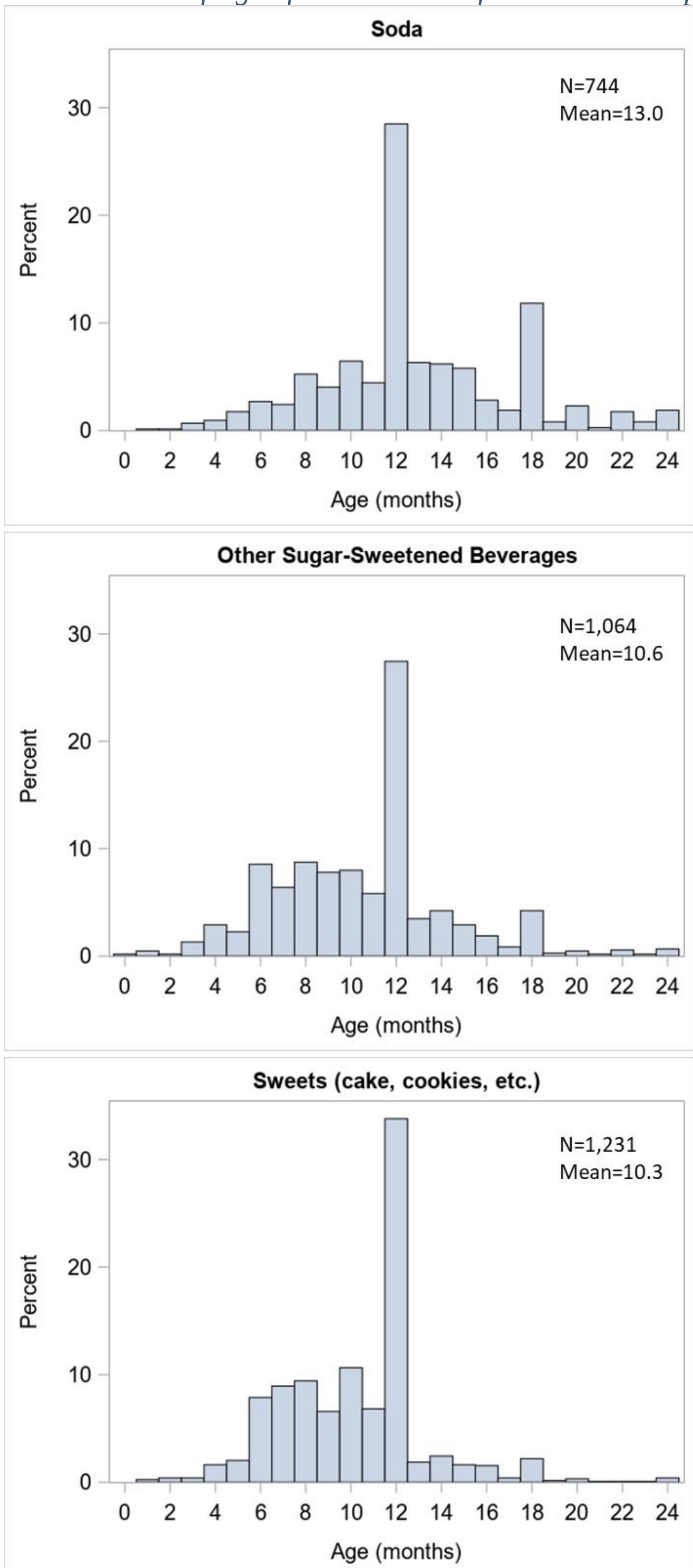
Appendix A: Additional details about timing of introduction of complementary food items

Appendix Table A1. Mean age of introduction of individual complementary food items

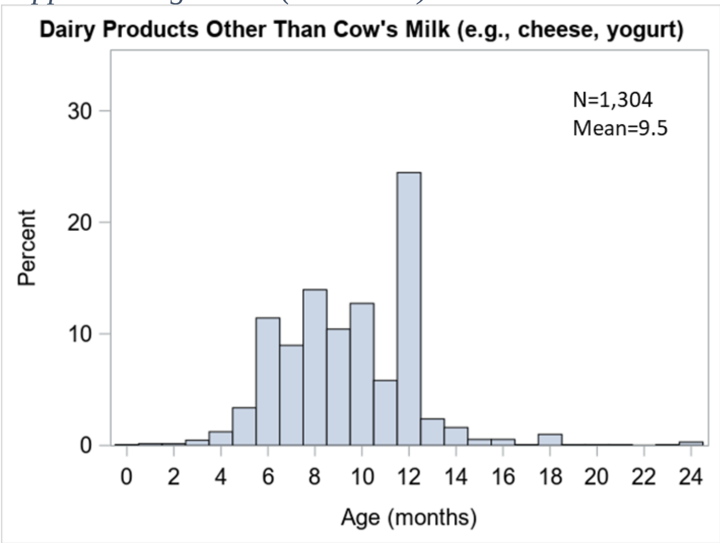
Food or Beverage	Mean age of introduction (among children who had been given the food item at or before 24 months) *Age (in months) (N)*	At 24 months, had not yet been introduced to food *N (%)*	Missing data on timing of introduction *N (%)*
Baby cereal	4.9 (1384)	35 (2.4)	50 (3.4)
Fruit	5.6 (1420)	2 (0.1)	47 (3.2)
Vegetables	5.6 (1420)	3 (0.2)	46 (3.1)
100% fruit juice	7.4 (1390)	11 (0.7)	68 (4.6)
Meats	7.9 (1386)	7 (0.5)	76 (5.2)
Salty snacks	8.9 (1304)	50 (3.4)	115 (7.8)
Beans	9.3 (1210)	136 (9.3)	123 (8.4)
Other dairy products	9.5 (1304)	52 (3.5)	113 (7.7)
Other drinks and liquids	9.6 (794)	464 (31.6)	211 (14.4)
Eggs	9.8 (1334)	30 (2.0)	105 (7.1)
Sweets	10.3 (1231)	91 (6.2)	147 (10.0)
Other sweetened beverages	10.6 (1064)	229 (15.6)	176 (12.0)
Other cereal (besides baby cereal)	10.7 (1206)	100 (6.8)	163 (11.1)

