The Pennsylvania State University
The Graduate School
College of Health and Human Development

A MULTI-METHOD INVESTIGATION OF
INFANT BEHAVIORAL STATES AND WEIGHT STATUS

A Dissertation in
Human Development and Family Studies
by
Stephanie Anzman Frasca

© 2011 Stephanie Anzman Frasca

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

August 2011
The dissertation of Stephanie Anzman Frasca was reviewed and approved* by the following:

Leann L. Birch  
Distinguished Professor of Human Development & Family Studies  
Director, the Center for Childhood Obesity Research  
Dissertation Adviser  
Chair of Committee

Ian M. Paul  
Associate Professor of Pediatrics and Public Health Sciences  
Penn State College of Medicine  
Department of Pediatrics

Michael J. Rovine  
Professor of Human Development & Family Studies

Cynthia A. Stifter  
Professor of Human Development & Family Studies and Psychology

Douglas M. Teti  
Professor of Human Development & Family Studies and Psychology  
Graduate Professor-in-Charge, Human Development & Family Studies

*Signatures are on file in the Graduate School.
ABSTRACT

Childhood obesity has reached epidemic proportions; one way to address this problem before obesogenic behaviors and obese phenotypes emerge is to intervene in infancy. The goal of this dissertation was to examine infant behavioral states associated with subsequent obesity risk. Multiple methods were used to study these behaviors in three empirical studies, all in the context of a pilot childhood obesity intervention, with a final sample of 110 well-educated, predominantly White, primiparous mother-infant dyads intending to breastfeed at infant birth.

The goal of the first empirical study (Chapter 2) was to describe changes over time in and relationships among infant behavioral states and to test a model where effects of a "Soothe/Sleep" intervention on weight are explained by increases in total daily sleep duration and decreases in feeding time. Overall, total sleep, nighttime awake/calm time, total and nighttime fussing/crying, and total and nighttime feeding time decreased, and nighttime sleep and total awake/calm time increased over the first four months of infancy. Cross-sectional analysis of relationships between behavioral states at each time point revealed that sleeping and feeding were negatively related at 3 weeks, and these inverse relations strengthened over time for the nighttime period but not over 24-hour periods. The hypothesis that increases in total daily sleep and decreases in feeding time contributed to Soothe/Sleep intervention effects on weight status was supported in breastfeeding dyads but not in formula-feeding dyads.

The second study (Chapter 3) examined infants' behavioral transitions using Markov models, demonstrating fewer transitions out of sleep at 16 weeks compared to 3 weeks, as well as substantial individual differences in the likelihood of transitioning out of a fussing/crying state at both time points. Transitions out of fussing/crying were malleable and predictive of weight outcomes: the likelihood of transitioning from fussing/crying to feeding was positively associated with maternal pre-pregnancy BMI and with subsequent infant weight status. Additionally, the pilot intervention focused on infant soothing and sleeping increased the likelihood of
transitioning from fussing/crying to awake/calm at 16 weeks. There was evidence that transitions out of fussing had different implications depending on the average duration of a fussing episode preceding a transition to feeding.

In the third study (Chapter 5), infant temperament was explored as an outcome, a predictor, and a moderator, and results highlighted the importance of a comprehensive investigation of the role of temperament in behavioral intervention studies. The Soothe/Sleep intervention increased mothers' reports of infant negativity; infants in the intervention group also had higher observed infant self-regulation at 1 year. Infants with greater observed negativity at 1 year whose mothers were low on initial parenting self-efficacy demonstrated the greatest weight gain from 1 to 3 years, suggesting that promoting early maternal self-efficacy could be protective against increased obesity risk in highly negative infants. Infant regulation was inversely associated with weight status but was not related to weight gain over time. Initial infant negativity moderated the effects of the Soothe/Sleep intervention on some, but not all, outcomes. Negative infants who participated in the Soothe/Sleep intervention showed the least weight gain from birth to age 3, and their mothers showed improved parenting satisfaction.

These studies confirm that early infancy is a promising time to intervene on a behavioral level to promote healthy behaviors and decreased obesity risk, and results elucidated some of the mechanisms through which a pilot intervention focused on infant soothing and sleeping had its effects, including increased sleep duration, decreased feeding time, and increased transitions from a fussing state to awake/calm. Weight status data from the current study showed upward BMI-for-age percentile crossing by age 1 on average, suggesting that early interventions are currently needed even in "low-risk" samples. The findings related to infant temperament support the idea that a consideration of individual differences is crucial in behavioral interventions. Given the homogeneity of the current sample, this point will be particularly relevant in subsequent testing of similar interventions in the broader population.
# TABLE OF CONTENTS

LIST OF FIGURES .................................................................................................................. vii

LIST OF TABLES ........................................................................................................................ ix

ACKNOWLEDGMENTS ................................................................................................................... x

CHAPTER 1: A MULTI-METHOD INVESTIGATION OF INFANT BEHAVIORAL STATES AND WEIGHT STATUS .................................................................................................................................................................................. 1

REFERENCES ........................................................................................................................................ 8

FIGURE ........................................................................................................................................ 11

CHAPTER 2: A PREVENTIVE INTERVENTION FOCUSING ON INFANT SOOTHING AND SLEEPING AFFECTS SLEEP AND WEIGHT STATUS IN BREASTFED INFANTS .................................................................................................................................................................................. 13

METHODS .......................................................................................................................................... 24

RESULTS ......................................................................................................................................... 30

DISCUSSION ..................................................................................................................................... 37

REFERENCES .................................................................................................................................... 47

TABLES ........................................................................................................................................ 55

FIGURES ........................................................................................................................................ 59

CHAPTER 3: INFANTS’ TRANSITIONS OUT OF A FUSSING/CRYING STATE ARE MODIFIABLE AND HAVE IMPLICATIONS FOR WEIGHT STATUS .................................................................................................................................................................................. 72

METHODS .......................................................................................................................................... 83

RESULTS ......................................................................................................................................... 89

DISCUSSION ..................................................................................................................................... 92

REFERENCES .................................................................................................................................... 100

TABLES ........................................................................................................................................ 105
FIGURES.................................................................109

CHAPTER 4: INFANT TEMPERAMENT AND OBESITY RISK: A REVIEW OF THE LITERATURE .................................................................116
REFERENCES ...........................................................................................................131

CHAPTER 5: THE ROLES OF INFANT NEGATIVITY AND SELF-REGULATION IN A BEHAVIORAL CHILDHOOD OBESITY PREVENTIVE INTERVENTION ........................................................................139
METHODS ..................................................................................................................148
RESULTS ......................................................................................................................156
DISCUSSION ................................................................................................................164
REFERENCES ..............................................................................................................174
TABLES .......................................................................................................................179
FIGURES .....................................................................................................................185

CHAPTER 6: INTEGRATIVE DISCUSSION ................................................................189
REFERENCES ..............................................................................................................195

APPENDIX: DATA ANALYSIS PLAN AND RESULTS FROM STRUCTURAL EQUATION MODELS ........................................................................196
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Chapter-Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>Conceptual model linking constructs investigated in this dissertation</td>
<td>12</td>
</tr>
<tr>
<td>2-1</td>
<td>Initial hypothesized model of Soothe/Sleep intervention effects</td>
<td>59</td>
</tr>
<tr>
<td>2-2</td>
<td>Overall changes in weight status in this sample</td>
<td>60</td>
</tr>
<tr>
<td>2-3</td>
<td>Changes in total sleep from 3 to 16 weeks</td>
<td>61</td>
</tr>
<tr>
<td>2-4</td>
<td>Changes in nightly sleep from 3 to 16 weeks</td>
<td>62</td>
</tr>
<tr>
<td>2-5</td>
<td>Changes in daily awake/calm from 3 to 16 weeks</td>
<td>63</td>
</tr>
<tr>
<td>2-6</td>
<td>Changes in nighttime awake/calm from 3 to 16 weeks</td>
<td>64</td>
</tr>
<tr>
<td>2-7</td>
<td>Changes in total fussing/crying from 3 to 16 weeks</td>
<td>65</td>
</tr>
<tr>
<td>2-8</td>
<td>Changes in nighttime fussing/crying from 3 to 16 weeks</td>
<td>66</td>
</tr>
<tr>
<td>2-9</td>
<td>Changes in total feeding time from 3 to 16 weeks</td>
<td>67</td>
</tr>
<tr>
<td>2-10</td>
<td>Changes in nighttime feeding from 3 to 16 weeks</td>
<td>68</td>
</tr>
<tr>
<td>2-11</td>
<td>Final aggregate model of intervention effects on behavioral changes and weight status</td>
<td>69</td>
</tr>
<tr>
<td>2-12</td>
<td>Final model of Soothe/Sleep intervention effects on sleep and weight status in breastfeeding dyads</td>
<td>70</td>
</tr>
<tr>
<td>2-13</td>
<td>Final model of Soothe/Sleep intervention effects on sleep and weight status in formula-feeding dyads</td>
<td>71</td>
</tr>
<tr>
<td>3-1</td>
<td>Infants' probabilities of transitioning from sleeping to feeding at 3 and 16 weeks</td>
<td>109</td>
</tr>
<tr>
<td>3-2</td>
<td>Infants' probabilities of transitioning from sleeping to fussing at 3 and 16 weeks</td>
<td>110</td>
</tr>
<tr>
<td>3-3</td>
<td>Infants' probabilities of transitioning from fussing to feeding at 3 and 16 weeks</td>
<td>111</td>
</tr>
<tr>
<td>3-4</td>
<td>Infants' probabilities of transitioning from fussing to awake and calm at 3 and 16 weeks</td>
<td>112</td>
</tr>
<tr>
<td>3-5</td>
<td>Maternal pre-pregnancy BMI positively predicted infant transitions from fussing to feeding</td>
<td>113</td>
</tr>
<tr>
<td>3-6</td>
<td>The Soothe/Sleep intervention increased infants' probabilities of transitioning from a fussing/crying state to awake/calm at 16 weeks</td>
<td>114</td>
</tr>
<tr>
<td>3-7</td>
<td>Infants' probabilities of transitioning from fussing to feeding at 3 weeks positively predicted their weight status at ~6 months</td>
<td>115</td>
</tr>
</tbody>
</table>
Mothers' initial parenting self-efficacy moderates the relationship between observed infant negativity and weight gain from age 1 to 3

Mother-reported regulation at 1 year is inversely associated with concurrent weight status

Initial infant negativity moderates the effects of the Soothe/Sleep intervention on weight gain

Initial infant negativity moderates the effects of the Soothe/Sleep intervention on mothers' parenting satisfaction at 1 year
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Chapter-Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1</td>
<td>Descriptive statistics for dyads completing study and by control vs. intervention groups</td>
<td>55</td>
</tr>
<tr>
<td>2-2</td>
<td>Descriptive statistics for behavioral variables of interest at ages 3 and 16 weeks</td>
<td>56</td>
</tr>
<tr>
<td>2-3</td>
<td>Significant moderators of changes in infant behavioral states</td>
<td>57</td>
</tr>
<tr>
<td>2-4</td>
<td>Cross-sectional inter-correlations between infant behavioral states</td>
<td>58</td>
</tr>
<tr>
<td>3-1</td>
<td>Descriptive statistics for dyads completing study and by control and vs. intervention groups</td>
<td>105</td>
</tr>
<tr>
<td>3-2</td>
<td>Transition matrix for total sample at infant age 3 weeks</td>
<td>106</td>
</tr>
<tr>
<td>3-3</td>
<td>Transition matrix for total sample at infant age 16 weeks</td>
<td>107</td>
</tr>
<tr>
<td>3-4</td>
<td>Transition probabilities from person-specific Markov models</td>
<td>108</td>
</tr>
<tr>
<td>5-1</td>
<td>Descriptive statistics for dyads completing study and by control and vs. intervention groups</td>
<td>179</td>
</tr>
<tr>
<td>5-2</td>
<td>Selective attrition: Demographic differences between study completers and drop-outs</td>
<td>180</td>
</tr>
<tr>
<td>5-3</td>
<td>Descriptive statistics for variables of interest</td>
<td>181</td>
</tr>
<tr>
<td>5-4</td>
<td>Most indices of negativity and regulation were inversely correlated at 16 weeks and 1 year</td>
<td>182</td>
</tr>
<tr>
<td>5-5</td>
<td>The Soothe/Sleep intervention increased mother-reported infant negativity at 1 year</td>
<td>183</td>
</tr>
<tr>
<td>5-6</td>
<td>The Soothe/Sleep intervention increased observed infant self-regulation at 1 year</td>
<td>184</td>
</tr>
</tbody>
</table>
Acknowledgments

Reflecting on the list of people who made this achievement possible is humbling. First, I owe a big thank you to each of my committee members, all of whom have supported me through numerous graduate school milestones. To Drs. Leann Birch, Cynthia Stifter, Ian Paul, Michael Rovine, and Douglas Teti, I appreciate all of your time and encouragement, and I will take pieces of what I have learned from each of you with me wherever I go next.

To Leann, my committee chair and advisor, I learned more from you than I ever could have anticipated: lessons both in our substantive area and also about the kind of professional that I would like to be. Your ability to balance work and life is inspiring, and the enthusiasm with which you mentor students is something I will try to emulate as I move forward. I appreciate how you made sure that my activities as a research assistant were useful and appropriate for my stage in the program, providing training across a wide range of skills and opportunities for collaboration. The way I see it, my job now is to pay it forward: to continue to contribute to this area of research with enthusiasm and to foster my own students’ motivations and abilities. Also, I will work on the appropriate use of the word whereas...

Cindy, since my days in your temperament seminar as a first-year graduate student, you have helped shape the way I think about individual differences and influenced my passion for integrating temperament and obesity (and health research more broadly). I am grateful that I was able to take your temperament seminar, to do some work in your lab, and to have you on my Masters, Candidacy, and dissertation committees. As I introduced temperament into my work, it has been fun to see you incorporate obesity into yours! I wish you the best of luck as you move forward with B2BB and other projects. Ian, I am thankful to be a part of the collaborative efforts between our Center and Hershey Medical. Your clinical insights help me to see new perspectives that are beneficial in terms of thinking about the real-world implications of the work that we do. I look forward to more inter-disciplinary learning as we continue to work
together. Mike, I hope that you will see how you have influenced me as you read the methods sections of the papers that follow. I learned many methodological techniques from you, in the formal classroom setting and through research collaborations. You provide a wonderful example of how to teach difficult concepts in an accessible, enjoyable way. Doug, I appreciate that you have challenged me in my previous defenses and in your parenting class. You have encouraged me to expand my thinking, and the inclusion of certain parenting concepts in this dissertation is due to your influence.

I am also grateful to the supportive, knowledgeable, and dynamic HDFS faculty, graduate students, and administrative staff and to my coworkers at the Center for Childhood Obesity Research. In particular, thank you to Peter Molenaar for helping me troubleshoot some questions about LISREL and to Katie Gates and Siwei Liu for teaching me about running Markov Models in R. Thank you also to Michele Marini for heading up the effort to organize and clean the diary data used throughout this dissertation and for being a master of SAS syntax.

I would also like to acknowledge my support system in my personal life: particularly my parents, my best friend K, and my husband Mike. Each of these individuals communicates in their own way that it is important to work hard, but that work isn’t all there is to life: from my Mom and Dad telling me to “do my best” in childhood, to college, where K and I would switch fluidly from intellectual conversations over Friday morning breakfast to a range of activities too silly to mention in the pages of a doctoral dissertation, and finally, to Mike, who started out as “smiley kid” and ended up as my supportive, kind (and so far, still smiley) husband.

A number of dedicated teachers have also influenced and motivated me over the years. My second grade teacher Miss Doran taught me to love reading and writing and encouraged me to write short stories and pursue my early dream of being a writer. My teachers at Delaware Valley High School, particularly Ms. Maier and Mr. Dennis, were amazing science and math
educators (and generous and fun people) who challenged me to think critically. Lastly, thank you to Drs. Kevin Myers and Chris Boyatzis for peaking my interest in psychology and research and for highlighting a path by which I could combine my interests in child development, eating behavior, science, math, writing, and teaching (and to Kevin for pointing out Leann’s work, undoubtedly leading to a meaningful transition in my own developmental trajectory).

So, even though I like to think that I’m independent, the reality is that hard work and ideas are not enough to complete a Ph.D. program. It takes a team of supporters, and I am very fortunate to call these people my team. Thank you for everything. I hope I’ve made you proud.
Chapter 1

A Multi-method Investigation of Infant Behavioral States and Weight Status

Childhood obesity has reached epidemic proportions over the past few decades. The most recent data from the National Health and Nutrition Examination Survey (NHANES) showed that 31.7% of American children aged 2 to 19 were overweight, and 16.9% were obese. Even the youngest children are affected by this problem; approximately 10% of infants and toddlers have a weight status at or above the 95th percentile for age and sex (Ogden, Carroll, Curtin, Lamb, & Flegal, 2010), suggesting that school-age prevention approaches may be too late (Paul, Bartok, Downs, Stifter, Ventura, & Birch, 2009; Summerbell, Waters, Edmunds, Kelly, Brown, & Campbell, 2005). Children in developed countries are born into obesogenic environments, characterized by inexpensive and accessible energy-dense foods and sedentary lifestyles. Such environments necessitate a consideration of preventive interventions from the earliest days of life (Paul et al., 2009). Most childhood obesity prevention efforts have been short-term studies focused on eating and/or physical activity behaviors in school-age children, and most of these efforts have shown little to no effect on body mass index (BMI; Summerbell et al., 2005; Kamath, Vickers, Ehrlich, McGovern, Johnson, Singhal, et al., 2008).

In addition to a higher likelihood of affecting health before the onset of obesity, interventions in early life are promising due to the numerous rapid changes that occur during infancy. While infants' behavioral repertoires are relatively simple (i.e. infants spend most of their time sleeping, fussing, feeding, or engaging in simple activities while awake and calm), the durations and characteristics of these behaviors change
drastically in the first year of life. There are individual differences in the patterns of changes (e.g., Barr, 1990; Iglowstein, Jenni, Molinair, & Largo, 2003), but the average trends have been confirmed by multiple studies. Total sleep time tends to decrease, and sleep becomes consolidated into a nocturnal sleep pattern over the course of infancy (Iglowstein et al., 2003). Infant crying increases from birth, peaks in the second month of life, and then decreases (Barr, 1990). There are also rapid transitions in feeding. During the first few months after birth, infants consume only breast milk or formula, and as the infant develops, the number of daily feedings declines and the size of feedings tends to increase. Infants then rapidly transition to solid foods in the middle of infancy and to table foods by the end of the first year.

Dynamic systems theories (DST) posit that such periods of rapid changes offer the best opportunities for intervention; the DST framework depicts development as probabilistic, plastic, and self-organizing, such that large enough changes at a given level of analysis could lead to a disruption in stability as the different levels co-act and reorganize to express qualitatively new phenotypes specific to a new developmental stage (Gottlieb, 2007; van Geert, 2003). According to this view, development is not predetermined by genes but is better characterized as probabilistic epigenesis and tends to involve increases in complexity, the emergence of novel forms, and stable attractor states where different levels of analysis interact to dynamically maintain a phenotype for a period of time (van Geert, 2003). Because obesity seems to be a stable state in the current environment, as evidenced by high levels of tracking once the phenotype is established (e.g., Whitaker, Wright, Pepe, Seidel, & Dietz, 1997), affecting behavioral predictors of obesity during the relative instability of early life is a promising
approach to childhood obesity prevention (Anzman, Rollins, & Birch, 2010; Birch & Anzman, 2010).

In order to intervene to establish infant lifestyles that predict the early establishment of healthy weight trajectories, it is necessary to consider not only which behaviors predict obesity risk, but also the developmental trajectories of these behaviors. An investigation of changes in behavioral states in early infancy and their relationships with weight status can inform efficacious interventions. In this study, behavioral data from a pilot childhood obesity intervention were analyzed in order to gain insight on these points. Mother-infant dyads participating in the SLIMTIME (SLeeping and Intake Methods Taught to Infants and Mothers Early in life) pilot study were randomized to one cell of a 2 x 2 design, to receive zero, one, or two interventions. Beginning at about 3 weeks postnatally, dyads in the Soothe/Sleep intervention were given tools to increase infant sleep (e.g., emphasizing day and night differences) and to initially respond to fussing and crying with soothing mechanisms that did not involve food (e.g., swaddling). Dyads in the Introduction to Solids intervention were instructed to delay the introduction of complementary foods until 4- to 6 months; after solids were introduced, the majority of this intervention’s lessons were implemented, centering on how to introduce these new foods to infants. Further details about these interventions are available elsewhere (Paul, Savage, Anzman, Beiler, Marini, Stokes, et al., 2011). Recruited mothers were primiparous and intended to breastfeed, but by the time infants were 16 weeks old, about half of the sample was no longer predominantly breastfeeding. Investigations of the interventions’ effects on weight status showed that infants who were assigned to both the Soothe/Sleep and Introduction to Solids
interventions had the lowest weight-for-length percentiles at age 1 year, compared to
the other groups, and predominantly breastfed infants in the Soothe/Sleep intervention
had increased sleep durations and decreased feeding frequencies compared to their
control group counterparts (Paul et al., 2011).

The goal of this dissertation was to study infant behavioral states with multiple
methods, including studying the effects of the Soothe/Sleep intervention on infant
behaviors, as well as changes in behavioral states on multiple time scales, individual
differences in behavioral states, and relationships between varying behavioral patterns
and weight outcomes. Infant behavioral states (i.e. time spent sleeping, awake/calm,
fussing/crying, and feeding) were assessed using four-day infant behavior diaries at
infant ages 3, 4, 8, and 16 weeks. Each of three empirical studies focuses on a
particular aspect of infant behavior, and taken together, the results have implications for
future preventive interventions. A characterization of normative behavioral changes
during this early period of rapid transition can inform the timing and content of
intervention efforts, and individual differences in intervention effects and behavioral
patterns can inform the design of subsequent universal or targeted interventions.
Accordingly, demographic, temperament, and parenting variables were considered as
moderators in many of the specific research questions that were posed.

In Chapter 2, changes in four infant behavioral states over the developmental
period from 3 to 16 weeks are described, and a number of demographic and behavioral
variables are explored as moderators of these changes. Cross-sectional correlations
between the infant behavioral states were also investigated to highlight which behaviors
were tightly coupled and when. Lastly, structural equation modeling was used to test a
hypothesized model of Soothe/Sleep intervention effects on weight through changes in sleeping and feeding behaviors in the first four months of life. Short sleep has been highlighted as a potential obesity risk factor in children and adults (Cappuccio, Taggart, Kandala, Currie, Peile, Stranges, et al., 2008). Yet the nature of this relationship is unclear in infancy, and causality has not been strongly established in any age group.

The overall goal of this chapter was to characterize infant behavioral states in this sample and to explain the extent to which changes in sleep explain intervention effects on infant weight status in breastfed and formula-fed infants.

While total sleep from 3 to 16 weeks was expected to play a causal role in weight outcomes, changes in and implications of fussing/crying behaviors in this intervention study were hypothesized to have their effects on a micro-level time scale. In Chapter 3, the focus shifts to transitions between behavioral states within a given time point, with a particular focus on fussing/crying. The aims of this chapter were to test whether transitions out of behavioral states were less likely at 16 weeks compared to 3 weeks (i.e. are behaviors becoming more stable and consolidated in time?) and to test whether there were individual differences in the likelihood of transitioning from fussing/crying to other behavioral states like feeding. There is an emerging literature that suggests that the use of food to soothe infant distress could be a risk factor for excessive weight gain (e.g., Baughcum, Burklow, Deeks, Powers, & Whitaker, 1998; Stifter, Birch, Anzman-Frasca, & Voegtline, under review). Relationships between transitions out of fussing and demographic factors, the Soothe/Sleep intervention, and weight status were tested, with a hypothesis that the Soothe/Sleep intervention increased the likelihood of transitioning from fussing to awake/calm and decreased the likelihood of transitioning
from fussing to feeding. Another goal was to test whether the implications of transitioning from fussing to feeding were different depending on the duration of the fussing/crying episode that preceded the transition. The predominant analysis in this chapter was Markov modeling, a methodology that allows the time series nature of the data to be retained and that makes it possible to conduct person-specific models, facilitating an investigation of individual differences in behavioral transitions.

Individual differences were conceptualized in another way in Chapter 5: as relatively stable behavioral styles, or temperament. This chapter is preceded by a review of the literature on temperament and weight status, which suggests that greater infant negativity could be a risk factor for childhood obesity, and greater self-regulation could be protective (e.g., Darlington & Wright, 2006; Graziano, Calkins, & Keane, 2010; Slining, Adair, Goldman, Borja, & Bentley, 2009). We investigated these relationships in our sample, as well as the role of temperament as an outcome and as a moderator. It was hypothesized that the lessons of the Soothe/Sleep intervention would result in a heightened awareness of infant distress in mothers and improved, observed self-regulation in infants. It was also hypothesized that early infant temperament moderated the effects of the Soothe/Sleep intervention on a number of outcomes, following the theory that more negative infants may be differentially susceptible to environmental manipulations (Belsky, 2007).

The overall aim of these chapters was to provide a comprehensive understanding of the behavioral mechanisms of the Soothe/Sleep component of the SLIMTIME Project, including the roles of sleep, fussing/crying, and temperament in this intervention, which were explored using different time scales and methodologies.
Figure 1 is a conceptual model, depicting the hypothesized connections among the variables of interest. The three studies described herein support the idea that infancy is a promising time period for behaviorally-focused childhood obesity preventive interventions, and the nature of the findings can inform the timing and targeting of future interventions.
References


Behavioral states in early infancy*:

Sleeping  Awake/calm  Fussing/crying  Feeding

*Main effects and interactions

Parenting

Infant temperament

Soothe/Sleep intervention

Parenting

Infant feeding mode

Infant growth, Weight status

Infant self-regulation

Demographic factors: E.g., maternal BMI, income

*Inter-related and changing over time
Figure 1. Conceptual model linking constructs investigated in this dissertation. Relationships between infant behavioral state and weight status will be explored in the context of a preventive intervention focusing on soothing and sleeping in infancy. Chapter 2 describes how infants’ behavioral states change over the first four months of infancy and tests whether changes in total sleep and feeding explain intervention effects on weight status. In Chapter 3, daily transitions between behavioral states are described, and intervention effects on transitions out of fussing/crying are examined, as well as relationships between these transitions and demographic factors and weight status. Lastly, Chapter 5 examines the role of infant temperament in the Soothe/Sleep intervention. This chapter is preceded by a review of the literature on temperament and weight status. Then, specific research questions are posed to investigate links between infant temperament, the Soothe/Sleep intervention, and weight outcomes: Does the Soothe/Sleep intervention affect infant negativity and/or regulation? Is temperament related to weight status in this study? Are intervention effects on regulation, parenting satisfaction, and weight status modified by early negativity?
Chapter 2

A Preventive Intervention Focused on Infant Soothing and Sleeping
Affects Sleep and Weight Status in Breastfed Infants

Too much weight gain in infancy has been highlighted as a risk factor for childhood obesity (Ong & Loos, 2006). In the context of the current childhood obesity epidemic, it is important to promote healthy growth, as well as the development of healthy behaviors, from the earliest days of life. Infants' energy intake and energy expenditure are linked to growth, as is infant feeding mode (breast or formula; Owen, Martin, Whincup, Smith, & Cook, 2005); more recently, infant sleep and fussing/crying have been highlighted as behavioral states that are associated with weight status (e.g., Darlington & Wright, 2006; Tikotzky, De Marcas, Har-Toov, Dollberg, Bar-Haim, & Sadeh, 2010). Infancy offers an opportunity to intervene and affect behavioral states at a time when behavioral repertoires are limited, caregivers have a high degree of control, and development is in flux, before the emergence of obese phenotypes. The goal of this study is to characterize changes in infant behavioral states over the first four months of life and to test whether a randomized intervention focused on infant soothing and sleeping affected weight status through changes in time spent sleeping and feeding.

Infants spend most of their time sleeping, fussing, feeding, or engaging in simple activities while awake and calm, but the proportion of time spent in each of these behavioral states changes dramatically during infancy and varies across individuals. On average, total sleep time decreases, and sleep becomes consolidated into a nocturnal sleep pattern (Iglowstein, Jenni, Molinari, & Largo, 2003). Infant crying increases,
peaks in the second month of life, and then decreases (Barr, 1990). Time spent feeding decreases, and there are also qualitative changes in feeding as infants transition from consuming only breast milk or formula, to the introduction of solid foods, and finally to consuming table foods. These changes are inter-related; for example, as time spent crying and feeding decreases, the time that infants spend awake and calm increases (Walker & Menaham, 1994).

Other relationships between infant behavioral states have been demonstrated, including negative associations between time spent sleeping and fussing/crying (St. James-Roberts, Conroy, & Hurry, 1997) and sleeping and feeding (Keener, Zeanah, & Anders, 1988). If early feeding patterns affect or are affected by other behavioral states, these links may impact weight outcomes. For many infants, associations between behavioral states decrease in magnitude as infancy progresses, and the infant’s behavioral repertoire increases in complexity and stability. There is substantial reorganization in sleep and waking cycles in the first 12 weeks of life (St. James-Roberts et al., 1997), and St. James-Roberts and Plewis (1996) found that infant sleep was moderately stable beginning at 6 weeks of age. Early behavioral instability highlights infancy as a promising period for preventive interventions (Gottlieb, 2002; van Geert, 2003); if behavioral reorganization is occurring, this presents an opportunity to affect it in a positive direction. This early instability also means that inter-individual variability in infant behavior is particularly high in the first few months. For example, Iglowstein and colleagues (2003) noted that inter-individual variability in sleep patterns is greater during infancy than at any other period of the lifespan.
The aim of this chapter is to describe average changes and individual differences in infant sleep, awake and calm time, fussing/crying, and feeding during the first four months of life using infant behavior diaries, which have been validated as a tool to measure infant behavioral states. In general, diary assessments and objective recordings of behavioral states are positively correlated, representing agreement between these measures on a relative scale and leading to characterization of consistent average trends (e.g., developmental decreases in total sleep time). Barr and colleagues (1988) found that audio recordings of negative vocalizations were positively correlated with the frequency of diary-reported fussing and crying and the duration of diary-reported crying. The correlation coefficients were .64 and .67, respectively, but increased to .85 and .90 when an outlier was omitted. In terms of absolute durations, diaries can lead to over or under-reporting, but researchers have concluded that diaries are a valid proxy for infant behavior, especially because this tool allows for the inexpensive, feasible observation of large numbers of infants over time.

