Published in final edited form as:
Nurs Res. 2004 ; 53(5): 304–313.

Factors Contributing to Preterm Infant Engagement During Bottle-Feeding

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Abstract

Background: Preterm infants have difficulty maintaining engagement throughout early oral feedings, which can lead to less efficient feeding and prolonged feeding skill development.

Objective: To examine contributions of the infant, mother, and feeding context to infant engagement during bottle-feeding.

Methods: Bottle-feedings of very-low-birthweight infants (n = 22) by their mothers were observed. Infant and maternal behaviors were coded and synchronized with physiologic measures. At completion of the feeding, the mothers were interviewed, and their working model of feeding coregulation was scored. Feedings were subdivided into feeding episodes (n = 114). Using multilevel linear regression analyses, four dyadic characteristics (working model of the caregiver's role as coregulator, birthweight, postconceptional age, baseline oxygen saturation) and five episode characteristics (readiness at episode onset, episode baseline oxygen saturation, mean oxygen saturation during the episode, maternal feeding behavior, and phase of feeding) were examined as potential predictors of feeding episode engagement.

Results: Conditions observed during the feeding observation explained most of the variation in engagement. Engagement was more likely to occur during the early phase of feeding ($p < .05$), during feeding episodes that began with infant readiness ($p < .05$), and during feeding episodes with higher mean oxygen saturation during the episode ($p < .05$). Feeding episodes with less jiggling of the nipple had a significantly greater amount of engagement ($p < .05$).

Conclusions: The ability of the preterm infant to maintain engagement during bottle-feeding cannot be explained by characteristics of the infant or by the prefeeding condition of the infant alone. Rather, engagement is coregulated by the caregiver and the infant throughout the feeding. Strategies to assist infants in maintaining physiologic stability during bottle-feeding and further study of effective and contingent caregiver feeding behaviors are needed.

Keywords

feeding behavior; multilevel model; premature infant

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Editor's Note Materials supplementing the content of this article are posted at http://sonweb.unc.edu/nursing-research-editor

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Oral feeding is one of the first activities the preterm infant learns. During feeding, the infant learns to regulate breathing while sucking and swallowing. At the same time, the infant is positioning the head and neck to create an optimal airway, positioning the trunk for optimal chest expansion, managing a volume of milk without aspiration or drooling, and regulating the flow of external stimuli such as touch, light, and sound. In this process, the infant makes ongoing adjustments to changes as they arise to meet internal and external demands.

One necessary component of early oral feeding skill is the infant's ability to modulate external and internal challenges sufficiently to maintain readiness for feeding. Infant behaviors that characterize readiness for interaction and participation in the environment have been defined as engagement behaviors (Beebe & Stern, 1977). Beebe and Stern conceptualized a continuum of engagement and disengagement as normal adaptive behaviors available to the infant to manage stimulation within a comfortable range, or to cue the caregiver to adjust his or her behavior. Engagement is also theorized to be an important condition for infant learning (Rogoff, 1990; Thoman, 1993) and therefore, for the development of infant feeding skills.

Related Literature

Feeding skill is reflected in the preterm infant's ability to coordinate sucking, swallowing, and breathing while accomplishing adequate nutritional intake for growth, maintaining physiologic regulation, and remaining engaged in the feeding process (Thoyre, 2003). Engagement behaviors such as alerting and orienting the body to the activity signify that the infant is making appropriate adaptations and is not overwhelmed by the activity. Disengagement behaviors such as active or passive withdrawal from the activity signify the need to defend against harm from demands that may exceed the infant's capacity to modulate. Caregivers use these behaviors to adapt their interactions with infants to provide the right level and timing of stimulation, thus minimizing disengagement behaviors (Beebe & Stern, 1977).

Als (1982, 1986, 1998) identified preterm infant behaviors indicative of physiologic regulation, motoric stability, state organization, attentional–interactional agenda, and self-regulation. Using Als' behavioral framework and maintaining consistency with Beebe and Stern's (1977) conceptualization of engagement–disengagement behaviors, several clinical reports have specified preterm infant approach–avoidance behaviors or stress indicators during feeding for the guidance of caregivers in providing care that is responsive to the infant's capacities (Shaker, 1999; Vandenberg, 1990). Identification of these behaviors has advanced understanding of the ways preterm infants communicate readiness for feeding, and has set the stage for examination of factors that support or coregulate feeding engagement.

Theoretically, the ability to maintain engagement in an activity is dependent on the infant's sleep–wake state, capacity to attend and orient to an activity, the capacity to maintain physiologic stability, and on the caregiver's coregulatory skills (Als, 1998; Fogel, 1993; Porges, 1994; Posner & Rothbart, 1998). An infant who is engaged has an awake state of arousal, and is directing his or her attention to the feeding, holding his or her body in a flexed body posture with the body oriented toward the midline, and demonstrating energy for feeding.