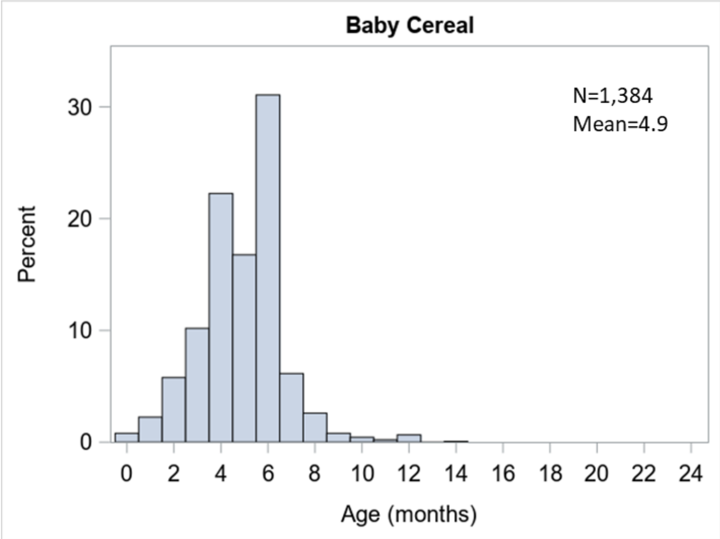
Cow's milk	11.0 (1344)	11 (0.7)	114 (7.8)
Peanut butter	12.1 (999)	270 (18.4)	200 (13.6)
Soda or soft drinks	13.0 (744)	486 (33.1)	239 (16.3)

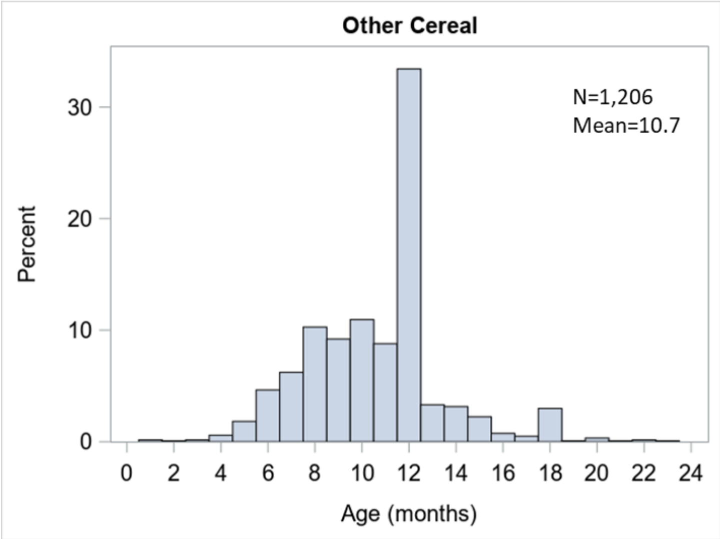
Appendix Figure A1. Distribution of Age of Introduction of Individual Complementary Foods



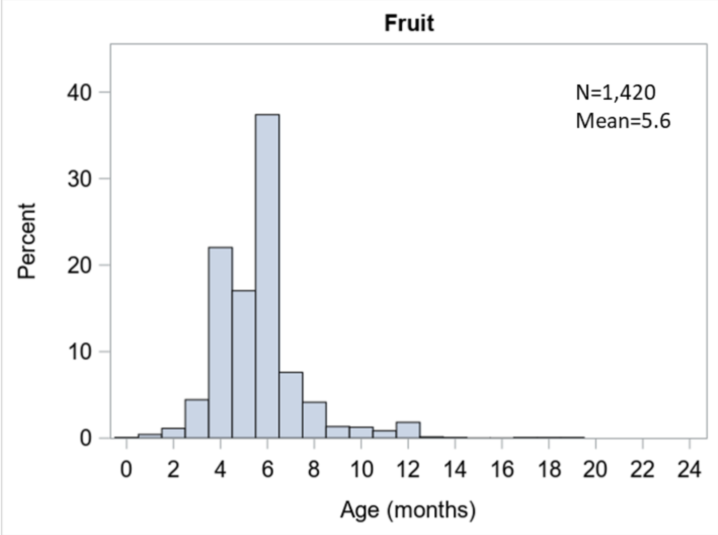
Appendix Figure A1 (continued)