After characterizing normative trends for the behavioral states assessed by the diaries, individual differences will be investigated by introducing variables hypothesized to moderate these changes. Characterizing these individual differences could provide insight as to which infants are at risk of developing problematic behavior patterns and potentially, subsequent obesity. The literature addressing variables linked to infant behavioral state and to subsequent obesity risk highlights potential moderators of early change in infant behavioral states. Infant temperament has been linked to infant sleep (Keener et al., 1988), fussing/crying (Barr, Kramer, Pless, Boisjoly, & Leduc, 1989), and feeding (Barr et al., 1989; Stifter, Birch, Anzman-Frasca, & Voegtline, under review;
Wasser, Bentley, Borja, Goldman, Thompson, Slining, et al., 2011). More negative infants tend to have less regular sleep and more fussing/crying. There is also preliminary evidence that more negative infants may be fed more (Stifter et al., under review), infants who are more “difficult” in early infancy may be more likely to be formula-fed (Barr et al., 1989), and fussier infants may be introduced to complementary foods before the recommended age (Wasser et al., 2011).

Greater maternal pre-pregnancy weight status (Snethen, Hewitt, & Goretzke, 2007) and lower socioeconomic status (Shrewsbury & Wardle, 2008) have also been linked to childhood obesity risk, and lower maternal self-efficacy has been linked to lower parenting sensitivity (Teti, O’Connell, & Reiner, 1996). If mothers lower on self-efficacy are less persistent in their interactions with their infants, such interactions could affect infants’ developing behavioral repertoires. These variables, as well as the Soothe/Sleep intervention and infant feeding mode, were investigated as moderators of change in infant behavioral states during the first four months of life. Among the many factors contributing to individual differences in mean levels and trends in infant behavioral states, there is consistent evidence of behavioral differences between breastfed and formula-fed infants: for example, breastfed infants sleep less (Lucas & St. James-Roberts, 1998) and cry more frequently (Barr et al., 1989) than formula-fed infants. To decrease this variability, this pilot intervention was designed for dyads intending to breastfeed.

Developmental changes and individual differences in behavioral states imply plasticity, and intervention studies provide evidence that infant sleep (Pinilla & Birch, 1993; Taveras, Blackburn, Gillman, Haines, McDonald, Price, et al., 2010; Wake, Price,
Clifford, Ukoumunne, & Hiscock, 2011) and infant fussing/crying (Hunziker & Barr, 1986; van den Boom, 1994) are modifiable. Pinilla and Birch (1993) demonstrated that sleep time in the first eight weeks of life could be increased in breastfeeding infants by emphasizing day and night differences and engaging in alternate care-taking behaviors at night; they also demonstrated links between sleep and feeding as dropping a nighttime feeding led to increased sleep duration. Past demonstrations that infant sleep is modifiable highlight it as a potential behavioral intervention target in infancy, and it was one of the targets of the current pilot intervention. In addition to rapid changes in infant sleep and the potential to modify it, infant sleep must also be linked to subsequent weight outcomes in order for it to serve as a plausible targeted behavior in a childhood obesity intervention. In the pages that follow, literature examining the association between sleep and weight status is reviewed. Because studies on infant sleep and weight status are limited, evidence from other periods of the lifespan is reviewed while acknowledging the likely developmental differences in the mechanisms behind this link.

**Sleep and Weight Status: Evidence from Cross-sectional Studies**

Numerous epidemiological and cross-sectional studies have revealed an association between short sleep and obesity risk in adults and children (see Cappuccio, Taggart, Kandala, Currie, Peile, Stranges, & Miller, 2008), and a smaller number of longitudinal studies suggest that short sleep is predictive of increased obesity risk (see Patel & Hu, 2008). In the past few decades, average sleep duration has decreased in children and adults in developed nations (e.g., Iglowstein et al., 2003), and these decreases have been accompanied by concurrent increases in obesity rates (e.g., Cizza, Skarulis, & Mignot, 2005). It is important to note that these historical trends are
linked to many other aspects of our modern society (e.g., widespread sedentary pursuits and increased work demands), and the link between sleep and obesity may be complex. Although this relationship is not fully understood and may have different implications during different parts of the lifespan, the replication of this association among infants, children, adolescents, and adults in numerous countries highlights sleep as a potentially modifiable obesity risk factor, one which also has implications for other aspects of health, such as cognitive performance and psychological well-being (e.g., Smaldone, Honig, & Byrne, 2007).

Many studies have highlighted a cross-sectional relationship between sleep duration and weight status in children and adults. In adults, some studies show an inverse, cross-sectional relationship (e.g., Singh, Drake, Roehrs, Hudgel, & Roth, 2005), some show no association (e.g., Gortmaker, Dietz, & Cheung, 1990), and some show a curvilinear relationship between sleep and obesity, such that short and long sleepers are more likely to have a high weight status (e.g., Taheri, Lin, Austin, Young, & Mignot, 2004). This curvilinear relationship could explain the mixed findings in the adult literature (if some studies are only testing for linear relationships); this curvilinear relationship does not seem to exist in children. The literature on children is consistent, with studies highlighting an inverse, linear relationship. For example, Sekine and colleagues (2002) found that shorter sleep duration was associated with increased obesity risk using parent-reported sleep and measured BMI in a cohort of 8,274 Japanese children ages 6 to 7, and Gupta and colleagues (2002) came to the same conclusion when measuring sleep via 24-hour actigraphy in a sample of 383 American 11-16-year-olds. Although the relationship between short sleep and obesity seems to
be robust, particularly in children, the authors of a recent systematic review on sleep and obesity concluded that the evidence for causality and mechanisms explaining the relationship is not sufficient (Cappuccio et al., 2008). Longitudinal studies and experimental manipulations, such as intervention studies that manipulate sleep duration, can help to investigate causal effects of sleep on weight outcomes.

**Sleep and Weight Status: Evidence from Longitudinal Studies**

As in the cross-sectional research on this topic, investigations of prospective relationships between sleep and obesity risk have yielded equivocal results in adults (e.g., Gangwisch, Malaspina, Boden-Albala, & Heymsfield, 2005; Patel, Malhotra, White, Gottlieb, & Hu, 2006; Stanges, Cappuccio, Kandala, Miller, Taggart, Kumari, et al., 2007) and more consistent results in children. In a nationally representative sample of 3-to-12-year-old children, children who slept less at their first assessment had a higher weight status five years later, adjusting for baseline BMI (Snell, Adam, & Duncan, 2007); additional studies have highlighted a relationship between shorter sleep at age 3 and subsequent obesity risk (e.g., Agras, Hammer, McNicholas, & Kraemer, 2004; Reilly, Armstrong, Dorosty, Emmett, Ness, Rogers, et al., 2005). In the latter two studies, sleep duration was assessed via one question, and sleep duration was analyzed either as a continuous variable (Agras et al., 2004) or as a dichotomous variable where short sleep was defined as less than 10.5 hours (Reilly et al., 2005). There are fewer observational studies on the relationship between sleep and weight status in infancy: Tikotzky and colleagues (2010) demonstrated an inverse, cross-sectional relationship between sleep and weight status in 6-month-old Israeli infants. In two prospective studies, shorter total (24-hour) sleep in infancy predicted greater
overweight risk in childhood (Taveras, Rifas-Shiman, Oken, Gunderson, & Gillman, 2008), and shorter nighttime sleep at a baseline assessment (age 0-4 years) predicted subsequent increased obesity risk (Bell & Zimmerman, 2010).

The evidence shows that the prospective relationship between sleep and weight status is more robust in children (Patel & Hu, 2008), but why is this so? Are children's environments less complex (thus involving fewer mediating or moderating mechanisms)? Are their weight statuses less "set" and more susceptible to these effects because they are still growing? The answers to these questions are not yet clear, but research is consistent with the idea that the mechanisms behind the sleep-weight status association could differ by developmental period. The literature highlights obesity-promoting mechanisms that may be caused by short sleep: increased appetite and intake, alterations in levels of hormones that regulate appetite (leptin and ghrelin), decreased physical activity levels, decreased secretions of growth hormone, and more time available to eat. It is also possible that the relationship between sleep and obesity could be partially explained by confounding variables predicting both short sleep and obesity, such as poor health status, low socioeconomic status, psychiatric comorbidities, or other lifestyle characteristics (Cappuccio et al., 2008).

The extent to which these variables explain the sleep-weight status relationship may differ depending on the period of the lifespan. For example, one confounder that may relate to sleep and weight status in adults is depression (Cappuccio et al., 2008); this factor is less likely to be relevant in early childhood. One link between sleep and weight status in early childhood may be increased secretions of growth hormone in children who sleep more, resulting in a greater height and thus a lower weight-for-height.
(Tikotzky et al., 2010); this factor is less likely to be relevant in adulthood. Of the mechanisms considered above, only some are plausible in infancy. It is plausible that decreased sleep may affect hormones like leptin and ghrelin, thus impacting infants' appetite and feeding behavior. Similarly, infants who sleep less are awake for more hours and may be fed more frequently by virtue of their increased awake time. Infants who have difficulty sleeping may awaken more frequently at night; parents may feed these infants to soothe them back to sleep. Reverse causality where increased appetite causes infants to awaken is also a possibility. If short sleep is a causal factor in the obesity epidemic, then its effects should occur through increased energy intake and/or decreased energy expenditure. So far, research has not confirmed mediating influences of intake or energy expenditure (e.g., Hasler, Buysse, Klaghofer, Gamma, Adjacic, Eich, et al., 2004), but there are many limitations around the accurate measurement of these variables.

**Is Short Sleep Duration Causally Linked to Obesity Risk?**

Given the potential of confounding factors and developmental differences, the best way to continue to research the link between sleep and obesity is to manipulate sleep (Patel & Hu, 2008). If individuals are randomly assigned to groups where sleep is manipulated, and if those manipulations affect intake, activity, or weight, then this area of research will attain the causal evidence that is lacking but necessary for the utilization of this link in successful obesity interventions. Such studies have the potential to rule out reverse causality or third variables and to highlight mediating mechanisms. There are a small number of such studies in the literature, including a randomized controlled trial on adults that is currently in progress (Cizza, Marincola, Mattingly, Williams, Mitler,
In a recent pilot intervention targeting sleep, TV, feeding, and physical activity in infants and their mothers through health educator counseling and parenting groups, the intervention group demonstrated greater increases in nighttime sleep duration from infant age 2 weeks to 6 months. Intervention and control infants did not differ on weight status at age 6 months, but there was a trend such that intervention infants were less likely to be in the highest weight status quartile (Taveras et al., 2010). In another study, intervention effects on infant sleep did not translate into subsequent effects on weight (Wake et al., 2011) although this study was not designed to affect weight, a substantial number of participants were lost to follow-up, and sleep and weight status were not correlated in this sample, a finding that is divergent from the growing body of research on sleep and weight. The dearth of experimental studies in this area and the contrasting results highlight the need for additional research. In the current study, sleep manipulations were explored through a pilot intervention designed to reduce obesity risk by promoting infants’ ability to self-soothe and return to sleep without feeding. Initial findings from this study showed intervention effects on infant weight status at age 1 year (Paul, Savage, Anzman, Beiler, Marini, Stokes, et al., 2011).

The current study tested the prospective sleep-weight status relationship in this intervention sample, as well as mechanisms explaining this relationship. This study’s design allows us to investigate whether random assignment to an intervention focused on infant soothing and sleeping causes increases in infant sleep and if these effects predict decreased weight status. The mechanisms explaining the sleep-weight
association may be particularly simple in infancy; the hypothesis guiding the current study was that this association is explained by less time spent feeding in infants who sleep more. These effects were investigated for the total sample and separately by feeding mode because infant behavioral states differ by feeding mode and because this intervention was designed for breastfeeding mother-infant dyads.

**Specific Aims**

The specific aims of the current study were:

1. To describe changes in infant behavioral states and weight status, including:
   - Changes in infant BMI-for-age z-scores over the course of the study
   - Changes in the average daily durations of four behavioral states (time spent sleeping, awake/calm, fussing/crying, and feeding) in early infancy
   - Potential moderators of these changes (intervention group, infant temperament, infant feeding mode, maternal pre-pregnancy BMI, maternal self-efficacy, and socioeconomic status)

2. To explore cross-sectional correlations between the four behavioral states

3. To test a structural equation model where the intervention increased total sleep, which affected subsequent weight status through decreased feeding time
   - A plan was made to alter the hypothesized model based on the modification indices provided, aiming to arrive at a structural equation model where changes in one or more behavioral states would be highlighted as mediators of intervention effects on weight status.
• Predominant infant feeding mode (breast or formula) was tested as a moderator of these paths to determine whether a two-group model would allow a more precise characterization of intervention effects.

• Final modifications were made to the best-fitting model based on insights gained from the previous exploratory aims.

Methods

Participants

Mothers were recruited from the maternity ward of an academic medical center in Pennsylvania and were eligible if they intended to breastfeed and to follow-up with a University-affiliated primary care provider and if they were primiparous and English-speaking. Other inclusion criteria were singleton birth and at least 34 weeks’ gestation. Dyads were excluded if the mother or infant had a morbidity that would affect postpartum care or infant sleeping or feeding or if the mother stayed in the hospital for more than 7 days postpartum.

At study entry, there were 160 mother-infant dyads. Dyads were assessed at birth, and infant ages 3, 4, 8, 16, and 36 weeks and 1 year. Following recruitment, mother-infant dyads were randomized to a control group or a Soothe/Sleep intervention, where mothers were trained on alternate soothing methods, including avoiding feeding as a first response to fussiness; the Soothe/Sleep intervention was administered at the 3-week home visit. There was also a feeding intervention that addressed the introduction of solid foods that was administered to some families after infants were 4 months old. This intervention is not the focus of this study, but models were adjusted.
for a dummy-coded variable representing participation in this second intervention where applicable. There were no significant demographic differences between study groups although there were trend-level differences between the intervention and control group on infant birth weight and sex (Table 1). There was also selective attrition, such that mothers who did not complete the study ($n=50$) were more likely to be single and non-White and tended to be younger and less educated than the mothers who participated through the entire year (Paul et al., 2011); while this is problematic in some ways, a homogeneous sample can be advantageous when parsing out the mediating mechanisms of a pilot intervention. Of the 110 dyads who completed the study, 51% of the infants were female, and the mean birth weight for gestational age percentile was 45.0 (SD = 28.7). The majority of mothers were non-Hispanic White, college-educated, and earned more than $50,000 per year (Table 1). Primary analyses will be conducted on the 110 mother-infant dyads who completed the one-year study. The Human Subjects Protection Office of the Penn State College of Medicine approved all procedures, and mothers provided consent for the dyad's participation before the study began.

**Intervention**

The key messages of the Soothe/Sleep intervention were administered at a nurse home visit at infant age 3 weeks. Dyads randomized to the Soothe/Sleep intervention received a commercially-available video (Karp, 2006) that instructed parents on alternate responses to infant distress aside from feeding; these alternatives included swaddling, side or stomach position, shushing, swinging, and (non-nutritive) sucking. Parents were also taught to emphasize day/night differences and to establish
nighttime routines that included initially responding to night wakings with alternatives to feeding to help the infant to self-soothe and return to sleep, as done by Pinilla and Birch (1993). Both intervention and control participants were given a standard infant parenting book, and nurses answered questions about general infant care.

**Measures**

**Infant behavioral states: Sleep, awake/calm, fussing/crying, and feeding.** Mothers completed 24-hour diary cards during four days at infant ages 3, 4, 8, and 16 weeks, indicating every 15 minutes whether their infant was sleeping, awake and calm, fussing/crying, or feeding. At each time point, the total minutes spent in each state was summed for each day, and the mean of these daily totals was calculated to obtain the average daily time spent in each behavior during that week. Daily totals were considered missing if there were less than 720 minutes of diary data for the day, and average daily variables were considered missing if there were less than three days of diary data for that week. The resulting composite variables of interest include: total sleep (average hours of sleep during a 24-hour period), nighttime sleep (average hours of nightly sleep from 9pm to 6am), total awake/calm time (average minutes spent awake and calm during a 24-hour period), nighttime awake/calm (average minutes of nightly awake/calm time from 9pm to 6am), total fussing/crying (average minutes spent fussing and crying during a 24-hour period), nighttime fussing/crying (average nightly minutes of fussing and crying from 9pm to 6am), total feeding time (average minutes spent feeding during a 24-hour period), and nighttime feeding (average nightly minutes spent feeding from 9pm to 6am). Operationalization of these behavioral states was based on past research and current hypotheses.
**Weight status.** Infant weight and length were measured by research nurses at a home visit following the introduction of solids (~6 months) and at a visit to a University-affiliated General Clinical Research Center at age one year. Infant weights were measured using a calibrated Medela BabyChecker™ scale (McHenry, IL), and lengths were measured using the Seca 210 Mobile Measuring Mat for Infants and Toddlers (Hanover, MD). Birth weight was obtained from infants' medical charts and was included as a covariate in analyses involving the intervention group due to the trend where the intervention group weighed more than the control group at birth (Table 1). Heights and weights were obtained from participants' medical charts at their age 2 and 3 well-child visits, so weight status at age 2 and 3 is also available for some participants ($n=72$ with age 3 data; $n=70$ with both age 2 and 3 data). BMI-for-age z-scores were calculated from the World Health Organization growth charts, which are the current recommended growth standards for children younger than two years (Grummer-Strawn, Reinold, Krebs, & Centers for Disease Control and Prevention, 2010).

**Temperament.** Average daily minutes of fussing/crying were calculated from diary data at age 3 weeks; this variable was used as an index of initial infant temperament/negativity.

**Feeding mode.** Mothers used a visual scale to report the percent of milk feeds that were breast milk at age 16 weeks. Mothers who indicated that at least 80 percent of milk feeds were breast milk were categorized as breast-feeders, and mothers who indicated that less than 80 percent of milk feeds were breast milk were categorized as formula-feeders as done previously (Li, Fein, & Grummer-Strawn, 2008).
Maternal self-efficacy. Mothers completed the Parenting Sense of Competence Scale (PSOC; Gibaud-Wallston & Wandersman, 1978) at infant age 3 weeks. Parental self-efficacy is one of two subscales created from this measure and is defined as a parent’s belief that he or she can adequately care for his or her child and can handle upcoming situations involving the child (Johnston & Mash, 1989).

Demographic variables. Demographic variables were assessed at infant birth by reviewing medical records and by maternal interview; these included total annual family income before taxes, infant birth weight, and maternal pre-pregnancy height and weight, which were used to calculate maternal pre-pregnancy BMI.

Statistical Analyses

Analyses corresponding to the first two aims of this study were conducted using SAS Version 9.2 (Cary, NC). To model change in the four behaviors assessed by the daily diaries and in weight status, repeated measures analysis of variance was conducted in Proc Mixed; this analysis accommodates the repeated measures nature of the data, allows for consideration of the unequal spacing between time points, and uses all available data as opposed to list-wise deletion. First, a repeated measures ANOVA was conducted in Proc GLM in order to obtain polynomial coefficients in the M matrix. These values were used to calculate linear, quadratic, and cubic trends that correspond to the actual spacing of the diary data points (3, 4, 8, and 16 weeks); this was also done when analyzing change in BMI-for-age z-scores (except the time points were 3 and 36 weeks, and 1, 2, and 3 years). These calculated polynomial trends were used as predictors when conducting the repeated measures ANOVAs in Proc Mixed, testing patterns of change in the four infant behavioral states and in weight status. Before
arriving at final models, different error structures were tested for each analysis, and the models were compared using the AIC and BIC. For changes in total and nighttime sleeping, awake/calm time, and fussing/crying, a first-order autoregressive error structure best accommodated the interdependence in the data and was used in the mixed models investigating these behavioral states. For changes in feeding time and in weight status, an unstructured error structure fit the data best. After determining the appropriate error structure for each model, the repeated measures ANOVAs were used to test linear, quadratic, and cubic trends overall, as well as the interactions of linear and quadratic trends in behavioral states with hypothesized moderators. Models were re-tested adjusting for dummy coded variables representing participation in the Soothe/Sleep and Introduction to Solids interventions given the stratified nature of the dataset. The final descriptive analysis was to calculate inter-correlations among the four infant behavioral states, both total durations (in an average 24-hour period over the four diary days) and at nighttime (9pm to 6am).

Analyses corresponding to the third aim of this study were conducted using the student edition of LISREL (Lincolnwood, IL). The initial hypothesis was that the intervention caused increases in total sleep, which led to decreases in feeding time and lower subsequent weight status (Figure 1). The modification indices provided in the output were used to repeatedly alter the initial hypothesized model until arriving at a final model that was satisfactory, both conceptually and statistically. This process was repeated for a two-group model to determine whether the pattern of free and fixed pathways was similar or different when investigating breastfeeding and formula-feeding dyads separately. A detailed description of the steps taken to arrive at the final models
appears in the appendix. All models were tested with birth weight and infant sex as covariates because these were the variables that approached significance when testing for initial differences between the intervention and control group.

Results

All variables of interest approximated a normal distribution. The means and standard deviations of the behavioral variables of interest are presented in Table 2, and overall weight status change is presented in Figure 2. The significant moderators of changes in infant behavioral states are summarized in Table 3, and significant moderators are also depicted in the figures illustrating developmental changes in the individual behaviors (Figures 3-10).

Aim 1: Changes in the Average Durations of Four Behavioral States during Early Infancy

Changes in total daily sleep and nighttime sleep. There was a significant linear decrease in total sleep across the four diary time points ($F(284,1)=49.88$, $p<.0001$); neither the quadratic nor cubic time trends were significant ($p=.82$ and $p=.75$ respectively). Initial infant temperament moderated linear decreases in total sleep ($F(263,1)=7.29$, $p<.01$); adding this variable to the analyses also revealed a quadratic trend that was moderated by initial infant temperament ($F(263,1)=7.13$, $p<.01$; Figure 3). Less negative infants showed a more drastic decrease in total sleep over time, particularly from 4 to 8 weeks. More negative infants showed a less drastic decrease in total sleep, characterized by nearly stable sleep from 3 to 8 weeks. Maternal pre-pregnancy BMI moderated quadratic change in sleep ($F(251,1)=5.27$, $p<.05$), but when
these two significant moderators were entered into the same model, the interaction with pre-pregnancy BMI became non-significant.

There was a significant linear increase \((F(280,1)=177.46, p<.0001)\) and quadratic trend \((F(280,1)=4.81, p<.05)\) in nighttime sleep. The initial increase in nighttime sleep from 3 to 4 weeks was steeper than the subsequent increase. Initial infant temperament moderated linear changes in nighttime sleep \((F(260,1)=7.09, p<.01; \text{Figure 4})\), such that infants higher on initial negativity showed greater increases in nighttime sleep from 3 to 16 weeks on average. More negative infants started out sleeping less \((\beta=-.30, p<.01)\), but by 16 weeks, initial negativity no longer predicted nighttime sleep \((p=.73)\). Maternal pre-pregnancy BMI also moderated linear changes in nighttime sleep \((F(266,1)=5.69, p<.05)\), but when these two significant moderators were entered into the same model, the interaction with pre-pregnancy BMI became non-significant.

**Changes in total daily awake/calm time and nighttime awake/calm time.**

There was a significant linear increase \((F(284, 1)=180.29, p<.0001)\) and a significant quadratic trend \((F(284, 1)=17.53, p<.0001)\) in total awake/calm time, such that the increase from 3 to 8 weeks was steeper than the increase from 8 to 16 weeks. Infant feeding mode moderated the linear change in awake/calm time \((F(278,1)=8.05, p<.01)\): breastfed infants showed a greater increase in awake/calm time, starting out with less awake/calm time at 3 weeks \((t(90)=-2.78, p<.01)\), compared to formula-fed infants, and ending up with similar amounts of total awake/calm time at 16 weeks \((p=.57; \text{Figure 5})\).
There was a significant linear decrease \( F(280, 1)=20.01, p<.0001 \) and a significant quadratic trend \( F(280, 1)=4.44, p<.05 \) in nighttime awake/calm from 3 to 16 weeks. Maternal pre-pregnancy BMI moderated the quadratic trend \( F(266,1)=5.08, p<.05 \): for infants of heavier mothers, there was an increase in nighttime awake/calm from 3 to 8 weeks, followed by a decrease; infants of lighter mothers only showed a linear decrease over time (Figure 6).

**Changes in total daily fussing/crying and nighttime fussing/crying.** Overall, there was a significant linear decrease in total daily fussing/crying from 3 to 16 weeks \( F(284,1)=61.45, p<.0001 \); quadratic and cubic trends were non-significant \( p=.11 \) and \( p=.81 \) respectively. Initial infant temperament moderated linear \( F(263,1)=72.01, p<.0001 \) change in total fussing/crying and revealed a quadratic trend that interacted with temperament \( F(263,1)=18.08, p<.0001 \); Figure 7). Infants lower on initial negativity showed less of a developmental decrease in fussing/crying from 3 to 16 weeks, as well as a slight increase from 3 to 4 weeks and less fussing/crying across time points.

There was a significant linear decrease \( F(280,1)=35.11, p<.0001 \), as well as a significant quadratic trend \( F(280,1)=5.96, p<.05 \) in nighttime fussing/crying. Initial infant temperament moderated the linear \( F(260,1)=28.16, p<.0001 \) and quadratic change \( F(260,1)=7.25, p<.01 \) in nighttime fussing/crying, and maternal pre-pregnancy BMI moderated the linear change in nighttime fussing/crying \( F(266,1)=6.90, p<.01 \); Figure 8). Infants who were lower on negativity at 3 weeks showed less of a decrease in nighttime fussing/crying from 3 to 16 weeks and were lower on fussing/crying on average. Infants of heavier mothers showed less of a decrease in nighttime
fussing/crying, reaching higher levels of nighttime fussing/crying at age 16 weeks compared to infants of lighter mothers (β=.32, p<.01). When the significant interaction terms with initial negativity and maternal pre-pregnancy BMI were entered into the same model, all of the interactions remained significant predictors of nighttime fussing/crying.

**Changes in total daily feed time and nighttime feeding.** There was a significant linear decrease ($F(284,1)=237.02, p<.0001$) and a significant quadratic trend ($F(284,1)=16.61, p<.0001$) in total feeding time from 3 to 16 weeks. Infant feeding mode moderated quadratic change in total feed time ($F(101,1)=6.17, p<.05$). Breastfed infants’ change in feeding time was characterized by a sharp decrease from 3 to 8 weeks, followed by a less steep decrease from 8 to 16 weeks. Formula-fed infants showed a less steep, more linear decrease over time (Figure 9).

For changes in nighttime feeding, the linear ($F(106,1)=248.18, p<.0001$), quadratic ($F(106,1)=21.57, p<.0001$), and cubic trends ($F(106,1)=5.06, p<.05$) were all significant; decreases in nighttime feeding were steeper from 3 to 4 weeks and from 8 to 16 weeks than in the middle of the time period although these differences were subtle, and the overall linear decrease was the trend with the largest magnitude (Figure 10). None of the hypothesized moderators interacted with change in nighttime feeding.

In sum, total daily sleep decreased, nighttime sleep increased, total and nighttime awake/calm time increased, total and nighttime fussing/crying decreased, and total and nighttime feed time decreased on average in early infancy. All of the changes in infant behavioral states from 3 to 16 weeks were characterized by an overall linear trend, and some were qualified by additional quadratic or cubic trends, which described...
changes in the pace of the overall linear increase or decrease. In all cases, the linear trend was stronger than other polynomials, and in all cases, the significant trends were consistent when adjusting for participation in the Soothe/Sleep and Introduction to Solids interventions. Three variables emerged as moderators of changes in infant behavioral states (Table 3): 1) initial infant temperament moderated changes in total and nighttime sleep and total and nighttime fussing/crying; 2) maternal pre-pregnancy BMI moderated changes in total and nighttime sleep, nighttime awake/calm, and nighttime fussing/crying; and 3) infant feeding mode moderated changes in total awake/calm time and total feed time.

**Aim 2: Cross-sectional Relationships among Infant Behavioral States**

Correlation matrices were generated to explore cross-sectional relationships between the four behavioral states at ages 3, 4, 8, and 16 weeks during the 24-hour day and at night (Table 4). At 3 weeks, infant behavioral states were interrelated, such that more daily sleep was associated with fewer daily feeds, less time fussing/crying, and less time awake and calm. More time spent feeding was associated with less time in a non-feeding, awake/calm state but was not associated with fussiness, and time spent fussing/crying was not associated with time spent awake and calm. Relationships at night were similar: more nighttime sleep was associated with fewer nighttime feeds, less nighttime fussing/crying, and less time awake and calm at night. Nighttime feeds were not associated with nighttime fussing/crying or awake/calm, and nighttime fussing/crying was not associated with nighttime awake/calm. Cross-sectional relationships between the behavioral states were similar at 4 weeks, with some changes in the patterns at 8 and 16 weeks, such that the negative relationships between total sleep and the other
behavioral states diminished, and a positive relationship between fussing/crying and feeding emerged.

