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Infants' Transitions out of a Fussing/Crying State Are Modifiable and Are Related to Weight Status

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Abstract

Currently, about 10% of infants have a weight for length greater than the 95th percentile for their age and sex, which puts them at risk for obesity as they grow. In a pilot obesity prevention study, primiparous mothers and their newborn infants were randomly assigned to a control group or a Soothe/Sleep intervention. Previously, it has been demonstrated that this intervention contributed to lower weight-for-length percentiles at 1 year; the aim of the present study was to examine infant behavior diary data collected during the intervention. Markov modeling was used to characterize infants' patterns of behavioral transitions at ages 3 and 16 weeks. Results showed that heavier mothers were more likely to follow their infants' fussing/crying episodes with a feeding. The intervention increased infants' likelihood of transitioning from a fussing/crying state to an awake/calm state. A shorter latency to feed in response to fussing/crying was associated with a higher subsequent weight status. This study provides preliminary evidence that infants' transitions out of fussing/crying are characterized by inter-individual differences, are modifiable, and are linked to weight outcomes, suggesting that they may be promising targets for early behavioral obesity interventions, and highlighting the methodology used in this study as an appropriate and innovative tool to assess the impact of such interventions.

Currently, about 10% of infants have a weight for length greater than the 95th percentile for their age and sex, and this puts them at risk for obesity as they grow (Ogden, Carroll, Kit & Flegal, 2012). Infancy has been highlighted as a promising period to intervene to prevent childhood obesity for multiple reasons. First, parents and caregivers have a high degree of control over their infant's experiences and environments. In addition, there is evidence that infant behavioral states, such as sleep and fussing/crying, are linked to weight outcomes (e.g., Darlington & Wright, 2006; Tikotzky et al., 2010). Finally, infancy precedes the onset of obesity in many individuals and is characterized by substantial, rapid change and instability (Institute of Medicine, 2011). Such periods of transition are prime opportunities for intervention as changes to the immediate environment, coupled with ongoing changes like physical and neural growth and learning, result in a greater likelihood of systemic reorganization and new behavioral phenotypes (Gottlieb, 2002; Van Geert, 2003). Links between rapid infant growth and subsequent weight status suggest that shifting early developmental trajectories could have a lasting impact (Gillman, 2008; Singhal et al., 2010). These factors advocate behavioral interventions during infancy as a way to affect obesity risk. However, intervening to prevent childhood obesity during infancy is an emergent approach (Hesketh & Campbell, 2010), and building an evidence base and interventions that are effective necessitates a thorough understanding of the development of infant behaviors and their relationships with weight outcomes.

There is a small, but growing body of evidence suggesting that infants with greater levels of negative affect may be at increased risk for subsequent obesity, particularly if this negativity is coupled with insensitive parenting styles (Wu, Dixon, Dalton, Tudiver & Liu, 2011). More specifically, high levels of fussing and crying may lead to excessive weight gain if caregivers transition infants into a feeding state following each fuss/cry episode (Stifter, Anzman-Frasca, Birch & Voegtline, 2011). If these transitions occur repeatedly, a greater number of feedings would be offered to infants who fuss and cry more, which could result in excessive weight gain. Early rapid weight gain can have long-term effects (Gillman, 2008). There is evidence that growth during early infancy is a more robust predictor of subsequent obesity, compared to weight gain that takes place later in development (Ekelund et al., 2007). Infants who are indiscriminately fed in response to fussing and crying that is not hunger-related may also learn associations between feeding and emotional states rather than learning to pair feeding with hunger, which could perpetuate excessive energy intake as development continues.

The idea that infants who fuss and cry more may be at risk for excessive weight gain due to indiscriminate feeding in response to fussiness has been invoked before (e.g., Carey, 1985; Darlington & Wright, 2006), but there is a dearth of studies that explicitly measure feeding in response to fussiness or "feeding to soothe" (Stifter et al., 2011). As part of the current study, nurses taught mothers in a "Soothe/Sleep" intervention group a number of developmentally-appropriate ways to respond to a non-hungry, fussy infant (e.g., swaddling, white noise) when their infants were 3 weeks old (Paul et al., 2011). It was hypothesized that mothers who learned these strategies would be less likely to indiscriminately follow fussing/crying episodes with a feeding. The goal of the current study was to use daily diaries and time series methodology to operationalize feeding to soothe behaviors on a micro-level and to test relationships between this construct and demographic variables, participation in the Soothe/Sleep intervention, and weight outcomes.

Assessing Behavioral Transitions in Microtime

Development includes change in macrotime and microtime (Ram & Gerstorf, 2009). Research questions involving macrotime in infancy include patterns of fussing and crying over the first months of life (e.g., Barr, 1990). 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. Development on a microtime scale includes transitions between these behavioral states and the formation of contingencies and daily behavior patterns. The likelihood of transitioning from one behavioral state to another is likely to differ across mother-infant dyads. In turn, patterns of transitions may be altered through intervention and may predict early growth and obesity risk. In the current study, individual differences among infants and modifiability of behavioral transitions were characterized using diary data obtained in an obesity prevention pilot study during the first 4 months of life (Paul et al., 2011). Markov modeling, a type of time series analysis, provides an appropriate methodological tool for characterizing such behavioral transitions in microtime.

A time series refers to a group of observations made sequentially in time (Chatfield, 2004), such as sequences of behaviors recorded in daily infant behavior diaries. Markov modeling allows an exploration of processes in microtime via research questions such as, “What is the likelihood of transitioning from a fussing state to a feeding state?” (Baum & Petrie, 1966; Visser, Raijmakers & Molenaar, 2002). In contrast to the traditional focus on average levels of behaviors, time series methods allow a comprehensive investigation of the temporal ordering of behaviors. Markov models yield the probabilities of starting in each category or state, as well as transition probabilities, which are the set of values that describe the likelihood of transitioning from each state to each other state (Rovine, Sinclair & Stifter, 2010; Visser, Raijmakers & Molenaar, 2007). We used Markov models to characterize transitions between behavioral states at different time points during infancy, particularly the likelihood of transitioning from a fussing/crying state to a feeding state or to an awake and calm state.