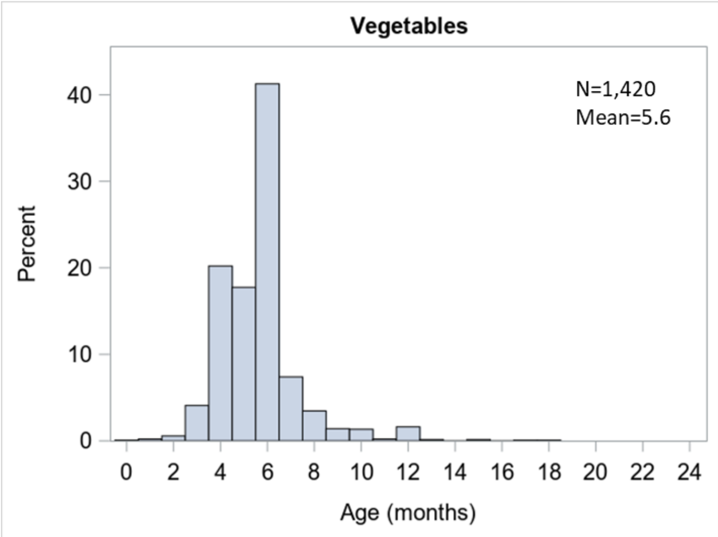


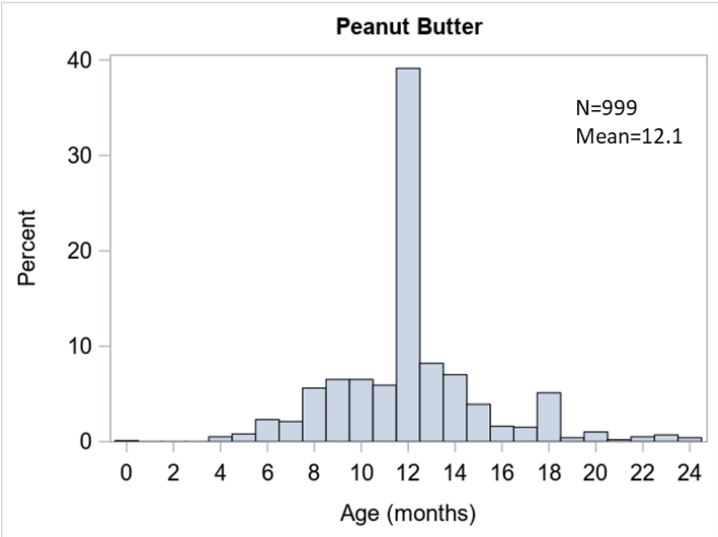




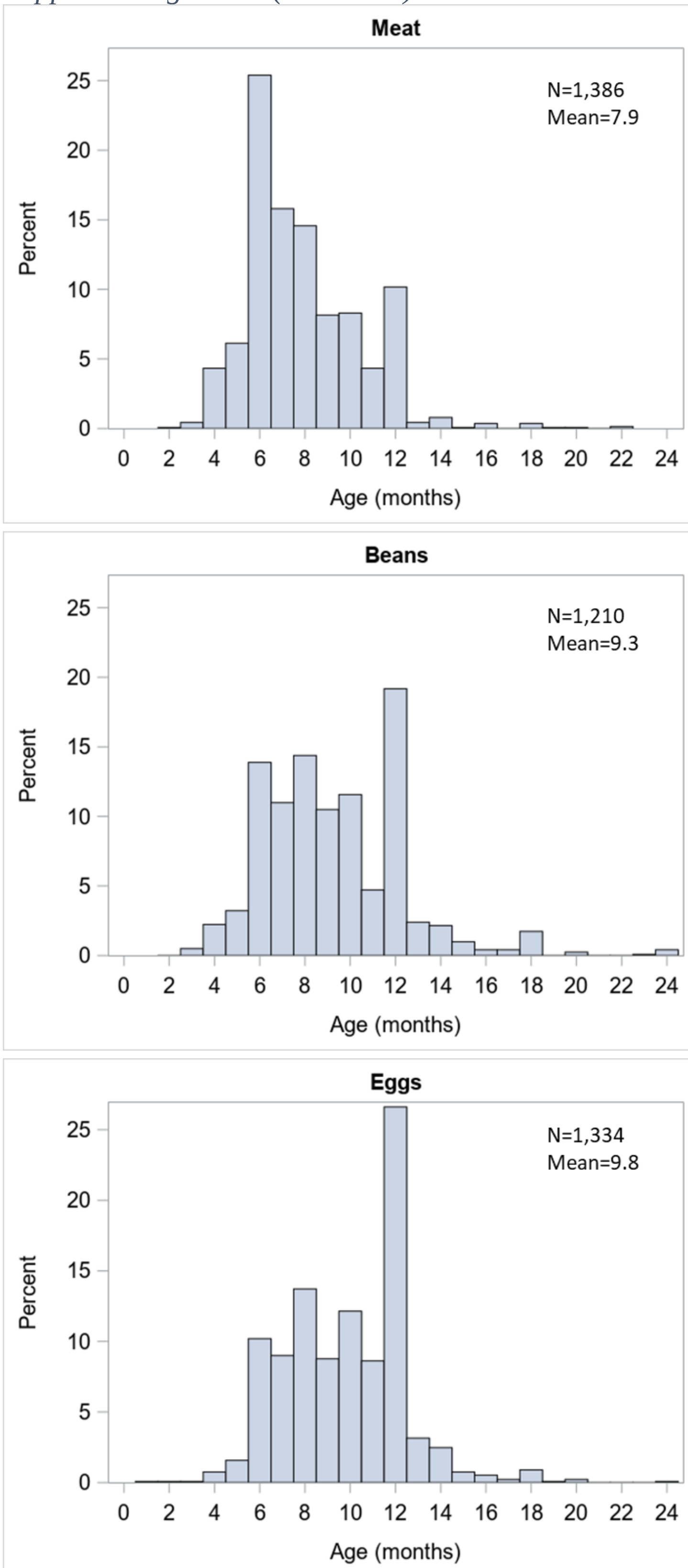
Appendix Figure A1 (continued)