Taken together, the descriptive analyses were consistent enough with our hypothesized model of sleeping, feeding, and weight change (e.g., early inverse relationships between total sleep and feed time, linear change over time), so we proceeded with testing the a priori hypothesized model (Figure 1).

Aim 3: Testing and Refining a Model of Intervention Effects on Weight Status through Infant Behavioral States.

Testing total daily sleep and feed time as mediators of intervention effects on weight status. The hypothesized model was tested for all dyads who completed the study (n=110), with a series of adjustments based on an a priori analysis plan and the output from each subsequent model (see Appendix for more details). These changes led to the final model for the total sample (\(\chi^2(75)=115.42, p = .0019, \text{RMR}=.082, \text{CFI}=.93, \text{NNFI}=.91\); Figure 11), which demonstrated an acceptable fit as indicated by two of the less conservative fit indices (CFI, NNFI), and which was a marked improvement over the original hypothesized model (\(\Delta\chi^2(1)=17.12, p<.001\)). However, the beta parameter representing the (small) effect of the intervention on infant sleep was opposite the hypothesized direction; based on this finding and based on previous evidence that the Soothe/Sleep intervention may have worked differently in breast-feeding and formula-feeding dyads (Paul et al., 2011), this model was explored in a two-group framework to more precisely characterize intervention effects on behavioral state.
Two-group model investigating the role of infant feeding mode. The initial input for the two-group model was the final aggregate model (Figure 11), and the patterns of free and fixed parameters, but not the values of the parameters, were initially constrained to be equal across groups. The chi-squared value for this initial model was 220.05 (df=150, \( p = .00017 \)), demonstrating that the model was significantly different from the observed relationships in the data, and the less conservative fit indices demonstrated a need for improvement as well (standardized RMR = .11, CFI = .89, and NNFI = .86). A similar series of steps were followed to modify the two-group model (Appendix), and the final, two-group model (Figures 12-13) had an acceptable fit according to the chi-square (\( \chi^2(158)=192.01, p = .043 \)) and NNFI (.94) and an excellent fit according to the CFI (.95). Results supported the idea that a two-group model was appropriate for these data. In the final model, hypothesized intervention effects through effects on sleeping and subsequent changes in feeding were upheld in breastfeeding dyads but not in formula-feeding dyads. Although the intervention did not increase total sleep in formula-fed infants, the final, modified model for this group revealed an inverse association between sleep time at 3 weeks and subsequent weight status.

Testing additional covariates based on descriptive analyses in the previous aims. After testing and modifying the hypothesized model, the final step was to test the impact of adding two additional covariates highlighted in the previous aims as potentially important: maternal pre-pregnancy BMI and initial negativity. However, when introducing these two additional variables as covariates predicting sleep at 3 weeks, they did not improve model fit and thus were not added to the final, two-group model.
Discussion

On average, infants showed increases in relative weight status, as assessed by the World Health Organization, over the course of the study. In the total sample of study completers, infants went from a weight status around the 50th percentile at birth to a weight status around the 60th percentile at age 1 year. Change over time in infant behavioral states was characterized largely by linear trends, with some of the behavioral states demonstrating additional quadratic or cubic trends. Overall, total sleep, nighttime awake/calm time, total and nighttime fussing/crying, and total and nighttime feeding time decreased, and nighttime sleep and total awake/calm time increased over the first four months of infancy. Three variables emerged as moderators of these average changes over time, highlighting that individual differences had an impact on overall trends: 1) initial infant temperament moderated changes in total and nighttime sleep and total and nighttime fussing/crying; 2) maternal pre-pregnancy BMI moderated changes in total and nighttime sleep, nighttime awake/calm, and nighttime fussing/crying; and 3) infant feeding mode moderated changes in total awake/calm time and total feed time. Individual differences were greatest at the earliest time points. Cross-sectional analysis of relationships between behavioral states at each time point revealed that sleeping and feeding were negatively related at 3 weeks, and these inverse relations strengthened over time for the nighttime period but not 24-hour periods. Time spent fussing was unrelated to feeding early on; these variables were significantly positively related by 16 weeks. Finally, the hypothesis that changes in infant sleep and feeding time contributed to Soothe/Sleep intervention effects on weight status was supported although some modifications to the original model were needed, and the hypothesis was only supported in breastfeeding dyads.
Some of the current findings on mean levels and changes in infant behavioral states differed from the literature. For example, a study of 21 infants using mother-reported diaries found that infants slept for an average of 15.5 hours, cried for 2 to 2.5 hours, and were fed for about 3 hours per day at age 8 weeks (Walker & Menaham, 1994). In a sample of 493 infants, average total sleep at age 4 weeks was ~14 hours (Iglowstein et al., 2003). In our study, infants slept for ~14 hours at 4 weeks, and slept for ~13 hours, cried for ~1 hour, and were fed for ~3 hours at 8 weeks, demonstrating more consistency with the larger, more recent study in terms of sleep, and demonstrating discrepancies from the literature in terms of fussing/crying. The linear increase in total sleep and decrease in nighttime sleep were consistent with trends in the literature (e.g., Iglowstein et al., 2003). However, the “normal crying curve” demonstrated across studies involves a quadratic trend, with a peak around 6-8 weeks (Barr, 1990); compared to the literature, our data were characterized by lower levels of fussing/crying and an overall linear decrease with no quadratic peak. One potential explanation for differences is that our sample was comprised exclusively of first-born infants whose mothers intended to breastfeed; this is not a representative sample of U.S. infants and differs from samples used in past studies on normative infant behavior. The literature would lead us to expect more fussing/crying in breastfed infants, but perhaps their first-born status allowed their mothers to focus attention exclusively on them, resulting in more contingent care-giving and less time fussing/crying.

Another possibility is that fussing/crying peaked before 8 weeks, and that we missed this peak by not collecting data between 4 and 8 weeks. Lastly, it is also possible that something about our nurse home visits (in both the control and
intervention groups as there was no significant moderation by study group) modified infant fussing/crying to attenuate this peak. In their intervention studies on supplemental infant carrying, Hunziker and Barr (1986) have shown that it is possible to modify the "normal crying curve," so that the two-month peak in infant crying does not occur. They conclude that this curve is only normal with respect to infants’ usual contexts, and that it is amenable to intervention. Although it is not possible to parse these explanations here, it is important to keep these possibilities in mind when interpreting the results and considering their implications.

In this sample, changes in infant behavioral states were modified by initial negativity, maternal pre-pregnancy BMI, and infant feeding mode. Because of the homogeneity in this sample and the inclusion criteria, variability among these moderators is likely lower in this study than in other populations, and it may be for this reason that other hypothesized moderators like family income did not reach significance. However, variability was great enough to highlight initial negativity, maternal pre-pregnancy BMI, and infant feeding mode as important individual differences characteristics with regards to infant behavioral states. Infants who were higher on initial negativity showed less drastic decreases in total sleep, greater increases in nighttime sleep, and more of a decrease in total and nighttime fussing and crying; it is possible that their behaviors became more adaptive over time because their caregivers were developing adaptive strategies or because they were regressing to the mean after starting at a disadvantage. There also may have been infants with colic in this group, obscuring the meaning of initial negativity and decreasing in their fussiness over time as colic ceased.
Mothers with greater pre-pregnancy BMIs had infants who showed a greater
decrease in total sleep and a less drastic increase in nighttime sleep, as well as a
smaller decrease in nighttime fussing/crying and higher levels of nighttime
fussing/crying at 16 weeks. Most of these significant interactions were relevant at night,
raising the question of whether heavier mothers may engage in different care-taking
practices at night, potentially creating contingencies that work against increasing
nighttime sleep and decreasing nighttime fussing/crying. Feeding mode moderated
changes in awake/calm and feeding time, such that breastfed infants showed greater
increases in total awake/calm time and greater decreases in total feed time compared to
formula-fed infants. It is important to remember that these results cannot be
generalized to all breastfed and formula-fed dyads as all of these mothers initially
intended to breastfeed; here, formula-feeding dyads are those who were no longer
predominantly breastfeeding at 16 weeks. Taken together, these results highlight that
there are inter-individual differences in developmental changes in infant behavioral
states, even within a fairly homogeneous sample. These inter-individual differences
could have implications for the establishment of contingencies, future behaviors, and
weight status.

Correlations between the behavioral states confirmed that the four infant
behavioral states are not independent, and that the pattern of relationships between
them changes over time. Most relevant to the aims of this chapter, total daily sleep and
feeding time appear to be tightly coupled during the first month of life and less so during
the subsequent months; this is consistent with findings in the literature that nighttime
sleep undergoes substantial consolidation in the first few months of life (Henderson,
France, & Blampied, 2011). The developmental change in the relationship between total sleeping and feeding time is accompanied by the emergence of a significant positive correlation between nighttime fussing and feeding at 8 weeks and a positive correlation between total fussing and feeding at 16 weeks. Sleeping and feeding continue to be strongly, inversely coupled at night through 16 weeks. Overall, there are developmental changes in the patterns of relationships between these behavioral states, and the substantial change in some of the patterns around 8 weeks is consistent with the idea that reorganization occurs at this point, such as that around the consolidation of nighttime sleep.

The descriptive analyses from the first two aims were generally consistent with the theory that led to the a priori hypothesized model of intervention effects through total sleeping and feeding. Thus, this model was tested and modified, leading to the conclusion that the Soothe/Sleep intervention affected weight status through changes in sleeping and feeding in breastfed dyads. Intervention effects on behavioral state and weight status differed by feeding mode, as indicated by Paul et al. (2011). This study differs from that of Paul et al. (2011) in its focus on the Soothe/Sleep intervention exclusively, as well as its inclusion of behavioral states and weight status at multiple time points in the same model, to further pinpoint behavioral mediators of intervention effects. The initial hypothesized model required modification in both groups to achieve an acceptable fit. In the final model for breastfeeding dyads, the Soothe/Sleep intervention leads to increased sleep at 4 weeks, which predicts decreased feeding time at 4 weeks, which is stable until 8 weeks and predicts a lower weight status at 1 year. The model demonstrates stability in both sleep and feeding at consecutive time points,
and an inverse relationship between feeding time at 4 and 16 weeks. The latter, unpredicted finding may highlight that 16 weeks is a period where feeding behavior is in flux as solid foods are being introduced.

In formula-feeding dyads, the picture is more chaotic, and more modifications to the original hypothesized model were needed to fit the data. In this group, feeding time seemed to drive sleep, rather than vice versa, and the intervention predicted less, not more, total sleep. Greater feeding time at 16 weeks also predicted a lower weight status; again, counterintuitive findings at 16 weeks could be linked to the manner in which solid foods are introduced. In this model, there was a significant, negative relationship between total sleep at 3 weeks and BMI-for-age z-scores at 1 year, which is consistent with the literature. Perhaps sleep is an especially important protective factor in formula-fed infants, who are at heightened risk for obesity, but this intervention designed for breastfeeding dyads did not increase sleep in formula-feeders.

The seemingly counterintuitive findings in this model suggest that these behavioral mechanisms may function differently in formula-fed infants, compared to breastfed infants. For example, a longer feeding time may be a good thing in formula feeders, because it may reflect more child-centered, sensitive feeding practices, which may be less likely in the case of a bottle feed. Behavioral differences between breastfeeding and bottle-feeding sessions is one possible reason why breastfed infants tend to be protected against early obesity (Bartok & Ventura, 2009). The finding that feeding was driving sleep is also consistent with the idea that bottle-feeding may be a more parent-centered mode of feeding compared to breastfeeding: parents deciding when to formula feed could affect the child’s sleep patterns, while in breastfeeding
dyads parents may learn to trust the child’s natural cycles and cues, letting the child’s behavior patterns drive feeding time. Another major factor that could be confounding the formula-feeding group is that these individuals had all stopped predominantly breastfeeding by 16 weeks, but there was variability in terms of the time point at which they stopped. Thus, with regards to the 4 week and 8 week time points specifically, it is likely that the sample was partially composed of breastfeeders and partially composed of formula-feeders, adding variability to the model. Because of this, and because this intervention was designed for breastfeeding dyads, it makes sense to interpret and focus on that model.

The Soothe/Sleep intervention was part of a larger pilot study in which dyads were assigned to zero, one, or two interventions, the other intervention focusing on the introduction to solids. Paul et al. (2011) reported that protective effects on weight status at 1 year were greatest in infants assigned to both interventions. Taken together, the results of these studies suggest that the Soothe/Sleep intervention affected early sleeping and feeding behaviors in breastfeeding dyads, but that there were additional benefits of behaviorally-focused interventions continuing throughout the first year. It is also possible that the Soothe/Sleep intervention could have affected other infant behavioral states (like fussing/crying), and that this could have contributed to overall effects. Such a cumulative process is likely as the strength of the specific path from behavioral state to weight status in the final structural equation model is small as is the Soothe/Sleep intervention effect on sleep in breastfed infants. Nevertheless, the confirmation of intervention effects on behaviors and on subsequent weight status is
important as even within this low-risk sample, infants’ patterns of weight gain translated into upward percentile crossing on average.

A number of strengths and limitations should be considered when interpreting the results reported herein. Strengths include randomized assignment to conditions, intervention content and format informed by the literature (i.e. nurse home visits have been effective in other interventions; e.g., Olds, 2006), repeated assessments of predictors and outcomes, and weights and lengths measured by research nurses. Additionally, the analyses used herein accommodated the repeated assessments and the unequal spacing between them. Limitations include that the nurses were not blind to group assignment, and these nurses also conducted evaluation (e.g., administering questionnaires over the phone, weighing the infants). The nurses did not administer the infant behavior diaries, which were the main measure used in this chapter. These diaries have their own limitations (i.e. there are often absolute differences between diary-measured durations versus objectively-measured durations of behaviors), but diaries have been validated in a relative sense (e.g., Barr et al., 1988) and offer a more comprehensive assessment of infant behavioral states than questionnaire items. Another limitation is the loss of 50 mother-infant dyads over time, resulting in selective attrition, which added to the homogeneity of the sample. The sample of this pilot intervention was homogeneous in terms of race/ethnicity, socioeconomic status, parity, and intended feeding mode. On one hand, this homogeneity is a strength, in that it decreases variability (i.e. noise) in the data and allows a precise characterization of intervention effects in this initial sample. This idea is supported by the more clear-cut intervention effects in dyads who continued to predominantly breastfed to 16 weeks.
However, this homogeneity is also a limitation as our results cannot be generalized beyond White, well-educated, primiparous mothers who intend to breastfeed and their infants. It is likely that culturally-sensitive intervention messages that accommodate the heterogeneity in infant feeding decisions will be needed to result in a more broadly efficacious intervention. The nature of such messages and their effects on behavioral states can be informed by the literature (e.g., literature on different feeding practices by socioeconomic status, different infant behavioral states by feeding mode). If appropriate messages are administered effectively, it is likely that intervention effects could be even greater in ethnic minority, lower-income, and formula-feeding dyads who are at greater risk for rapid infant weight gain and subsequent overweight.

The current findings and previous findings from this sample (Paul et al., 2011) confirm that infancy is a promising developmental period for intervention, particularly the early months. The rapid transitions and behavioral instability of the first few months highlight this period as amenable to change. These transitions were highlighted both in the exploration of changes in behavioral states from 3 to 16 weeks, as well as in the changes in the patterns of correlations among behaviors from 3 to 16 weeks. This study confirmed the hypothesized effects on sleeping and feeding only in breastfeeding dyads although the relationship between early sleep and weight status in formula-feeders suggests that this factor is also important in formula-feeding dyads. Clearly, behavioral states differ by feeding mode, but the current results do not preclude intervention with formula-feeders at a behavioral level. Instead, the current results may be explained by the fact that the intervention was targeted at breastfeeding dyads: thus, our “formula feeders” were really a group of mothers who stopped breastfeeding,
potentially due to some kind of problem. They are not representative of formula feeders more broadly, and it is likely that they perceived aspects of the current intervention as no longer applicable to them once they switched feeding modes.

Future interventions should target both breastfeeding and formula-feeding dyads as the literature suggests that the establishment of early sleep is a problem in many breastfeeding dyads, and that formula-feeding dyads are at heightened risk for childhood obesity. Formula-feeding dyads are also more likely to be lower income and of racial/ethnic minority status; these demographic groups are also at increased risk for childhood obesity and are important to target in subsequent interventions. Testing of interventions where those intending to formula feed are recruited and where messages are not phrased explicitly for breastfeeding dyads will elucidate the extent to which interventions can be universal or will need to be adapted.
References


### Tables

**Table 1**  
*Descriptive Statistics for Dyads Completing Study and by Control vs. Intervention Groups*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall (n=110)</th>
<th>Control (n=59)</th>
<th>Intervention (n=51)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Maternal education</td>
<td>65% completed college</td>
<td>61%</td>
<td>69%</td>
</tr>
<tr>
<td>2. Family income</td>
<td>72% earned &gt;$50,000</td>
<td>69%</td>
<td>74%</td>
</tr>
<tr>
<td>3. Maternal age</td>
<td>M = 27.1 (4.7)</td>
<td>27.5 (4.9)</td>
<td>26.6 (4.6)</td>
</tr>
<tr>
<td>4. Infant sex</td>
<td>51% female</td>
<td>59% #</td>
<td>41% #</td>
</tr>
<tr>
<td>5. Infant race</td>
<td>90% White</td>
<td>86.4%</td>
<td>94.1%</td>
</tr>
<tr>
<td>6. Maternal BMI*</td>
<td>M = 25.1 (5.7)</td>
<td>24.4 (4.8)</td>
<td>25.8 (6.6)</td>
</tr>
<tr>
<td>7. Infant birth weight (kg)</td>
<td>M = 3.33 (.48)</td>
<td>3.25 (.47) #</td>
<td>3.43 (.47) #</td>
</tr>
<tr>
<td>8. Predominant feeding mode at age 16 weeks</td>
<td>51% breast</td>
<td>47.4%</td>
<td>55%</td>
</tr>
<tr>
<td>9. BMI z-scores at 1 yr</td>
<td>.30 (.93)</td>
<td>.40 (.81)</td>
<td>.19 (1.05)</td>
</tr>
</tbody>
</table>

*pre-pregnancy, #significantly different at p<.10*
Table 2

*Descriptive Statistics for Behavioral Variables of Interest at Ages 3 and 16 Weeks*

<table>
<thead>
<tr>
<th>Variable</th>
<th>At 3 weeks</th>
<th>At 16 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total (24-hour):</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Sleep minutes</td>
<td>829.8 (112.1)</td>
<td>739.7 (87.0)</td>
</tr>
<tr>
<td>2. Awake/calm minutes</td>
<td>247.5 (92.0)</td>
<td>402.0 (110.7)</td>
</tr>
<tr>
<td>3. Fussing/crying minutes</td>
<td>87.4 (59.9)</td>
<td>44.5 (38.5)</td>
</tr>
<tr>
<td>4. Feeding minutes</td>
<td>244.5 (92.8)</td>
<td>132.8 (58.4)</td>
</tr>
<tr>
<td><strong>Nighttime:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Sleep minutes</td>
<td>377.0 (57.0)</td>
<td>468.7 (50.0)</td>
</tr>
<tr>
<td>6. Awake/calm minutes</td>
<td>40.3 (32.2)</td>
<td>25.4 (29.2)</td>
</tr>
<tr>
<td>7. Fussing/crying minutes</td>
<td>29.1 (26.7)</td>
<td>11.3 (16.1)</td>
</tr>
<tr>
<td>8. Feeding minutes</td>
<td>82.8 (34.7)</td>
<td>30.2 (22.7)</td>
</tr>
</tbody>
</table>

*Sleep is shown in minutes here, so that all behavioral states can be viewed on the same scale. Sleep is depicted in the more easily interpretable scale of hours in the figures that follow.*
Table 3

*Significant Moderators of Changes in Infant Behavioral States*

<table>
<thead>
<tr>
<th></th>
<th>Infant temperament</th>
<th>Feeding mode</th>
<th>Maternal BMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total sleep</td>
<td>**</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Nighttime sleep</td>
<td>**</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Total awake/calm</td>
<td></td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>Nighttime awake/calm</td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Total fuss/crying</td>
<td>****</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nighttime fuss/crying</td>
<td>****</td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>Total feeding time</td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Nighttime feeding</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p<.05, ** p<.01, *** p<.001, **** p<.0001

These models were adjusted for infant birth weight and sex, and results were consistent when also adjusting for participation in the Soothe/Sleep and Introduction to Solids interventions.

A box shaded in black indicates a significant moderator of the linear trend in the behavioral state listed at the left. A box shaded in gray indicates a significant moderator of a higher-order trend only. The nature of these effects is shown in Figures 3-10. Neither the Soothe/Sleep intervention, maternal self-efficacy at 3 weeks, nor family income moderated change in any of the infant behavioral states. Moderation of changes in sleep by maternal BMI became non-significant when entered in the same model with infant temperament, so this variable is not depicted in the figures.
Table 4

Cross-sectional Inter-correlations between Infant Behavioral States

<table>
<thead>
<tr>
<th>At age (weeks):</th>
<th>3</th>
<th>4</th>
<th>8</th>
<th>16</th>
</tr>
</thead>
</table>

Correlation between:

**Total (24-hour)**

1. Sleep and awake/calm  - .31**  - .43****  - .25*  .08
2. Sleep and fussing  - .43****  - .28**  - .14  .01
3. Sleep and feeding  - .37***  - .35****  - .13  .21*
4. Awake/calm and fussing  - .14  - .15  - .28**  - .21*
5. Awake/calm and feeding  - .44****  - .40****  - .39****  - .13
6. Fussing and feeding  .04  - .01  .15  .33***

**Nighttime (9pm to 6am)**

7. Sleep and awake/calm  - .31**  - .54****  - .61****  - .66****
8. Sleep and fussing  - .52****  - .56****  - .54****  - .57****
9. Sleep and feeding  - .48****  - .62****  - .61****  - .55****
10. Awake/calm and fussing  - .01  .20  .04  .11
11. Awake/calm and feeding  - .20  - .06  - .06  .07
12. Fussing and feeding  .08  .07  .31*  .30**

*p<.05, **p<.01, ***p<.001, ****p<.0001
The initial hypothesis was that the Soothe/Sleep intervention affected infant weight status via increases in early total sleep, which affected energy balance via decreases in total feeding time.

Figure 1. Initial hypothesized model of Soothe/Sleep intervention effects.
Figure 2. Overall changes in weight status in this sample. On average, infants were born at a normal weight status and significantly increased in relative weight status over time (mean BMI-for-age z-score at 3 years = .60). When investigating changes in BMI-for-age z-scores in the infants with follow-up data at ages 2 and 3, repeated measures ANOVA results revealed that the overarching trend was a linear increase ($F(109,1)=43.83, p<.0001$), with significant higher-order trends as well (quadratic: $F(109,1)=9.03, p<.01$; quartic: $F(109,1)=15.67, p<.001$).
Figure 3. Changes in total sleep from 3 to 16 weeks. Initial infant temperament moderated linear ($F(263,1)=7.29, p<.01$) and quadratic ($F(263,1)=7.13, p<.01$) changes in total sleep. From the beginning, more negative infants (labeled as “high fuss” above) were sleeping less than their less negative (“low fuss”) counterparts ($\beta=-.44, p<.001$). Infants higher on initial negativity also slept less across all time points ($F(90,1)=14.93, p<.001$). A median split was used to depict initial temperament groups in this figure, but this moderator was analyzed as a continuous variable.
Figure 4. Changes in nightly sleep from 3 to 16 weeks. Initial infant temperament moderated linear changes in nighttime sleep ($F(260,1)=7.09$, $p<.01$), such that infants higher on initial negativity showed greater increases in nighttime sleep from 3 to 16 weeks on average. More negative infants started out sleeping less ($\beta=-.30$, $p<.01$), but by 16 weeks, initial negativity no longer predicted nighttime sleep ($p=.73$). A median split was used to depict initial temperament groups in this figure, but this moderator was analyzed as a continuous variable.
Figure 5. Changes in daily awake/calm time from 3 to 16 weeks. Infant feeding mode moderated the linear change in total awake/calm time ($F(278,1)=8.05, p<.01$): breastfed infants showed a greater increase in awake/calm time, starting out with less awake/calm time at 3 weeks ($t(90)=-2.78, p<.01$), compared to formula-fed infants, and ending up with similar amounts of awake/calm time at 16 weeks ($p=.57$). Breastfeeders were defined as those infants still predominantly breastfeeding at 16 weeks (>80% of milk feeds were breast milk; $n=55$); all others were categorized as formula-feeders ($n=53$).
Figure 6. Changes in nighttime awake/calm from 3 to 16 weeks. For nighttime awake/calm, maternal pre-pregnancy BMI moderated the quadratic trend ($F(266,1)=5.08$, $p<.05$). For infants of heavier mothers, there was an increase in nighttime awake/calm from 3 to 8 weeks, followed by a decrease; infants of mothers with lower BMIs showed a linear decrease over time. A median split was used to depict maternal BMI groups in this figure, but this moderator was analyzed as a continuous variable.
Figure 7. Change in total fussing/crying from 3 to 16 weeks. Initial infant temperament moderated linear ($F(263,1)= 72.01, p<.0001$) and quadratic change ($F(263,1)= 18.08, p<.0001$) in total fussing/crying. Infants lower on initial negativity (labeled as “low fuss”) showed less of a developmental decrease in fussing/crying from 3 to 16 weeks, as well as a slight increase, as opposed to a decrease, from 3 to 4 weeks and less fussing/crying across time points. A median split was used to depict initial negativity groups in this figure, but this moderator was analyzed as a continuous variable.
Figure 8. Change in nighttime fussing/crying from 3 to 16 weeks. Initial infant temperament moderated the linear ($F(260,1)=28.16, p<.0001$) and quadratic change ($F(260,1)=7.25, p<.01$) in nighttime fussing/crying, and maternal pre-pregnancy BMI moderated the linear change in nighttime fussing/crying ($F(266,1)=6.90, p<.01$). Infants who were lower on negativity/fussiness at 3 weeks showed less of a decrease in nighttime fussing/crying from 3 to 16 weeks and were lower on fussing/crying on average. Infants of mothers with a greater pre-pregnancy BMI showed less of a decrease in nighttime fussing/crying, ending with higher levels of nighttime fussing/crying than infants of mothers with lower BMIs ($\beta=.32, p<.01$). When the significant interaction terms with initial temperament and maternal pre-pregnancy BMI were entered into the same model, all of the interactions remained significant predictors of nighttime fussing/crying, so four mutually exclusive groups incorporating individuals’ standing on each of these factors are shown here. Median splits on maternal pre-pregnancy BMI and initial temperament were used to create the four groups, but analyses were conducted on continuous predictors.
Figure 9. Changes in total feeding time from 3 to 16 weeks. Infant feeding mode moderated quadratic change in total feed time ($F(101,1)=6.17$, $p<.05$). Breastfed infants’ change in feed time was characterized by a sharp decrease from 3 to 8 weeks, followed by a less steep decrease from 8 to 16 weeks. Formula-fed infants showed a less steep, more linear decrease over time. In this sample, breastfeeders were defined as those infants still predominantly breastfeeding at 16 weeks ($\geq80\%$ of milk feeds were breast milk; $n=55$); all others were categorized as formula-feeders ($n=53$).
Figure 10. Changes in nighttime feeding from 3 to 16 weeks. Time spent feeding at night decreased over time, with significant linear ($F(106,1)=248.18$, $p<.0001$), quadratic ($F(106,1)=21.57$, $p<.0001$), and cubic trends ($F(106,1)=5.06$, $p<.05$). Decreases in nighttime feeding were steeper from 3 to 4 weeks and from 8 to 16 weeks than they were in the middle of the time period although these differences were subtle, and the overall linear decrease was the trend with the largest magnitude. None of the hypothesized moderators interacted with changes in nighttime feeding.
Figure 11. Final aggregate model of intervention effects on behavioral changes and weight status. The initial model was modified substantially to arrive at this acceptable, aggregate model (see Appendix). This model depicts stability in sleeping and feeding behaviors, but the (small) intervention effects on sleep and weight status were opposite the hypothesized direction. Given this finding and the initial evidence that Soothe/Sleep effects on behaviors were different by feeding mode (Paul et al., 2011), a two-group model was tested to further refine the pathways separately for breastfeeding and formula-feeding dyads.
Figure 12. Final model of Soothe/Sleep intervention effects on sleep and weight status in breastfeeding dyads. In general, this model is consistent with the hypothesis that the Soothe/Sleep intervention affected weight by increasing total sleep duration and thus decreasing time spent feeding. Some modifications were made, as detailed in the appendix, so that the precise pathways depicted differ slightly from the original model. Specifically, the Soothe/Sleep intervention increases sleep at 4 weeks, which in turn decreases feeding time at 4 and 8 weeks; feeding time at 8 weeks positively predicts weight status at 1 year (but not at ~6 months). There was significant tracking in sleeping and feeding time over the four-month period although there was also an unanticipated negative relationship between feeding time at 4 and 16 weeks. This could reflect developmental reorganization as solid foods are introduced. Total sleeping and feeding time were only inter-related at the early time points, consistent with the simple correlations from Aim 2. Beta parameters connecting the Soothe/Sleep intervention to sleep duration and connecting feeding time to weight status were modest, highlighting that other behavioral changes may have also contributed to intervention effects on weight status.
Figure 13. Final model of Soothe/Sleep intervention effects on sleep and weight status in formula-feeding dyads. The original hypothesized model did not hold up for formula-feeding dyads. Two of the main pathways, that from the Soothe/Sleep intervention to sleeping and that from feeding to weight status, had beta parameters that were opposite the hypothesized direction of effects (and thus attenuating the effects in the overall aggregate model). It is unclear whether these processes work differently in formula-feeding dyads or if this intervention was not effective here because its messages were tailored toward dyads intending to breastfeed. There was an inverse relationship between sleep duration at 3 weeks and weight status at 1 year.
Chapter 3

Infants’ Transitions out of a Fussing/Crying State are Modifiable and have Implications for Weight Status

Development can be conceptualized as macro-level and micro-level change (or change in macrot ime and microtime; Ram & Gerstorf, 2009). Research questions involving macrot ime in infancy include the nature of changes in time spent sleeping, fussing/crying, and feeding over the first four months of life. A complete picture of development should also consider patterns of infant behavioral states on a microtime scale. Infants experience sequences of sleeping, awake/calm time, fussing/crying, and feeding over the course of minutes, hours, and days. Patterns of changes across these smaller time scales, including the transitions between the behavioral states and the formation of contingencies and daily behavior patterns, are subject to inter-individual differences and may predict growth and obesity risk. In this study, individual differences in and modifiability of transitions were characterized, as well as relationships between these transitions and demographic factors and weight outcomes. In particular, behavioral transitions from fussing/crying to feeding were a focus; the diary data used in this study presented opportunities to operationalize the use of food to soothe infant distress over four days at different time points during infancy.