Engagement at the beginning of the feeding is proposed to be an indication of neurodevelopmental readiness for feeding (Shaker, 1990). Although an awake state of arousal is not sufficient to characterize the infant as engaged in feeding, it is a necessary condition for engagement to occur. Findings have shown that infant arousal to alert, inactive, or quiet awake states before feeding has a positive effect on sucking competence (McGrath & Medoff-Cooper, 2002) and feeding intake (Anderson, et al., 1990; McCain, 1995). In addition, infants who are able to maintain awake states during the feeding have more organized sucking patterns (McGrath & Medoff-Cooper, 2002) and are more likely to complete their feeding orally (McCain, 1997). Preterm infants have decreased sucking behavior and state of arousal as feedings progress (Dubignon & Cooper, 1980; Hill, Kurkowski, & Garcia, 2000; McGrath & Medoff-Cooper, 2002).

Prefeeding interventions have successfully increased feeding readiness behaviors such as hand to mouth, mouthing, and rooting (White-Traut et al., 2002), and have modulated the infant's state to more optimal awake states before the feeding (Gill, Behnke, Conlon, & Anderson, 1992; McCain, Gartside, Greenberg, & Lott, 2001; Pickler, Frankel, Walsh, & Thompson, 1996; White-Traut et al., 2002). The cited studies demonstrate that caregiver actions can contribute positively to infants' feeding readiness. However, interventions aimed at preparing the infant have not consistently demonstrated an effect on the infant's ability to sustain an optimal state throughout the feeding (McCain, 1995; Pickler et al., 1996). Maintenance of an awake state throughout early oral feeding is difficult, leading to less efficient feeding (McCain, 1997; McGrath & Medoff-Cooper, 2002) and prolonged development of feeding skills.

Studies that examine the potential for intervention during feeding to assist the infant in maintaining engagement in feeding are lacking. An initial step in this process is to increase understanding of the factors that promote or constrain the maintenance of engagement.

The purpose of this study was to explore maternal and infant factors and characteristics of the feeding experience that contribute to infant engagement during bottle-feeding (see Figure 1 at the Editor's Web site: http://sonweb.unc.edu/nursing-research-editor). During a typical feeding observation, infants have periods of feeding (feeding episodes) and periods of resting or burping, during which the nipple is not in the infant's mouth. Feeding episodes typically end when the infant demonstrates distress or loss of interest in feeding. These are important cues for the caregiver to monitor. In addition, once the bottle is removed, the caregiver needs to determine whether the infant would benefit from rearousal or a period of restoration, and when or if the feeding should be resumed.

Each feeding episode, therefore, has common features. All have a clear beginning (nipple in mouth) and ending (nipple removed from mouth); all began with infants' cues of readiness or nonreadiness when the nipple is introduced; all begin with a similar demand placed on the infant (to adapt his or her breathing to a pattern that allows for sucking and swallowing); and all require, at minimum, starting and ending decisions by the caregiver. The approach adopted involved analyzing contributions to infant engagement during feeding episodes using a nested multilevel modeling approach (see Figure 2 at the Editor's Web site: http://sonweb.unc.edu/nursing-research-editor) (Goldstein, 1995).

Methods

Setting and Sample

Using a convenience sample, a cross-sectional study was conducted in two midwestern neonatal nurseries over a 6-month period. Both nurseries had similar feeding practices. Oral feeding was initiated at approximately 34 weeks post-conceptional age (PCA). Principles of developmental care were used during feedings, and families were encouraged to participate.

All very-low-birthweight infants, 40 weeks PCA or younger, who were bottle-fed during at least 50% of their daily feedings and had no significant congenital problems (including smallness or largeness for gestational age or intraventricular hemorrhage exceeding Grade 2) were considered eligible for the study. All the mothers of the infants who met the study's criteria and spoke English were invited to participate. The study was approved by an Institutional Committee for Protection of Human Subjects, and the mothers gave informed consent.

Procedure

Demographic data were collected before the feeding. The mothers bottle-fed their infants in a quiet parent visitation room of the nursery during a scheduled oral feeding. Once the infants were settled into their mothers' arms, physiologic data (oxygen saturation, heart rate) were collected for 5 minutes. After this, the mothers were instructed to begin feeding whenever they determined that their infant was ready to feed. Collection of physiologic measures continued while the feeding interaction was videotaped. When the mothers signaled that the feeding was finished, the physiologic data collection and videotaping stopped. The mothers then were interviewed regarding their role in feeding their preterm infant.