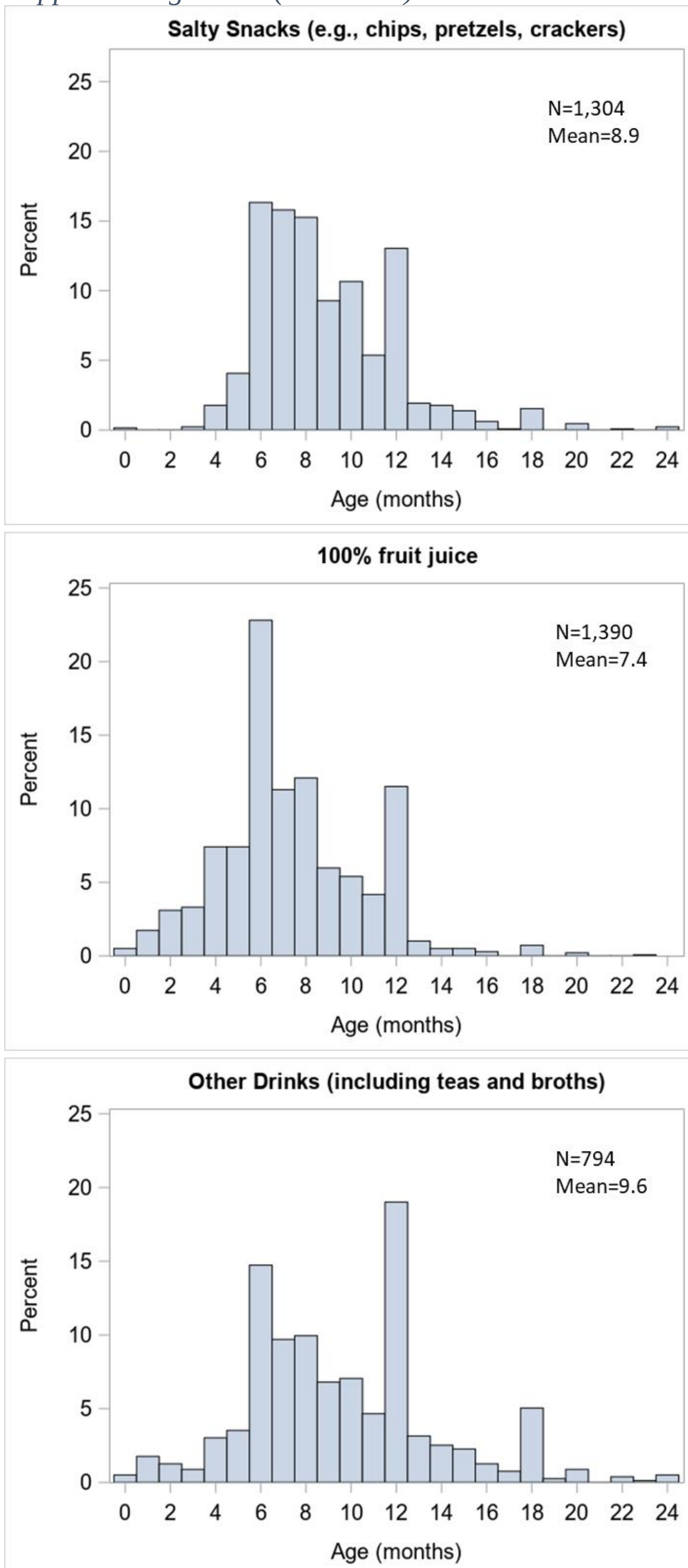




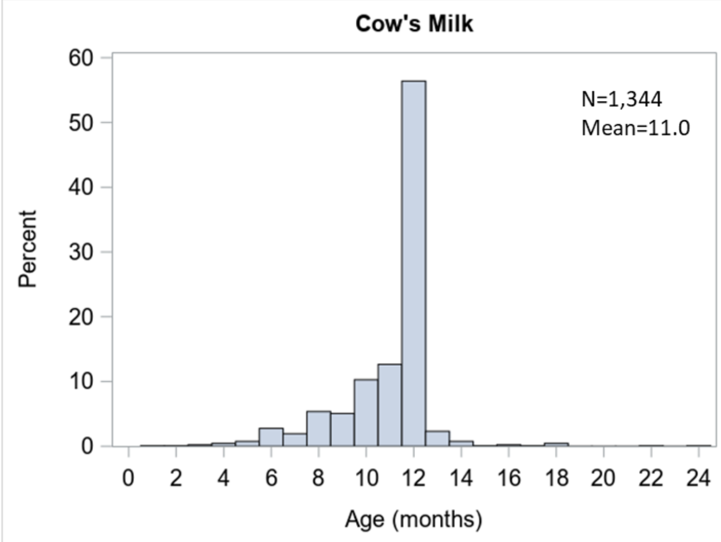
Appendix Figure A1 (continued)



Appendix Figure A1 (continued)



Appendix Figure A1 (continued)



Appendix B1: Study 1 Sensitivity Analyses

Appendix Table B1.1 Mixed Effects Linear Regression Models: Association Between Duration of Any Breastfeeding and Repeated Weight-for-Length Z-scores, WIC ITFPS-2 Study (n=1,445)

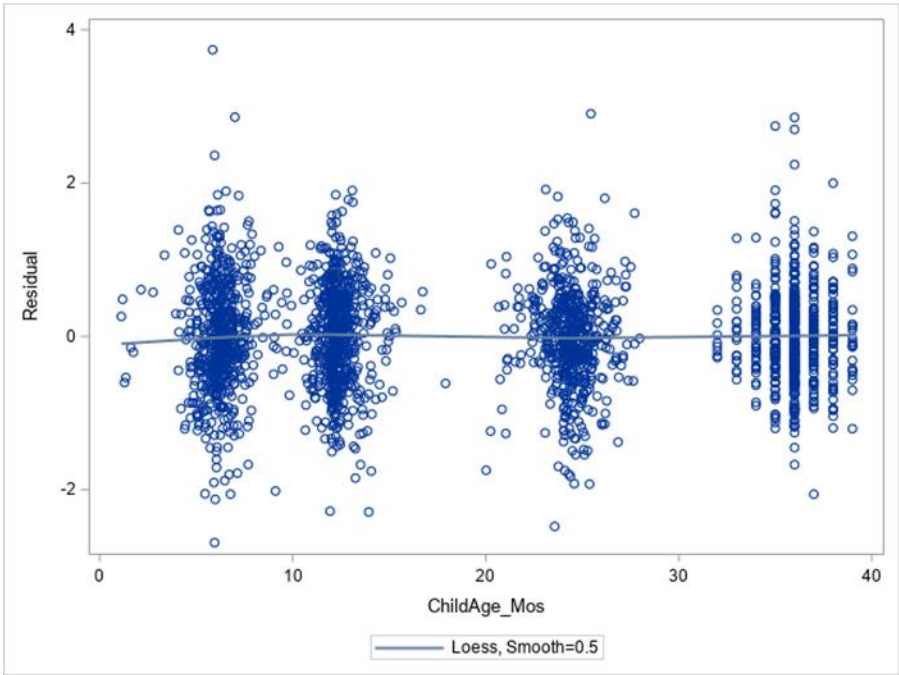
Coefficients	Male (n=739) β (SE)	Female (n=706) β (SE)
Intercept	0.524 (0.145)***	0.634 (0.144)***
Breastfeeding Duration		
Never BF (ref)	-	-
<6 mo	0.180 (0.120)	0.127 (0.124)
≥6 mo	0.310 (0.138)*	0.128 (0.139)
Age (months)	0.044 (0.013)***	0.061 (0.014)***
Age^2	-0.001 (0.000)***	-0.002 (0.000)***
Age*Breastfeeding Duration		
Age*Never BF (ref)	-	-
Age*<6 mo	-0.010 (0.015)	-0.028 (0.015)†
Age*≥6 mo	-0.048 (0.016)**	-0.064 (0.017)***
Age^2*Breastfeeding Duration		
Age^2*Never BF (ref)	-	-
Age^2*<6 mo	0.000 (0.000)	0.001 (0.000)
Age^2*≥6 mo	0.001 (0.001)**	0.002 (0.001)***