Behavioral transitions in microtime may be particularly important in the case of two of the infant factors that are related to weight status: short sleep (e.g., Tikotzky, De Marcas, Har-Toov, Dollberg, Bar-Haim, & Sadeh, 2010) and infant fussing/crying (e.g., Darlington & Wright, 2006). One way that sleeping and fussing/crying may lead to too much weight gain is if caregivers transition infants into a feeding state following each
waking or each fuss/cry episode. If these transitions occur repeatedly, it follows that infants who sleep less and fuss/cry more would experience more feeds, and thus may have a positive energy balance that promotes excess weight gain during this sensitive period of early life. They may also learn associations between feeding and emotional states rather than feeding in response to a hunger state (e.g., they may learn that crying leads to feeding). A small body of literature suggests that being fed in response to fussiness is problematic in terms of obesity risk (e.g., Stifter, Birch, Anzman-Frasca, & Voegtline, under review); in the current study, a pilot intervention that focused on infant soothing and sleeping was designed in part to prevent this contingency from forming (Paul, Savage, Anzman, Beiler, Marini, Stokes, et al., 2011). Measuring the average duration of fussing/crying and of feeding at different time points over a macrotime scale would not show whether the intervention was effective at reducing feeding in response to fussiness. Time series analyses allow an investigation of whether the intervention predicts microtime transitions, such as the likelihood of transitioning from fussing/crying to feeding, or alternatively, to an awake/calm state, in early infancy.

Infancy has been highlighted as a promising period to intervene to prevent childhood obesity, both because this is a time period before the onset of obesity in many individuals and because it is a period characterized by substantial, rapid change and instability. Such early periods of transitions are prime opportunities for intervention because they involve changes in one or more levels of analysis, resulting in a greater likelihood of systemic reorganization and new behavioral phenotypes (Gottlieb, 2002; van Geert, 2003). Parents and caregivers also have a high degree of control over their infant’s experiences and environments, and infant behavioral states, such as sleep and
fussing/crying, have been linked to weight outcomes (e.g., Darlington & Wright, 2006; Tikotzky et al., 2010). These factors highlight behavioral interventions during infancy as a promising path to affect infant behavioral states and weight trajectories, and they highlight parents as logical targets of these interventions. However, intervening to prevent childhood obesity at the behavioral level during infancy is an emergent approach (Hesketh & Campbell, 2010), and building an evidence base and interventions that are efficacious and effective necessitates a thorough understanding of infant behaviors on multiple time scales.

Time series analyses are a broad category of analysis that allow an exploration of patterns and processes at the group or individual level. A time series refers to a group of observations made sequentially in time. Time series may be continuous or discrete; these terms refer to the timing of measurements (Chatfield, 2004). In most applications, the time series are discrete, with measurements taken at specific time points, rather than continuously. The type of time series analysis described herein is Markov modeling (Baum & Petrie, 1966; Visser, Raijmakers, & Molenaar, 2002), which is an expansion upon state-space models. Markov modeling is akin to modeling a first-order autoregressive process, capturing stochastic (or random) sequences where the next categorical observation depends only upon the previous time point. Markov Models can accommodate non-linear patterns and sudden, qualitative transitions and are well equipped to characterize development as it unfolds dynamically and probabilistically in real-time (Gottlieb, 2007). These models can also be useful when not much is known about a process, such as the pattern of change or approximate time point at which large shifts are expected. Markov models may be conducted at the
individual or group level, and the output yields probabilities of starting in each category or state, as well as the probabilities of transitioning between states for the individual or group (Rovine, Sinclair, & Stifter, 2010; Visser, Raijmakers, & Molenaar, 2007).

In the case of hidden Markov models, a probabilistic element is added as behaviors can co-occur, and variables from multivariate time series combine to create latent states. In hidden Markov models, individuals have a certain probability of being in a given latent state; this is different from a Markov model with one variable or mutually exclusive variables, where each state is determined or observed (Visser et al., 2007). Stifter and colleagues provide an example where the same dataset is analyzed using correlations and hidden Markov models (Jahromi, Putnam & Stifter, 2004; Rovine et al., 2010; Stifter, Rovine, & Sinclair, under review). Jahromi et al. (2004) videotaped 2- and 6-month-old infants after inoculations to investigate maternal soothing strategies and infant responses. Initially, the data were analyzed using correlations and contingency analyses, the latter of which can test the relationship between one variable and the lag of another behavior (in this case one change in infant distress level and one type of maternal soothing behavior). The authors reported that holding and rocking with vocalization was an appropriate combination of strategies, and that the most effective strategies are relative to crying intensity. They also noted that, for different soothing strategies, there may be variations in the amount of time that is required before the behavior becomes regulatory, but their mode of data analysis did not allow an in-depth investigation of this point.

In subsequent hidden Markov modeling of analyses, Stifter, Rovine, et al. (under review) were able to analyze the entire process simultaneously, including all infant
distress levels and all maternal soothing behaviors across time. This analysis yielded some of the same information (holding and rocking with vocalization was an effective state at high levels of infant distress) but also highlighted more nuanced aspects of trajectories and differences between individuals. For example, a higher number of latent states fit the 6-month data, suggesting that dyadic soothing interactions became more organized with development. Here, 2-month-olds were compared to 6-month-olds. The authors also examined whether the soothing interactions differed by infant temperament and found that more irritable infants did show differences suggesting that they are more difficult to soothe; keeping these infants calm prior to the inoculation seemed to be an effective strategy to attenuate these differences. Rovine et al. (2010) discuss another approach to investigating individual differences in this sample, by examining posterior probabilities to see how well the aggregate Markov model represents individual dyads. Another alternative is to generate a unique model for each dyad.

The four behavioral states in the current study were coded as mutually exclusive behaviors, so there were no latent states in the models. Thus, the methodology was Markov modeling, as opposed to hidden Markov models. Data from infant behavior diaries were used to characterize transitions between behavioral states at different time points during infancy. Thus, changes in microtime (the behavioral transitions) and macrot ime (looking at different time points during infancy; e.g., age 3 weeks versus 16 weeks) were investigated. Microtime and macrot ime need not be studied independently as it is the piecing together of these two approaches that provides a comprehensive understanding of development, and it is possible that the dynamics of microtime can
change with macrotime (Ram & Gerstorf, 2009). For example, frequent behavioral transitions may be more likely early in infancy given the substantial reorganization that occurs during this period of instability and rapid change. Characterizing this instability may highlight ideal periods for intervention before stable states are achieved (van Geert, 2003). Measurement burst designs are one way to study microtime in the context of macrotime; these designs involve collecting time series data at multiple time points over the course of a longitudinal study.

In addition to characterizing change over multiple time scales, a comprehensive picture of development in a given domain necessitates a consideration of individual differences. Many statistical models are designed to assess mean levels and trends, but there have been demonstrations that this type of information is not always representative of even one individual (e.g., Lebo & Nesselroade, 1978). Only ergodic processes permit generalization from the group to the individual. A process is ergodic when means, variances, and covariances are invariant in time (Molenaar, 2004; Molenaar, Huizenga, & Nesselroade, 2000). Given the nature of a developmental process, it follows that most conclusions drawn from traditional variable-specific methods cannot be generalized to individuals. The variability between individuals at a given time point is not representative of the variability within an individual across time. Thus, a traditional longitudinal analysis will often yield results that differ from one or more person-specific, time series analyses of intra-individual variability (Molenaar et al., 2000). Lebo and Nesselroade (1978) demonstrated the non-ergodicity of personality by conducting dynamic factor analyses such that individual datasets represented multiple occasions within a person, rather than multiple persons at one occasion. None of the
individuals’ factor patterns mapped onto the Big Five personality factors, suggesting that an in-depth study of individuals is necessary to verify the generalizability of existing measurement models. Such in-depth studies can provide insight about individual differences in developmental processes, considering persons as unique individual dynamic systems, where levels of analysis interact to propel the individual along his or her own unique probabilistic trajectory (Molenaar et al., 2000). This information can then be aggregated into subgroups if desired.

In this study, Markov models were conducted at the group level, generating transition matrices that described transitions between infant behaviors in the overall sample at different time points; in addition, person-specific Markov models were also conducted (one model for each infant, generating the probabilities that each infant transitioned from one behavioral state to another). These individual transition matrices elucidated whether the corresponding information from the group-level analysis was an accurate portrayal of most (or any) individuals; person-specific models also allow an exploration of relationships between transition probabilities and covariates (e.g., who is most likely to transition from fussing to feeding?). While person-specific models were utilized in this study, no individual’s time series of data was interpreted on its own. Such a purely person-specific analysis is useful in some areas, such as clinical psychology and medical decision making (e.g., Sonnenberg & Beck, 1993). Individual differences were characterized using a middle-of-the-road approach here, analyzing relationships between the individual transition probabilities and the Soothe/Sleep intervention, weight outcomes, and other variables, allowing generalization beyond the current sample of individuals.
Individual differences factors hypothesized to predict the likelihood of transitioning from fussing to feeding included maternal pre-pregnancy BMI, family income, maternal education, and the infant’s initial temperament. These factors were chosen based on literature linking demographic, parent, and infant factors and feeding practices. Although the literature on the use of food to soothe infant distress is sparse, there is a larger body of literature on factors associated with healthy versus unhealthy feeding practices. Higher maternal education has been associated with positive infant feeding practices (Hendricks, Briefel, Novak, & Ziegler, 2006). Mothers with a higher pre-pregnancy BMI are more likely to endorse unhealthy feeding practices like restriction (Rifas-Shiman, Sherry, Scanlon, Birch, Gillman, & Taveras, 2011).

Introducing complementary foods before age 4 months is another maladaptive practice and was more likely in the case of fussier infants (Wasser, Bentley, Borja, Goldman, Thompson, Slining, et al., 2011). The sparse literature on the use of food to soothe infant distress has indicated that this practice may be more likely in families with fussier infants (Bentley, Gavin, Black, & Teti, 1999; Stifer, Birch, et al., under review), as well as in lower-income families (Baughcum, Burklow, Deeks, Powers, & Whitaker, 1998). Conducting person-specific Markov models allowed an investigation of relationships between such factors and the likelihood of transitioning the infant from fussing to feeding. The effects of the Soothe/Sleep intervention on transition probabilities was also examined, with a hypothesis that teaching mothers alternate soothing strategies besides feeding increased the likelihood of transitioning from fussing to awake/calm and decreased the likelihood of transitioning directly from fussing to feeding. A growing
body of literature suggests that indiscriminate feeding in response to infant fussing and crying has negative implications for subsequent weight status.

There is evidence that the demographic groups at higher risk of using food to soothe infant distress also show greater childhood obesity risk (e.g., Baughcum et al., 1998). Additional indirect evidence of a link between the use of food to soothe and weight comes from studies investigating temperament and weight status. Greater infant negativity is predictive of greater weight status or weight gain (e.g., Darlington & Wright, 2006; Slining, Adair, Goldman, Borja, & Bentley, M., 2009), and researchers have hypothesized that this could be explained by a greater use of food to soothe in these families where infants are likely to elicit more parental soothing behaviors (Carey, 1985; Darlington & Wright, 2006). There is a paucity of direct evidence to this point. In a recent cross-sectional pilot study aiming to operationalize the use of food to soothe and to explore its relationship with temperament and weight status, Stifter, Birch, et al. (under review) found that greater child negativity and higher mother-reported use of food to soothe acted in concert to predict a greater child weight status. One aim of the current study is to add to this body of literature using the fuss to feed transitions to gain insight into the use of food to soothe.

Markov models provide a characterization of infants’ transitions between behaviors in microtime, and conducting these models across multiple time points and individuals depicts macrot ime changes in microtime transitions and individual differences in these transitions and changes. However, these models do not incorporate information on the frequency or duration of each behavioral state. For
example, if an infant is transitioned to feeding every time he or she is fussy, but if he or she is rarely fussy, this may not have the same implications for contingency formation and outcomes compared to an infant who has a high number of fuss episodes. In addition, it is likely to mean something quite different if an infant only fusses for a short time before being fed, versus an infant who transitions from fussing to feeding after a long period of fussing. In the latter case, the parent may be trying a number of other soothing techniques before resorting to feeding, and the decision to ultimately feed may mean that the infant is hungry. Such a scenario would be encouraged in the Soothe/Sleep intervention, which focuses on alternate soothing techniques. To address such issues, the transition probabilities from the Markov models were supplemented with a consideration of the average time infants spent in a given state (e.g., fussing/crying) before transitioning to another state (e.g., feeding). It was decided to label this variable that captures the latency to feeding as “the use of food to soothe,” with the assumption that infants fed shortly after beginning to fuss are being fed to soothe their distress while infants who fuss for longer may be experiencing other soothing attempts. This food to soothe variable will be analyzed along with the probability of transitioning from fussing to feeding. The latter tells us whether an infant is likely to be transitioned directly from fussing/crying to feeding, and the former tells us how long parents wait before doing so.

Specific Aims

The overall aim of this study was to use an alternative methodological approach that retained the time series nature of diary data in order to investigate transitions between the infant behaviors of interest. The specific aims were:
1. To investigate patterns of transitions over time in the total sample using group-level Markov models
   - It was hypothesized that, compared to infants at 3 weeks, infants at 16 weeks would transition out of sleep less often and would be less likely to transition from fussing to feeding.

2. To investigate individual differences in transitions at 3 and 16 weeks using person-specific Markov models
   - There would be sizable individual differences in transition probabilities, particularly transitions at 3 weeks, when behavioral patterns were becoming established, and particularly transitions around fussing and crying
   - It was hypothesized that transitioning from fussing/crying to feeding would be more likely in dyads with greater maternal BMIs, lower maternal education, lower family income levels, and greater initial infant negativity
   - It was hypothesized that infants in the Soothe/Sleep intervention would be more likely to transition from fussing/crying to awake/calm and less likely to transition from fussing/crying to feeding at 16 weeks, compared to control group infants
   - It was hypothesized that the transition from fussing/crying to feeding would be positively related to subsequent weight status

3. To investigate the average minutes spent in a fussy state before transitioning out
   - It was hypothesized that the Soothe/Sleep intervention would lead to a longer latency from fussing/crying to feeding (operationally defined as a
lower use of food to soothe) at 16 weeks, and that these effects would be strongest in breastfeeding dyads.

- It was hypothesized that the implications of transitioning from fussing/crying to feeding would differ depending on the amount of time spent fussing/crying before making that transition: A greater use of food to soothe (i.e., a shorter latency from fussing/crying to feeding) would predict a greater weight status.

**Methods**

**Participants**

Mothers were recruited from the maternity ward of an academic medical center in Pennsylvania and were eligible if they intended to breastfeed and to follow-up with a University-affiliated primary care provider and if they were primiparous and English-speaking. Other inclusion criteria were singleton birth and at least 34 weeks’ gestation. Dyads were excluded if the mother or infant had a morbidity that would affect postpartum care or infant sleeping or feeding or if the mother stayed in the hospital for more than 7 days postpartum.

At study entry, there were 160 mother-infant dyads. Dyads were assessed at birth, and at infant ages 3, 16, and 36 weeks and 1 year. Following recruitment, mother-infant dyads were randomized to a control group or a Soothe/Sleep intervention, where mothers were trained on alternate soothing methods, including avoiding feeding as a first response to fussiness; the Soothe/Sleep intervention was administered at the 3-week home visit. There was also a feeding intervention that addressed the
introduction of solid foods that was administered to some families after infants were 4 months old. This Introduction to Solids intervention is not the focus of this study, but models will be adjusted for participation in this second intervention where applicable.

There were no significant demographic differences between study groups although there were trend-level differences between the intervention and control group on infant birth weight and sex (Table 1). There was also selective attrition, such that mothers who did not complete the study (n=50) were more likely to be single and non-White and tended to be younger and less educated than the mothers who participated throughout the entire year (Paul et al., 2011). Of the 110 dyads who completed the study, 51% of the infants were female, and the mean birth weight for gestational age percentile was 45.0 (SD = 28.7). The majority of mothers were non-Hispanic White, college-educated, and earned more than $50,000 per year (Table 1). Primary analyses will be conducted on the 110 mother-infant dyads who completed the one-year study. The Human Subjects Protection Office of the Penn State College of Medicine approved all study procedures, and mothers provided consent before the study began.

**Intervention**

The key messages of the Soothe/Sleep intervention were administered at a nurse home visit at infant age 3 weeks. Dyads randomized to the Soothe/Sleep intervention received a commercially-available video (Karp, 2006) that instructed parents on alternate responses to infant distress aside from feeding; these alternatives including swaddling, side or stomach position, shushing, swinging, and (non-nutritive) sucking. Parents were also taught to emphasize day/night differences and to respond to night wakings with alternate soothing and care-taking responses, as done by Pinilla
and Birch (1993). Both intervention and control participants were given a standard infant parenting book, and nurses answered questions about general infant care.

**Measures**

**Behavioral states.** For this study, the diary data were not aggregated but were kept in the univariate format, where there is a status (sleeping, awake/calm, fussing/crying, or feeding) indicated every 15 minutes for each participant for each of the four days at ages 3 and 16 weeks. These time series data were used in the Markov Models. The diary data were also used to quantify infants’ total daily minutes fussing/crying at age 3 weeks (an index of initial temperament) and average minutes spent fussing/crying before transitioning to feeding at 3 and 16 weeks. This latter variable was referred to as the use of food to soothe, where a shorter amount of time fussing/crying before feeding indicates a higher use of food to soothe.

**Feeding mode.** Mothers used a visual scale to report the percent of milk feeds that were breast milk at age 16 weeks. Mothers who indicated that at least 80 percent of milk feeds were breast milk were categorized as breast-feeders, and mothers who indicated that less than 80 percent of milk feeds were breast milk were categorized as formula-feeders as has been done previously (Li, Fein, & Grummer-Strawn, 2008).

**Demographic variables.** Demographic variables were assessed at infant birth by reviewing medical records and by maternal interview; these included total annual family income before taxes, mothers’ highest completed year of education, infant birth weight, and maternal pre-pregnancy height and weight, which were used to calculate maternal pre-pregnancy BMI.
Weight status. Infant weights and lengths were measured by research nurses at a home visit following the introduction of solids (~6 months) and at a visit to a University-affiliated General Clinical Research Center at age 1 year. Infant weights were measured using a calibrated Medela BabyChecker™ scale (McHenry, IL), and lengths were measured using the Seca 210 Mobile Measuring Mat for Infants and Toddlers (Hanover, MD). Age- and sex-specific BMI z-scores were calculated using the World Health Organization (WHO) growth charts, which are now the recommended growth standards for children younger than age 2 (Grummer-Strawn, Reinold, Krebs, & Centers for Disease Control & Prevention, 2010). Birth weight was obtained from infants’ medical charts and was included as a covariate in analyses involving the intervention group due to a trend where the intervention group weighed more than the control group at birth (Table 1).

Statistical Analyses

R Version 2.9.2 (Vienna, Austria) was used to conduct the Markov models. To prepare the dataset for these models, all diary data that were previously removed due to a priori restrictions (i.e., deleting days with less than 720 minutes and weeks with less than 3 days) were added back in, and place holders were added to mark any legitimately missing data. The Markov model requires a dataset with all possible data points included, but it is acceptable if some of these data points are coded as missing data. The datasets were altered, so that there was a dummy coded variable for each mutually exclusive state. Then, R was used to analyze the data, first generating output for the total n=110 sample at 3 and 16 weeks, yielding two transition matrices showing the overall probability of transitioning from any one of the four states to any other state.
at that time point. T-tests were conducted to compare transition probabilities of interest to see whether infants were less likely to transition from sleep to feeding and from sleep to fussing over time (e.g., at 3 weeks versus 16 weeks) and to see whether infants were less likely to transition from fussing to feeding and more likely to transition from fussing to awake and calm over time.

The second aim of this study was to investigate individual differences in transitions. Person-specific Markov models were conducted on each infant’s time series of diary data at 3 and 16 weeks, yielding 220 individual transition matrices. Transitions of interest were plotted to characterize variability across individuals and over time. Ordinary least squares regression was used to test whether infants from lower-income families, with less-educated mothers, with mothers with a greater pre-pregnancy BMI, or with a more negative initial temperament were more likely to have a high probability of transitioning from fussing to feeding. Ordinary least squares regression was also used to test whether the Soothe/Sleep intervention decreased the likelihood of transitioning from fussing to feeding and increased the likelihood of transitioning from fussing to awake and calm at 16 weeks and whether this effect was moderated by feeding mode. Analyses involving the Soothe/Sleep intervention group were adjusted for infant birth weight, sex, and participation in the Introduction to Solids intervention. Lastly, BMI-for-age z-scores at ~6 months and 1 year were regressed on individuals’ probabilities of transitioning from fussing to feeding to test whether this transition could be a potential risk factor for a subsequent high weight status.

When investigating the output from the individual Markov models, we excluded individuals who did not provide enough diary data to meet a priori cut-offs, so that our
sample would be consistent with other papers investigating the diary data from this project. Thus, this sample differs slightly from that of the group-level analysis in Aim 1, with three fewer infants at 3 weeks and one fewer infant at 16 weeks, but t-tests on transition probabilities of interest at 3 versus 16 weeks showed that overall results were consistent between the two samples.

The third aim of the study was to supplement information about transitions between behaviors with information about duration. SAS Version 9.2 (Cary, NC) was used to calculate the average time spent fussing before transitioning to feeding at ages 3 and 16 weeks. Briefly, arrays were used to aggregate all of an individual’s transitions from fussing to feeding, and the amount of time spent in the fussing state before transitioning to feeding was averaged across these instances. Again, a shorter amount of time spent fussing before transitioning to feeding (i.e. a shorter latency) was considered to indicate a higher use of food to soothe. We regressed food to soothe at 16 weeks on Soothe/Sleep intervention, feeding mode, and the interaction between the two to investigate whether the Soothe/Sleep intervention affected the amount of time spent before deciding to feed the infant, and whether these effects varied by feeding mode. Additionally, weight status was regressed on the use of food to soothe to test whether a high use of food to soothe is a plausible risk factor for a subsequent higher weight status, and food to soothe was added to the models investigating relations between transitions out of fussing and weight status to test whether these relationships could be explained by the use of food to soothe.
Results

All variables of interest approximated a normal distribution. There were some outliers on the transition probabilities, and in these cases, results were investigated with and without the individuals as reported below. The means and standard deviations of variables of interest are presented in Table 1, with the exception of the transition probabilities, which are presented in subsequent tables as described below.

Aim 1: To Investigate Patterns of Transitions Over Time in the Total Sample

Tables 2 and 3 show the transition probabilities for the total sample at infant ages 3 and 16 weeks, from the group-level Markov models. Transitions of interest were compared at 3 versus 16 weeks to investigate mean-level developmental change. Infants were more likely to transition from sleeping to feeding at 3 weeks than they were at 16 weeks ($t(1)=10.66, p<.05$). Infants were also more likely to transition from sleeping to fussing at 3 weeks than they were at 16 weeks ($t(1)=6.68, p<.05$). There were no changes over time in the overall sample in the likelihood of transitioning from fussing to feeding or from fussing to awake/calm.

Aim 2: To Investigate Individual Differences in Transitions at 3 and 16 Weeks, Specifically in Transitions around Fussing/Crying

The mean values across individuals’ transitions of interest (from the person-specific Markov models) were consistent with the results from the group-level models (Table 4). However, the variability in these transitions illustrates that additional information is gained from these individual models, particularly with regards to transitions around fussing/crying, which showed the greatest inter-individual differences (see standard deviations in Table 4 and Figures 1-4). For example, the standard
deviation of the transition from fussing to feeding was .17 at both 3 and 16 weeks (Range = 0 - .991) while the standard deviation of the transition from sleeping to feeding was .01 (Range = 0 - .059).

**Variability in transition probabilities across time.** We investigated whether variability in the following transition probabilities of interest decreased over time, from 3 to 16 weeks: fussing to awake/calm, fussing to feeding, sleeping to fussing, and sleeping to feeding. Instead, we found that there was substantial inter-individual variability in transitions at both time points, particularly in transitions out of fussing/crying (Table 4; Figures 1-4), justifying the decision to focus on transitions out of fussing/crying in the subsequent hypothesis tests.

**Who is more likely to be transitioned from fussiness to feeding?** It was hypothesized that transitioning from fussing/crying to feeding would be more likely in dyads with lower family income levels, lower maternal education, greater maternal pre-pregnancy BMIs, and greater initial infant negativity. Of these variables, transitioning from fussing/crying to feeding at 3 weeks was only associated with maternal pre-pregnancy BMI. Heavier mothers were more likely to feed their infants in response to a fussing/crying episode at age 3 weeks (β=.26, p=.01). This remained the case when entering all of these predictors in the same regression model predicting fussing to feeding at 3 weeks and when adding covariates (intervention group, birth weight, sex, feeding mode) although the model became non-significant in the latter case, due to using additional degrees of freedom without explaining much additional variance. (Neither birth weight, sex, nor feeding mode was associated with the transition from fussing to feeding.) None of the maternal, infant, or demographic
variables that were investigated predicted the likelihood of transitioning from fussiness to feeding at 16 weeks, but the likelihood of transitioning from fussing to feeding at 3 weeks did ($\beta=.43, p<.001$), demonstrating some relative stability in this transition.

**Does the Soothe/Sleep intervention affect transitions out of fussing?**

Intervention group dyads did not differ from control group dyads on the likelihood of transitioning from fussing to feeding at 3 ($p=.99$) or 16 weeks ($p=.58$); results were consistent when adjusting for infant birth weight, sex, and participation in the Introduction to Solids intervention and when investigating feeding mode as a moderator of intervention effects. However, the Soothe/Sleep intervention did increase the likelihood of transitioning from fussing/crying to awake and calm at 16 weeks; this effect was significant when adjusting for infant birth weight, sex, and participation in the Introduction to Solids intervention ($F(97,4)=5.84, p<.05$) and when removing an outlier on the transition from fussing to awake/calm (for this individual, the transition probability was .996). This effect was not moderated by infant feeding mode. The intervention and control groups did not differ on the transition from fussing/crying to awake/calm at 3 weeks ($p=.16$). Because the absence of effects on fussing/crying to feeding transitions was unexpected, a post-hoc test was added to test whether the intervention decreased transitions from fussing to sleeping at 16 weeks, but it did not.

**Do transitions out of fussing/crying predict subsequent weight status?** The probability of transitioning from fussing to feeding at 3 weeks was positively associated with BMI-for-age z-scores at ~6 months ($\beta=.23, p<.05$), and this relationship remained significant when adjusting for maternal pre-pregnancy BMI and infant birth weight. This finding was accompanied by inverse relationships between the probability of staying in a
fussing state and weight status at ~6 months (β=-.34, p<.001) and at 1 year (β=-.21, 
p<.05). Transitioning from fussing to feeding at 3 weeks was not related to weight 
status at 1 year, and neither transitioning from fussing to feeding at 16 weeks nor any of 
the transitions out of sleep was related to weight status at either time point.

**Aim 3: To Investigate the Use of Food to Soothe in Fussing/Crying to Feeding **

**Transitions**

Neither the Soothe/Sleep intervention, nor feeding mode or the interaction 
between the two affected the use of food to soothe (i.e. the average minutes spent in 
the fussing state before transitioning to feeding) at 16 weeks. The time spent fussing 
before transitioning to feeding at 3 weeks was inversely related to weight status at ~6 
months (β=-.24, p<.05) and 1 year (β=-.21, p<.05). Also, when adjusting for the use of 
food to soothe, the relationship between the fussing to feeding transition at 3 weeks and 
weight status at ~6 months was no longer significant (p=.13), and when adjusting for the 
use of food to soothe, the relationship between the fussing to awake/calm transition at 3 
weeks and weight status at ~6 months became significant (β=-.22, p<.05). Thus, once 
the use of food to soothe was held constant, transitioning an infant from fussing/crying 
to feeding was no longer risky with regards to weight status, and transitioning from 
fussing/crying to awake/calm was associated with a lower weight status.