After the data collection, the interviews were transcribed verbatim. Maternal and infant behaviors were coded from the videotape and synchronized with the physiologic data. One data file per infant was created.

Within each infant's data file, feeding observations were subdivided into feeding episodes (periods that the infant had the bottle nipple in his or her mouth). Examples of two infant feedings are depicted in Figure 1. In the reliability assessment, agreement on the number of episodes per feeding was 100%, with agreement on the length of individual feeding episodes within 1.8 seconds.

Measures and Instruments

For a description of measures and instruments, see Figure 3 at the Editor's Web site (http://sonweb.unc.edu/nursing-research-editor).

Dependent Variable: Engagement During the Feeding Episodes

Engagement during the feeding episodes (ENG) was determined by behavioral coding using the SSR data collection program (Stephenson, 1984). Infant behavior was coded as one of three continuous, mutually exclusive behaviors each second: high ENG, low ENG, or disengagement (see Table 1 at the Editor's Web site: http://sonweb.unc.edu/nursing-research-editor). Two coders were trained to 80% coding agreement, with 23% of the entire feedings randomly selected for independent coding by the second observer. The Cron-bach alpha coefficient of reliability between coders for the engagement variable was 92% (Cronbach, Gleser, Nanda, & Rajaratnam, 1972). High ENG rarely occurred (mean proportion of feeding episodes, .08 ± .10), with eight infants experiencing no periods of high ENG. Therefore, periods of high and low ENG were combined to create one code of ENG. The proportion of each feeding episode that ENG occurred was calculated for each episode.

Independent Variables at the Dyad Level

Working Model of the Caregiver's Role as Coregulator—Mothers were interviewed concerning their perceived role as a feeder (Pridham et al., 1999). Transcribed interviews were rated for the mother's working model of coregulation (WM) on a 6-point scale (see Table 2 at the Editor's Web site: http://sonweb.unc.edu/nursing-research-editor). The higher the score, the more the mother viewed feeding as an outcome she could influence, the more she valued her infant's participation in the feeding, and the more specifically she described her role in supporting her infant's feeding skills. Five interviews were coded by two independent coders. The percentage of intercoder exact agreement (number of agreements divided by the number of agreements plus disagreements) was 73.3%, with 93.3% agreement within one scale point. A detailed description of the coding process and the sample's working models of feeding coregulation has been published previously (Thoyre, 2000).

Infant Health—Two independent variables were used to describe infant health status at the time of the study. Birthweight (BW) provided an historic measure of the infant's health, specifying how premature the infant was at birth. Baseline oxygen saturation ($BASEO_2$), on the other hand, was a measure of current health status. The correlation between the two measures was essentially zero ($r = .01$; $p > .10$). The average oxygen saturation during a 30-second window prefeeding, in which there was minimal variability in oxygen saturation and the infant was quiet and not sucking on a pacifier, was selected as the infant's $BASEO_2$.

Infant Maturity—Infant maturity at the time of the study was measured as PCA.

Independent Variables at the Episode Level

Behavioral Readiness for Feeding—Viewing the videotape, two independent coders scored each feeding episode onset as either 1 (infant ready at onset, seeking the nipple, opening the mouth, and moving head forward to meet the nipple), or 0 (infant not demonstrating readiness, not seeking the nipple when offered, distressed, withdrawing, or in a sleep state). There was 96% agreement between the two coders on readiness (number of agreements divided by the number of agreements plus disagreements and multiplied by

100). The coders discussed all nonagreements and mutually agreed on a final score for each episode.

Physiologic Readiness for the Feeding Episode—The infants' heart rate and oxygen saturation were recorded at 1-second intervals before and throughout the feeding using a neonatal cardiorespiratory monitor (Siemens Model Sirecust 404N; Malvern, PA) and a pulse oximeter (Datex Ohmeda 3700; Boulder, CO). The movement artifact on the oxygen saturation data was removed by comparing the pulse oximeter's pulse data with the heart rate data from the cardiorespiratory monitor. Physiologic readiness for the feeding episode was measured as the mean oxygen saturation during the 10-second period immediately before the insertion of the nipple at all episode onsets ($EPIO_2$).

Physiologic Stability During the Feeding Episode—Physiologic stability during the episode was measured as the mean oxygen saturation during the feeding episode ($MEANO_2$).

Caregiver Behavior—Maternal behaviors were coded every second from the videotaped feeding as one of five continuous, mutually exclusive behaviors and two momentary codes (see Table 1 at http://sonweb.unc.edu/nursing-research-editor). Because MOVE NIPPLE GENTLY rarely occurred (M = .02 ± .02), it was omitted from the analysis. ALTER MILK FLOW occurred in only one dyad. Because this action may change the feeding condition for the infant in ways similar to that caused by jiggling of the nipple, the one feeding with ALTER MILK FLOW was recoded using JIGGLE to represent alteration of milk flow. Omitting MOVE NIPPLE GENTLY and combining ALTER MILK FLOW with JIGGLE left two behaviors other than insertion or removal of the nipple to characterize maternal feeding behavior during the feeding episodes: JIGGLE and holding the bottle STILL. The proportion of each feeding episode during which STILL occurred was calculated. Reliability between coders for the STILL variable was 99.9% (Cronbach et al., 1972).