Characterizing Individual Differences in Behavioral Transitions

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 information may not represent even one individual (e.g., Lebo & Nesselroade, 1978). In the current study, individual Markov models were conducted for each infant, generating the probabilities that each infant transitioned from one behavioral state to another. Individual models are possible when extensive measurements are obtained from each participant, which allows for pooling over the time dimension instead of across individuals. While the diary data collected in this study afforded such an analysis, no individual’s time series of data were 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); here, individual differences were characterized by analyzing relationships between the individual transition probabilities and other variables of interest, allowing both a consideration of individual differences and generalization beyond the current sample.

Individual and family factors hypothesized to predict differences in the likelihood of transitioning from fussing to feeding included maternal pre-pregnancy body mass index (BMI), family income, maternal education, and the infant's initial temperament. These factors were chosen based on literature linking demographic, parent, and infant factors to infant feeding practices. Although the literature about feeding in response to infant fussiness is sparse, there is a larger body of research revealing factors associated with healthy versus unhealthy feeding practices. For example, higher maternal education has been associated with positive infant feeding practices (Hendricks, Briefel, Novak & Ziegler, 2006), and mothers with a higher pre-pregnancy BMI were more likely to endorse unhealthy feeding practices like restriction (Rifas-Shiman et al., 2011). Introducing complementary foods before age 4 months is another maladaptive practice and was more likely in the case of more negative, or "fussier" infants (Wasser et al., 2011). The small body of literature on feeding to soothe infant distress has indicated that this practice may also be more likely in families with fussier infants (Bentley, Gavin, Black & Teti, 1999; Stifter et al., 2011), and it has also been endorsed by lower-income families in focus groups (Baughcum, Burklow, Deeks, Powers & Whitaker, 1998).

In addition to links with infant and family factors, the effects of the Soothe/Sleep intervention on transition probabilities was also examined, to test the hypothesis that teaching mothers to use alternate soothing strategies other than feeding increased the likelihood of transitioning from fussing to awake/calm and decreased the likelihood of transitioning infants directly from fussing to feeding. Such effects could contribute to intervention effects on weight status. As mentioned, greater infant negativity is predictive of greater weight status or weight gain (e.g., Darlington & Wright, 2006; Slining, Adair, Goldman, Borja & Bentley, 2009), and researchers have hypothesized that this relationship is the result of more frequent feeding as an attempt to soothe infant distress in families where negative infants elicit more parental soothing behaviors (Carey, 1985; Darlington & Wright, 2006). There is a small, but growing body of evidence related to this point. First, there is a broader literature on responsive feeding, which can be defined as "prompt, contingent and developmentally appropriate responses to the infant's hunger and satiety cues" (DiSantis, Hodges, Johnson & Fisher, 2011), following the definition of sensitive responsiveness in the developmental literature (Ainsworth, Blehar, Waters & Walls, 1978). In two recent reviews, a positive association was found between non-responsive parent feeding practices and child weight status (DiSantis et al., 2011; Hurley, Cross & Hughes, 2011), leading the former group of authors to call for more rigorous research on responsive feeding interactions in early life. In a recent cross-sectional pilot study, Stifter et al. (2011) developed a new parent-report instrument to specifically measure parents' use of food to soothe their infant or child's distress and found that greater child negativity and higher mother-reported use of food to soothe acted in concert to predict a greater child weight status. We aim to add to this body of literature, using fuss to feed transitions to gain further insight into the construct of feeding to soothe. It should be noted that "food" will typically be breast milk or formula in this study, given the infants' ages.

In addition to examining the likelihood of transitioning from fussing/crying to feeding, the durations of the behavioral states are also of interest. For example, 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. To directly address such issues, we also explored the average time infants spent fussing/crying before transitioning to feeding. This latency to feeding variable can be considered an index of feeding to soothe as it indicates how long caregivers waited before feeding in response to infant distress.

Taken together, the overall goal of this study was to follow up on previously-published tests of intervention effects (Paul et al., 2011) by focusing on the Soothe/Sleep intervention and using a novel methodological approach to investigate its effects on behavior on a microtime scale. Specifically, the primary aim was to use Markov models to investigate individual differences in patterns of transitions out of a fussing/crying state at infant ages 3 and 16 weeks, and the hypotheses related to Aim 1 were:

1A. Transitioning from fussing/crying to feeding at 3 and 16 weeks would be more likely in dyads with lower family income levels, lower maternal education, higher maternal BMIs, and greater initial infant negativity.

1B. Infants in the Soothe/Sleep intervention would be more likely to transition from fussing/crying to an awake/calm state and less likely to transition from fussing/crying to feeding at 16 weeks, compared to controls. There would be no differences between groups at 3 weeks as the soothing techniques taught during the 3-week nurse home visit would not have been implemented yet.

1C. The likelihood of transitioning from fussing/crying to feeding at 3 and 16 weeks would be positively related to subsequent weight status.

A secondary aim was to qualify these analyses with an exploratory investigation of the duration of time spent in a fussy state before transitioning to feeding to see whether the implications of transitioning from fussing to other behavioral states changed when incorporating the typical latency to feeding.

METHOD

Participants

Mothers were recruited from the maternity ward of an academic medical center in Pennsylvania and were eligible if they intended to breastfeed, intended to follow-up with a University-affiliated primary care provider, were primiparous, and were English-speaking. Other inclusion criteria were singleton birth and gestational age of at least 34 weeks. 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 randomly assigned to a Soothe/Sleep intervention or control group and were assessed at infant birth, at 3 and 16 weeks, and at ~6 months and 1 year. These time points were selected because: the 3 week assessment provided a baseline measure prior to Soothe/Sleep intervention implementation; 16 weeks and 6 months are time points at the beginning and end of the range during which it is recommended that parents introduce solid foods, a time of rapid transitions in infant feeding and other areas of infant development; and age 1 year marked the end of the study.