**Discussion**

This study highlighted developmental changes and individual differences in 
infants' behavioral transitions in microtime. Transitions out of sleep became less likely 
over time, demonstrating increased stability in this behavioral state. Transitions out of
fussing/crying did not change from age 3 weeks to 16 weeks; there were substantial individual differences in transitions out of fussing/crying at both time points. Further investigation highlighted transitions out of fussing/crying as malleable and predictive of weight outcomes: the likelihood of transitioning from fussing/crying to feeding was positively associated with maternal pre-pregnancy BMI and with infant weight status. The pilot intervention focused on infant soothing and sleeping increased the likelihood of transitioning from fussing/crying to awake/calm at 16 weeks. The use of food to soothe, operationalized as the average time spent fussing/crying before feeding, was not related to demographic variables or to the intervention, but the inclusion of this variable changed the relationships between transitions out of fussing and weight status, suggesting that the use of food to soothe has implications for weight status. Taken together, the results demonstrate the utility of investigating individuals’ behavioral transitions in the context of a behavioral childhood obesity intervention.

When taking an average of the transition probabilities, the aggregated results from the person-specific Markov models were consistent with the results from the models that were conducted on the total sample. However, the standard deviations and scatter plots of the transitions around fussing/crying illustrate that substantial information is lost when characterizing these transitions by the mean values. By generating transition probabilities for each individual, this variability became apparent. Transitions around fussing/crying were highlighted as a behavioral state that was in flux at both 3 and 16 weeks. The substantial individual differences in transition probabilities around the fussing/crying state, as well as the relationships between these transitions and maternal characteristics, the intervention, and weight outcomes, highlight these
transitions as promising targets of preventive interventions and highlight Markov modeling as an appropriate method to test intervention effects on behavioral transitions.

The pattern of results was largely consistent with the hypotheses although not all hypotheses were confirmed. Family income, maternal education, maternal pre-pregnancy BMI, and initial infant negativity were all hypothesized as factors that would be associated with the likelihood of transitioning from fussing/crying to feeding, based on literature suggesting that these factors predict healthy versus unhealthy parental feeding practices. However, only maternal pre-pregnancy BMI predicted a greater likelihood of mothers feeding in response to their infant's fussing. One explanation for this finding could be the homogeneity of our sample. Mothers were well-educated, and families had a high income; thus, perhaps the variability on these factors was not high enough to predict differences in this specific feeding practice. Similarly, the inability to confirm predicted relationships between infant feeding mode and these transitions could be explained by the lack of variability in feeding mode (or in these other demographic variables, which are linked to feeding mode; e.g., Grossman, Fitzsimmons, Larsen-Alexander, Sachs, & Harter, 1990). Although the sample was made up of breastfeeders and formula-feeders, all of these mothers initially breastfed, and it is also possible that feeding behaviors could be more like breastfeeding mothers than formula-feeding mothers even after switching to formula.

Consistent with the argument that a lack of variability in many demographic factors precluded relationships between those factors and fuss to feed transitions, there was substantial variability in maternal pre-pregnancy BMI (see Figure 5), the one factor that did significantly predict the transition from fussing to feeding at 3 weeks. It was
surprising that initial infant temperament (operationalized as average daily minutes of fussing/crying at 3 weeks) did not predict transitions from fussing to feeding based on a small body of work suggesting that feeding in response to distress is more likely in fussier infants. When operationalizing feeding to soothe as the duration of time spent fussing before transitioning to feeding, however, there was a positive relationship between feeding to soothe and initial infant temperament at 3 weeks. This finding supports the idea that transitioning from fussing to feeding has a different meaning, depending on the time spent fussing/crying before food is offered, as do the findings that the relationships between transitions out of fussing and weight status changed when incorporating the use of food to soothe into the models.

The finding that the time spent in a fussing state before transitioning to feeding was inversely related to weight status at 6 months and 1 year suggests that mothers may have tried other soothing techniques before feeding in dyads with a longer latency to feed. In those cases, infants may have actually been hungry if the other soothing techniques were not working. It is not possible to tell whether infants were hungry or fussing/crying for other reasons from the diary data, but findings support the idea that the time spent fussing/crying before feeding is a reasonable index of the use of food to soothe. The fact that relationships between transitions out of fussing at 3 weeks and subsequent weight status changed when incorporating the use of food to soothe into the model also highlights the utility of this variable. Fussing to feeding was no longer positively related to weight status when the use of food to soothe was added to the model, but the use of food to soothe was, suggesting that it is the use of food to soothe that has implications for weight status. A longer latency to feeding (low food to soothe)
was associated with a lower weight status at 6 months and 1 year, consistent with the emerging literature on food to soothe and obesity risk (e.g., Stifter, Birch, et al., under review). On the other hand, the transition from fussing to awake and calm became negatively related to weight status when the use of food to soothe was added to the model, suggesting that variability in the use of food to soothe was suppressing the protective impact of adaptive soothing techniques, an unexpected finding. Given the inverse relationship between the use of food to soothe and initial infant temperament in this study, it is also possible that this finding implies that the protective impact of more frequent transitions from fussing to awake/calm may be revealed when initial temperament is held constant. Although this association may seem counterintuitive, it likely reflects that the “average” time spent fussing before feeding is greater in infants who cry for longer durations overall.

Another unexpected finding was that the relationships between fussing transitions and other variables differed depending on the specific variable (i.e. fussing to awake vs. fussing to feeding) and time point (i.e. 3 vs. 16 weeks). The transition from fussing to feeding at 3 weeks was positively related to weight status. In contrast, the transition from fussing to awake at 16 weeks was affected by the intervention. One implication of these findings is that contingencies between fussing and feeding are relevant even at a time point as early as 3 weeks: Perhaps if the preventive intervention had started earlier developmentally, transitions around fussing/crying would have been impacted earlier, resulting in greater effects on weight status. It is also possible that systematic relationships with feeding-related transitions are difficult to detect at 16 weeks as solid food is likely to be introduced around this time, resulting in a period of
developmental transitions and flux in the feeding domain. Another developmental
difference between 3 and 16 weeks is that infant distress becomes differentiated into
multiple emotions; it is likely that mothers are becoming better at reading infant cues
with these changes and with their own parenting experience. These changes could
impact their approach to soothing, decreasing feeding as an indiscriminate response to
fussiness. However, there was a significant positive relationship between the
probabilities of transitioning from fussing to feeding at 3 to 16 weeks, indicating some
stability in this transition.

While there are some plausible explanations for developmental differences in the
pattern of relationships, it is more difficult to envision how the intervention increased the
transition from fussing to awake/calm without also decreasing the transition from fussing
to feeding. Future research should attempt to elucidate these mechanisms. One
interpretation of these findings is that the intervention increased transitions from fussing
to awake/calm, displacing other behavioral patterns, but not systematically (i.e. for some
individuals, these new, more adaptive transitions could be taking the place of transitions
from fussing to feeding, and for others, the default contingency may have been to fuss
to sleep). This idea is supported by the post-hoc analysis revealing that the intervention
did not affect transitions from fussing to sleeping either. It also is possible that
measurement issues could obscure certain findings. For example, mothers may be
more likely to be truthful with regards to fussing to awake transitions than fussing to
feeding transitions. In some ways, it is encouraging that there were group differences
on the transition that is less likely to be affected by social desirability.
Additional limitations related to measurement are that the diaries do not allow us to ascertain whether infants were fussing due to hunger or other reasons, nor did they involve a specification of soothing techniques that mothers were using (i.e. it is not possible to know more information about what was taking place during periods of fussing/crying or awake/calm). Thus, some of the conclusions herein, such as the conclusion that a longer fuss period prior to feeding reflects adaptive soothing, are suppositions that warrant further study. As mentioned, it is also possible that longer fuss periods simply reflect fussier infants. Another limitation of this research is the homogeneity of the sample, which resulted in restriction of range when attempting to assess relationships between behavioral transitions and demographic factors, and which precludes generalizing beyond White, well-educated, initially-breastfeeding mother-infant dyads. Strengths of this research include the randomized design and the use of time series methodology to inform individual differences in microtime behavioral transitions. Results suggest that such an approach is valuable to precisely characterize relationships between fussing/crying, soothing, feeding, and weight status.

In sum, results demonstrate the utility of investigating behavioral transitions in the context of a behavioral childhood obesity intervention. One goal of the Soothe/Sleep intervention was to increase transitions from fussing to adaptive soothing strategies when the infant was in a non-hungry state, and the intervention’s effects on the transition from fussing to awake/calm provide evidence that this goal was achieved. This transition was also related to weight status when adjusting for the use of food to soothe. If the methods used had not been an appropriate match for the hypotheses and the intensive diary data, these findings may have been overlooked (Collins, 2006).
Exploring individual transition probabilities also highlighted substantial individual
differences in transitions out of fussing; these differences and the relationships between
these transitions and the intervention and weight status confirm that transitions out of
fussing/crying are promising intervention targets.
References


### Table 1

**Descriptive Statistics for Dyads Completing Study and by Control vs. Intervention Groups**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall (n=110)</th>
<th>Control (n=59)</th>
<th>Intervention (n=51)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Maternal education</td>
<td>65% completed college</td>
<td>61%</td>
<td>69%</td>
</tr>
<tr>
<td>2. Family income</td>
<td>72% earned &gt;$50,000</td>
<td>69%</td>
<td>74%</td>
</tr>
<tr>
<td>3. Maternal age</td>
<td>M = 27.1 (4.7)</td>
<td>27.5 (4.9)</td>
<td>26.6 (4.6)</td>
</tr>
<tr>
<td>4. Infant sex</td>
<td>51% female</td>
<td>59% #</td>
<td>41% #</td>
</tr>
<tr>
<td>5. Infant race</td>
<td>90% White</td>
<td>86.4%</td>
<td>94.1%</td>
</tr>
<tr>
<td>6. Maternal BMI*</td>
<td>M = 25.1 (5.7)</td>
<td>24.4 (4.8)</td>
<td>25.8 (6.6)</td>
</tr>
<tr>
<td>7. Infant birth weight (kg)</td>
<td>M = 3.33 (.48)</td>
<td>3.25 (.47) #</td>
<td>3.43 (.47) #</td>
</tr>
<tr>
<td>8. Predominant feeding mode</td>
<td>51% breast</td>
<td>47.4%</td>
<td>55%</td>
</tr>
<tr>
<td>at age 16 weeks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. BMI-for-age z-scores+</td>
<td>.30 (.93)</td>
<td>.40 (.81)</td>
<td>.19 (1.05)</td>
</tr>
</tbody>
</table>

*pre-pregnancy, #significantly different at p<.10
Table 2

*Transition Matrix for Total Sample (n=110) at Infant Age 3 Weeks*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sleeping</td>
<td>.950 (.001)</td>
<td>.011 (.000)</td>
<td>.012 (.000)</td>
<td>.025 (.001)</td>
</tr>
<tr>
<td>2. Awake and calm</td>
<td>.052 (.002)</td>
<td>.867 (.002)</td>
<td>.038 (.001)</td>
<td>.042 (.001)</td>
</tr>
<tr>
<td>3. Fussing/crying</td>
<td>.074 (.003)</td>
<td>.057 (.003)</td>
<td>.714 (.006)</td>
<td>.156 (.004)</td>
</tr>
<tr>
<td>4. Feeding</td>
<td>.087 (.002)</td>
<td>.075 (.002)</td>
<td>.020 (.001)</td>
<td>.819 (.003)</td>
</tr>
</tbody>
</table>

Note: For this table and the table that follows, values are the overall probability of transitioning from the states listed in the column (beneath the word “from”) to the states listed in the row (beneath the word “to”); values in parentheses are the standard errors. Values along the diagonal are the probabilities of staying in that state (instead of transitioning out).
Table 3

*Transition Matrix for Total Sample (n=110) at Infant Age 16 Weeks*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sleeping</td>
<td>.963 (.001)</td>
<td>.017 (.001)</td>
<td>.008 (.000)</td>
<td>.013 (.000)</td>
</tr>
<tr>
<td>2. Awake and calm</td>
<td>.025 (.001)</td>
<td>.915 (.002)</td>
<td>.021 (.001)</td>
<td>.039 (.001)</td>
</tr>
<tr>
<td>3. Fussing/crying</td>
<td>.110 (.005)</td>
<td>.084 (.005)</td>
<td>.651 (.008)</td>
<td>.155 (.006)</td>
</tr>
<tr>
<td>4. Feeding</td>
<td>.089 (.003)</td>
<td>.143 (.003)</td>
<td>.012 (.001)</td>
<td>.756 (.004)</td>
</tr>
</tbody>
</table>
Table 4

*Transition probabilities from person-specific Markov models*

<table>
<thead>
<tr>
<th>Transition of interest</th>
<th>Mean transition probability at 3 weeks (SD)</th>
<th>Mean transition probability at 16 weeks (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sleeping to feeding</td>
<td>.025 (.01)</td>
<td>.016 (.01)</td>
</tr>
<tr>
<td>2. Sleeping to fussing</td>
<td>.014 (.01)</td>
<td>.008 (.01)</td>
</tr>
<tr>
<td>3. Fussing to feeding</td>
<td>.174 (.15)</td>
<td>.170 (.18)</td>
</tr>
<tr>
<td>4. Fussing to awake/calm</td>
<td>.063 (.06)</td>
<td>.093 (.12)</td>
</tr>
</tbody>
</table>
Figures

Figure 1. Infants’ probabilities of transitioning from sleeping to feeding at 3 and 16 weeks. This figure demonstrates that there was overall relative stability in this transition over time ($r=.29$, $p<.01$), and that individuals’ probabilities of transitioning from sleeping to feeding fell within a small range at both time points (possible range = $0 – 1$).
Figure 2. Infants' probabilities of transitioning from sleeping to fussing at 3 and 16 weeks. This figure demonstrates that there was overall relative stability in this transition over time ($r = .37$, $p < .001$), and that individuals' probabilities of transitioning from sleeping to fussing fell within a small range at both time points (possible range = 0 – 1).
Figure 3. Infants’ probabilities of transitioning from fussing to feeding at 3 and 16 weeks. This figure demonstrates that there was overall relative stability in this transition over time ($r = .42, p < .0001$), and that there were substantial individual differences in the probability of transitioning from fussing to feeding at both time points (possible range = 0 – 1).
Figure 4. Infants’ probabilities of transitioning from fussing to awake and calm at 3 and 16 weeks. This figure demonstrates that there was overall relative stability in this transition over time ($r = .48$, $p < .0001$), and that there were individual differences in the probability of transitioning from fussing to awake/calm at both time points (possible range = 0 – 1).
Figure 5. Maternal pre-pregnancy BMI positively predicted infant transitions from fussing to feeding. Mothers with a higher pre-pregnancy BMI were more likely to report feeding their infants immediately after a fussing episode at 3 weeks. This finding highlights infants of heavier mothers as a group that may be at heightened risk of learning a contingency between fussing/crying and being fed. Maternal pre-pregnancy BMI was not related to the time the infant spent fussing before they were fed (i.e. the use of food to soothe).
Figure 6. The Soothe/Sleep intervention increased infants’ probabilities of transitioning from a fussing/crying state to awake/calm at 16 weeks. This finding provides evidence that the soothing strategies taught to intervention group mothers were affecting infant behavioral transitions in an adaptive way ($p<.05$). There were no study group differences in this transition at infant age 3 weeks.
Infants' probabilities of transitioning from fussing to feeding at 3 weeks positively predict their weight status at ~6 months. Infants who had a higher probability of transitioning from fussing to feeding at 3 weeks were likely to have greater BMI-for-age z-scores at the study visit around age 6 months, suggesting that this early pattern of transitions could have negative implications for subsequent weight status. Results were consistent in an adjusted model that included maternal pre-pregnancy BMI.
Chapter 4

Infant Temperament and Obesity Risk: A Review of the Literature

Most theorists agree that temperament is a rubric of constitutionally-based traits, which are reflected as relatively stable behavioral tendencies that are expressed in response to an eliciting context (Goldsmith, Buss, Plomin, Rothbart, Thomas, Chess, Hinde, & McCall, 1987). Temperament’s constitutional basis implies that it is an inherent quality at the “core” of the individual, not a product of environmental influences or experiences, and that it is relatively stable over time. Most theorists agree on these aspects of temperament, but the specific dimensions of temperament assessed and the procedures used to assess them vary. According to Rothbart and colleagues, individual differences in reactivity and self-regulation are the bases of temperament (Rothbart, 1981; Rothbart & Bates, 2006). Reactivity refers to the ease of motor and affective arousal and includes specific assessments of excitability, thresholds, latency, intensity, rise time, and recovery time. Self-regulation refers to processes that moderate reactivity and includes dimensions like inhibitory control and attentional focusing.

Rothbart and colleagues have developed a number of measures to assess temperament at different periods of the life span, including a parent-report questionnaire of infant temperament (The Infant Behavior Questionnaire-Revised, or IBQ-R; Gartstein & Rothbart, 2003), and a series of laboratory tasks designed to elicit certain observable dimensions of temperament (The Laboratory Temperament Assessment Battery, or LAB-TAB; Goldsmith & Rothbart, 1996). Parents completing the IBQ-R respond to a number of statements about their infant’s typical behavior, indicating how frequently during the past week that their infant has engaged in certain behaviors. These items
load onto 14 subscales that tap specific aspects of infant temperament (e.g., distress to limitations, soothability). These subscales load onto the three super-factors of temperament: Negativity, Surgency, and Orienting/Regulation. Negativity and Surgency map onto the reactivity aspect of temperament, and Orienting/Regulation maps onto the early, emerging self-regulation abilities of late infancy. When temperament is assessed using the LAB-TAB, participants are placed in developmentally-appropriate, standardized eliciting contexts to allow the observation of their levels of certain temperamental qualities, like fear or anger. For example, infants’ reactions to having their arms gently restrained may be observed to quantify individual differences in anger or frustration. Another example of a standardized task designed to elicit individual differences in frustration is the Toy Removal Task, where infants’ reactions are observed when an interesting toy is placed behind a Plexiglas barrier (Goldsmith & Rothbart, 1996) or out of reach (as in Stifter & Braungart, 1995).

In addition to Rothbart and colleagues’ measures, there are additional parent-report and observational measures of temperament developed by other researchers. For example, in the literature linking temperament and child weight status, some researchers use the fussy/difficult subscale of Carey’s Infant Temperament Questionnaire (Carey, 1970; McDevitt & Carey, 1978). There is some evidence for cross-sectional relationships between the same temperamental constructs measured via different modalities although relationships are often modest and/or subject to moderation by other parent and child characteristics (Forman, O'Hara, Laren, Coy, Gorman, & Stuart, 2003; Leerkes & Crockenberg, 2003). Parade and Leerkes (2008) administered the IBQ-R, as well as tasks to elicit anger (Arm Restraint) and fear (Novel
Toy) and found some associations between parent-reported and observed temperament. For example, mother-reported fear was positively associated with observed fear and anger. Yet many hypothesized associations were not supported. For example, mother-reported approach was not inversely correlated with observed fear. These findings support the idea that parent-report and observational measures may tap different aspects of temperament; parent-report measures allow for a more global assessment of temperament across everyday contexts and may also be impacted by parents’ own characteristics or biases. The latter point is supported by evidence that some associations between reported and observed temperament were moderated by parent depression (Parade & Leerkes, 2008). Taken together, it can be concluded that the inclusion of both reported and observed temperament is ideal, along with a consideration of parent characteristics.

In addition to investigating cross-sectional relationships between temperament constructs measured via different modalities, researchers have also examined longitudinal relationships between temperament constructs measured via the same modality. Such studies provide evidence to support temperamental stability, an important part of temperament’s definition.

Temperament is Relatively Stable, Not Static

Research has demonstrated the relative, robust, longitudinal stability of temperament, measured by laboratory tasks and by parent report (e.g., Durbin, Hayden, Klein, & Olino, 2007; Rothbart, Derryberry, & Hershey, 2000; Kochanska, Murray, & Coy, 1997). Evidence for constitutional bases of temperament comes primarily from early life, consistent with the idea of the infant as a model system (Goldsmith et al.,
1987) and with the assertion that, after infancy, the developing system becomes increasingly complex, and "pure" temperament is apparent only at times of novel environmental challenges (Thomas & Chess, 1977). Although individuals' relative ranks on temperament dimensions tend to be stable beyond these early periods, temperament is not static: it develops, with continuous mean-level change as well as drastic periods of reorganization. Rothbart acknowledges discontinuities in temperament as individuals encounter periods of developmental transition (Goldsmith et al., 1987). Temperament's changes over time include developmentally and contextually appropriate changes in its expression, as well as apparent discontinuity during the periods of reorganization that precede such changes.

This view of temperament parallels dynamic systems theories (DST), a framework depicting development as probabilistic, plastic, and self-organizing, such that large enough changes at a given level of analysis could lead to a disruption in stability as the levels co-act and reorganize to express qualitatively new phenotypes specific to a new developmental stage (Gottlieb, 2007; van Geert, 2003). According to DSTs, development is not predetermined by genes but is better characterized as probabilistic epigenesis and tends to involve increases in complexity, the emergence of novel forms, and stable attractor states where different levels of analysis interact to dynamically maintain a phenotype for a period of time (van Geert, 2003). An incorporation of temperament as one level of such systems shows how temperament navigates the tension between predispositions and plasticity: individuals may be predisposed to particular reactions, but changes in physiology and environments interact with these predispositions, resulting in probabilistic developmental trajectories. If data are
collected during periods of systemic reorganization due to certain developmental milestones or changes in eliciting contexts, relative stability of temperament may be obscured (e.g., Hsu & Porter, 2004). Examples of such developmental periods include the neurobehavioral reorganization that takes place at 2 months, the differentiation between different types of distress and the emergence of fear around 6 months, and the emergence of self-regulation at the end of the first year.

**Temperamental stability and the development of self-regulation.** Some temperament dimensions do not emerge until late infancy or early childhood (Rothbart & Bates, 2006). For example, self-regulation emerges at the end of infancy. Due to cognitive and motor limitations, 6-month-old infants' repertoire of self-regulation strategies is restricted to simple gaze aversion. Parents usually assist the infant with regulating their emotions and behavioral states during this early period, scaffolding the development of self-regulation (e.g., Jahromi, Putnam, & Stifter, 2004). By 12 and 18 months, infants are able to engage in more complex self-soothing and self-distracting behaviors (Mangelsdorf, Shapiro, & Marzolf, 1995), and self-regulation further develops into more purposeful effortful control in childhood. As children enter toddlerhood and begin to gain more autonomy, parents can support these developments by scaffolding their children's movement from parental regulation of distress and behavior to self-regulation (Fox & Calkins, 2002).

Developmental changes in self-regulation have implications for the rubric of temperament as a whole, because in addition to relationships between the same temperament dimensions assessed at multiple time points or by multiple measures, there are also relationships among different aspects of temperament. These
relationships may be longitudinal (i.e. children learn about emotional control partially via their parents' responses to their early distress; Fox & Calkins, 2003), or they may be cross-sectional (e.g., an individual's expression of self-regulation abilities is relative to his or her reactivity). To expand upon the latter point, two individuals may seem equally able to self-regulate and modulate their negative reactivity in observations, but if one of the individuals never shows much negative reactivity in other contexts, then their behavior is better described as low reactivity, not high regulation. Rothbart and Bates (2006) discuss the analogy of reactive dimensions as the "accelerator" and self-regulation as the "brakes," two entities that do not act in isolation. One implication of this relationship is that assessments of self-regulation should be adjusted for some parallel index of reactivity. Another implication is that the apparent stability of reactive temperament dimensions may be disrupted as self-regulatory abilities come online.

**Temperamental stability and the role of context.** In addition to changes in the individual's temperament, development also brings changes in the expression of temperament. Temperament may be “masked” by regulation, socialization, and contextual elements. As mentioned, the development of self-regulation modulates the expression of reactivity; additionally, socialization is an ongoing process where children learn which emotions and behaviors are appropriate to exhibit in their overarching culture, and within this environment, the specific situations (or eliciting contexts) that an individual experiences influences which temperamental traits are expressed at any given time. In considering the role of the eliciting context in temperament expression, one could argue that temperament’s expression is stable because we tend to remain in stable macro-level environments (Blumberg, 2005; Gottlieb, 2002; Harshaw, 2008), and
that the interaction of constitutional bases with the environment would evoke different phenotypes if the broader environmental context were to drastically change. Kagan's (2003) comment that temperament is a measure of susceptibility to certain environments is consistent with this point.

Rothbart and Bates (2006) acknowledge the possibility of plasticity in temperament and point to the need for a focus on this issue in future temperament research. Temperament may be plastic under certain conditions, but contexts need to be manipulated and biological indices assessed to determine how plastic it may be and whether it is temperamental expression or the neurophysiological substrate (i.e. the actual temperamental "core") that changes (Rothbart & Bates, 2006). Intervention studies provide one way to test temperamental plasticity as they often change aspects of the individual's environment or eliciting context. The intervention literature supports the idea that preventive interventions may alter parents' perceptions of their infants (e.g., Olafsen, var Kaaresen, Handegard, Ulvund, Dahl, & Ronning, 2008) or observed infant characteristics (van den Boom, 1994). Environmental change can also take place on a more macro-level: The broader contexts in which many individuals now live have changed to become increasingly obesogenic. Certain temperamental dimensions may confer particular risk for or protection from health-related outcomes like overweight in this environment.

**Links between Temperament and Weight Status**

Although there is a substantial literature linking temperament dimensions to adjustment, including internalizing problems like depression and anxiety and externalizing problems like delinquency and aggression (Eisenberg, Cumberland,
Spinrad, Fabes, Shepard, Reiser, et al., 2001) the evidence that certain temperament dimensions may also increase or decrease childhood obesity risk is more limited. This body of research has been conducted from two different disciplinary perspectives, including the developmental literature, where the temperament side of the equation is a primary focus, and the nutrition literature, where food intake and weight outcomes are the primary focus. Although the experts in these two areas typically work from different perspectives, they often study similar constructs. A recently-published handbook of self-regulation illustrates this point by including chapters on emotional and cognitive regulation, as well as self-regulation in a number of specific domains (Vohs & Baumeister, 2011). Specifically, there is a chapter on self-regulation from a temperament perspective, where Rothbart and colleagues (2011) discuss infant orienting and child effortful control, as well as a chapter on the self-regulation of eating, where Herman and Polivy (2011) discuss dietary restraint, or cognitive control of one’s intake, portraying such regulation as a dynamic process in which the individual's ability to regulate and the salience of the stimulus interact to determine self-regulatory success or failure. Although there is a history of different terminology and measurement between disciplines, Herman and Polivy's ideas fit with a temperament framework where the implications of individual differences are relative to environmental stimuli, and these parallels elucidate the role of the current food environment as an eliciting context that could affect relationships between temperament and obesity risk (or resilience).

Individual differences in temperament, or predispositions to exhibit certain reactive or regulatory behaviors, could impact individuals' likelihood of maintaining healthy eating and activity behaviors in the obesogenic environment. In other words,
the pervasive food cues that are characteristic of the modern environment may be more or less salient to individuals of different temperaments. This hypothesis illustrates the role of historical change in environments (i.e. eliciting contexts) in temperament research. On a phylogenetic scale, the evolutionary retention of individual differences in temperament is adaptive, increasing the probability that some individuals will be equipped to deal with a given environmental change. For most of human history, the broader environment was one of food scarcity. In these environments, high approach tendencies may have been important in order to secure food and survive. The implications of temperamental dimensions for healthy physical development are likely quite different today than they were in environments of scarcity. For example, in the face of ubiquitous, palatable, energy-dense food and tempting sedentary entertainment options, self-regulation is likely an important aspect of temperament, allowing subdominant, healthy responses to be purposefully executed, as opposed to the dominant responses to these ever-present stimuli (Anzman & Birch, 2009; Whitaker & Gooze, 2009). There is preliminary evidence that both reactive and regulatory aspects of temperament have implications for childhood obesity in the current environment. This evidence will be reviewed herein, excluding that which focuses on low birth weight, activity level, and/or older children.

**Infant negative reactivity and weight outcomes.** Associations between infants' negative reactivity (e.g., irritability, distress, and negative emotionality) and weight outcomes have been fairly consistent across studies although this research is methodologically heterogeneous. In general, high irritability, high negative mood, and high distress tend to predict greater weight status or more rapid weight gain, leading to
the interpretation that parents of more negative infants may overfeed them in an attempt to soothe their irritability and distress. Such studies vary in their conceptualization of negativity, choosing to measure only one dimensions or clustering multiple dimensions together to comprise an overall "difficult" temperament.

Carey (1985) used The Infant Temperament Questionnaire (Carey, 1970), to investigate whether difficult infants tended to show more rapid weight gain. Rapid gainers were more likely to be rated as difficult by their mothers in infancy; difficult infants were defined as those low on rhythmicity, approach, and adaptability and high on negative mood and intensity. The only individual dimension that related to rapid weight gain was negative mood, suggesting that the link between high negative mood and rapid weight gain between 6 and 12 months was driving the relation between difficult temperament and weight gain. Carey proposed the overfeeding hypothesis as one potential explanation for relations between reactive temperament dimensions and weight gain, positing that caregivers feed difficult infants more often as an attempt to soothe them. Recent studies have been consistent with Carey’s original findings. Using the Infant Behavior Questionnaire (IBQ; Rothbart, 1981) to assess temperament, Wells and colleagues (1997) found that easily soothable infants tended to have lower body fatness at a follow-up assessment (age 2-3.5 years).