Time Within the Feeding—The impact of time on the infant's ability to maintain engagement was assessed by subdividing each infant's feeding into thirds labeled as Phase 1, Phase 2, and Phase 3 (Figure 1). The phase of the feeding within which each feeding episode began was then identified. The time variable was dummy coded with Phase 1 as the referent for Phase 2 and Phase 3.

Data Analysis

Descriptive statistics were used to characterize the infants and mothers in the sample. The outcome of interest was the proportion of engagement during individual feeding episodes. Because the data were multileveled, with episodes nested within dyad feedings, a multilevel modeling approach was followed (Rasbash et al., 2000). Multilevel analysis techniques use a random coefficient approach to adjust for the effects of nonindependent data and to provide more appropriate estimates of standard errors (Rasbash et al., 2000).

The multilevel approach also allowed the influence of dyadic and individual episode variables to be studied by simultaneously accounting for the variation in engagement that occurred between dyads and between feeding episodes (Goldstein, 1995). Three models were developed using the MlWiN analysis program, version 1.10 (Rasbash, Browne, Healy, Camerson, & Charlton, 2001). First, the unconditional model estimated dyadic- and episode-level sources of variation in engagement with no explanatory variables added. Next, a dyad model was formulated that analyzed the variation of episode engagement as an outcome to be explained by differences between dyads (covariates: WM, BW, PCA, and $BASEO_2$). Finally, the full model (the episode model) was formulated, which analyzed the variation of engagement between feeding episodes as an outcome of differences between dyads as well as more immediate differences between feeding episodes (covariates: behavioral readiness for feeding, $EPIO_2$, $MEANO_2$, STILL Phase 2, and Phase 3) (see Appendix at the Editor's Web site: http://sonweb.unc.edu/nursing-research-editor).

In the multilevel linear regression model, tests of overall model fit are performed using the deviance statistic (−2log likelihood). The difference in likelihood follows a χ^2 distribution, with degrees of freedom equal to the number of explanatory variables. The statistical significance of each coefficient was tested using the Wald *z*-value. The proportion of variance accounted for in the models was based on differences in variance estimates, with the unconditional model as the reference. Statistical significance was defined as a *p* value less than .05 for all analyses.

Missing Data

Seven feeding episodes, derived from six of the feedings, were excluded from the analyses because of missing $EPIO_2$ data (i.e., artifact removed before analysis).

Results

A total of 27 infants were eligible for the study. Of the 26 mothers who consented to participate in the study, 24 completed the data collection. Data from two of the mother–infant dyads were later not incorporated into the analysis because of incomplete physiologic data. The final sample therefore consisted of 22 mother–infant dyads. The characteristics of these dyads are shown in Table 1. Although the infants varied in BW, gestation age, and PCA at the time of the study, they were similar in their feeding skill. Within 5 days of the study, 86% of the infants were oral feeding totally and discharged to their homes (standard deviation, 8 days; range, 1–38 days). The pulmonary health of the infants varied. Respiratory distress syndrome was diagnosed in 19 infants (86.4%) shortly after their birth. The average length of time the infants required supplemental oxygen was 42 days (median, 41 ± 34 days; range, 1 day in three cases to 97 days). Seven infants (31.8%) required oxygen at the time of the study.

Although the range of maternal experience with bottle-feeding varied, 19 of the 22 mothers had five or more opportunities to bottle-feed their preterm infant before the study feeding (median, 11 days). Eight mothers were, in addition, learning to breast-feed their infants. Most of the mothers (86%) anticipated that they would be the primary feeder of their infant after discharge.

Feedings averaged 21.1 ± 11.5 minutes in length (r = 6.1–45.5 minutes). The average number of episodes per dyad was 5.5 ± 2.5 (r = 1–10). The duration of the episodes averaged 151 ± 144 seconds (r = 5–677 seconds). The proportion of engagement per infant for each feeding episode (Figure 2) demonstrated a temporal trend toward decreasing engagement as feedings progressed. There was a wide range of variability in the total duration of the feedings and in the proportion of engagement during feeding episodes both within and across infants.

Descriptive statistics for all the model variables are provided in Table 2. The WM scores ranged from 1 to 6 (mean score, 3.32).