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). Notably, the trend level differences on birth weight are such that the intervention infants tended to be heavier than the control infants at baseline. 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). However, neither study group nor maternal pre-pregnancy BMI was related to participants' likelihood of withdrawing from the study before completion.

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). Most mothers were non-Hispanic White, college-educated, and earned more than $50,000 per year (Table 1). Primary analyses were conducted using the dataset of 110 mother-infant dyads who completed the 1-year study; those who dropped out before study completion were excluded. 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

Following recruitment, mother-infant dyads were randomized to a control group or a Soothe/Sleep intervention, where mothers were taught to use alternate soothing strategies other than feeding as a first response to fussiness. All intervention and control participants were given a standard infant parenting book (American Academy of Pediatrics, 2010), and nurses answered questions about general infant care. In addition, all families received two nurse home visits, one at infant age 3 weeks and the other after mothers indicated that solid foods had been introduced (for most families, this was around 6 months of age). At the 3 week visit, dyads in the Soothe/Sleep intervention group received a commercially-available video (Karp, 2006) that instructed parents on infant soothing techniques, including swaddling, side or stomach position, shushing, swinging, and non-nutritive sucking. Nurses watched a 10-min portion of the video with the mothers and discussed the five soothing techniques with them; the video was left with the family after the visit. During the visit, nurses also taught intervention group mothers to emphasize day/night differences and to respond to night waking with alternate soothing and care-taking responses, as done by Pinilla and Birch (1993). For those not in the Soothe/Sleep intervention group, the 3 week home visit was a "control" visit, which consisted of information about developmental milestones; nurses also answered general parenting questions and helped with breastfeeding problems. They did not address issues around soothing or sleeping.

The current study is part of a larger project with a 2 × 2 study design; in addition to the Soothe/Sleep intervention, there was also an Introduction to Solids feeding intervention that was administered to some mother-infant dyads at the second home visit, around 6 months of age (Paul et al., 2011). These participants were taught how to introduce new solid foods, and for those not assigned to the feeding intervention, the home visit at this time point was a "control" visit as described above. The Introduction to Solids intervention is not the focus of the present study. Although it does introduce some variability into the Soothe/Sleep intervention and control groups, it is important to note that an equal number of participants were randomized to each of the four study arms. Thus, about half of the study completers in the Soothe/Sleep intervention group also received the Introduction to Solids intervention (22 of 51 dyads), and about half of the study completers in the Soothe/Sleep control group received the Introduction to Solids intervention (29 of 50 dyads). Also, because the Introduction to Solids intervention was not administered until around age 6 months, it should not affect the results of Hypotheses 1A and 1B. Nevertheless, analyses were adjusted for participation in this second intervention as described herein.

Measures

Infant behavioral states, infant negativity, and the use of food to soothe infant distress—Diary data were used to operationalize each of these three variables. We used an adapted version of Barr and colleagues' infant behavior diaries, which have been validated with tape-recorded infant behavior, including number of crying episodes and duration of crying (Barr, Kramer, Boisjoly, McVey-White & Pless, 1988). Nurses provided mothers with diary cards and explained how to complete them (Figure 1). Using these cards, mothers reported on their infants' mutually exclusive behavioral states (sleeping, awake/calm, fussing/crying, or feeding) in 15-min intervals over 4 days at ages 3 and 16 weeks. The data were kept in the univariate format, so that each participant had a status indicated for each 15-min interval.

Markov models were used to generate (i) transition probabilities from these data, yielding each infant's matrix of probabilities of transitioning from each behavioral state (e.g., fussing/crying) to each other behavioral state (e.g., feeding). The diary data were also aggregated to quantify infants' (ii) average daily minutes spent fussing/crying at age 3 weeks, which were averaged across the four diary days and used as a proxy for initial temperament. Lastly, the (iii) the average minutes spent fussing/crying before transitioning to feeding at 3 and 16 weeks was calculated by aggregating all of an individual's transitions from fussing to feeding and calculating the average amount of time spent in the fussing state before transitioning to feeding. This variable is referred to herein as the "latency to feeding."

Infant 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 BabyCheckerTM scale (McHenry, IL), and lengths were measured using the Seca 210 Mobile Measuring Mat for Infants and Toddlers (Hanover, MD). Age- and geneder-specific BMI *z*-scores were calculated using the World Health Organization (WHO) growth charts, which are the current recommended growth standards for children younger than age 2 (Grummer-Strawn, Reinold & Krebs, 2010). 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).

Maternal weight status—Maternal pre-pregnancy BMI was calculated using pre-pregnancy heights and weights from medical charts reviewed at infant birth. A dichotomous variable was also created to reflect whether mothers were overweight (prepregnancy BMI ≥25) versus non-overweight (pre-pregnancy BMI <25).

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

Demographic variables—Demographic variables were reported by mothers at infant birth and included total annual family income before taxes and mothers' highest completed year of education.