The directionality of this relationship cannot be ascertained from these studies, and there is also evidence of links between early weight and subsequent temperament. Darlington and Wright (2006) found a positive association between rapid weight gain from birth to 8 weeks and distress to limitations at 8 weeks, and using a sample of twins, Riese (1994) found that the twin with a larger birth weight tended to be more
irritable and more difficult to soothe at hospital discharge. Niegel and colleagues (2007) explored relationships between difficult temperament and weight gain in an epidemiological study of Norwegian infants; they found small associations between weight gain in the first six months of infancy and difficult temperament at six months. These associations do not necessarily support reverse causality (i.e. weight status affecting reported temperament) as the analyses were not adjusted for earlier temperament. However, there is a study with multiple measurements of both temperament and weight status, and this study supports the temporal precedence of temperament: in a cohort of African-American infants, cross-lagged analyses of distress to limitations and weight status at multiple time points supported the hypothesis that earlier distress was positively associated with subsequent weight status (at 1 year), as well as increases in fatness over the course of infancy. Distress to limitations was not related to weight status in cross-sectional analyses (Slining, Adair, Goldman, Borja, & Bentley, 2009). This pattern of relationships between early temperament and subsequent but not concurrent weight suggests that the negativity itself may not be problematic, but rather that the typical caregiver response to it and the longitudinal implications of this response may be. As mentioned, one possible response is that easily distressed, highly negative infants may be more likely to elicit overfeeding from their caregivers.

In the past few decades, the relationship between infant negativity and weight gain has been fairly well-established, and more the directionality of recent evidence is consistent with the hypothesis that highly negative infants are fed more to soothe their distress, leading to increased weight. At present, only a limited number of studies have
specifically addressed the use of food to soothe. Slining and colleagues (2009) did not find that dietary intake mediated the relationship between distress to limitations and subsequent weight status using dietary recall data. Yet there is qualitative evidence that low-income mothers use food to shape their children's behavior (Baughcum, Burklow, Deeks, Powers, & Whitaker, 1998) and quantitative evidence that infant temperament is linked to maternal feeding patterns, specifically the provision of sweet foods and drinks (Vollrath, Tonstad, Rothbart, & Hampson, 2011). A cross-sectional pilot study provides initial evidence that such pathways have negative implications for child weight status. In this study, the use of food to soothe was not a mediator of the relationship between temperamental negativity and weight status but was a moderator instead. Weight status was highest for children high on negativity whose parents reported using food to soothe often, consistent with the idea that negativity itself may not be problematic, but higher negativity paired with the response of feeding to soothe may be (Stifter, Birch, Anzman-Frasca, & Voegtline, under review). Preliminary results from a longitudinal study that is in progress are consistent with this finding (Stifter, Anzman-Frasca, Lickenbrock, & Voegtline, 2011). This evidence does not suggest that all highly negative infants are more likely to be fed to soothe their distress, but obesity risk seems to be heightened if they are.

If some highly negative infants are more likely to be overfed in response to their distress, what are the long-term implications of this contingency? Rather than learning associations between hunger and eating, these individuals may learn to eat in response to their emotions. There is substantial literature on links between emotions and intake in adults, such as van Strien and colleagues' work on emotional disinhibition (e.g.,
Spoor, Bekker, van Strien, & van Heck, 2007). Additionally, Carey and colleagues (1988) suggested that one consequence could be subsequent disruptions in children’s developing self-regulatory abilities. A small body of literature suggests that poor self-regulation is implicated in childhood overweight (Braet & Van Winckel, 2000; Cohen, Gelfand, Dodd, Jensen, & Turner, 1999; Israel, Guile, Baker, & Silverman, 1994). These studies focused on children and/or adolescents who were attempting to lose weight, collectively demonstrating that groups who underwent self-regulation training showed beneficial outcomes (Braet & Van Winckel, 2000; Israel et al., 1994) and that those who were able to maintain weight loss reported more self-regulation (Cohen et al., 1999). In addition, Johnson (2000) demonstrated that children’s abilities to self-regulate their intake could be improved by training them to focus on internal hunger and satiety cues. More recently, researchers have also begun to study this connection from a temperament perspective. It seems plausible that both negative reactivity and self-regulation have implications for subsequent weight outcomes, and that the effects of negativity, self-regulation, and parenting are intertwined and unfold over time.

Self-regulation and weight outcomes. If overfeeding and learned contingencies between negative emotions and food continue to influence weight status through subsequent poor regulation, then it follows that temperament dimensions like inhibitory control should relate to weight status and weight gain over time, particularly for individuals who started out high on negativity and were fed to soothe their distress. In addition to potential links through negativity, there could also be a link between self-regulation and obesity risk through intake if children with low levels of inhibitory control have trouble resisting the easily-accessible, palatable, energy-dense foods that
characterize the current environment. Because such foods are prevalent in the current environment, the ability to limit consumption is a necessary skill (Hill, Wyatt, Reed, & Peters, 2003).

Research supports hypothesized associations between lower self-regulation and overweight risk in the current environment. Francis and Susman (2009) found that low impulse control during a Snack Delay task was related to higher BMI z-scores and more rapid BMI increases. Outside of the eating context, Nederkoorn (2006) found that obese children tended to have lower inhibitory control and higher impulsivity. Nederkoorn (2006) conceptualized impulsivity and inhibitory control as the reward/motivation and inhibition components of a single dimension, positing that impulsivity leads obese children to find food irresistible. However, it is possible to be high on both inhibitory control and impulsivity, and these two dimensions have been found to differentially relate to various outcomes (e.g., unintentional injury; Schwebel, 2004). Anzman and Birch (2009) operationalized inhibitory control as an independent dimension using Rothbart and colleagues’ Child Behavior Questionnaire (Rothbart, Ahadi, Hershey, & Fisher, 2001) and found that lower inhibitory control at age 7 was linked to weight gain from age 7 to 15 and overweight risk at age 15 in a longitudinal sample of girls. Observed self-regulation outside of the eating context has also been linked to overweight risk: lower emotion regulation, inhibitory control, and reward sensitivity at age 2 (in tasks like the delay of gratification) were predictive of obesity risk at age 5.5, adjusting for BMI at age 2 (Graziano, Calkins, & Keane, 2010). In general, this small body of literature shows that lower self-regulation is cross-sectionally and longitudinally related to a higher weight status. One study showed a different pattern of
results when investigating regulation at 1 year and obesity risk at age 6: for male infants, lower attention span was related to greater obesity risk, and for females, greater soothability was related to greater obesity risk (Faith & Hittner, 2010). This difference could be related to their use of different temperament dimensions or other methodological differences, or this could be an example where relationships look different during periods of reorganization as age 1 year is a period of reorganization with respect to self-regulation.

In sum, there is a growing body of evidence that high levels of infant negativity may be a risk factor for childhood obesity, and increased self-regulation may be protective. More research is needed to elucidate the extent to which these relationships emerge using observational assessments of temperament and to test the hypothesis that the use of food to soothe is the mediating mechanism explaining effects of infant negativity (and perhaps also of infant regulation) on subsequent weight outcomes. This research should also acknowledge that the implications of temperament are relative to the environment in which temperamental styles are expressed. There is an extensive literature on temperament-by-parenting interactions in other domains, as well as a few studies in this particular area, demonstrating that the implications of temperament for weight outcomes vary depending on parenting practices (e.g., Anzman & Birch, 2009). Continuing collaboration between developmentalists and obesity researchers on these issues could lead to a more precise characterization of early individual differences in obesity risk, with implications for the advice given to parents and practitioners and for targeted obesity prevention efforts.
References


Chapter 5

The Roles of Infant Negativity and Self-Regulation in a Behavioral Childhood Obesity Preventive Intervention

In the context of the current obesity epidemic (Ogden, Carroll, Curtin, Lamb, & Flegal, 2010), the majority of individuals are at risk of developing obesity during their life spans. However, there are individual differences in obesity risk, and early temperament is one factor that differentially predicts weight outcomes in the current environment (Paul, Bartok, Downs, Stifter, Ventura, & Birch, 2009). In particular, greater infant negativity has been linked to greater weight status or weight gain (e.g., Darlington & Wright, 2006; Slining, Adair, Goldman, Borja, & Bentley, 2009), suggesting that a highly negative temperament could be an obesity risk factor. Also, greater self-regulation predicts a lower weight status (e.g., Francis & Susman, 2009; Graziano, Calkins, & Keane, 2010), suggesting that self-regulation is a protective factor. It is unlikely that these two constructs work in isolation as the reactive and regulatory aspects of temperament are inextricably linked. Once self-regulation emerges at the end of infancy, it acts as the “brakes” that attenuate expressions of reactivity (Rothbart & Bates, 2006). Early infancy offers an opportunity to investigate negative reactivity before regulatory abilities come online.

Infancy is also a promising time for the implementation of preventive interventions targeting obesity-promoting behaviors. Infancy is a time of rapid transitions, rapid growth, and learning; intervening during this developmental period offers the opportunity to affect developmental trajectories before behavioral patterns and obesity are established in many individuals. This is an emergent approach, and
pilot work provides initial evidence that such interventions can affect energy-balance-related behaviors and weight outcomes (Paul, Savage, Anzman, Beiler, Marini, Stokes, et al., 2011; Taveras, Blackburn, Gillman, Haines, McDonald, Price, & Oken, 2010; Wen, Baur, Rissel, Wardle, Alperstein, & Simpson, 2007). The main thesis of this chapter is that it is critical for early obesity preventive interventions to consider individual differences in temperament. Not only is there evidence that temperament is linked to weight outcomes, but interventions can affect parents’ perceptions of their infants’ temperaments (e.g., Olafsen, var Kaaresen, Handegard, Ulvund, Dahl, & Ronning, 2008). Also, temperament can moderate the effects of an intervention (e.g., Klein Velderman, Bakermans-Kranenburg, Juffer, & Van IJzendoorn, 2006). The current study aims to clarify the role of infant temperament in a Soothe/Sleep intervention, in which mothers were taught techniques to soothe their infants besides using feeding as a first response to infant fussing and crying (Paul et al., 2011). Is temperament an intervention outcome, a predictor of weight status, a moderator of intervention effects, or all three? Because of the extensive literature on temperament-by-parenting interactions, and because mothers were the target of this intervention, both temperament and parenting variables are included in this chapter’s research questions, which were influenced by goodness of fit and differential susceptibility theories.

**Temperament-by-Environment Interactions**

Temperament may predispose individuals to certain behaviors, but predispositions are not destiny. As mentioned, outcomes are dependent on many factors, including developmental period and environmental context. There is a large body of literature on temperament-by-environment interactions, where certain
environments moderate the influence of temperament on outcomes in predictable ways. Temperament-by-parenting interactions are prevalent in the literature and suggest that the implications of these constructs in many domains are relative to one another. For example, 18-month-olds who were high on distress were more likely to be angry and aggressive at 24 months when they experienced low positive parenting (Calkins, 2002), and the relation between poor regulation and problem behaviors was exacerbated when parenting was negative or harsh rather than gentle (Rothbart & Bates, 2006). In temperament-by-parenting interactions, it is also possible to portray temperament as the moderator and the parenting environment as the main effect. This decision reflects theoretical perspectives and the phrasing of results, but from a methodological perspective, the implications are the same.

In general, there are many types of interactions that involve temperament and parenting (Aiken & West, 1991; Belsky, 2007). In an additive interaction, a high standing on two dimensions has different implications than a high standing on one or neither of the dimensions. The finding that the combination of temperamental negativity plus greater use of food to soothe had the worst implications for child weight status is an example of an additive interaction (Stifter, Birch, Anzman-Frasca, & Voegtline, under review). The phrase “it depends” characterizes multiplicative interactions; for example, Kochanska, Aksan, and Joy (2007) found contrasting effects: optimal parenting styles were relative to child fearfulness, such that fearful children fared best with gentle discipline, an ineffective strategy for fearless children, who instead required a positive parent-child relationship to motivate compliance. Belsky (2007) elaborates upon different types of multiplicative interactions and focuses specifically on the differential
susceptibility model, or interactions where a moderator improves the outcomes of one group (e.g., from poor adjustment to exceptional adjustment), and the other group is unaffected by the moderator (e.g., with average adjustment outcomes across levels of the moderator). This and other theoretical concepts guide researchers’ thinking on what types of interactions to expect in different substantive areas.

**Goodness of fit (and the potential role of parental efficacy).** Goodness of fit is a theory that developmental outcomes do not depend on individual characteristics or environmental aspects alone, but on the fit between person and context. According to this theory, individuals with a particular standing on a temperament dimension are more likely to be at risk for negative outcomes if their perceived environment is incongruent with their behavioral style (Lerner, Baker, & Lerner, 1985). Goodness of fit is evident in temperament by parenting interactions, in which the outcomes associated with a certain temperamental dimension depend on the type of parenting that the child experiences (or, outcomes associated with a certain parenting practice depend on the child’s temperament). For example, high maternal attention predicts high exploration among inactive 15-month-old children but predicts low exploration among active 15-month-old children (Gandour, 1989), suggesting that parental stimulation may be advantageous for children low on activity while active children are hindered by it. In another widely replicated temperament by parenting interaction, oversolicitous mothers tend to have children whose fearfulness is correlated with their behavioral inhibition, but there is no association between mother-reported fear and behavioral inhibition with peers for children whose mothers are low in oversolicitousness (Rubin, Hastings, Stewart, Henderson, & Chen, 1997). Additionally, children’s poor self-regulation was associated
with more behavior problems when mothers were also intrusive and hostile (Rubin, Burgess, Dwyer, & Hastings, 2003).

Such interactions between temperament and parenting are also possible in the childhood obesity realm. Girls with lower inhibitory control and high perceived parental restrictive feeding had faster weight gain and higher BMIs than girls with higher inhibitory control; girls with lower inhibitory control and lower restriction were not significantly different from either of these groups (Anzman & Birch, 2009). Such interactions support the idea that there is no ideal standing on a given temperament dimension if the environment is congruent with the individual’s characteristics. Given that parents (or other caregivers) play a large role in structuring infants’ and children’s environments in early life, the implications of temperament for weight outcomes partially depend on the physical and psychological eliciting contexts created by the caregivers.

One broad predictor of such environmental construction may be parental self-efficacy; parents with lower self-efficacy may be more likely to construct negative micro-level environments with respect to the resources they provide or their parenting practices. Self-efficacy is an individual's belief that they can succeed in impending situations, and it mediates the relationship between knowledge and action. Self-efficacy has been shown to influence choices of activities and environments, as well as perseverance, performance, and goal attainment (Bandura, 1982; 1986). In the parenting domain, parenting self-efficacy represents a parent's belief that they can adequately care for their child and can handle upcoming situations involving their child (Johnston & Mash, 1989). In the research reported below, it was hypothesized that mothers’ initial parenting self-efficacy would interact additively with infant temperament:
infants whose temperaments increased their risk for childhood obesity (e.g., highly negative infants) would only be at increased risk if their mothers were also low on self-efficacy, a quality that should undermine their ability to persevere in the face of challenges like soothing a highly negative infant. In the goodness of fit theory framework, infant negativity and low maternal self-efficacy would represent a “bad fit.” Relationships between maternal self-efficacy and the likelihood of using food to soothe infant distress were also explored, overall and in the intervention and control groups.

**Differential susceptibility (and the role of initial temperament in the Soothe/Sleep intervention).** As mentioned, Belsky’s work on differential susceptibility exemplifies a different type of interaction, where individuals of a certain temperamental status are not affected by environmental variability, and individuals of another temperamental status do worse in "negative" environments and better in "positive" environments. For example, children with high negative emotionality seem have poorer outcomes when they are not raised in supportive environments, but they seem to benefit more from supportive environments than children with low negative emotionality (Belsky, 2007). In this model, temperament is the moderator of environmental impact, and the environment is often conceptualized in terms of parenting practices. However, just as individuals with different temperaments may be more or less susceptible to certain parenting practices, they may also respond differentially to an intervention. For example, intervention effects were greatest for highly reactive infants and their mothers in an intervention that uses video feedback to promote parenting sensitivity and secure attachment (Klein Velderman et al., 2006).
Similarly, the implementation of the Soothe/Sleep intervention could be viewed as a change in the environment, assuming all intervention group participants are implementing our recommended soothing and sleeping techniques, and the control group participants are not. It was hypothesized that differential susceptibility plays a role in this intervention's effects, such that infants with higher initial negativity would have better outcomes with intervention and poorer outcomes without it; for infants lower on negativity, the intervention would explain less variability in their outcomes. Outcomes that may be influenced by such differential susceptibility include infant self-regulation and weight gain, as well as maternal use of food to soothe and maternal parenting satisfaction and self-efficacy following the intervention. The latter outcomes were included because the intervention was designed to give mothers tools to adequately soothe their infants and to help their infants sleep. These tools may be particularly useful to mothers of negative infants and may increase their self-efficacy via successful interactions around infant fussing and crying (or "performance accomplishments," Bandura, 1982; 1986).

**Specific Aims**

In sum, the developmental literature highlights the role of temperament in childhood obesity research; this link could have implications for behavioral childhood obesity interventions. This intervention may affect perceptions and/or expression of developing infant temperament. The literature also suggests that infants with higher negativity and/or lower self-regulation may be at increased risk of weight outcomes that are predictive of childhood obesity, and that infant negativity may moderate the effects of the intervention on weight and other outcome variables. Integrating both
temperament and parenting as key variables in childhood obesity research could shed light on individual differences in behaviorally-mediated obesity risk; it is likely that the "main effects" that emerge from a more aggregate approach are attenuated and only represent some individuals in some environments. These possibilities were explored, with the following specific aims:

1. To assess whether the Soothe/Sleep intervention affected temperament at the end of infancy, including reported and observed negativity, as well as reported and observed regulation
   - It was hypothesized that the intervention group would be higher on mother-reported negativity at 1 year, but that the groups would not differ on total observed negativity.
   - It was hypothesized that the intervention group would demonstrate higher observed self-regulation at 1 year, but that the groups would not differ on mother-reported regulation.
   - It was hypothesized that intervention effects on reported negativity and observed self-regulation would be explained by less frequent use of food to soothe.

2. To examine whether temperament was related to weight status in this sample, and to see if these relationships were moderated by initial maternal self-efficacy and by the use of food to soothe
   - It was hypothesized that higher early negativity would be related to higher BMI z-scores at ~6 months and 1 year.
Initial maternal self-efficacy at 3 weeks would moderate the association between early infant negativity and subsequent weight gain, such that negativity would predict greater weight gain in infants of mothers lower on self-efficacy.

Mothers lower on self-efficacy would be more likely to use food to soothe.

The use of food to soothe would also moderate the association between infant negativity and subsequent weight gain, such that negativity would predict greater weight gain in infants who are more likely to be fed to soothe.

It was hypothesized that higher regulation (observed and reported) would be related to lower weight status and weight gain.

3. To test interactions between early negativity and the Soothe/Sleep intervention

It was hypothesized that infants with higher negativity would be differentially susceptible to the Soothe/Sleep intervention. Intervention group dyads with highly negative infants would show less weight gain and greater self-regulation in the infant, as well as greater maternal parenting satisfaction and efficacy and less frequent use of food to soothe at 1 year, compared to intervention infants lower on negativity and all control group infants.
Methods

Participants

Mothers were recruited from the maternity ward of an academic medical center in Pennsylvania and were eligible if they intended to breastfeed and to follow-up with a University-affiliated primary care provider and if they were primiparous and English-speaking. Other inclusion criteria were singleton birth and at least 34 weeks’ gestation. Dyads were excluded if the mother or infant had a morbidity that would affect postpartum care or infant sleeping or feeding or if the mother stayed in the hospital for more than 7 days postpartum. At study entry, there were 160 mother-infant dyads. Dyads were assessed at birth, and at infant ages 3, 8, 16, and 36 weeks and 1 year; 110 mother-infant dyads completed the one-year study. Additionally, weight and height were obtained from medical charts at age 3 year well-child visits for 72 participants.

Following recruitment, mother-infant dyads were randomized to a control group or a Soothe/Sleep intervention, where mothers were trained on alternate soothing methods, including avoiding feeding as a first response to fussiness; the Soothe/Sleep intervention was administered at the 3-week home visit. There was also a feeding intervention that addressed the introduction of solid foods that was administered to some families after infants were 4 months old. This intervention is not the focus of this study, but models will be adjusted for participation in this second intervention where applicable. There were no significant demographic differences between study groups although there were trend-level differences between the intervention and control group on infant birth weight and sex (Table 1). There was also selective attrition, such that mothers who did not complete the study ($n=50$) were more likely to be single and non-White and tended to be younger and less educated than the mothers who participated
throughout the entire year (Table 2). Of the 110 dyads who completed the study, 51% of the infants were female, and the mean birth weight for gestational age percentile was 45.0 (SD = 28.7). The majority of mothers were non-Hispanic White, college-educated, and earned more than $50,000 per year (Table 1). Unless otherwise indicated, the sample included the 110 mother-infant dyads who completed the one-year study. The Human Subjects Protection Office of the Penn State College of Medicine approved all study procedures, and mothers provided consent for the dyad's participation before the study began.

**Intervention**

The key messages of the Soothe/Sleep intervention were administered at a nurse home visit at infant age 3 weeks. Dyads randomized to the Soothe/Sleep intervention received a commercially-available video (Karp, 2006) that instructed parents on alternate responses to infant distress aside from feeding; these alternatives including swaddling, side or stomach position, shushing, swinging, and (non-nutritive) sucking. Parents were also taught to emphasize day/night differences and to establish night time routines that included initially responding to night wakings with alternatives to feeding to help the infant to self-soothe and return to sleep, as done by Pinilla and Birch (1993). Both intervention and control participants were given a standard infant parenting book, and nurses answered questions about general infant care.

**Measures**

**Temperament: Negativity.** Infant negativity was assessed by mother-report, observation, and diary data. Mothers completed an adapted version of the Infant Behavior Questionnaire-Revised (IBQ-R; Gartstein & Rothbart, 2003) at age 16 weeks,
allowing calculation of the temperament subscale of distress to limitations. The adapted version contained all of the items needed to calculate five of the 14 IBQ-R subscales. The complete IBQ-R was administered at 1 year, allowing calculation of the subscale distress to limitations as well as the super-factor of negativity. At age 1 year, infants were also observed during an adapted version of the LAB-TAB Toy Removal Task (Goldsmith & Rothbart, 1996) as described by Stifter and Braungart (1995). During this procedure, the infant was allowed to play with an interesting toy for two minutes. Then, the toy was removed and placed out of the infant’s reach but within sight. After one minute, the toy was returned, and the infant was able to play with it for another minute. Trained research assistants coded infant reactivity and regulation during this procedure. The reactivity data contain the proportion of time spent in mild, moderate, and high intensity negativity (as well as neutral and positive affect). Weighted intensity scores were calculated from the reactivity data during the minute-long toy removal: 

\[ ((0 \times \text{proportion of time spent exhibiting non-negative emotions}) + (1 \times \text{mild negativity proportion score}) + (2 \times \text{moderate negativity proportion score}) + (3 \times \text{high negativity proportion score})) \] 

The weighted intensity score during the Toy Removal is referred to as observed negativity. This variable was also used as a covariate in analyses of observed regulation. Finally, average daily minutes of fussiness calculated from diary data at age 3 weeks was used as an index of initial temperament/negativity.

**Temperament: Regulation.** Infant regulation was assessed by mother-report and observation. At age 16 weeks, the adapted IBQ-R was administered, allowing the calculation of the temperament subscale of soothability. At age 1 year, the complete IBQ-R was administered, allowing calculation of the subscale of soothability, as well as
the temperament super-factor of Orienting/Regulation. This super-factor is composed of items tapping soothability, cuddliness, duration of orienting, and low intensity pleasure, which are phrased to capture the infant’s usual response in specific, everyday situations outside of the feeding domain. Regulation was also coded during the Toy Removal Task. Trained research assistants coded regulatory behaviors in three passes as some of these behaviors co-occur. The regulatory behavior of interest was the proportion of time spent engaging in self-comforting behaviors, including behaviors like hair twirling and sucking fingers; these were coded during the second pass through the footage taken during the Toy Removal (i.e. the part of the task intended to elicit frustration).

**Food to soothe.** Multiple variables were used as proxies for the use of food to soothe. First, the average amount of time spent fussing before transitioning to feeding was calculated from infant behavior diaries at 3 and 16 weeks. A longer amount of time spent fussing before feeding indicates that feeding was not used as an indiscriminate first response to infant fussing. The Babies' Basic Needs Questionnaire (BBN) also provides information about maternal responses to infant fussing/crying. A food to soothe composite was calculated from items asking about the frequency with which food is used to soothe infant distress as done by Stifter et al. (under review). A food to soothe proportion score was also created by dividing the frequency with which parents used food to soothe by the sum of the frequency with which parents endorsed all soothing techniques included in the instrument (e.g., rocking, holding). This newly-developed questionnaire was added to the study protocol after the one-year visits began, so these data are only available for a sub-sample of participants (n=79).
**Weight status.** Infant weights and lengths were measured by research nurses at a home visit following the introduction of solids (~6 months) and at a visit to a University-affiliated General Clinical Research Center at age 1 year. Infant weights were measured using a calibrated Medela BabyChecker™ scale (McHenry, IL), and lengths were measured using the Seca 210 Mobile Measuring Mat for Infants and Toddlers (Hanover, MD). BMI-for-age z-scores were calculated using the World Health Organization (WHO) growth charts, which are now the recommended growth standards for children younger than age 2 (Grummer-Strawn, Reinold, Krebs, & Centers for Disease Control & Prevention, 2010).

Birth weight was obtained from infants' medical charts and was included as a covariate in analyses involving the intervention group due to a trend where the intervention group weighed more than the control group at birth (Table 1). After the study's conclusion, heights and weights were collected from some participants' age 3 medical charts ($n=72$). Residualized weight gain scores were calculated from the residuals of regression models where weight at age 1 was regressed on birth weight, where weight at age 3 was regressed on birth weight, and where weight at age 3 was regressed on weight at age 1. These calculated variables allow investigations as to whether certain individuals are experiencing more weight change relative to the sample over time periods of interest. We also tested BMI gain scores, and results were similar unless otherwise mentioned in the results.

**Maternal self-efficacy and parenting satisfaction.** Mothers completed the Parenting Sense of Competence Scale (PSOC; Gibaud-Wallston & Wandersman, 1978) at infant ages 3 weeks and 1 year, and maternal self-efficacy and satisfaction were the
two subscales created from this measure. The former is an instrumental subscale, reflecting mothers' feelings of competence in the parenting role, and the latter is an affective subscale, reflecting mothers' frustrations and motivations around parenting (Johnson & Mash, 1989).

**Statistical Analyses**

Analyses were conducted using SAS Version 9.2. The first aim was to assess whether the randomized Soothe/Sleep intervention affected infant temperament. First, effects on reported or observed negativity were tested. Analysis of variance was used to examine whether the intervention and control groups differed on mother-reported negativity at 1 year (from the IBQ-R) or on observed negativity after the toy removal. Birth weight, infant sex, and participation in the feeding intervention were tested as covariates in these analyses; because dyads were randomly assigned into the intervention and control groups, only covariates that differed between the two groups were included. Regression analyses were used to examine whether the use of food to soothe at 16 weeks (average amount of time spent fussing before feeding) and 1 year (food to soothe composite and proportion scores from the Babies' Basic Needs Questionnaire) explained intervention effects on negativity.

Next, intervention effects on the other main component of temperament, self-regulation, were tested. Analysis of variance was used to examine whether the study groups differed on mother-reported regulation (from the IBQ-R) or on observed regulation (e.g., proportion of time exhibiting self-comforting behaviors during the toy removal). Birth weight, infant sex, infant negativity, and participation in the feeding intervention were tested as covariates in these analyses. Regression analyses were
used to test whether the use of food to soothe at 16 weeks (average amount of time spent fussing before feeding) and 1 year (the food to soothe composites and proportions from the Babies Basic Needs Questionnaire) explained the Soothe/Sleep intervention’s effects on observed regulation.

Conducting these analyses using the general linear model means that cases with any missing data will be deleted. Due to this fact, as well as the apparent selective attrition in our study (Table 2), these analyses were repeated using multiple imputation to investigate whether results would be similar in the original 160 dyads that were recruited. The variables of interest at all available time points, as well as some demographic covariates, were used to multiply impute 40 datasets on which the analyses were repeated. The variables entered into PROC MI included: infant birth weight; feeding mode at 16 weeks; average daily fussing/crying at 3, 8, and 16 weeks; reported infant negativity at 1 year; mild, moderate, and high intensity negativity proportion scores during and after the toy removal; reported infant regulation at 1 year; observed infant regulation at 1 year (self-comforting proportion score); average minutes spent fussing before transitioning to feeding at 3 and 16 weeks, the probability of transitioning from fussing to feeding at 3 weeks, maternal parenting satisfaction at 1 year; maternal parenting self-efficacy at 3 weeks and 1 year; and infant weights, lengths, and ages at ~6, 12, and 36 month visits.

The following variables were not included in the multiple imputation but instead were re-calculated using the corresponding imputed data: negativity intensity scores were calculated indicating the proportion of time spent showing non-negative, mild negative, moderate negative, and high-intensity negative affect; BMI z-scores were
calculated by inputting age, sex, length, and weight data into the SAS macro that is based on the World Health Organization growth charts. Proc Mi was initially conducted without imputing any data in order to check convergence and diagnostics. Proc Mi converged in 179 iterations, and the program was implemented again, this time imputing the 40 complete datasets. Proc Reg and Proc Mianalyze were then used in order to repeat the main analyses of interest. This process was repeated for the second and third aims in order to investigate the effects of missing data in this study.

The second aim was to examine whether temperament was related to weight status in this sample. Regression analysis was used to test cross-sectional and longitudinal relationships between temperament and weight status. Reported and observed negativity at 1 year were used to test cross-sectional relationships between negativity and weight status at 1 year, and initial temperament at 3 weeks and distress to limitations at 16 weeks were used to explore longitudinal relationships between early negativity and weight status at ages ~6 months and 1 year. Initial maternal self-efficacy and the use of food to soothe (at 3 weeks) were investigated as moderators of relationships between negativity and weight gain. Reported and observed regulation at 1 year were used to test cross-sectional relationships between regulation and weight status, as well as relationships between regulation and weight gain from age 1 to 3. A parallel index of negativity was included as a covariate in all analyses investigating regulation. Soothability at 16 weeks was used to explore the longitudinal relationship between early forms of infant regulation and weight status at ages ~6 months and 1 year, as well as with residualized weight gain scores age 1 to 3. Infant sex, birth weight,
and feeding mode (Step 1) and intervention group(s) (Step 2) were tested as covariates in Aim 2 analyses.