Whereas 34 of the feeding episodes (29.8%) began with the infant behaviorally ready for the feeding, 80 episodes (70.2%) began with the infant not ready. Of all of the measures involving oxygen saturation, $EPIO_2$ had the lowest mean, ranging from 71% to 100%, indicating that feeding episodes often began with the infant physiologically less regulated. The $EPIO_2$ was lower than 90% at the beginning of 24 episodes (21%). Although the $MEANO_2$ mean was higher than the $EPIO_2$ mean, it averaged less than the mean of infant $BASEO_2$.

Multilevel Linear Regression Model Analysis

The analysis modeled the expectancy for the proportion of engagement during each feeding episode with four dyadic (WM, BW, PCA, $BASEO_2$) and six episodic (readiness, $EPIO_2$, $MEANO_2$, STILL, Phase 2, Phase 3) covariates. The parameter estimates, standard errors, and variance estimates for the three models specified are presented in Table 3. Model assumptions were assessed by examining the residuals. The residuals were approximately normally distributed, falling between −2.1 and 2.1 and randomly distributed about zero. There were no distinct patterns of variation in the plots. There were no major violations of the assumptions. Therefore, the parameter estimates can be considered with confidence. Although a negative (−2LL) was encountered for one model, this was the result of the small scaling in engagement. With a very small scale, the log likelihood at the maximum can be positive, which can make −2LL negative for a given model. However, the difference between deviances (values of −2LL) from a more and less restricted model still will be positive, and the model parameters should not be affected. Confirmation was accomplished by simply rescaling engagement from 0-1 to 0-100. The rescaled model provided a positive −2LL, with model parameter estimates and the difference between deviances identical to those of the nonscaled model, except for a factor of 100.

Random Effects

The fixed coefficient of the unconditional model represented the estimated average proportion of engagement for the entire sample, unexplained by any characteristics of the infant, mother, or context of the feeding episode. The greatest amount of variability in engagement occurred between feeding episodes (77.2%), with 22.7% attributed to dyad characteristics. The estimated variation at the episode level was statistically significant.

The second model (the dyad model) characterized engagement as explained by the mother and infant variables common to all their feeding episodes. The total unexplained variation was reduced by 10.9%. Addition of the dyad variables accounted for a 47.8% reduction in the dyad variance. The difference χ^2 value was not significant, indicating that no significant improvement in the model occurred with the addition of the dyad variables.

The two-level model (the episode model) characterized engagement as explained by the dyad variables and by the variables measured at the individual feeding episode. Total variation in engagement between episodes was reduced by 50.5% when the episodic explanatory variables were added to the episode model. Inclusion of the episode variables led to a statistically significant drop in residual variance (Δ-2*log likelihood = 78.55; $p < .05$), a change from 52.025 to −26.526, indicating a highly significant improvement in the model. This model explained a 47.8% reduction in the variability across dyads, and a 50% reduction across episodes.

Fixed Effects

Dyad Characteristics—In the dyad model, higher scores for the working model of feeding coregulation were associated with a higher proportion of engagement for the infant during feeding episodes. However, the effect observed for the WM variable decreased when feeding episode variables were included. Health status of the infant (BW, $BASEO^2$) and infant maturity (PCA) were not associated with a greater proportion of feeding engagement.

Feeding Episode Characteristics—All covariates at the episode level had a statistically significant influence on engagement, with the exception of $EPIO^2$. Although higher $EPIO^2$ was not predictive of engagement, higher $MEANO^2$ was predictive. Episodes that began with infant readiness had a significantly higher proportion of engagement. Episodes with a higher proportion of the maternal STILL behavior, as opposed to JIGGLE, had more engagement. Moreover, as expected, the proportion of feeding engagement diminished as the length of the feeding progressed. As compared with the first third of the feeding, there was less feeding engagement during Phase 2 and Phase 3.

Discussion

The aim of this study was to examine contributions of the infant, caregiver, and feeding context to engagement during feeding. Factors beyond infant state that have an impact on infants' ability to maintain engagement in the activity of feeding were examined. As such, the results of this study shed light on how feeding engagement among preterm infants may be supported.

The proportion of infant engagement during feeding episodes varied between dyads and within dyads. Infants did not maintain a consistent level of engagement from one feeding episode to the next. The marked individuality evident in the proportion of engagement during each infant's feeding episodes highlights the scientific challenges in understanding patterns during preterm infant feeding experiences. This analysis suggests that infants' ability to maintain engagement in feeding is determined by characteristics of the dyad and by the dynamic conditions created within the feeding. Conditions occurring within the feeding episode have the most significant effect on engagement.