* p < 0.05, ** p < 0.01, *** p < 0.001

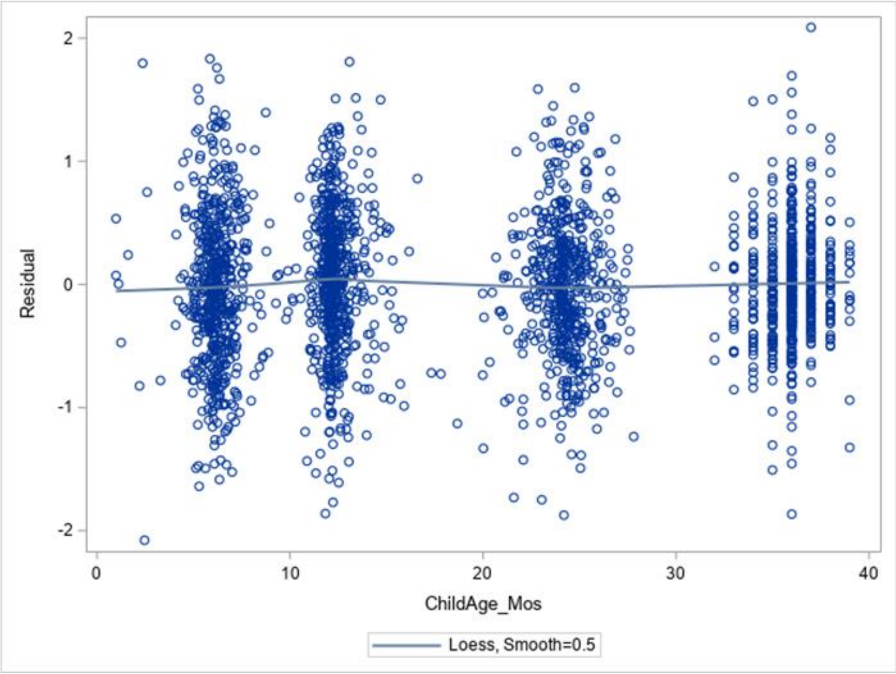
Note: models are age centered at 6 months of age; models control for race/ethnicity, delivery type household poverty level and food security status, and maternal age, marital status, education level, weight, and smoking status during pregnancy

Figure B1.1. Residual diagnostics for mixed effects linear regression models testing association between duration of any breastfeeding and repeated BMI-for-age z-scores

a. boys



b. girls



Appendix Table B1.2. Mixed Effects Linear Regression Models: Association Between Duration of Exclusive Breastfeeding and Repeated Weight-for-Length Z-scores by Sex, WIC ITFPS-2 Study (n=1,393)

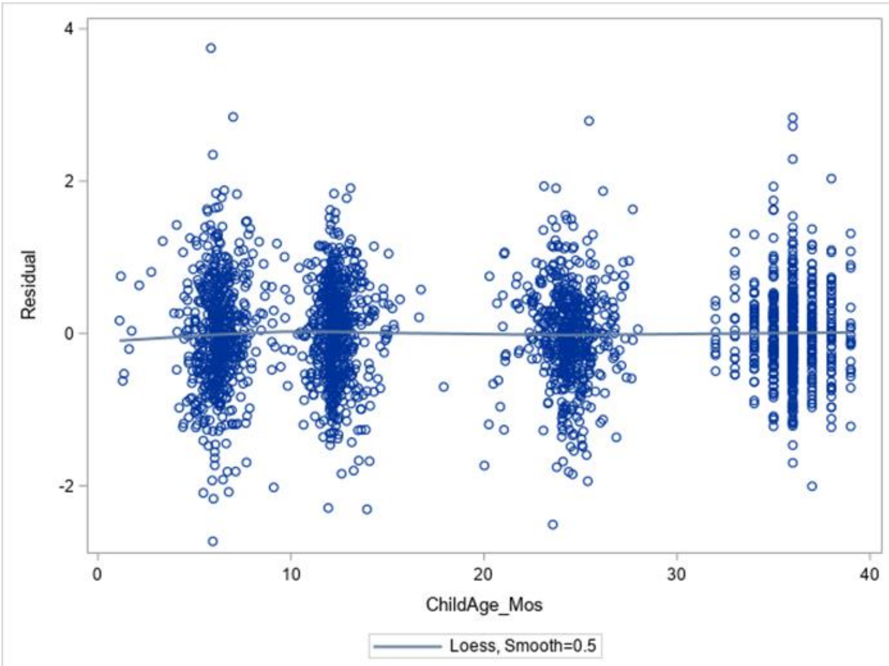
Coefficients	Male (n=720) β (SE)	Female (n=673) β (SE)
Intercept	0.517 (0.138)***	0.690 (0.130)***
EBF Duration		
Never EBF (ref)	-	-
EBF <3 mo	0.173 (0.109)	0.061 (0.107)
EBF ≥3 mo	0.259 (0.143)†	-0.044 (0.145)
Age[d] (months)	0.047 (0.012)***	0.055 (0.011)***
Age^2	-0.001 (0.000)***	-0.002 (0.000)***
Age*EBF Duration		
Age*Never EBF (ref)	-	-
Age*EBF <3 mo	-0.018 (0.013)	-0.030 (0.013)*
Age*≥3 mo	-0.062 (0.017)***	-0.049 (0.017)**
Age^2*EBF Duration		
Age^2*Never EBF (ref)	-	-
Age^2*<3 mo	0.000 (0.000)	0.001 (0.000)*
Age^2*≥3 mo	0.002 (0.001)**	0.001 (0.001)*