Statistical analyses

Markov models were conducted in R Version 2.9.2 (Vienna, Austria), using the package depmix (Visser, 2005). In the Markov model, patterns of transitions between states are summarized by a first-order autoregressive process where each categorical observation (e.g., the current behavioral state of the infant) depends upon the observation (or infant behavioral state) at the previous time point. The subject being studied is assumed to have N distinct states: S_1 through S_N. We denote the state that an individual is in at time t as q_t. As the probability of currently being in a particular state only depends on knowledge of the prior state, the probability of being in the current state, S_j, coming from the previous state, S_i, is the transition probability: $a_{ij} = P[q_t = S_j | q_{t-1} = S_i]$. The set of a_{ij} forms a N by N transition matrix, A, which describes the probability of transitioning between any two states across the whole time series. In our analysis, there were four mutually exclusive states (sleeping, awake/calm, fussing/crying, or feeding), and each was dummy coded to indicate that the individual was either in that state or not in that state during a given interval. This analysis yields a 4 by 4 transition matrix A. Four additional parameters $\pi_i = P[q_1 = S_i]$ denote the probability of starting in a particular state Si. The parameters in A and π are estimated such that the probability of observing the data is maximized. Let $\pi_i = P[q_1 = S_i]$ be the probability of starting in a particular state Si; then $\lambda = (A, \pi)$ represent the parameters of the model. We then find the set of λ that make the probability of observing the data most likely (Rovine et al., 2010). Methods for estimating the parameters for these models have been developed in the engineering literature (Rabiner, 1989) and have been implemented in R by Visser (Visser, 2005; Visser, Raijmakers & van der Mass, 2009).

After recoding diary data, so that there was a dummy coded variable for each mutually exclusive state, R was used to analyze the data: individual Markov models were conducted on each infant's time series of diary data at 3 and 16 weeks, yielding an individual transition matrix for each participant at each time point. Thus, the output revealed each infant's overall probability of transitioning from each state to each other state at 3 weeks and at 16 weeks. These probabilities were used as continuous variables in regression analyses that tested the hypotheses within our primary aim. For these regression analyses, cases where diary data

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were sparse were excluded, defined as days with <720 min of data and weeks with <3 days of data. As a result, 16 cases were excluded at age 3 weeks, and 8 cases were excluded at age 16 weeks. Ordinary least squares regressions were used to test Hypothesis 1A: 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 had a greater probability of transitioning from fussing to feeding at 3 or 16 weeks. Ordinary least squares regressions were also used to test Hypothesis 1B: 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. As a follow-up test to this hypothesis, we also explored whether the variables from Hypothesis 1A (income, education, maternal BMI, temperament) mediated or moderated the results of Hypothesis 1B. The analysis plan was to test any variables that were significantly associated with fuss to feed transitions as mediators and to test all four as potential moderators of intervention effects on transitions out of fussing/crying. Finally, ordinary least squares regressions were used to test Hypothesis 1C: 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.

The secondary aim of this study was to supplement information about transitions between behaviors with information about the duration of time spent fussing/crying before transitioning to feeding. The average time spent fussing before feeding was calculated using SAS 9.2 (Cary, NC), as described above. This variable was labeled as latency to feeding, and its implications were tested by: (i) testing whether the Soothe/Sleep intervention affected latency to feeding at 16 weeks, (ii) regressing weight status on latency to feeding at 3 weeks to test whether a shorter latency to feeding is a plausible early risk factor for a subsequent higher weight status, and (iii) adding latency to feeding to the models investigating relations between transitions out of a fussing/crying state and weight status to test whether these relationships could be explained by the time spent fussing before being fed, as opposed to simply transitioning from (any duration of) fussing to a feeding state.

Infant birth weight, sex, and intervention group(s) were tested as covariates in all regression models. In addition, feeding mode was explored as a covariate and moderator in analyses predicting fuss to feed transitions, and analyses involving weight outcomes were also adjusted for maternal pre-pregnancy BMI. Given that this investigation is part of a pilot intervention study, the alpha level for this study was set at $p < .10$, with a plan to report results with a p-value between .05 and .10 as trends.

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 outliers 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 Table 2.

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Aim 1: To investigate individual differences in transitions at 3 and 16 weeks

There was substantial inter-individual variability in behavioral transitions at both time points, particularly in transitions out of fussing/crying (Table 2), justifying the focus on transitions out of fussing/crying in subsequent analyses. For example, the standard deviation of the transition from fussing to feeding were .15 and .18 at 3 and 16 weeks, respectively (range = 0–.991) whereas the standard deviation of the transition from sleeping to fussing/crying was .01 at both time points (Range = 0–.05).

1A: Who is more likely to transition 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. When testing these predictors in separate, univariate regression models, maternal pre-pregnancy BMI was the only significant predictor of transitioning from fussing/crying to feeding at 3 weeks. Heavier mothers were more likely to feed their infants in response to a fussing/crying episode at age 3 weeks ($\beta = .26$, $p = .01$). This remained the case when entering all of these predictors in the same multivariate regression model predicting fussing to feeding at 3 weeks and when adding covariates (intervention groups, birth weight, sex, feeding mode) although the overall model became non-significant in the latter case, due to using additional degrees of freedom without explaining much additional variance in the outcome (Table 3). Results were also consistent when operationalizing maternal weight status as a dichotomous variable: overweight mothers were more likely to feed in response to fussing/crying ($p < .05$), compared to non-overweight mothers. The likelihood of transitioning from fussing to feeding at 3 weeks predicted the likelihood of this transition at 16 weeks ($\beta = .43$, $p < .001$), demonstrating relative stability in this transition, but none of the aforementioned infant or family factors predicted the likelihood of transitioning from fussiness to feeding at 16 weeks.

1B: 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 (intervention group mean = .12; control group mean = .07). This effect was significant when adjusting for infant birth weight, sex, and participation in the Introduction to Solids intervention ($F(4, 97) = 5.84$, $p < .05$) and when removing an outlier on the transition from fussing to awake/calm (probability = .996). This effect was unchanged when adjusting for maternal pre-pregnancy BMI, and it was not moderated by predominant feeding mode at 16 weeks, temperament, family income, or maternal education. Thus, the Soothe/Sleep intervention increased the likelihood of transitioning from fussing to awake and calm regardless of the dyad’s standing on these factors. The intervention and control groups did not differ on transitions from fussing to awake and calm at 3 weeks. As the absence of effects on fussing/crying to feeding transitions was unexpected, a post-hoc test was added to test whether the intervention affected transitions from fussing to sleeping at 16 weeks, but it did not.