The health and maturation of the infant, as indicated by BW, PCA, and $BASEO_2$, all characteristics of preterm infants used broadly to characterize the potential feeding skill of infants, did not predict the infant's ability to maintain feeding engagement. However, the way the caregiver viewed her role as a coregulator of the infant's feeding skill was influential. The WM scores indicate that most mothers viewed infant participation as a desired but unnecessary condition of feeding. They viewed their role as that of acting on the infant's compelling cues and of ensuring intake. Although adequacy of the feeding was in the foreground, the mothers were, as a whole, beginning to integrate the infant's agenda and the infant's experience of feeding into their feeding goals.

In the dyad model of engagement, the higher mothers scored on the coregulation component of the working model measure, the more their infants were engaged in feeding during feeding episodes. This finding links the caregivers' ideas about feeding a preterm infant with their perceptions of their role as a coregulator along with infant behavior. As such, this finding is significant for the study of caregiving. Mothers with higher scores on coregulation viewed the infant's participation in the feeding as a highly valued and necessary condition for regulation of the feeding. These mothers related their flexibility and proactive approach in the feeding while taking into account their infants' capacities and potential needs for support (Thoyre, 2000).

When episode level variables were added to the dyad model, the WM variable became statistically insignificant. This suggests that factors within the episodes more appropriately explain this portion of the variance. Alternatively, the inclusion of various episodic factors may override or suppress the WM effects. Nonetheless, because the WM variable shows a trend toward significance in the episode model, it may be worth pursuing further with a larger sample.

Conditions within the feeding episode explained most of the variance in infant engagement. Behavioral readiness at the onset of the feeding episode significantly contributed to the infants' ability to maintain engagement throughout the episode. This finding sheds light on the importance of infant readiness at the onset and provides support for Shaker's (1990) theory that if an infant responds to a nipple touching the lips with active seeking of the nipple, he or she is demonstrating signs of neurodevelopmental readiness. In this sample, readiness contributed to the infant's ability to sustain arousal, attention, and orientation to the feeding.

High variability was observed in how mothers began feeding episodes, and this was a topic of feeding that mothers frequently discussed (Thoyre, 2001). For some feeding episodes, infants were seeking the nipple even before the mother presented it. At other times, mothers touched the nipple to the infant's mouth to test infant readiness, then either waited for the infant to indicate readiness before placing the nipple or went ahead and placed the nipple before the infant became fully active in seeking the nipple. Finally, some feeding episodes began with mothers manually pulling the infant's chin down and placing the nipple in the infant's mouth.

This study clarifies the role of the caregiver at the onset of feeding episodes. The bottle nipple is most appropriately placed in the infant's mouth contingent upon the infant's behavioral cues of readiness. When infant readiness was not attained before nipple placement, infants were less likely to maintain engagement during the subsequent feeding episode.

The $MEANO_2$ of the feeding episode was associated positively with infant feeding engagement. This finding is consistent with Porges' (1994) proposal that infant physiologic regulation provides a supportive framework for infant behavioral organization. Als (1986), in her synactive theory of development, proposed that the first task of preterm infant development is to achieve control over the autonomic system, and that autonomic system development influences and supports the development of an infant's motor and state systems. In this study, the higher the $MEANO_2$, as a reflection of fewer and less severe oxygen desaturations during the feeding episode (i.e., more effective physiologic regulation), the more the infant was able to engage in feeding at the behavioral level. This finding supports the need to develop interventions that promote physiologic regulation during preterm feeding.

Feeding engagement was not associated with $BASEO_2$ or $EPIO_2$. Lower baseline oxygen contributed to more frequent and more severe desaturation events during feedings (Thoyre & Carlson, 2003a; Shiao, Brooker, & Difiore, 1996). The current findings extend these ideas, demonstrating that during the feeding, $MEANO_2$ must be maintained at a sufficient level for maintenance of feeding engagement. Oxygen desaturations or downward drifts in oxygen saturation during feeding need to be minimized. Monitoring infants' oxygen saturation and breathing pattern and aiming to prevent breathing disorganization throughout feeding may facilitate physiologic stability (Thoyre & Carlson, 2003b), and therefore support engagement during feeding.

Mothers' feeding behavior of holding the nipple still rather than jiggling it contributed positively to infant feeding engagement. Holding the nipple still places fewer new demands on the infant, in contrast to jiggling of the nipple, particularly if jiggling occurs when the infant is regulating his or her breathing after a sucking burst, or if the jiggling increases the fluid in a drowsy infant's mouth. Overall, this finding demonstrates that jiggling of the nipple does not facilitate infant engagement in feeding. It must be noted, however, that coding of maternal behavior in this study was general and not contextual. Holding the nipple securely during a pause in sucking while the infant reorganizes his or her breathing pattern may be supportive, but there likely are times during a feeding when it would be more supportive to remove the nipple and provide a break (e.g., when the infant is in distress or passively withdrawing from the feeding). Understanding the relations between caregiver behaviors and infant physiologic and behavioral responses during feeding requires further study of caregiver actions under specific conditions.