For the final aim of this study, regression analysis was used to test whether intervention effects were moderated by infant temperament, using fussing/crying behavior at 3 weeks as a proxy for early negativity. Intervention outcomes assessed included observed infant self-regulation at 1 year and weight gain from birth to 1 year and from 1 to 3 years, as well as maternal self-efficacy and parenting satisfaction and the use of food to soothe at 1 year. Infant birth weight, sex, participation in the feeding intervention, and feeding mode were included as covariates in these analyses. For all interaction analyses, predictors were standardized.

**Results**

All variables of interest approximated a normal distribution except observed negativity. Infants were much more likely to show low observed negativity than to have scores in the higher extremes, so observed negativity was investigated as both a continuous variable and also as a dichotomous variable. The means and standard deviations of variables of interest are presented in Table 3. The distress to limitations and soothability subscales from the IBQ-R were relatively stable from 16 weeks to 1 year ($r=.32, p<.01; r=.42, p<.001$, respectively). Corresponding mother-reported and observational indices of temperament were not inter-correlated at 1 year (negativity: $r=.0031, p=.98$; regulation: $r=-.021, p=.85$), suggesting that reported and observed measures were tapping different aspects of temperament. Measures of negativity and regulation were inversely related (Table 4).
Aim 1: To Assess Whether this Randomized Intervention Affected Infant Temperament

The intervention and control groups did not differ on early indices of temperament or parenting, including infant fussing/crying at 3 and 16 weeks ($p=.44, .27$), distress to limitations ($p=.20$) at 16 weeks, soothability ($p=.56$) at 16 weeks, and maternal parenting satisfaction ($p=.31$) and self-efficacy ($p=.60$) at 3 weeks.

Effects on mother-reported negativity at 1 year. It was hypothesized that the intervention group would be higher on mother-reported negativity, but that the groups would not differ on total observed negativity at 1 year. Results were consistent with this hypothesis: In an unadjusted model, there was a trend for Soothe/Sleep intervention infants to be rated higher on negativity than control group infants ($t(90)=1.70, p<.10$). When adjusting for infant birth weight, sex, participation in the Introduction to Solids intervention, and time spent fussing before feeding at 16 weeks, intervention group ($\beta=.25, p<.05$) and time spent fussing before feeding ($\beta=.29, p<.01$) positively predicted reported infant negativity at 1 year, and the overall model was significant ($F(81,5)=2.74, p<.05$; Table 5). The use of food to soothe at age 1 was also tested in the sub-sample of participants who completed the Babies' Basic Needs Questionnaire (BBN) at age 1 ($n=79$): When adjusting for the food to soothe composite from the BBN, as well as infant birth weight, sex, and participation in the Introduction to Solids intervention, Soothe/Sleep intervention no longer affected mother-reported negativity ($p=.11$), and neither the use of food to soothe ($p=.12$) nor the overall model ($p=.25$) was significant. When using the food to soothe proportion scores, which assessed the use of food to soothe as a proportion of all soothing strategies used, both intervention group ($\beta=.34,$
and the food to soothe proportion scores ($\beta=.33, p=.01$) positively predicted reported infant negativity at 1 year in an overall significant model ($F(61,5)=3.03, p<.05$). The intervention group did not differ from the control group in the time spent fussing before feeding at 16 weeks ($p=.85$) or in the food to soothe proportion scores at 1 year ($p=.49$).

Multiple imputation was used to test whether these results were consistent in the original, 160 dyads who enrolled or whether selective attrition influenced the results. No relationship between Soothe/Sleep intervention group and mother-reported negativity at age 1 was detected using the imputed data ($p=.19$) and when adjusting for infant birth weight, sex, and participation in the Introduction to Solids intervention. When adding average minutes spent fussing before transitioning to feeding at 16 weeks to the model, Soothe/Sleep intervention remained non-significant, but time spent fussing before feeding significantly positively predicted mother-reported negativity ($t(136.93)=2.47, p<.05$). When adding the food to soothe proportion scores at 1 year to the original model, this variable did not relate to mother-reported negativity ($p=.24$).

**Effects on observed negativity at 1 year.** The Soothe/Sleep intervention did not affect observed temperamental negativity, neither in an unadjusted model, nor when adjusting for infant birth weight, sex, and participation in the Introduction of Solids intervention ($p=.91$). Because observed negativity was not normally distributed, this variable was also split at the median (.35), and a chi-square test was conducted. Results were consistent with those reported for negativity as a continuous variable; infants in the intervention group were no more likely to show observed negativity than
control infants ($\chi^2(96) = .09, p = .77$). Results were also consistent when multiple imputation was employed.

**Effects on mother-reported self-regulation at 1 year.** It was hypothesized that the intervention group would be higher on observed self-regulation, but that the groups would not differ on mother-reported regulation at 1 year. Results were consistent with this hypothesis. The intervention did not affect mother-reported soothability at 1 year ($p = .39$). In an unadjusted model, there was no effect of the Soothe/Sleep intervention on mother-reported infant regulation at 1 year; similarly, the intervention and control groups did not differ on mother-reported regulation when adjusting for infant birth weight, sex, negativity, and the Introduction to Solids intervention ($p = .46$).

**Effects on observed self-regulation at 1 year.** In an unadjusted model, there was a trend such that the Soothe/Sleep intervention increased the use of self-comforting behaviors at age 1 year ($t(75.752) = -1.71, p = <.10$). When adjusting for infant birth weight, sex, negativity, participation in the feed intervention, and time spent fussing before feeding at 16 weeks, the Soothe/Sleep intervention became a significant predictor of improved self-regulation ($\beta = .23, p < .05$; Table 6). When the food to soothe composite at age 1 was added to the adjusted model predicting self-regulation, the overall model was non-significant ($p = .12$); the same was true for the food to soothe proportion score ($p = .33$). When multiple imputation was employed, and the original 160 participants were tested, the Soothe/Sleep intervention did not affect reported or observed self-regulation at 1 year ($p = .94$ and $p = .23$, respectively).
In sum, the results from Aim 1 show that the Soothe/Sleep intervention increased mother-rated infant negativity but did not affect observed negativity during a standardized frustration task. The use of food to soothe at 16 weeks was positively predictive of negativity at 1 year, but this variable did not explain the intervention’s effects on reported negativity. Results were similar when using the food to soothe proportion score at 1 year in a sub-sample. The Soothe/Sleep intervention did not affect mother-rated infant regulation, but those in the Soothe/Sleep intervention group tended to show a higher proportion of self-comforting behaviors during the Toy Removal at 1 year, which is a measure of observed regulation. This trend became significant when the use of food to soothe at 16 weeks was added to the model; this finding was not significant when using the two food to soothe indices from the Babies’ Basic Needs Questionnaire at 1 year. When multiple imputation was used to investigate these effects in the original 160 recruited dyads, the intervention effects on reported negativity and observed regulation were non-significant.

Aim 2: To Examine Whether Temperament is Related to Weight Status in our Sample

Infant negativity and weight status. It was hypothesized that greater negativity would positively predict BMI-for-age z-scores at ~6 months and 1 year. Neither fussing/crying at 3 weeks nor mother-reported infant distress to limitations at 16 weeks was related to BMI z-scores at age ~6 months ($p= .73, .91$) or 1 year ($p= .12, .28$); results were consistent when adjusting for infant birth weight, sex, and predominant feeding mode. Neither mother-reported infant negativity ($p= .95$) nor observed negativity ($p= .41$) at 1 year was related to BMI z-scores at 1 year in adjusted or unadjusted models.
It was hypothesized that initial maternal self-efficacy would moderate relationships between infant negativity and weight gain. This hypothesis was not confirmed in analyses of mother-reported infant temperament but was confirmed when adding initial maternal self-efficacy to the model investigating relationships between observed negativity at 1 year and weight gain from 1 to 3. Initial maternal self-efficacy moderated the relationship between observed negativity and weight gain ($\beta = -0.40$, $p < 0.01$), such that greater infant negativity predicted greater weight gain when mothers were lower on self-efficacy, but negativity and weight gain were not related for mothers with higher self-efficacy (Figure 1). Results were consistent when operationalizing observed negativity as a dichotomous variable. The use of food to soothe at 3 weeks did not moderate the relationship between negativity and weight gain.

Results were consistent in the multiple imputation analyses in that there were no direct relationships between negativity and weight status. However, the interaction between negativity and maternal self-efficacy was no longer significant in this sample ($t(123.7) = -1.38$, $p = 0.17$). Consistent with the initial analyses, the use of food to soothe did not moderate the relationship between negativity and weight gain.

**Infant regulation and weight status.** It was also hypothesized that higher self-regulation would be related to lower BMI z-scores at ~6 months and 1 year and slower weight gain from birth to 1 year and birth to 3 years. Mother-reported soothability at 16 weeks, an early precursor of self regulation, was not related to BMI z-scores at ~6 months or 1 year. Greater reported self-regulation at 1 year was related to lower BMI z-scores at 1 year in the unadjusted model ($\beta = -0.26$, $p = 0.01$; Figure 2); results were consistent when adjusting for infant birth weight, sex, feeding mode, and mother-rated
negativity. Adjusting for earlier indices of infant negativity (e.g., fussing/crying at 3 weeks, distress to limitations at 16 weeks) did not explain this association, and results were also consistent when testing reported soothability at 1 year in place of the broader construct of regulation. Observed regulation was not related to BMI z-scores at 1 year in unadjusted ($p=.82$) or adjusted regression models. Neither mother-reported regulation nor observed regulation at 1 year predicted weight gain from 1 to 3 years ($p=.71$, $p=.46$).

Results were consistent when investigated in the original 160 participants, including the relationship between mother-reported regulation and BMI z-scores at 1 year, which remained significant ($t(191.42)=-2.02$, $p<.05$). In all Aim 2 analyses, results were consistent when adding the additional dichotomous covariates representing participation in either of the two interventions (data not shown). The impact of adding maternal education and/or family income into the models was also explored. Results were consistent in these initial explorations, but it was decided to leave these variables out of the final models given the homogeneity of our sample (e.g., ~85% of mothers reported that their education consisted of at least “some college”) and the small sample size.

In sum, neither reported nor observed infant negativity predicted concurrent or subsequent weight status, but observed negativity predicted greater weight gain in infants of mothers with lower self-efficacy. Higher mother-reported infant regulation at 1 year predicted a lower concurrent weight status. Observed infant regulation was not linked to weight status, and neither index of infant regulation was related to subsequent changes in weight. The relationship between the mother-reported regulation super-
factor from the IBQ-R and weight status at 1 year was particularly robust as demonstrated by the consistent results when investigating the relationships in the \(n=160\) sample.

**Aim 3: To Test Early Negativity as a Moderator of Intervention Effects**

**Effects on infants.** It was hypothesized that more highly negative infants would benefit more from the Soothe/Sleep intervention, showing greater self-regulation at 1 year and less weight gain over the course of the study. As in Aim 1, there was a main effect of the Soothe/Sleep intervention on observed self-regulation at 1 year, but this effect was not modified by initial negativity \((p=.28)\). There was a trend toward an interaction between initial infant negativity and the Soothe/Sleep intervention predicting weight gain from birth to age 3, adjusting for infant birth weight, sex, participation in the feeding intervention, and predominant feeding mode \((\beta=-.24, p=.06)\). In the intervention group, infants higher on negativity tended to show less weight gain while control group infants higher on negativity showed greater weight gain (Figure 3). When repeating these analyses on the 160-participant sample, there was no interaction between initial negativity and the Soothe/Sleep intervention in predicting infant self-regulation at one year, nor was there a main effect of the Soothe/Sleep intervention \((p=.22)\) in this sample. Also, the trend toward an interaction between initial negativity and the Soothe/Sleep intervention in predicting weight gain was no longer significant \((t(112.42)=-.60, p=.55)\).

**Effects on mothers.** It was hypothesized that mothers of more negative infants would benefit more from the Soothe/Sleep intervention, showing less frequent use of food to soothe and greater parenting self-efficacy and satisfaction at 1 year. Negativity
and the Soothe/Sleep intervention did not interact to predict self-efficacy or the use of food to soothe as measured by the Babies’ Basic Needs Questionnaire. The interaction was significant in predicting parenting satisfaction, both in the unadjusted ($\beta=.26, p<.05$) model, and in a model adjusted for infant birth weight, sex, feeding mode, participation in the Introduction to Solids intervention, and initial parenting satisfaction at 3 weeks (Figure 4). Mothers of more negative infants were differentially susceptible to intervention effects, with higher parenting satisfaction in the intervention group and lower parenting satisfaction in the control group. This interaction was not significant in the original sample of 160 participants ($p=.21$).

In sum, early negativity did not moderate the effect of the Soothe/Sleep intervention on infant self-regulation but did tend to moderate the effect of the Soothe/Sleep intervention on weight gain, such that the intervention decreased weight gain in individuals who were higher on initial negativity. Early negativity did not moderate the effect of the Soothe/Sleep intervention on parenting self-efficacy or the use of food to soothe, but it did moderate effects on parenting satisfaction, such that those in the Soothe/Sleep intervention were protected from the inverse relationship between early negativity and later parenting satisfaction. These interactions were not significant when investigated in the original 160 participants using multiple imputation.

**Discussion**

In this study, temperament was explored as 1) an outcome, 2) a predictor, and 3) a moderator, and results highlighted the importance of a comprehensive investigation of the role of temperament in behavioral interventions. The pilot Soothe/Sleep intervention
increased mothers’ reports of infant negativity, but infants in the Soothe/Sleep intervention also had higher observed infant self-regulation at 1 year. There were no straightforward relationships between infant negativity and weight outcomes, but infants with greater observed negativity at 1 year whose mothers were low on initial parenting self-efficacy demonstrated greater weight gain from 1 to 3 years. Infant regulation was inversely associated with weight status but was not related to weight gain over time. Initial infant negativity moderated the effects of the Soothe/Sleep intervention on some, but not all, outcomes. Negative infants who participated in the Soothe/Sleep intervention tended to show less weight gain from birth to age 3, and their mothers showed improved parenting satisfaction, an affective parenting dimension reflecting parenting frustration and motivation (Johnston & Mash, 1989).

Each hypothesis was also investigated using multiple imputation to test whether results were similar in the original 160 recruited dyads. Most of the significant relationships were not replicated in the multiple imputation analyses, with the exception of the relationship between self-regulation and weight status. It is not surprising that results are different when comparing the recruited sample to the final sample as many differences were demonstrated when comparing the 110 mother-infant dyads that completed the study to the 50 dyads that dropped out. For example, those who completed the study tended to be more highly educated, with a higher income, a lower likelihood of having a minority status, and a greater likelihood of being married. This intervention’s effects on temperament, weight gain, and parenting satisfaction may not be generalizable to less-educated or lower-income samples, to racial or ethnic minorities, or to single mothers. One potential factor that could explain these discrepant
results is the inclusion criteria of the intent to breastfeed. Correspondingly, breastfeeding support was part of the current intervention. In the United States, there is an association between a higher likelihood of breastfeeding and a higher socioeconomic status (Grossman, Fitzsimmons, Larsen-Alexander, Sachs, & Harter, 1990). It is possible that the lower socioeconomic status participants were more likely to stop breastfeeding, and that this intervention became less relevant for them after doing so.

Regardless of the reason that these processes worked differently in the total sample, it will be important in subsequent intervention efforts to assess the varying demographic characteristics and behaviors of participants and to provide interventions that are inclusive and culturally and socially relevant. The current study was a pilot intervention to test whether the hypothesized processes worked in this initial, homogeneous sample. Thus the homogeneous sample and our inability to generalize beyond it could be interpreted as a strength in this phase of piloting (Lerner et al., 1985) as homogeneity can provide a clearer picture of findings in a given population. Although the intervention functioned differently in the original sample than in the 110 mother-infant dyads that completed the intervention, overall relationships between regulation and weight status were robust, suggesting that it should be a universal goal to promote infant self-regulation.

Overall, results in the 110 dyads that completed the study were consistent with hypotheses, with some exceptions. In the case of Aim 1, the main hypotheses were confirmed: the intervention affected reported but not observed negativity and observed but not reported regulation. However, intervention effects on temperament were not explained by the use of food to soothe. It was hypothesized that intervention mothers
would be less likely to use food to soothe, and that this would increase their awareness of infant distress/negativity but would also help establish infant self-regulation as these infants would have more opportunities to learn associations between distress and appropriate soothing responses, rather than associations between distress and feeding. One possibility is that this hypothesis was not confirmed due to measurement problems. The use of food to soothe was predictably related to some variables in this study (e.g., infant negativity at 1 year) but not others. One problem with the diary indices of the use of food to soothe is that it is impossible to tell whether the decision to feed following fussiness was informed by the infant showing hunger cues. The more global questionnaire assessment of food to soothe using the BBN was only administered to a subsample. It should be noted that Stifter et al. (under review) also found an unexpected (positive) relationship between maternal self-efficacy and the use of food to soothe using the Babies’ Basic Needs measure of food to soothe. As mentioned, this construct has been alluded to for some time but is only beginning to be studied; more research on its operationalization and relationship with other variables is needed.

One particularly robust and unexpected finding related to the use of food to soothe was its inverse relationship with subsequent infant negativity ratings, which remained significant in the multiple imputation analyses. Infants who had a longer latency to a feeding after a fussing/crying episode were more likely to be subsequently rated as higher on distress by their mothers. Similar to the possibility that a Soothe/Sleep intervention heightens maternal awareness of infant distress, this finding could indicate that these mothers are more “in tune” with their infants, feeding to soothe less but also picking up on infant negativity (which is probably expressed more as
adaptive soothing practices are sometimes more labor intensive and difficult, at least at first). The intervention effects on increased perceived negativity and increased observed self-regulation, as well as the interaction between infant temperament and the intervention in predicting parenting satisfaction, highlight that a heightened awareness of infant negativity is not necessarily a negative outcome. Furthermore, the absence of intervention effects on negativity in the multiple imputation analysis suggests that awareness of infant negativity was not responsible for attrition in the intervention group (although again, the lack of these and other group differences in the multiple imputation sample suggests that the intervention may not have been working in the dyads that dropped out, which could mean that its messages did not apply to these dyads or that they were not implementing the curriculum).

Although the exact mechanism explaining the Soothe/Sleep intervention’s effects on temperament in the study completers is not known, the effects on observed regulation are promising, as appropriate parental scaffolding of soothing should benefit infants’ self-regulation at this important developmental period of reorganization when such abilities are emerging (Fox & Calkins, 2003). The literature suggests that emergent self-regulation, as well as infant negativity, have implications for weight status. Results from our second aim demonstrate some relationships between negativity, regulation, and weight status; the temperamental constructs that were related to weight status (observed negativity, reported regulation) were opposite those that were affected by the intervention (reported negativity, observed regulation). This is consistent with the lack of relationships between the reported and observed temperament measures in this study and the conclusion that these measures were
tapping different aspects of reactivity and regulation. Taken together, these findings could mean that observed negativity and perceptions of self-regulation were the more robust and stable measures of temperament: our intervention did not affect them, and in turn, they were predictably related to weight outcomes.

In the literature, infant negativity, and more specifically distress to limitations, has been reliably, positively associated with weight outcomes, including weight status, weight gain, fatness, and overweight risk (e.g., Darlington & Wright, Slining et al., 2009). Our results diverge from this pattern in that reported negativity was not related to weight outcomes, but observed negativity was. Because this intervention was changing the parenting experience and parents’ perceptions of their infants, observed negativity is a more objective way to explore relationships between negativity and weight status in our sample. That being said, there was no straightforward association between negativity and weight gain: for highly negative infants, lower self-efficacy tended to predict greater weight gain, and higher self-efficacy tended to predict less weight gain. This finding is consistent with a goodness of fit perspective, that the implications of temperamental traits depend how well the environment fits with those traits. It was hypothesized that mothers higher on self-efficacy would be less likely to use food to soothe, responding to their infant’s higher levels of fussing/crying with more adaptive soothing techniques instead. The evidence did not support this hypothesis (not shown). Again, measurement issues could be at play, or more efficacious mothers may have employed some other behavior and/or environmental feature that protected their negative infants from too much weight gain, such as more adaptive bedtime behaviors that encourage nighttime sleep or more adaptive feeding practices.
In contrast to the infant negativity results, there was a straightforward (inverse) relationship between reported infant self-regulation and weight status at 1 year. Mothers who reported that their infants had higher self-regulation abilities (using the global super-factor from the IBQ-R that taps infant soothability, low pleasure intensity, duration of orienting, and cuddliness across a range of everyday situations) were more likely to have infants who were lighter. This relationship is consistent with the findings in the literature that higher self-regulation is associated with lower weight status although it cannot be concluded from these findings that self-regulation was protecting infants from weight gain. This relationship was cross-sectional, so some other factor (e.g., negativity, the intervention, or parenting) could have been causing both increased self-regulation and decreased weight status. Adding earlier negativity to the model did not attenuate the relationship between regulation and weight status. This relationship's emergence in both the initial and multiple imputation analyses suggests that it is not limited to the homogeneous final sample (although relatively speaking, the initial sample was homogeneous as well).

The fact that this sample was well-educated and homogeneous could explain the lack of some predicted relationships with negativity and food to soothe. Perhaps these mothers know not to use food to soothe, and either have an actual restriction of range on this variable or increased social desirability in reporting on it. The current study's mean value for the food to soothe composite from the BBN was similar to, but slightly lower than, that reported by Stifter et al. (under review). The mean values for mother-reported temperament subscales were consistent with previous findings. For example, Parade and Leerkes (2008) found a mean distress to limitations score of 3.19, and a
mean soothability score of 5.02 in a sample of 6-month-old infants. Additionally, although this sample was characterized by demographics and feeding practices that predict decreased obesity risk, the average infant weight status at 1 year already reflected upward percentile crossing (Table 3), reiterating the current need to test and apply early preventive interventions across demographic groups.

The final aim of this study was to test whether early temperament moderated the effects of the Soothe/Sleep intervention on weight outcomes and a variety of other domains. A differential susceptibility model guided the development of this hypothesis (Belsky, 2007): perhaps negative infants, those who would presumably be more at risk without the intervention, benefitted the most from it. If this was the case, this could explain some of the null findings in terms of links between early temperament and weight status across our sample. We investigated initial negativity 3 weeks as a moderator of intervention effects on infant regulation and weight gain and maternal use of food to soothe, self-efficacy, and parenting satisfaction. The intervention effects on observed self-regulation remained a significant main effect: the intervention increased self-regulation for everybody; it did not matter if one was a highly negative infant (who arguably would need the extra help promoting self-regulation) or a less negative infant. Temperament did moderate intervention effects on weight gain and parenting satisfaction, however. Highly negative infants in the Soothe/Sleep intervention group showed less weight gain from birth to age 3, compared to intervention group infants lower on negativity. This analysis was conducted on the sample of infants with follow-up weight status data at age 3, so it is a smaller sample ($n=72$). Additionally, highly negative infants in the Soothe/Sleep intervention group had mothers with higher
parenting satisfaction at 1 year, compared to highly negative infants in the control group and less-negative infants in the intervention group. Of these two interactions, the latter was more consistent with the theory of differential susceptibility; there was a greater difference in the outcome between control group and intervention group infants who were highly negative, compared to control versus intervention group infants who were lower on negativity.

Both the effects on weight gain and parenting satisfaction are highly relevant as weight outcomes were the main focus of this intervention, and parenting satisfaction increases in the more negative infants are notable, given the earlier finding that our intervention increased awareness of infant negativity. This provides further evidence that heightening parental awareness of infant negativity was not necessarily a problem. These findings also support the idea that intervention effects could be more powerful when offered to an at-risk sample, and this idea has implications for future obesity prevention research with lower income, lower educated, and racial/ethnic minority populations. As suggested by the multiple imputation analyses, tailoring of the intervention messages will be needed to accommodate these at-risk groups.

This selective attrition and the corresponding inability to generalize beyond well-educated, White, breastfeeding mother-infant dyads is one limitation of the current study. Additional limitations include a limited follow-up period (the study was designed to follow infants to age 1 year; subsequent height and weight data are not available for all participants) and limited measures of intervention implementation quality. As mentioned, the homogeneous sample could also be considered a strength in a pilot study like this one. Other strengths include randomized assignment to groups, a
longitudinal study design, intervention delivery by home-visiting nurses, measured weights and lengths, and the inclusion of multiple temperament measures.

In sum, this study showed that individual differences in temperament should be considered in behavioral childhood obesity interventions. The Soothe/Sleep intervention affected maternal perceptions of infant negativity, as well as observed self-regulation, and early temperament also moderated intervention effects on weight gain and parenting satisfaction. Efforts to promote infant self-regulation as it is emerging are a promising avenue toward early obesity prevention, and increasing children’s self-regulation could have benefits in multiple domains. Achieving such effects may mean a heightened awareness of infant distress, but this study provided numerous forms of evidence that such awareness is not necessarily a negative quality. However, parents need strategies to learn to efficaciously deal with infant negativity. Mothers lower on initial self-efficacy with negative infants were at heightened risk in this study. The current results highlight that infant temperament should be considered in future research efforts, and as these results cannot be generalized beyond well-educated, White, intent-to-breastfeed samples, the next step is to explore these mechanisms in samples at heightened obesity risk. Although a seemingly-daunting task, differential susceptibility theory suggests that understanding and implementing successful interventions in these populations could lead to even greater effects.
References


Available at: http://www.cdc.gov/mmwr/pdf/rr/rr5909.pdf.


## Tables

**Table 1**

*Descriptive Statistics for Dyads Completing Study and by Control vs. Intervention Groups*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall (n=110)</th>
<th>Control (n=59)</th>
<th>Intervention (n=51)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Maternal education</td>
<td>65% completed college</td>
<td>61%</td>
<td>69%</td>
</tr>
<tr>
<td>2. Family income</td>
<td>70% earned &gt;$50,000</td>
<td>67%</td>
<td>73%</td>
</tr>
<tr>
<td>3. Maternal age</td>
<td>M = 27.1 (4.7)</td>
<td>27.5 (4.9)</td>
<td>26.6 (4.6)</td>
</tr>
<tr>
<td>4. Infant sex</td>
<td>51% female</td>
<td>59% #</td>
<td>41% #</td>
</tr>
<tr>
<td>5. Infant race</td>
<td>90% White</td>
<td>86.4%</td>
<td>94.1%</td>
</tr>
<tr>
<td>6. Maternal BMI*</td>
<td>M = 25.1 (5.7)</td>
<td>24.4 (4.8)</td>
<td>25.8 (6.6)</td>
</tr>
<tr>
<td>7. Infant birth weight (kg)</td>
<td>M = 3.33 (.48)</td>
<td>3.25 (.47) #</td>
<td>3.43 (.47) #</td>
</tr>
<tr>
<td>8. Predominant feeding mode at age 16 weeks</td>
<td>51% breast</td>
<td>47.4%</td>
<td>55%</td>
</tr>
<tr>
<td>9. BMI-for-age z-scores+</td>
<td>.30 (.93)</td>
<td>.40 (.81)</td>
<td>.19 (1.05)</td>
</tr>
</tbody>
</table>

*pre-pregnancy, + from World Health Organization growth standards

# p<.10
Table 2

Selective Attrition: Demographic Differences between Study Completers and Drop-outs

<table>
<thead>
<tr>
<th>Variable</th>
<th>Study completers (n=110)</th>
<th>Drop-outs (n=50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Maternal education**</td>
<td>65% completed college</td>
<td>44%</td>
</tr>
<tr>
<td>2. Family income*</td>
<td>72% earned &gt;$50,000</td>
<td>69%</td>
</tr>
<tr>
<td>4. Minority status*</td>
<td>9% non-White</td>
<td>24% non-White</td>
</tr>
<tr>
<td>5. Maternal pre-pregnancy BMI</td>
<td>25.06 (5.72)</td>
<td>25.03 (5.14)</td>
</tr>
<tr>
<td>6. Infant birth weight</td>
<td>3.33 (.48)</td>
<td>3.33 (.51)</td>
</tr>
<tr>
<td>7. Still breastfeeding at 3 weeks #</td>
<td>75%</td>
<td>62%</td>
</tr>
</tbody>
</table>

* Significant difference between groups, * p < .05; ** p < .01; trend toward a difference, # p < .10

All of these items were assessed at infant birth except for breastfeeding status. Sample sizes are as indicated above except: Some mothers did not report on their family’s income (study completers n=102; drop-outs n=36); some attrition had already taken place by 3 weeks; for breastfeeding status at 3 weeks, the drop-outs n=42.
Table 3

Descriptive Statistics for Variables of Interest

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily fussing/crying minutes at 3 wk</td>
<td>87.4 ± 59.9</td>
<td>0 – 296.3</td>
</tr>
<tr>
<td>Distress to limitations at 16 wk</td>
<td>3.23 ± .78</td>
<td>1.50 – 5.31</td>
</tr>
<tr>
<td>Soothability at 16 wk</td>
<td>5.02 ± .67</td>
<td>3.72 – 6.88</td>
</tr>
<tr>
<td>Reported negativity at 1 yr</td>
<td>3.14 ± .55</td>
<td>1.82 – 4.44</td>
</tr>
<tr>
<td>Observed negativity at 1 yr</td>
<td>0.52 ± 0.56</td>
<td>0 – 2.73</td>
</tr>
<tr>
<td>Reported regulation at 1 yr</td>
<td>4.75 ± .64</td>
<td>3.25 – 6.33</td>
</tr>
<tr>
<td>Observed regulation at 1 yr</td>
<td>0.09 ± 0.12</td>
<td>0 – 0.57</td>
</tr>
<tr>
<td>FTS* at 16 weeks (diary)</td>
<td>11.9 ± 10.2</td>
<td>0 – 56</td>
</tr>
<tr>
<td>FTS* at 1 year (BBN composite)</td>
<td>2.38 ± .80</td>
<td>1 – 5</td>
</tr>
<tr>
<td>Maternal self-efficacy at 3 wk</td>
<td>4.50 ± 0.69</td>
<td>2.86 – 6.00</td>
</tr>
<tr>
<td>Maternal self-efficacy at 1 yr</td>
<td>5.06 ± 0.59</td>
<td>3.43 – 6.00</td>
</tr>
<tr>
<td>Maternal parenting satisfaction at 1 yr</td>
<td>4.77 ± 0.59</td>
<td>3.33 – 6.00</td>
</tr>
<tr>
<td>BMI-for-age z-scores ~6 mo</td>
<td>-0.27 ± 1.07</td>
<td>-3.14 – 2.42</td>
</tr>
<tr>
<td>BMI-for-age z-scores at 12 mo</td>
<td>0.30 ± 0.93</td>
<td>-3.97 – 3.57</td>
</tr>
<tr>
<td>BMI-for-age z-scores ~36 mo (n=72)</td>
<td>0.57 ± 1.06</td>
<td>-1.56 – 3.66</td>
</tr>
</tbody>
</table>

Note: Main effect variables were standardized in analyses involving interactions in order to avoid Heywood cases. Descriptive statistics are provided for raw variables, which are also used in the figures in the interest of interpretability.