1C: 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 infant 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. In adding these covariates to this model, maternal pre-pregnancy BMI became a non-significant predictor of infant weight status ($p = .11$). Thus, a higher probability of transitioning infants from fussing to feeding may mediate the significant relationship between pre-pregnancy BMI and infant weight status at 6 months ($p < .05$). Infants' probabilities of transitioning from fussing to feeding at 3 weeks was not related to weight status at 1 year, and transitioning from fussing to feeding at 16 weeks was not related to weight status at either time point. There was an inverse relationship between the probability of staying in a fussing state and weight status at ~6 months ($\beta = -.34$, $p < .001$) and at 1 year ($\beta = -.21$, $p < .05$).

Aim 2: To investigate the latency to feeding in fussing/crying to feeding transitions

Participation in the Soothe/Sleep intervention was not related to latency to feeding ($p = .80$). However, the latency to feeding at 3 weeks was inversely related to weight status at ~6 months ($\beta = -.24$, $p < .05$) and 1 year ($\beta = -.21$, $p < .05$). In other words, infants who were fed more quickly in response to distress at 3 weeks had a higher weight status at subsequent time points. Also, when adjusting for the latency to feeding, the relationship between the probability of transitioning from fussing to feeding at 3 weeks and weight status at ~6 months was no longer significant ($p = .13$; Figure 2), and when adjusting for the latency to feeding, the relationship between the fussing to awake/calm transition at 3 weeks and weight status at ~6 months became significant ($\beta = -.22$, $p < .05$). Thus, once the latency to feeding 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

Obesity prevention during infancy and the issue of feeding to soothe infant distress have emerged as new and promising research areas in the context of the childhood obesity epidemic (Hesketh & Campbell, 2010; Paul et al., 2011; Stifter et al., 2011). The current results provide evidence that infant transitions out of a fussing/crying state are modifiable and are linked to weight status, highlighting these transitions as potential targets for behavioral obesity interventions. Implications of these transitions on subsequent weight outcomes were qualified by the *latency* to feeding; thus, a key variable was how quickly the infant was transitioned from a fussy state to a feeding state, not simply whether the transition eventually occurred. Relationships between transitioning out of a fussing/crying state and infant weight status changed when including latency to feeding in the models, and a shorter latency to feeding was linked to a greater subsequent infant weight, suggesting that feeding immediately in response to a fussing/crying episode in early infancy may have problematic implications over time.

The current study adds to previous findings linking our interventions to weight outcomes at the end of infancy (Paul et al., 2011), by demonstrating that the Soothe/Sleep intervention, which taught alternative soothing strategies to new mothers and aimed to decrease feeding as an indiscriminate response to infant fussing and crying, increased infants' likelihood of transitioning from fussing/crying to an awake and calm state. Additional findings provide further evidence about which transitions out of fussing/crying are relevant for obesity prevention: as predicted in Hypothesis 1A, greater maternal pre-pregnancy BMI predicted a greater likelihood of feeding in response to infant fussing at age 3 weeks. Even within this demographically homogeneous sample with a universal intention to breastfeed, there was substantial variability on maternal pre-pregnancy BMI (Table 1), a variable that has been associated with infant weight outcomes (Anzman, Rollins & Birch, 2010). Previous research has shown that children with obese parents are more likely to be obese themselves (Whitaker, Wright, Pepe, Seidel & Dietz, 1997), and this study raises the possibility that this link may be partially explained by a modifiable behavioral strategy that is more likely in heavier mothers. In other words, feeding in response to infant distress may be one behavior contributing to intergenerational transmission of obesity risk. Our finding that a higher likelihood of transitioning from fussing to feeding mediated the relationship between maternal pre-pregnancy BMI and infant weight status at ~6 months is consistent with this idea. However, relationships between a higher maternal BMI and more frequent feeding in response to fussiness were not confirmed in other studies using questionnaire measures of feeding to soothe (e.g., Baughcum et al., 2001; Stifter et al., 2011), suggesting that further examination of this possibility is warranted.

Although there was substantial variability in BMI in the current study, the prevalence of maternal overweight was lower than in U.S. adult women overall (Flegal, Carroll, Kit & Ogden, 2012). Thus, it is possible that feeding in response to infant fussing may be more widespread in the broader population, an idea that is supported by focus group studies showing that demographic groups not represented here, such as lower-income mothers, report frequently offering food in response to infant distress (Baughcum et al., 1998). The restriction of range on demographic variables in the current sample could explain why we did not confirm the hypothesized relationships between fuss to feed transitions and other individual differences like maternal education and family income. Reflecting the sociodemographic characteristics of the region from which participants were recruited and consistent with the typical sociodemographic characteristics of breastfeeding mothers in the U.S. (e.g., Grossman, Fitzsimmons, Larsen-Alexander, Sachs & Harter, 1990), most mothers in this sample were well-educated, and families had higher incomes.

Even within this presumably low-risk sample with an average BMI-forage *z*-score of −.04 at birth, the average infant BMI-for-age *z*-score was .30 by age 1, and in a subsample of 72 children with follow-up data in toddlerhood, the average BMI-for-age *z*-score at age 3 was .57. These numbers underscore the current need for universal, early obesity prevention strategies, and the current results implicate parental responses to infant distress as plausible targets of early interventions. The Soothe/Sleep intervention increased the likelihood of transitioning from fussing to awake and calm (Hypothesis 1B), providing initial evidence that responses to infant fussing and crying are modifiable. In addition, early transitions from fussing/crying to feeding and the latency to feeding were associated with subsequent weight status (Hypothesis 1C, 2), consistent with the nascent literature on feeding to soothe infant distress (Stifter et al., 2011). Specifically, transitioning from fussing/crying to feeding was associated with a higher weight status, while remaining in a fussy state was associated with a lower weight status. Similarly, a longer latency from fussing to feeding was associated with a lower weight status.