* p < 0.05, ** p < 0.01, *** p < 0.001

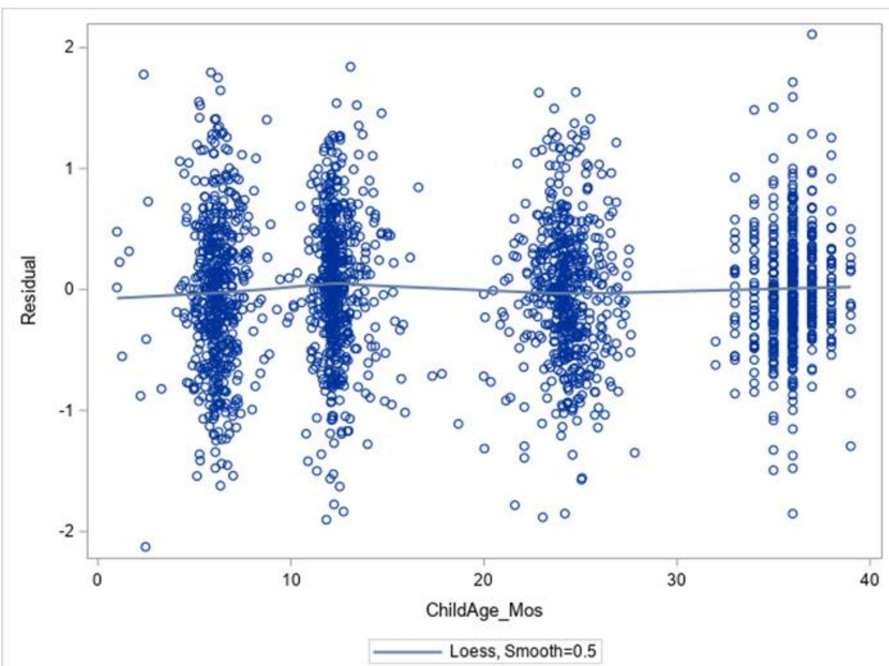
Note: models are age centered at 6 months of age; models control for race/ethnicity, delivery type household poverty level and food security status, and maternal age, marital status, education level, weight, and smoking status during pregnancy

Appendix Figure B1.2. Residual diagnostics for mixed effects linear regression models testing association between duration of exclusive breastfeeding and repeated BMI-for-age z-scores

a. boys



b. girls



Appendix B2: Study 2 Sensitivity Analyses

Appendix Table B2.1. Mixed Effects Linear Regression Models: Association Between Timing of Introduction of Complementary Foods and Repeated Weight-for-Length Z-scores by Sex, WIC ITFPS-2 Study (n=1,410)

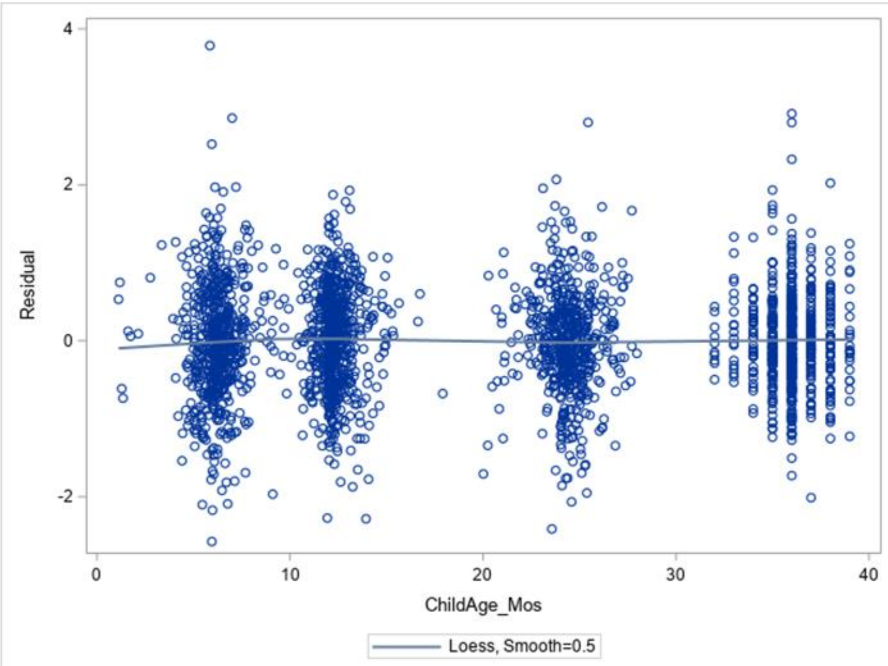
Effect	Male (n=727) β (SE)	Female (n=683) β (SE)
Intercept	0.7 (0.117)***	0.781 (0.116)***
Timing of CF Introduction		
4 to <7 mo (ref)	-	-
<4 mo	-0.039 (0.099)	0.048 (0.095)
≥7 mo	0.512 (0.187)**	-0.240 (0.180)
Age (months)	0.025 (0.006)***	0.019 (0.006)**
Age^2	-0.001 (0.000)***	-0.001 (0.000)***
Age*CF Introduction		
Age*4 to <7 mo (ref)	-	-
Age*<4 mo	0.003 (0.012)	0.019 (0.011)†
Age*≥7 mo	-0.027 (0.023)	0.032 (0.021)
Age^2*CF Introduction		
Age^2*4 to <7 mo (ref)	-	-
Age^2*<4 mo	0.000 (0.000)	0.000 (0.000)
Age^2*≥7 mo	0.001 (0.001)	-0.001 (0.001)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