*FTS = food to soothe
Table 4

*Most Indices of Negativity and Regulation were Inversely Correlated at 16 Weeks and 1 Year*

<table>
<thead>
<tr>
<th>Regulation:</th>
<th>IBQ-R Soothability (16 weeks)</th>
<th>IBQ-R Soothability (1 year)</th>
<th>IBQ-R Regulation (1 year)</th>
<th>Observed Regulation (1 year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negativity:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distress to Limitations (IBQ-R subscale, 16 wks)</td>
<td><strong>-.32</strong></td>
<td><strong>-.24</strong></td>
<td>.043</td>
<td><strong>-.21</strong></td>
</tr>
<tr>
<td>Distress to Limitations (IBQ-R subscale, 1 year)</td>
<td>-.20#</td>
<td><strong>-.21</strong></td>
<td><strong>-.22</strong></td>
<td>-.20#</td>
</tr>
<tr>
<td>IBQ-R Negativity (Super-factor, 1 year)</td>
<td><strong>-.25</strong></td>
<td><strong>-.22</strong></td>
<td>-.003</td>
<td><strong>-.19</strong></td>
</tr>
<tr>
<td>Observed Negativity (Toy Removal at 1 year)</td>
<td>-.003</td>
<td>.052</td>
<td>-.11</td>
<td>.058</td>
</tr>
</tbody>
</table>

# p<.10; * p<.05; ** p<.01
Table 5

_The Soothe/Sleep Intervention Increased Mother-reported Infant Negativity at 1 Year_

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unadjusted model (R² = .040)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intervention</td>
<td>.22</td>
<td>.11</td>
<td>.06#</td>
</tr>
<tr>
<td><strong>Adjusted model (R² = .16)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intervention</td>
<td>.29</td>
<td>.12</td>
<td>.25*</td>
</tr>
<tr>
<td>Infant birth weight (kg)</td>
<td>-.10</td>
<td>.12</td>
<td>-.09</td>
</tr>
<tr>
<td>Infant sex</td>
<td>.01</td>
<td>.11</td>
<td>.01</td>
</tr>
<tr>
<td>Participation in Intro to Solids</td>
<td>.13</td>
<td>.11</td>
<td>.12</td>
</tr>
<tr>
<td>Fussing before feeding at 16 weeks</td>
<td>.02</td>
<td>.01</td>
<td>.29**</td>
</tr>
</tbody>
</table>

# p<.10; * p<.05; ** p<.01
Table 6
*The Soothe/Sleep Intervention Increased Observed Infant Self-regulation at 1 Year*

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unadjusted model (R² = .032)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intervention</td>
<td>.042</td>
<td>.024</td>
<td>.18#</td>
</tr>
<tr>
<td><strong>Adjusted model (R² = .15)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intervention</td>
<td>.054</td>
<td>.025</td>
<td>.23*</td>
</tr>
<tr>
<td>Infant birth weight (kg)</td>
<td>-.006</td>
<td>.026</td>
<td>-.026</td>
</tr>
<tr>
<td>Infant sex</td>
<td>.021</td>
<td>.026</td>
<td>.086</td>
</tr>
<tr>
<td>Participation in Intro to Solids</td>
<td>-.060</td>
<td>.024</td>
<td>-.25*</td>
</tr>
<tr>
<td>Observed (concurrent) negativity</td>
<td>-.002</td>
<td>.022</td>
<td>-.008</td>
</tr>
<tr>
<td>Fussing before feeding at 16 weeks</td>
<td>-.002</td>
<td>.001</td>
<td>-.16</td>
</tr>
</tbody>
</table>

# p<.10; * p<.05
Figure 1. Mothers’ initial parenting self-efficacy moderates the relationship between observed infant negativity and weight gain from age 1 to 3. For infants whose mothers had lower parenting self-efficacy at 3 weeks, observed infant negativity during the Toy Removal task positively predicted weight gain from 1 to 3 years. Negativity and weight gain were not linked in infants whose mothers had higher self-efficacy, suggesting that early maternal self-efficacy could be protective against the increased obesity risk that seems to be present in highly negative infants. The interaction analysis was conducted on continuous variables, but a median split was used to depict two maternal self-efficacy groups to facilitate figure interpretability.
Figure 2. Mother-reported regulation at 1 year is inversely associated with concurrent weight status. Infants whose mothers report that they are higher on self-regulation abilities at age 1 are likely to have a lower BMI z-score, compared to infants with lower self-regulation. In the figure above, two outliers on weight status were removed. Results are consistent with and without these outliers (with the outliers removed: $r=-.26$, $p=.01$; with the outliers in: $r=-.30$, $p<.01$). BMI-for-age z-scores were calculated using the World Health Organization growth standards.
Figure 3. Initial infant negativity moderates the effects of the Soothe/Sleep intervention on weight gain. Intervention infants who had higher levels of initial negativity showed less weight gain relative to the rest of the sample. However, the Soothe/Sleep intervention may not have been a good fit for infants with the lowest levels of initial negativity. This finding supports the idea that temperament can moderate intervention effects but is not consistent with the hypothesis of differential susceptibility, which would have implied an interaction where infants higher on negativity did better with the intervention and worse without it. This analysis was conducted on the sample of individuals who had follow-up weight status data ($n=72$).
Figure 4. Initial infant negativity moderates the effects of the Soothe/Sleep intervention on mothers’ parenting satisfaction at 1 year. Mothers of highly negative infants were more susceptible to intervention effects on parenting satisfaction, suggesting that the soothing and sleeping curriculum may be particularly beneficial for these families.
Chapter 6
Integrative Discussion

The goal of this dissertation was to study infant behavioral states with multiple methods, including examining the effects of a Soothe/Sleep intervention on infant behaviors, as well as changes in behavioral states in macro and microtime, individual differences in behavioral states, and the implications of different behavioral patterns for infant weight outcomes. Each empirical study focused on a particular aspect of infant behavior, including sleep, fussing/crying, and temperament, and taken together, the results have implications for the targeting and timing of future preventive interventions.

An important descriptive finding with intervention implications was that infants of well-educated, initially-breastfeeding mothers demonstrated increases in relative weight status (according to World Health Organization growth standards) across the first year of life on average. Given that the demographic characteristics of this sample should decrease their likelihood of developing obesity, this finding suggests that in the current obesogenic environment, early intervention is universally warranted. Previous analyses demonstrated effects of the current intervention on weight status; infants who received the Soothe/Sleep intervention, as well as an Introduction to Solids intervention later in infancy, had a lower weight status at age 1 year, compared to infants receiving one or neither of these interventions (Paul, Savage, Anzman, Beiler, Marini, Stokes, et al., 2011). A universal need for intervention does not imply that the same intervention will work for all individuals, however, as indicated by the various findings reported herein (e.g., initial temperament moderated effects of the Soothe/Sleep intervention; many of the results failed to be replicated in the original 160 recruited dyads using multiple
Because obesity prevention in infancy is an emergent area of research, a first step was to characterize intervention effects and mediating and moderating mechanisms in a homogeneous sample; findings related to individual differences and selective attrition can inform subsequent efforts to modify and test the intervention in other populations.

In Chapter 2, one of the main aims was to test increases in infant sleep duration as a mediating mechanism of the Soothe/Sleep intervention's effects. Other aims were descriptive, including investigating behavioral changes on a macro-level time scale. Change over time in infant behavioral states over the first four months of life was characterized largely by linear trends, with some of the behavioral states demonstrating additional quadratic or cubic trends. Overall, total sleep, nighttime awake/calm time, total and nighttime fussing/crying, and total and nighttime feeding time decreased, and nighttime sleep and total awake/calm time increased over the first four months of infancy. Three variables emerged as moderators of these average changes over time, highlighting that individual differences impacted on these overall trends: 1) initial infant temperament moderated changes in total and nighttime sleep and total and nighttime fussing/crying; 2) maternal pre-pregnancy BMI moderated changes in total and nighttime sleep, nighttime awake/calm, and nighttime fussing/crying; and 3) infant feeding mode moderated changes in total awake/calm time and total feed time. Individual differences were greatest at the earliest time points. There were also developmental changes in the patterns of relationships between behavioral states: sleeping and feeding were inversely related at 3 weeks, and these inverse relations strengthened over time for the nighttime period but not 24-hour periods. Time spent
fussing was unrelated to feeding early on, but over time, these two variables became significantly, positively related. Finally, the hypothesis that changes in infant sleep and feeding time contributed to Soothe/Sleep intervention effects on weight status was supported, although some modifications to the original model were needed, and the hypothesis was only supported in breastfeeding dyads.

In Chapter 3, infants' behavioral transitions in microtime were the focus. Transitions out of sleep became less likely over time, demonstrating increased stability in this behavioral state. Transitions out of fussing/crying did not change from 3 to 16 weeks; there were substantial individual differences in the probability of transitioning from fussing/crying to feeding and to awake/calm at both time points. Further investigation highlighted transitions out of fussing/crying as malleable and predictive of weight outcomes: the likelihood of transitioning from fussing/crying to feeding was positively associated with maternal pre-pregnancy BMI and with infant weight status. The pilot intervention focused on infant soothing and sleeping increased the likelihood of transitioning from fussing/crying to awake/calm at 16 weeks; this finding could indicate that mothers in the intervention group are trying and using the adaptive soothing techniques that were taught to them, rather than using food to soothe infant distress. The use of food to soothe, operationalized in this study as the average time spent fussing/crying before feeding, was not related to demographics or to the intervention, but the inclusion of this variable changed the relationships between transitions out of fussing and weight status, suggesting that latency to feeding after a fussing episode has implications for weight status. A greater use of food to soothe (or a shorter latency to feeding from fussing) positively predicted weight status, and similarly,
a greater probability of staying in a fussing/crying state was inversely related to weight status. Taken together, the results demonstrated the utility of investigating person-specific behavioral transitions in the context of a behavioral childhood obesity intervention and supported the idea that relationships between fussing/crying and weight status may unfold over a micro-level time scale.

After exploring the roles of sleeping and fussing/crying in this intervention study, individual differences in behavior were conceptualized more broadly in Chapter 5; infant temperament was explored as an outcome, a predictor, and a moderator. Temperament, or individual differences in reactivity and regulation, provides clues as to the behaviors that an individual is predisposed to exhibit in a given eliciting context. Results highlighted the importance of a comprehensive investigation of the role of temperament in behavioral intervention studies. The Soothe/Sleep intervention increased mothers' reports of infant negativity, but infants in the intervention group also had higher observed infant self-regulation at 1 year. There were no straightforward relationships between infant negativity and weight outcomes, but infants with greater observed negativity at 1 year whose mothers were low on initial parenting self-efficacy demonstrated the greatest weight gain from 1 to 3 years, suggesting that promoting early maternal self-efficacy could be protective against increased obesity risk in highly negative infants. Infant regulation was inversely associated with weight status but was not related to weight gain over time. Initial infant negativity moderated the effects of the Soothe/Sleep intervention on some, but not all, outcomes. Negative infants who participated in the Soothe/Sleep intervention tended to show decreased weight gain from birth to age 3, and their mothers showed improved parenting satisfaction.
Taken together, the results from these three empirical studies have a number of implications. They highlight that early infancy is a promising time to intervene on a behavioral level to promote healthy behaviors and decreased obesity risk, and that even infants at decreased risk for obesity based on their demographics and/or feeding mode can benefit from such interventions. These studies also elucidate some of the mechanisms through which the Soothe/Sleep intervention had its effects. Macro-time changes in sleep, micro-time transitions out of fussing/crying, and infant self-regulation all seem to be viable behavioral targets that were affected by the Soothe/Sleep intervention and related to weight status. While these areas are promising behavioral targets, it is not necessary to try to decrease infant negativity. This point is supported by the lack of direct relationships between infant negativity and weight status, and the interactions where initial negativity did not have problematic implications in the context of the Soothe/Sleep intervention. Providing parents with tools to respond to infant distress and thus creating an environment that is a good fit for the infant could be the key to attenuating the link between temperamental negativity and obesity risk. Correspondingly, results also highlighted early parental self-efficacy and awareness of infant distress as potential areas to target.

This work confirms that a consideration of both developmental changes and individual differences is crucial in behavioral interventions. If individual differences played a role in this study conducted on a homogeneous sample, it is likely that they play an even larger role in the broader population. That being said, the next step is to test and refine interventions targeting the broader population, including those at increased obesity risk, such as formula-fed infants and infants born into families of a
lower socioeconomic status. There is evidence that these families may be less receptive to health-oriented interventions, and that they may not see childhood obesity or feeding to soothe as a problem (e.g., Baughcum, Burklow, Deeks, Powers, & Whitaker, 1998), even though their children tend to be heavier. However, “stealth interventions” (Robinson, 2010) such as the Soothe/Sleep intervention are promising because the primary outcome is not obvious; from parents' perspectives, the Soothe/Sleep intervention targeted not childhood obesity risk but the broader parenting domain, something that may be more universally appealing to families undergoing the transition to parenthood. Given this, as well as the developmental changes and flux in the first few months of infancy and findings linking weight outcomes to behavioral states and behavioral transitions at time points as early as 3 weeks, these interventions should start as early in the life span as possible and should provide parents with a tool kit of parenting strategies that they can adapt to their individual child’s behavior.

In addition to avoiding a focus on nutrition and obesity, interventions focusing on infant behavioral states, parental soothing, and the development of self-regulation also offer the possibility of effects in multiple domains. Greater self-regulation predicts positive outcomes in a myriad of domains (e.g., Eisenberg, Guthrie, Fabes, Reiser, Murphy, & Holgren, 1997); if these relations are especially robust in the case of supportive parents exerting developmentally-sensitive efforts to scaffold regulatory skills at various points in the life span, it is possible that interventions could be developed to combat both childhood obesity and other aspects of child well-being, like psychological adjustment and attention, maximizing resources and tackling multiple societal problems simultaneously.
References


Appendix. Data Analysis Plan and Results from Structural Equation Models

Data Analysis Plan

Analyses were conducted using the student edition of LISREL (Lincolnwood, IL). The initial hypothesis was that the intervention caused increases in total sleep, which led to decreases in feeding time and lower subsequent weight status. The modification indices were used to repeatedly alter the initial hypothesized model until arriving at a final model that was satisfactory, both conceptually and statistically. The input to test the initial model was as follows, where discor is a document containing the observed correlations between all of the variables of interest, and where the free beta parameters (be) represent paths in the model:

```
da no=110 ni=14 ma=km
km sy fi=discor.doc
la
interv slp3 fd3 slp4 fd4 slp8 fd8 slp16 fd16 bmiz6 bmiz12 brthwt sex feedgrp /
mo ny=14 ne=14 ly=id te=ze be=fu,fi ps=di,fr
fr be(1,12) be(1,13) be(1,14) be(2,1) be(3,2) be(4,2) be(5,3) be(5,4) be(6,4)
fr be(7,5) be(7,6) be(8,6) be(9,7) be(9,8) be(10,9) be(11,10)
ou it=999 ad=off
```

All models were tested with birth weight and infant sex as covariates because these are the variables that approach significance when testing for initial differences between the two study groups. The initial aggregate model (Figure 1) was refined according to the following process:

1. The modification indices provided by the program were consulted to locate any beta parameters that had been fixed at zero but that should have been estimated (i.e. included as a path in the model). These beta parameters were freed one by one, given their large modification indices, and the chi-square difference was assessed, comparing each modified model to the previous model. If a modified model demonstrated a significantly better fit, despite the loss in degrees of freedom, the newly-freed beta parameter was retained. Parameters were no longer added once the model demonstrated an acceptable absolute fit.
2. The estimated beta parameters were investigated to determine whether any were small enough to warrant fixing them at zero (i.e. removing this path from the model). These small beta parameters were fixed one by one, and the fit of each modified model was assessed. If the model was not significantly different from the previous, as indicated by a non-significant chi-square difference, then this new, more parsimonious model was retained.

3. The next step was to check that paths key to the a priori hypothesis under investigation were still included. In other words, if the pruning in the previous step resulted in removing the path connecting the intervention to infant sleep and/or connecting infant behavior(s) to weight status, the modification indices were re-visited to find the largest modification index in each of these categories and freeing the corresponding beta parameters. Given the a priori hypothesis, these changes were maintained as long as the resulting model did not demonstrate a poorer fit compared to the previous model.

4. Finally, any remaining beta parameters that were close to zero were fixed, and this change was retained as long as each new, more parsimonious model was not significantly different from the previous model.

The relative and absolute fit of the resulting final model were assessed to determine how the model fit the sample overall. Then, similar steps were carried out to test a two-group model to see whether breast-feeding and formula-feeding infants experienced the same intervention effects. The initial model for each group was the final model from the aggregate analysis. Parameters were initially constrained, so the groups had the same pattern (e.g., the same betas were freed and fixed in both groups), but the values of the parameters were allowed to differ. These constraints were altered based on model fit. An additional step in testing the two-group model was to set beta parameters to be equivalent across groups. This was done initially for
beta parameters that looked similar, adding additional constraints until a new model showed a poorer fit than the previous model.

The final step of this aim was to introduce to the hypothesized model any additional covariates that could be important based on the results of Aim 2 and to see if adding these additional parameters significantly improved the fit of the model. Based on the fit and the structure of the final models, conclusions were drawn with regards to whether a two-group model is needed, or whether one model is adequate to describe intervention effects on infant sleep and weight status.

Results: Refining the Aggregate Model

After running the initial model (Figure 1), the fit indices indicated that the model should be altered. The chi-squared value was 136.33 (df=75, \( p = .000019 \)), demonstrating that the model was significantly different from the observed relationships in the data, and the less conservative fit indices demonstrated a need for improvement as well: standardized RMR = .085 (<.05 is excellent, <.08 is acceptable; Molenaar, Class Notes, 2010), comparative fit index (CFI) = .89 (> .95 is excellent, > .90 is acceptable), and non-normed fit index (NNFI) = .87 (> .95 is excellent, > .90 is acceptable). The modification indices for the beta parameters were consulted, freeing the betas with the highest modification indices (i.e. adding paths). These steps were carried out one at a time, investigating the absolute fit and the relative improvement in fit each time and stopping this step after attaining both a significant relative improvement as well as an acceptable absolute model fit. After this, the beta matrix was examined to determine whether any betas were small enough to warrant fixing (i.e. removing paths).

The largest modification index was be(8,7), indicating that the path from total feed time at 8 weeks to total sleep time at 16 weeks should be free. A test of the improvement in fit indicated that this modified model was a significant improvement over the former (\( \Delta \chi^2(1)=4.12, p<.05 \)); the absolute fit is not quite acceptable (RMR=.086, CFI=.90, NNFI=.87). The next
largest modification index was be(8,3); upon freeing this additional path, this modified model was an improvement over the former ($\Delta \chi^2(1)=17.12, p<.001$), and the absolute fit was acceptable (RMR=.08, CFI=.93, NNFI=.91).

In the interest of parsimony and in testing a model similar to the original hypothesis, parameters were no longer added at this point, and the beta matrix of the most recent model was examined to see whether any paths could be removed before establishing a final model. The smallest betas were be(2,1) and be(10,9), so these were fixed at zero one at a time. After fixing be(2,1), the fit of the model was not significantly different (i.e., not significantly worse, $\Delta \chi^2=.04$), and a degree of freedom was gained. After fixing be(10,9) as well, the fit of the model was still not significantly different ($\Delta \chi^2=.08$), but again, a degree of freedom was gained, suggested that this more parsimonious model is preferable.

However, these changes have removed the paths from the Soothe/Sleep intervention to sleep at 3 weeks and from feeding at 16 weeks to weight status at ~6 months. In investigating hypotheses that the intervention affected behavior, it is conceptually necessary to check whether there is a way to reconnect the Soothe/Sleep intervention to one of the behaviors and to connect one of the behaviors to weight outcomes. Thus, as a final step, the modification indices were investigated for 1) any betas that would allow the Soothe/Sleep intervention to predict sleeping at any time point and 2) any betas that would allow sleeping or feeding at any time point to predict weight status. In each of these categories, the beta parameter with the largest modification index was freed, and the model was accepted if its fit was not significantly poorer than the previous model's. The beta in the first category with the largest modification index was be(6,1), or total sleep at 8 weeks regressed on the Soothe/Sleep intervention. This revised model did not fit worse than the previous model ($\Delta \chi^2(1)=2.57, p>.05$); given the improved conceptual fit, this added beta was retained. The beta in the second category with the largest modification index was be(11,9), or BMI-for-age z-scores at 1 year regressed on total feed time at 16 weeks. This modified model did not fit worse than the previous model.
given the improved conceptual fit, this added beta parameter was also retained.

The last step in establishing a model for the total sample was to fix any remaining beta parameters that were close to zero, with the exception of those that were added for conceptual reasons linked to the hypothesis (i.e. the two parameters added in the previous paragraph and the covariates that were depicted as predictors of the intervention). There were two betas that met these criteria: be(5,4) and be(7,6). These betas were removed one at a time, and each subsequent model gained a degree of freedom and was not significantly worse than the previous model ($\Delta \chi^2 = 2.27$ and 2.63, respectively).

Results: Refining and Testing a Two-group Model

To determine whether a more precise depiction of intervention effects could be obtained by investigating this model by feeding mode, a two-group model was tested, applying the final model from the previous section (Figure 10) to breast-feeders and formula-feeders. After running this initial two-group model with the patterns but not the values of the parameters constrained to be equal across groups, results indicated that the model should be altered. The chi-squared value was 220.05 (df=150, $p=.00017$), demonstrating that the model was significantly different from the observed relationships in the data, and the less conservative fit indices demonstrated a need for improvement as well: standardized RMR = .11, CFI = .89, and NNFI = .86.

The next step was to consult the modification indices for the betas in each group and to add paths where the modification indices were particularly high to try to improve the fit. The largest modification index was for be(11,2) in the formula feeding group, so this beta was freed in that group only. The chi-square difference between this and the previous model was 10.04 (df=1), which is a significant increase in model fit ($p<.01$). The alternative fit indices reflect this improvement but also indicate that the model could be improved further (RMR=.10, NNFI=.88,
Upon investigating the modification indices for the beta parameters of this model, the largest was be(9,5) in the breastfeeding group, so this beta was freed in that group only. The chi-square difference between this and the previous model was 7.83 (df=1; \( p < .01 \)), indicating an improved model fit, and RMR=.10, NNFI=.89, and CFI=.91. The next largest modification index was be(7,13) in the formula feeding group, and after freeing this parameter, the chi-square difference between this and the previous model was 8.83 (df=1, \( p < .01 \)), indicating an improved relative fit. The absolute fit was acceptable according to two of the alternative fit indices (RMR=.10, NNFI=.91, CFI=.92).

The next step was to investigate the beta values in each group and to attempt fixing any betas that were close to zero, with the exception of the covariates. In the breastfeeding group, betas that fit this description were be(6,1), be(8,3), be(8,7), and be(11,9). In the formula-feeding group, betas that fit this description were be(6,1) and be(9,8). These were removed, one at a time, from smallest to largest, and the new beta values and fit indices were checked each time before proceeding. Each time, the beta value was fixed if the fit of the resulting more parsimonious model was not significantly worse, and the next beta parameter on the list was tested if it had remained small in the most recent model. The subsequent steps were: be(11,9) was fixed in the breastfeeding group (\( \Delta \chi^2(1)=.01, p>.05 \)), be(8,7) was fixed in the breastfeeding group (\( \Delta \chi^2(1)=.15, p>.05 \)), be(9,8) was fixed in the formula-feeding group (\( \Delta \chi^2(1)=1.20, p>.05 \)), be(6,1) was fixed in the breastfeeding group (\( \Delta \chi^2(1)=1.58, p>.05 \)), be(6,1) was fixed in the formula-feeding group (\( \Delta \chi^2(1)=2.55, p>.05 \)), and be(8,3) was fixed in the breastfeeding group (\( \Delta \chi^2(1)=2.22, p>.05 \)).

After going through these steps, the models for each group were revised further by first adding back in parameters that were key to the hypothesis (connection between intervention and sleep, connection between behavior and weight status), choosing which beta parameter to free in each category based on the modification index that was the highest. In the breastfeeding group, be(4,1) was freed, and in the formula-feeding group, be(6,1) was freed. These
parameters, added for theoretical reasons, did not significantly alter the model fit ($\Delta \chi^2(2)=4.23, p>.05$), so they were retained. Then, in the breastfeeding group, be(11,7) was freed, and in the formula-feeding group, be(10,7) was freed. These added parameters did not significantly alter the model fit ($\Delta \chi^2(2)=5.31, p>.05$), so, given the hypothesis, they were retained as well.

Next beta values in this model were investigated to see whether any of them could be set as equal across groups. The first attempt was to set the following beta parameters, which had similar values to one another, to be equal across groups: be(3,2), be(5,3), be(6,4), be(7,5), be(1,12), be(1,13). This model did not have a significantly worse fit than the previous ($\Delta \chi^2(6)=.24, p>.05$), so these equivalences were maintained. More constraints were tested by setting the remaining betas estimated in both groups to be equal, but this worsened the fit rather than improving it. Thus, additional betas were not constrained to be equal across groups.

Next, the relationships between the same behaviors at different time points were constrained to be equal within each group: be(5,3), be(7,5), and be(9,7) were constrained to be equal to one another, as well as be(4,2), be(6,4), and be(8,6). This change resulted in a model that had a significantly poorer fit than the previous, so this constraint was not retained. The next attempt was to constrain only the parameters that were most similar to one another, setting be(6,4) and be(8,6) equivalent and be(5,3), be(7,5), and be(9,7) to be equivalent. When this slightly more conservative step was taken, the new model was not significantly different from the previous accepted model ($\Delta \chi^2(5)=7.02, p>.05$), so this constraint was maintained.

Final steps were to check whether any of the beta parameters in the model were small enough to warrant fixing to zero and to investigate the models at this point for correspondence with the original hypothesis and to adjust them accordingly if needed. These final changes were made for each group in turn. In the breastfeeding group, be(9,8) was small; thus, that parameter was fixed at zero. This modified model was not significantly different from the previous ($\Delta \chi^2(1)=1.70, p>.05$) and was more parsimonious, so be(9,8) remained fixed in the breastfeeding group. Given the original hypothesis, the next attempt was to free a beta
parameter connecting sleeping behavior to feeding behavior in the breastfeeding group. The modification indices were consulted, and be(5,4) had the largest modification index. This beta parameter was freed in the breastfeeding group, and this added parameter resulted in a significantly better model fit ($\Delta \chi^2(1)=8.48$, $p<.01$). In the formula-feeding group, no remaining estimated beta parameters were exceptionally small. Additional beta parameters in line with hypothesis were freed, but these modifications did not significantly improve the model. Also, at this point, this model has been modified to become substantially different from the hypothesized effects. Thus, the formula-feeding group model was left as is and was accepted at this point.

Overall, the two-group model had an acceptable fit according to the chi-square ($\chi^2(158)=192.01$, $p=.043$) and NNFI (.94) and an excellent fit according to the CFI (.95; Figures 11-12).
CURRICULUM VITAE:

Stephanie Anzman Frasca

The Center for Childhood Obesity Research
The Pennsylvania State University
129 Noll Laboratory, University Park, PA
Phone: 814-863-0607
Email: sla197@psu.edu
URL: stephanieanzman.weebly.com

EDUCATION

Ph.D. Human Development and Family Studies
The Pennsylvania State University, August 2011
Thesis: A multi-method investigation of infant behavioral states and weight status
Advisor: Dr. Leann L. Birch

M.S. Human Development and Family Studies
The Pennsylvania State University, May 2008
Thesis: Inhibitory control predicts weight gain and overweight in a longitudinal study of girls
Advisor: Dr. Leann L. Birch

B.A. Psychology, French
Bucknell University, May 2006
Summa cum laude, Honors in Psychology

POSITIONS HELD

2009-Present Instructor, Department of Human Development & Family Studies, The Pennsylvania State University

2006-Present Graduate Research Assistant, The Center for Childhood Obesity Research, The Pennsylvania State University

SELECTED PUBLICATIONS