Another way to think of our “latency to feeding” variable is as an operationalization of feeding to soothe, where a shorter latency represents a greater, indiscriminate use of feeding to soothe infant distress. To our knowledge, this is the first study operationalizing feeding to soothe in this manner, but this construct has been assessed using other methods and has been highlighted as a potential contributor to the childhood obesity epidemic and as a potential factor in the relationship between negative temperament and obesity risk. The use of food to calm infant distress is a subscale on Baughcum et al. (2001) Infant Feeding Questionnaire, and recently, Stifter et al. (2011) developed a parent-report questionnaire to assess more fine-grained aspects of feeding to soothe. Additional measures of feeding to soothe, such as the current approach using diary data, or observational approaches, can add to the understanding of this construct and its role in child weight gain.

Taken together, the current findings support the idea that a shorter latency to feeding, or *quickly* feeding in response to infant distress, is the aspect of fuss to feed transitions that is problematic in terms of future weight outcomes. The developmental literature conveys that prompt responses to infant distress are associated with positive outcomes, such as less crying at a subsequent time point (e.g., Bell & Ainsworth, 1972), but the current results highlight that responding must also be appropriate and contingent, consistent with the complete definition of sensitive responsiveness (Ainsworth, Blehar, Waters & Walls,1978). Indiscriminately responding to infant distress with an immediate feeding does not fit this definition, as infants cry for many reasons besides hunger. The finding that a shorter latency to feeding after fussing was associated with a higher 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, decreasing the likelihood of facilitating an association between negative emotions and feeding. In those cases, if the other soothing techniques were not working, infants may have been hungry, making an eventual feeding an appropriate response.

We also found that the probability of transitioning from fussing to feeding has a different meaning, depending on the time spent fussing/crying before food is offered. Incorporating the latency to feeding variable into analyses investigating transitions out of fussiness changed the implications of these transitions. At 3 weeks, the probability of moving from a fussing state to awake and calm was inversely related to subsequent weight status when adjusting for the latency to feeding, suggesting that variability in feeding to soothe behaviors was suppressing the protective impact of adaptive soothing techniques. In other words, transitioning from fussing to awake and calm does seem to have positive implications for weight status when feeding to soothe is held constant. In contrast, the positive relationship between fuss to feed transitions and weight status became non-significant when adding the latency to feeding to the model. Taken together, these findings suggest that a shorter average latency to feeding may confer risk of a greater weight status whereas more transitions from fussing to awake and calm, adjusted for these feeding to soothe behaviors, may be protective.

Most of the literature on feeding to soothe distress has focused on older infants and/or toddlers. In the current study, significant relationships between transitions out of fussing/crying and weight status were found early, at 3 weeks, and intervention effects on transitions from fussing to awake and calm emerged at 16 weeks. 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; this hypothesis is consistent with literature showing that early growth is predictive of later weight outcomes (e.g., Stettler, Kumanyika, Katz, Zemel & Stallings, 2003). It is also possible that systematic relationships with feeding-related transitions are difficult to detect at 16 weeks as solid foods are often introduced around this time, resulting in a period of developmental transitions and flux in the feeding domain. Another developmental change between 3 and 16 weeks is that infant distress becomes differentiated into multiple emotions (e.g., sadness, anger); 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 behavioral transition.

Although there are multiple explanations for the temporal patterning of the results, it is not clear how the intervention increased the transition from fussing to awake/calm without also significantly decreasing the transition from fussing to feeding. Other limitations of the current study are that the infant behavior diaries did not assess specific maternal behaviors when the infant was fussing or awake and calm and do not allow us to ascertain whether infants were fussing due to hunger or other reasons. Thus, some of the conclusions herein, such as the conclusion that mothers in the intervention group were more likely to follow a fuss period with adaptive soothing techniques, are suppositions that warrant further study. There was also selective attrition and a second (Introduction of Solids) intervention, which added variability to each group (although this variability should have been equal across study groups given the randomized, 2 × 2 design). Lastly, the sample was homogeneous and precludes generalization beyond White, well-educated, initially-breastfeeding mothers and their infants, a demographic group that tends to have a lower obesity risk and tends to show less rapid weight gain compared to other groups, such as formula-fed infants of a lower socioeconomic status (e.g., Wijlaars, Johnson, van Jaarsveld & Wardle, 2011). As mentioned, universal obesity prevention is currently needed, but future research should seek to examine whether the behavioral targets implicated by the current study would be plausible targets in other demographic groups and to validate transitions out of fussiness from diary data against other measures of mother-infant interactions, such as direct observation.

The current results demonstrate how an innovative methodological technique can shed light on the role of transitions out of fussiness in early obesity prevention. Strengths of the current research include the randomized design and the use of time series methodology to examine individual differences in microtime behavioral transitions. In addition to highlighting *which* behavioral transitions to focus on, another goal of this study was to illustrate *how* to characterize such behavioral transitions, consistent with the idea that appropriate methodology is key to accurately test hypotheses and interpret data (Collins, 2006). Results suggest that the current approach is valuable for characterizing relationships between fussing/crying, soothing, feeding, and weight status. 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 individual Markov models as an appropriate method to test intervention effects on and individual differences in these microtime behavioral transitions.

In sum, this study provides evidence that infants' transitions out of a fussing/crying state are characterized by substantial inter-individual differences in the first 4 months of life, are modifiable, and are linked to weight outcomes, suggesting that they may be promising targets for early behavioral obesity interventions. Results suggest that a shorter average latency to feeding following a fussing/crying episode may confer risk for a greater subsequent weight status whereas more frequent transitions from fussing/crying to awake and calm may be protective. Practical implications are that caregivers should wait before immediately feeding a distressed infant, decreasing the use of food to soothe, and increasing attempts to meet fussiness with contingent behaviors that map onto the source of the fussing and crying, transitioning the infant to an awake and calm state more often and to a feeding state only if hunger seems to be the source of distress. Future research should ascertain the extent to which these implications apply to lower socioeconomic status and formula-feeding families, but given their increased obesity risk, it may be particularly important to promote such practices in these groups. Additional longitudinal studies can also elucidate whether decreased feeding to soothe behaviors preclude the development of contingencies where eating occurs in response to negative emotions instead of hunger and whether this impacts subsequent eating behaviors and weight trajectories, important outcomes in the context of the current obesity epidemic.