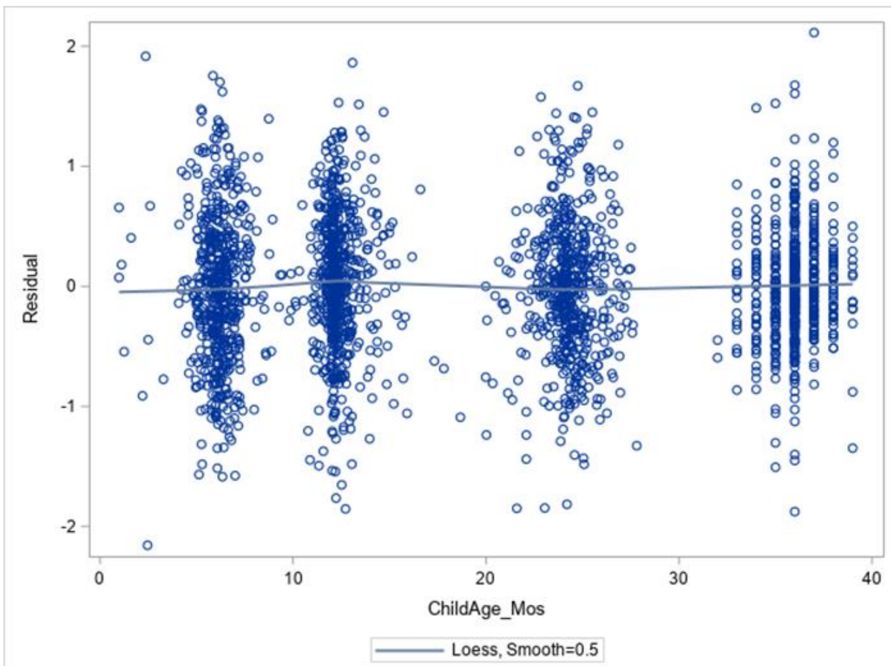
Note: models are age centered at 6 months of age; models control for race/ethnicity, delivery type, breastfeeding duration, household poverty level and food security status, and maternal age, marital status, education level, weight, and smoking status during pregnancy

Appendix Figure B2.1. Residual diagnostics for mixed effects linear regression models testing association between timing of introduction of complementary foods and repeated BMI-for-age z-scores

a. boys



b. girls



Appendix Table B2.2. Mixed effects linear regression models: association between timing of introduction of complementary foods and repeated weight-for-length z-scores among subsample of children with complementary food introduction between 4 to 6 months, WIC ITFPS-2 Study (n=932)

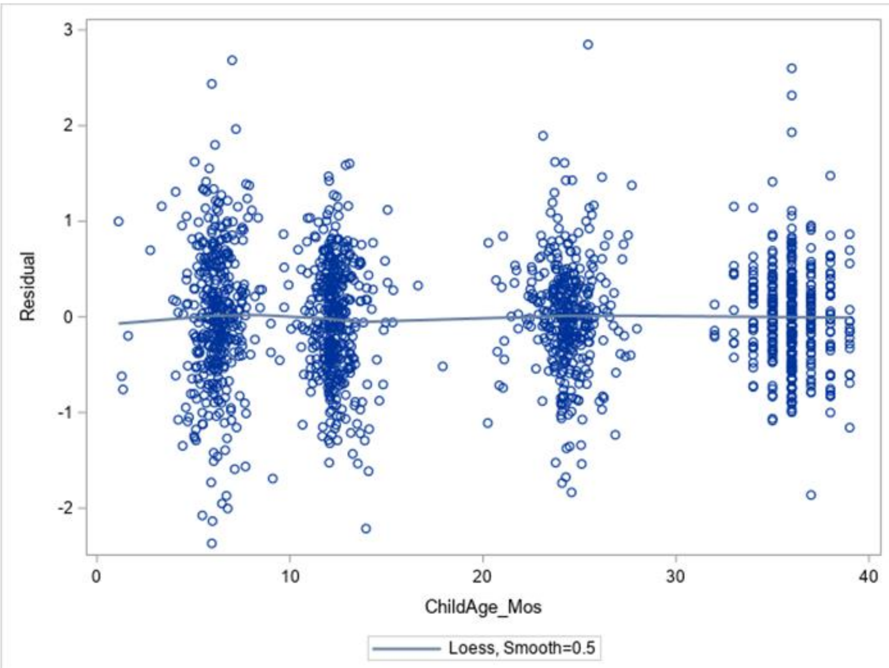
Coefficients	Male (n=486) β (SE)	Female (n=446) β (SE)
Intercept	0.661 (0.149)***	0.861 (0.155)***
Timing of CF Introduction		
5.5 - <7 mo (ref)	-	-
4 - <5.5 mo	0.007 (0.106)	-0.211 (0.104)*
Age (months)	0.026 (0.010)*	0.018 (0.009)*
Age^2	-0.001 (0.000)*	-0.001 (0.000)**
Age*CF Introduction		
Age*5.5 - <7 mo (ref)	-	-
Age*4 - <5.5 mo	-0.001 (0.013)	0.001 (0.012)
Age^2*CF Introduction		
Age^2*5.5 - <7 mo (ref)	-	-
Age^2*4 - <5.5 mo	0.000 (0.000)	0.000 (0.000)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

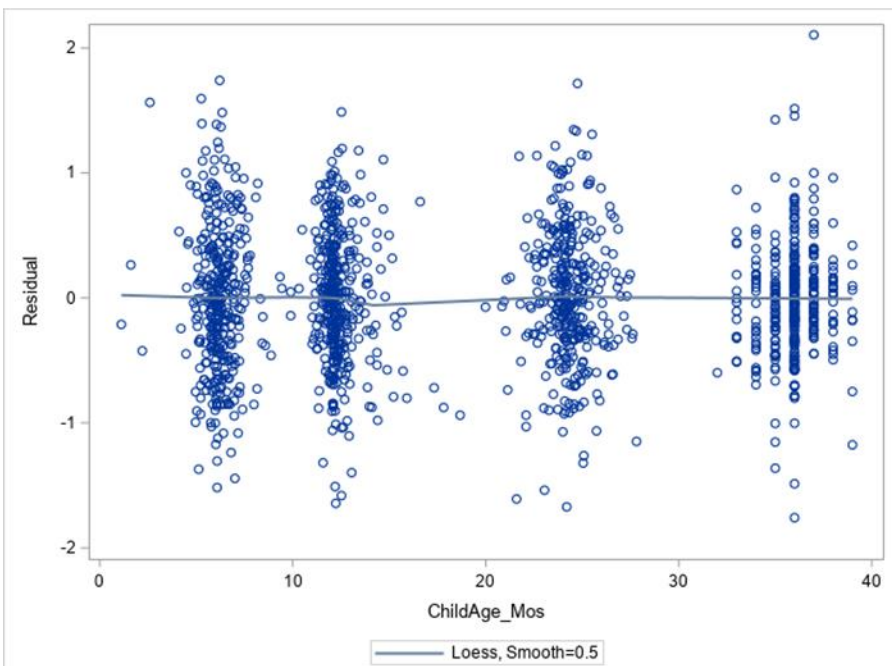
Note: models are age centered at 6 months of age; models control for race/ethnicity, delivery type, breastfeeding duration, household poverty level and food security status, and maternal age, marital status, education level, weight, and smoking status during pregnancy