As feedings progressed, infants were less able to engage in feeding. This finding is consistent with several other feeding studies that have collected data throughout an entire feeding period (Hill et al., 2000). The diminishing engagement in a feeding becomes an important area for further study.

The limitations of this study included a small sample that was diverse in BW, PCA, and respiratory health. Decreasing the variability of the sample may result in a more precise estimate of dyadic and feeding episode contributions to infant feeding engagement. A larger sample would allow more covariates to be tested. For example, it would be of interest to understand the contributions of bottle- and breast-feeding experience and the frequency of an offered opportunity for oral feeding (i.e., learning) to an infant's capacity to maintain engagement. Although the number of infants who also were breast-feeding in this sample was small, the findings did not show that the proportion of engagement during the feeding episodes was significantly different (mean proportion, 0.68 ± 0.24) from that of non-breast-feeders (mean proportion, 0.65 ± 0.16).

The results of this study shed light on coregulation during very-low-birthweight infant feeding and provide a model for the study of preterm oral feeding. This model involves observation of maternal and infant feeding activity at a behavioral level, simultaneous monitoring of infant physiologic regulation, and exploration of the caregiver's WM of feeding coregulation. The ability of the preterm infant to maintain engagement during oral feeding could not be explained by characteristics of the infant or by the prefeeding condition of the infant alone. Rather, engagement was coregulated by the caregiver and the infant throughout the feeding. The full engagement model proposes that adequate infant oxygenation, a marker of physiologic stability, provides necessary energy for the support of infant engagement during feeding. In addition, infant behaviors that signify readiness for the nipple to be introduced as well as mothers' actions and cognitions about their role as coregulator of feeding have a significant impact on infants' ability to maintain engagement in feeding.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This study was supported by NINR fellowship grant NR07052-02 and NINR grant K01NR07668.

The authors thank Karen F. Pridham, PhD, RN, FAAN, Professor Emeritus at the University of Wisconsin-Madison, School of Nursing, for her mentoring throughout the study, and Lorna Cisler-Cahill, MS, RN, Advanced Practice Nurse, Patient Care Services, Children's Hospital of Wisconsin, Milwaukee, for support in concept development.

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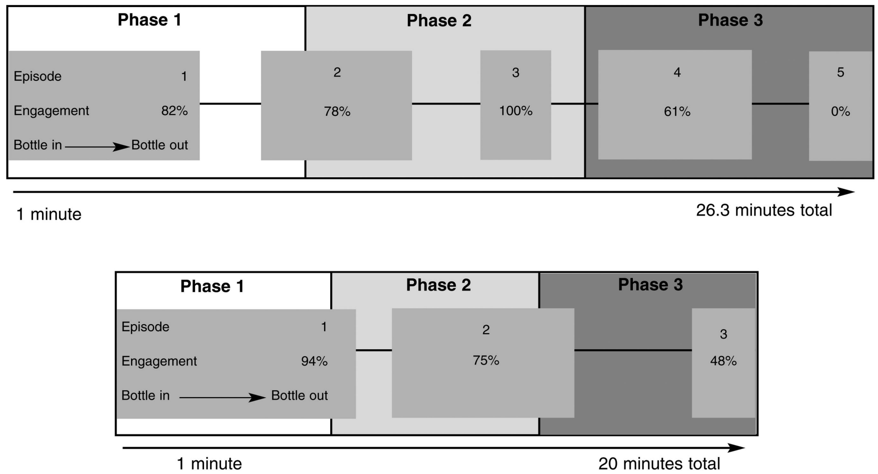

FIGURE 1.

Two examples of infant feedings that depict feeding episodes, phase of feeding, and engagement proportion. **Top:** Infant 9 had five feeding episodes. The respective proportions of engagement during each feeding episode were 82%, 78%, 100%, 61%, and 0%. The proportion of engagement for the infant's entire feeding observation was 74%. The feeding was further divided into Phases 1, 2, and 3. Episodes 1 and 2 began during Phase 1. Episode 3 began during Phase 2. Episodes 4 and 5 began during Phase 3. **Bottom:** Infant 18 had three feeding episodes. The respective proportions of engagement during each feeding episode were 94%, 75%, and 48%. The proportion of engagement for the infant's entire feeding observation was 80%. The feeding is further divided into Phases 1, 2, and 3. Episode 1 began during Phase 1. Episode 2 began during Phase 2. Episode 3 began during Phase 3.