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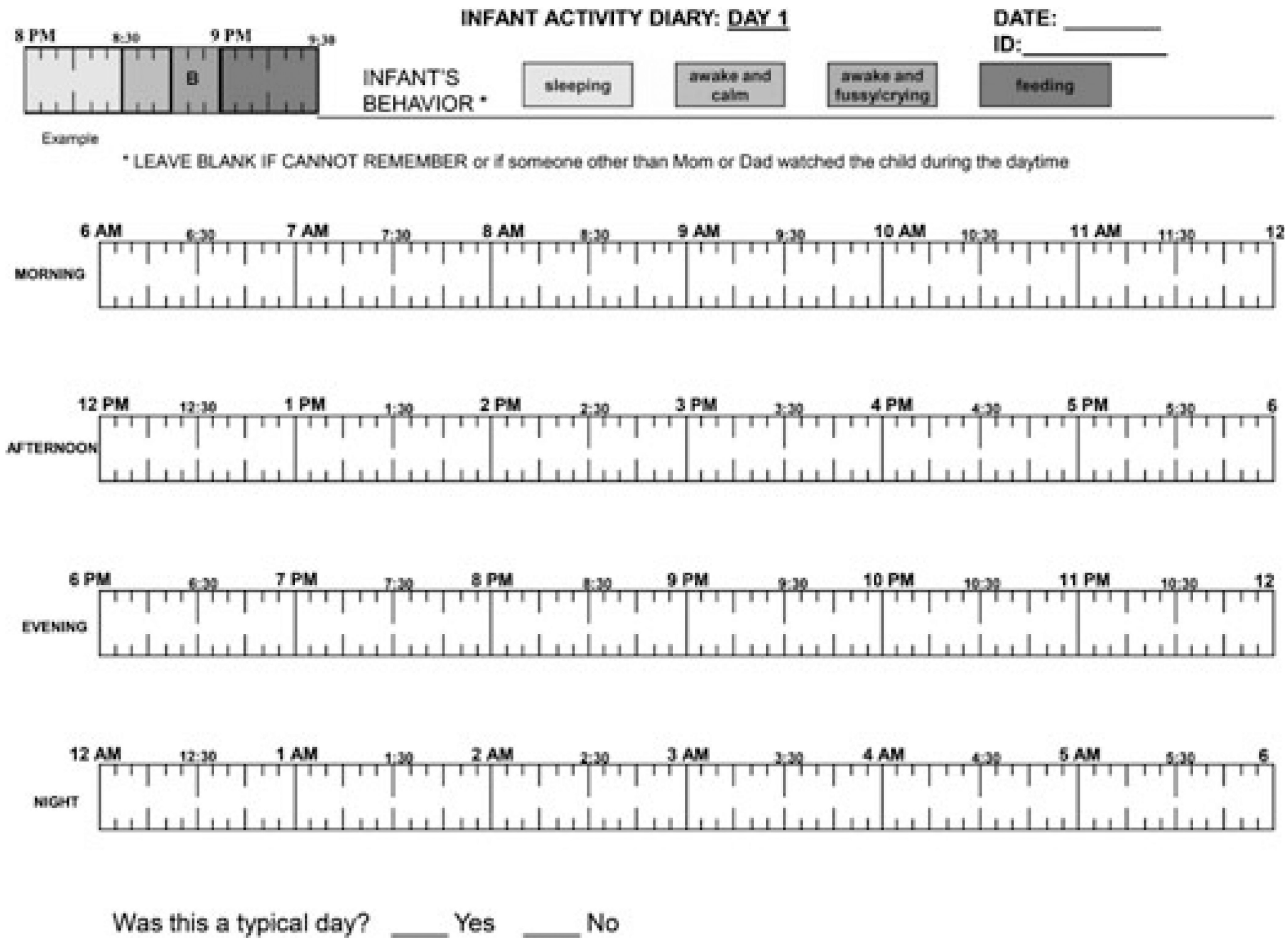
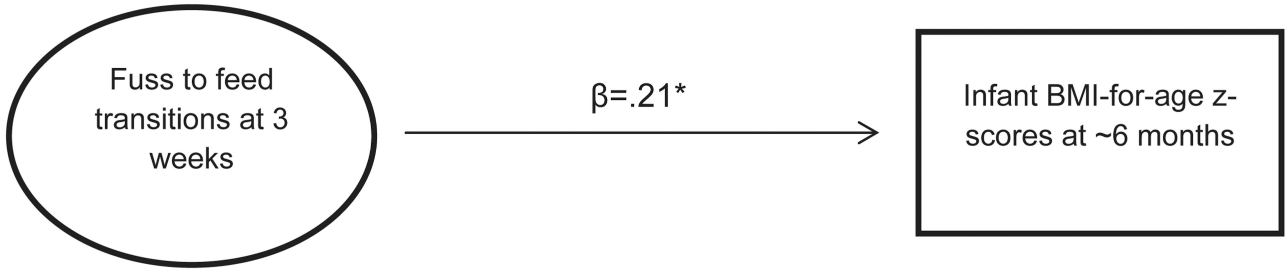
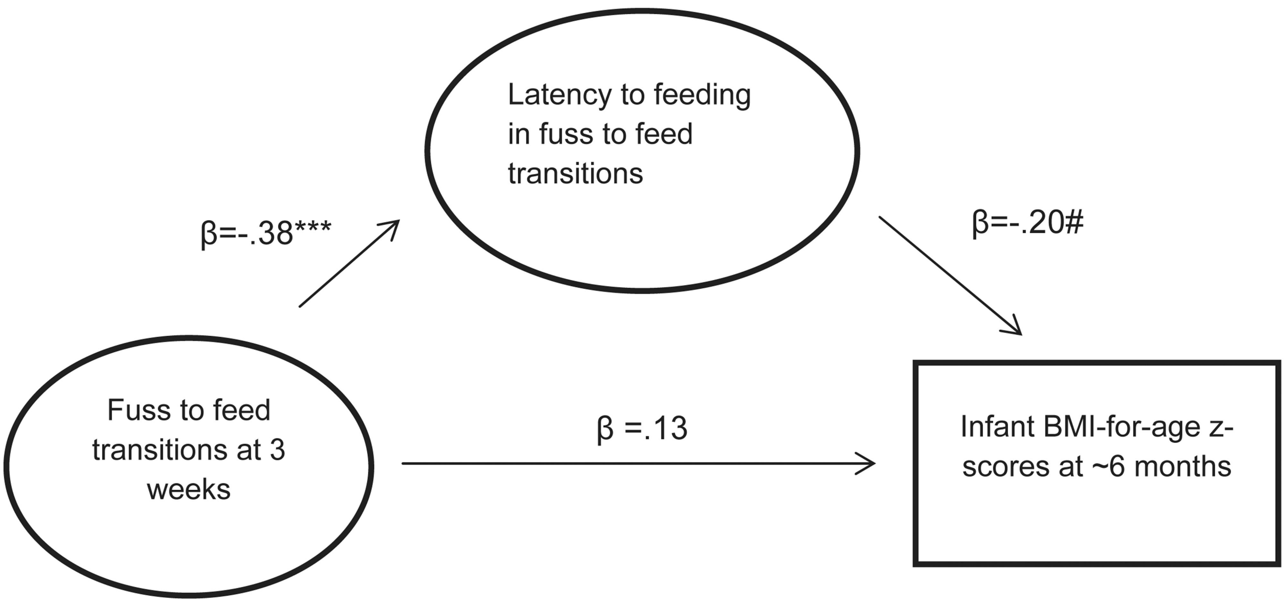