Appendix Figure B2.2. Residual diagnostics for fixed effects linear regression models testing association between timing of introduction of complementary foods and repeated BMI-for-age z-scores among subsample of children with complementary food introduction between 4 to 6 months

a. boys



b. girls



Appendix B3: Study 3 Sensitivity Analyses

Appendix Table B3.1. Mixed Effects Linear Regression Models: Association Between Early Introduction to Sugar-Sweetened Foods and Beverages and Repeated Weight-for-Length Z-scores by Sex, WIC ITFPS-2 Study (n=1,324)

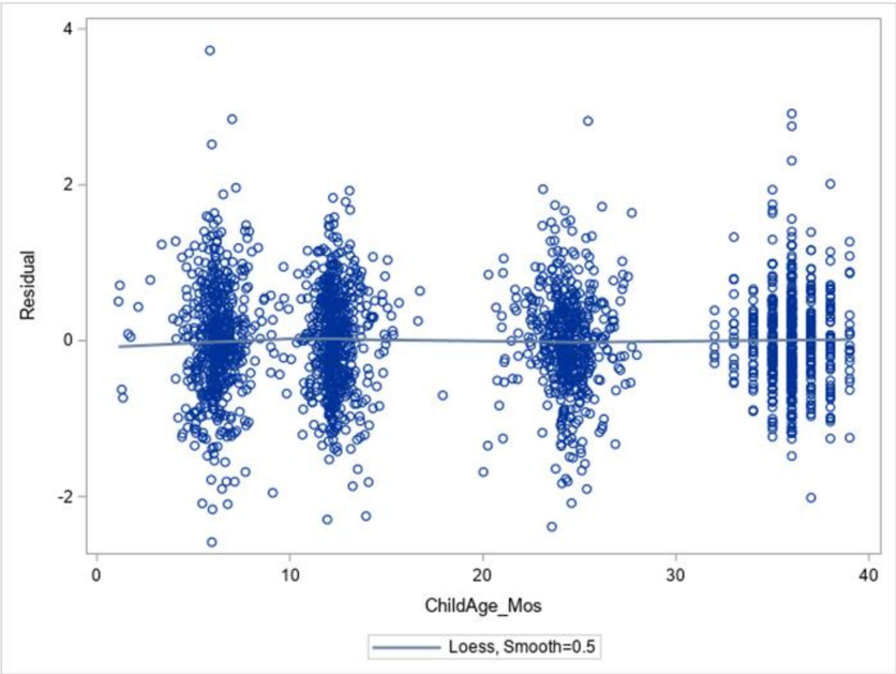
Coefficient	Male (n=682) β (SE)	Female (n=642) β (SE)
Intercept	0.700 (0.130)***	0.801 (0.128)***
Early Introduction[a] to SSFBs		
No (ref)	-	-
Yes	-0.009 (0.093)	0.008 (0.0890)
Age (months)	0.03 (0.009)***	0.026 (0.008)**
Age^2	-0.001 (0.000)**	-0.001 (0.000)***
Age*Early Introduction to SSFBs		
Age*No (ref)	-	-
Age*Yes	-0.009 (0.011)	-0.001 (0.011)
Age^2*Early Introduction to SSFBs		
Age^2*No (ref)	-	-
Age^2*Yes	0.000 (0.000)	0.000 (0.000)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

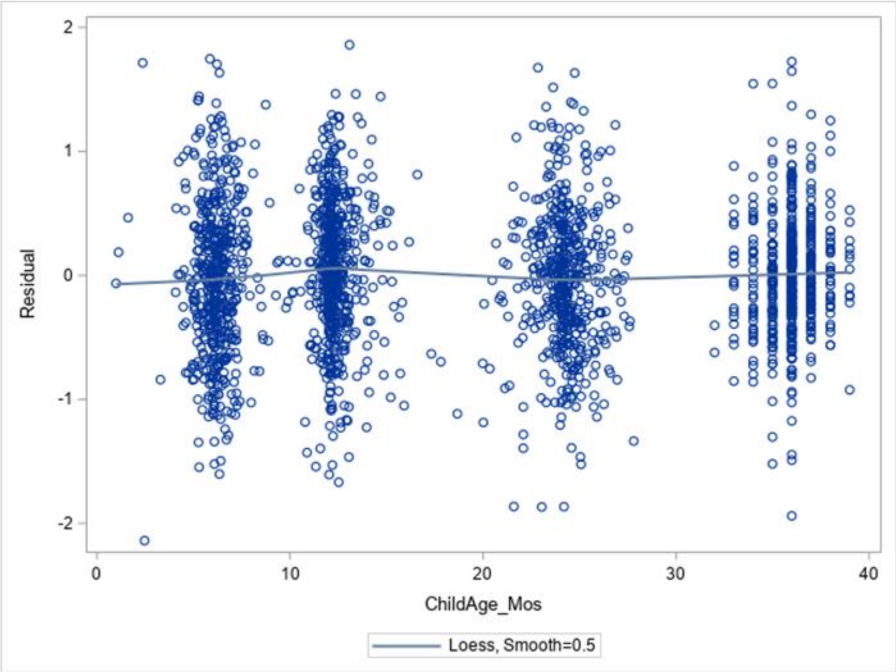
Note: age centered at 6 months of age; models control for race/ethnicity, delivery type, breastfeeding duration, household poverty level and food security status, and maternal age, marital status, education level, weight, and smoking status during pregnancy

Appendix Figure B3.1. Residual diagnostics for fixed effects linear regression models testing association between early introduction to sugar-sweetened foods and beverages and repeated BMI-for-age z-scores

a. boys



b. girls



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