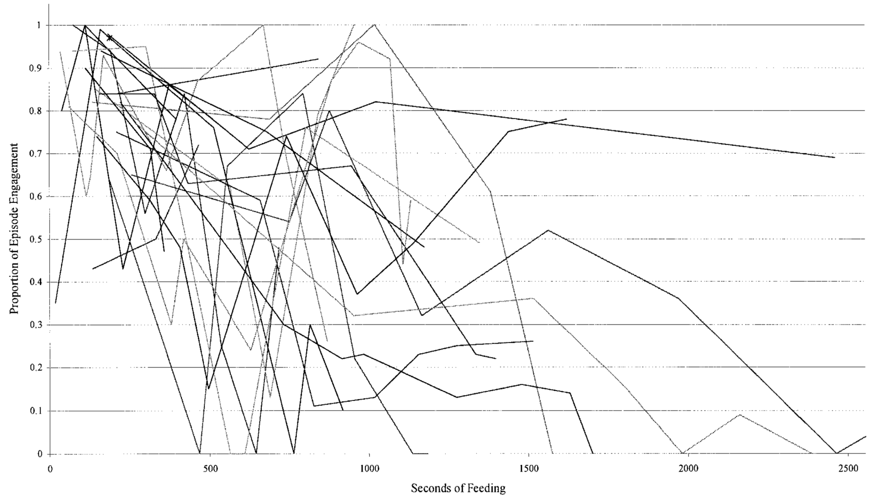

FIGURE 2.
Proportion unadjusted engagement per individual for each feeding episode represented at the midpoint of each episode.

TABLE 1

Characteristics of the Dyads

	Mean ± *SD*	**Range**
Mothers (*N* = 22)		
Age (years)	25.9 ± 6.7	15–39
Education (years)	13.8 ± 3.8	8–21
Experience bottle feeding (no. of previous feedings)	14 ± 11	1–47
Income < $15,000	32%	
Infants (*N* = 22)		
Birth weight (g)	1143 ± 307	620–1500
Weight at time of study (g)	2192 ± 302	1692–2720
Gestational age at birth (weeks)	28.1 ± 2.1	25–32
Postconceptional age at study	36.3 ± 1.5	33.5–39
Days bottle-fed prior to study	16 ± 6.4	6–30
No. of bottle feedings prior to study	62 ± 27	11–115
Length of transition to full oral feeding (days)	14.2 ± 5.8	5–28
Requiring O_2 at 36 weeks	36.4%	

TABLE 2

Descriptive Statistics of Model Variables

	Mean ± *SD*	Range
Dependent variable		
ENG[a]	0.55 ± 0.32	0–1.00
Predictor variables		
Dyad level (N = 22)[b]		
WM	3.32 ± 1.33	1–6
$BASEO_2$	96.86 ± 2.03	90–99
Episode level (N = 114)		
READY[c]	34	
$EPIO_2$	92.52 ± 4.73	71–100
$MEANO_2$	93.47 ± 3.98	81–99
STILL[a]	0.76 ± 0.28	0–1.00
PH2[d]	38	
PH3[d]	38	

Note.

[a]Proportion of feeding episode.

[b]BW and PCA data found in Table 1.

[c]Number of episodes beginning with infant coded as READY.

[d]Number of episodes beginning during this phase of the feeding.

TABLE 3

Multilevel Model of Fixed and Random Effects for the Proportion of Engagement During Feeding Episodes

	Unconditional Model (*N* = 114)		Dyad Model (*N* = 114)		Episode Model (*N* = 114)	
	Estimate	**(*SE*)**	**Estimate**	**(*SE*)**	**Estimate**	**(*SE*)**
Fixed effects						
Constant	0.573	(0.043)*	−2.088	(1.851)	−1.552	(1.607)
Dyad variables						
WM			0.073	(0.032)*	0.044	(0.028)
BW			0.000	(0.000)	0.000	(0.000)
PCA			0.017	(0.028)	−0.001	(0.025)
$BASEO_2$			0.018	(0.018)	−0.012	(0.017)
Episode variables						
READY					0.133	(0.053)*
$EPIO_2$					0.001	(0.005)
$MEANO_2$					0.028	(0.008)*
STILL					0.401	(0.079)*
PH2[a]					−0.111	(0.050)*
PH3[a]					−0.163	(0.053)*
Random effects						
Dyad variation	0.023	(0.012)	0.012	(0.008)	0.012	(0.006)*
Episode variation	0.078	(0.011)*	0.078	(0.011)*	0.039	(0.006)*
−2*Log likelihood	52.025		45.125		−26.526	
Difference in chi-square value			6.9, *df* 4		78.55 *df* 6	
			p = 0.141		*p*<.001	

Note.

*Indicates statistically significant at least at the .05 level.

[a]Dummy coded with Phase 1 as referent.