Figure 1.

Behavior diaries completed by mothers for 4 days at infant ages 3 and 16 weeks. Mothers were instructed by nurses on how to complete the diaries and indicated one of four mutually exclusive infant behavioral states for each 15-min interval depicted above. These diaries were adapted from Barr et al. (1988). The major difference is that fussing and crying were collapsed into one behavioral state in our version of the diaries.



(a) *The likelihood of transitioning from fussing to feeding predicts subsequent weight status*



(b) *Fuss to feed transitions no longer significantly predict subsequent weight status when latency to feeding is included in the model*

Figure 2.

The latency to feeding mediates the relationship between infants' probabilities of transitioning from fussing to feeding at 3 weeks and weight status at ~6 months. Thus, a shorter latency to feeding in response to infant distress seems to be the aspect of fuss to feed transitions that is problematic with regards to subsequent weight status. Regression models depicted in both a and b were adjusted for maternal pre-pregnancy BMI, infant birth weight, sex, and intervention group(s). Note: #p < .10, *p < .05, ***p < .001.

TABLE 1

Descriptive Statistics for Dyads Completing Study and by Control versus Intervention Groups

Variable	Overall (n = 110)	Control (n = 59)	Intervention (n = 51)
Maternal education	65% completed college	61%	69%
Family income	72% earned >$50,000	69%	74%
Maternal age	*M* = 27.1 (4.7)	27.5 (4.9)	26.6 (4.6)
Infant sex	51% female	59%[#]	41%[#]
Infant race	90% White	86.4%	94.1%
Maternal weight status[*]	36% overweight	34%	38%
Infant birth weight (kg)	*M* = 3.33 (.48)	3.25 (.47)[#]	3.43 (.47)[#]
Predominant feeding mode at 16 weeks	51% breast	47.4%	55%
BMI-for-age *z*-scores at age 1 year+	.30 (.93)	.40 (.81)	.19 (1.05)

BMI, body mass index.

[*]Calculated from pre-pregnancy BMI (range = 17.8–49.5, median = 23.7).

[#]$p < .10$.

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TABLE 2

Transition Probabilities Averaged Across Individual Markov Models

Transition of interest	Mean transition >probability at 3 weeks (SD)	Mean transition >probability at 16 weeks (SD)
Sleeping to feeding	.025 (.01)	.016 (.01)
Sleeping to fussing	.014 (.01)	.008 (.01)
Fussing to feeding	.174 (.15)	.170 (.18)
Fussing to awake/calm	.063 (.06)	.093 (.12)

TABLE 3

Heavier Mothers Were More Likely to Transition Infants from Fussiness to Feeding at Age 3 Weeks

Variable	B	SE B	β
Unadjusted model (R^2 = .067; model p = .01)			
Maternal pre-pregnancy BMI	.007	.003	.26*
Adjusted for other hypothesized predictors (R^2 = .10; model p = .05)			
Maternal pre-pregnancy BMI	.006	.003	.23*
Maternal education level	.007	.016	.04
Family income	.009	.008	.12
Infant fussiness at 3 weeks	−.0004	.0003	−.15
Full adjusted model with covariates (R^2 = .16; model p = .13)			
Maternal pre-pregnancy BMI	.007	.003	.28*
Maternal education level	.012	.018	.08
Family income	.010	.009	.12
Infant fussiness at 3 weeks	−.0003	.0003	−.12
Infant sex	.023	.033	.08
Infant birth weight	−.041	.035	−.13
Feeding mode at 16 weeks	−.030	.036	−.10
Soothe/Sleep intervention group	−.020	.033	−.07
Feeding intervention group	−.047	.034	−.16

BMI, body mass index.

*$p < .05$.