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Sleep-Wake States and Feeding Progression in Preterm Infants

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Abstract

Background: Previous studies demonstrated a short-term relationship between infant sleep-wake states and oral feeding performance, with state being an indication of infants' neurobehavioral readiness for feeding. However, the relationship between sleep-wake states and feeding skills has not been evaluated longitudinally during hospitalization.

Objectives: The purpose of this study was to examine preterm infants' sleep-wake state developmental trajectories and their associations with feeding progression during hospitalization.

Methods: This descriptive and exploratory study was a secondary analysis using data from a longitudinal two-group, randomized controlled trial evaluating the effects of early and late cycled light on health and developmental outcomes among extremely preterm infants who were born 28 weeks of gestational age. Sleep-wake states were assessed for two 2-hour interfeeding periods per day (day and night hours), 30 weeks postmenstrual age (PMA), and every three weeks until discharge. Occurrences of active sleep, quiet sleep, and waking were recorded every 10 seconds. Feeding progression was assessed based on an infant's PMA at five milestones: first enteral feeding, full enteral feeding, first oral feeding, half oral feeding, and full oral feeding. Trajectory analyses were used to describe developmental changes in sleep-wake states, feeding progression patterns, and associations between feeding progression and sleep-wake trajectories.

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This study was approved by the institutional human subjects review boards for Duke Medicine and Boston College.

The original trial was registered at clinicaltrials.gov, number , on May 21, 2014; the first participant was enrolled was June 2003. <https://clinicaltrials.gov/>

The authors have no conflicts of interest to report.

Results: Active sleep decreased while waking and quiet sleep increased during hospitalization. Two distinct feeding groups were identified: typical and delayed feeding progression. In infants with delayed feeding progression, rates of active and quiet sleep development during the day were delayed compared to those with typical feeding progression. We also found that infants with delayed feeding progression were more likely to be awake more often during the night compared to infants with typical feeding progression.

Discussions: Findings suggest that delays in sleep-wake state development may be associated with delays in feeding progression during hospitalization. Infants with delayed feeding skill development may require more environmental protection to further support their sleep development.

Keywords

development; feeding progression; oral feeding; preterm infant; sleep and wake states

Among infants born prematurely, the ability to orally feed solely from a bottle or breast is a major developmental task and a common criterion for safe discharge from the neonatal intensive care unit (NICU; Committee on Fetus and Newborn, American Academy of Pediatrics, 2008). The development of competent oral feeding skills is dependent on multiple factors; one of which is an infant's neurobehavioral maturation, which plays an important role in developing necessary skills needed for successful oral feeding, including motor organization, cardiorespiratory regulation, rhythmical sucking, and the ability to coordinate a suck-swallow-breath pattern (Park, Knafl, Thoyre, & Brandon, 2015; Silberstein et al., 2009; Van Nostrand, Bennett, Coraglio, Guo, & Muraskas, 2015).

Sleep and wake states are thought to be an indicator of the underlying maturation and stability of an infant's central nervous system function, thereby providing insight into an infant's neurologic development (Calciolari & Montirosso, 2011; Shellhaas, Burns, Barks, & Chervin, 2014). Several studies have examined the short-term relationship between infant sleep and wake states and their oral feeding performance, with the sleep and wake states being an indicator of the infants' neurobehavioral readiness for feeding. An awake state—particularly alertness—prior to and during feeding is associated with greater feeding performance (Griffith, Rankin, & White-Traut, 2017; McCain, 1997; McGrath & Medoff-Cooper, 2002). However, sleep and wake states not only affect an infant's immediate response to the environment, but can also have lasting effects on an infant's neurobehavioral competency. With the development of sleep and wake states, infants become more competent interacting with parents and other caregivers by presenting clear behavioral cues and changing states as a strategy to regulate themselves under stressful circumstances (Als, 1986, 1991; Bell, Lucas, & White-Traut, 2008). As infants increase their capacity to interact with the environment, they are able to accomplish necessary developmental milestones more effectively, such as the mastery of oral feeding. Moreover, the development of stable patterns of sleep and wake states allows for more consolidated and better quality sleep, which has an important role in learning, memory consolidation, secretion of growth hormone, energy storage, and illness recovery (Bonan, Pimentel Filho, Tristão, Jesus, & Campos Junior, 2015; Calciolari & Montirosso, 2011). Therefore, understanding sleep and wake state development and its relationship with an infant's emerging feeding skills may open new avenues for

feeding intervention that includes the support and promotion of sleep and wake state development. This could also provide support for the use of developmental patterns of sleep and wake states as an indicator identifying infants at risk for poor oral feeding outcomes. However, the relationship between the development of sleep and wake states and feeding progression during hospitalization remains unknown.

The purpose of this study was to examine the relationship between preterm infants' sleep and wake state developmental trajectories and feeding progression based on the timing of attainment of the following early feeding milestones during hospitalization: first enteral feeding, full enteral feeding, first oral feeding, half oral feeding, and full oral feeding. Specific aims were to: (a) describe the developmental trajectories for sleep and wake states; (b) identify different feeding progression trajectories; and (c) determine the relationship between feeding progression and sleep and wake state trajectories among premature infants.

Methods

Participants

The sample of 94 preterm infants (< 28 weeks of gestational age [GA] at birth) was drawn from a longitudinal two-group, randomized controlled trial that evaluated the effects of early (28 weeks of postmenstrual age [PMA]; 0–5 weeks of near darkness, followed by 12–16 weeks of cycled light) and late cycled light (36 weeks of PMA; 8–13 weeks of near darkness, 4–8 weeks of cycled light) on health and developmental outcomes of preterm infants (Brandon et al., 2017). Infant's PMA was calculated as ultrasound-based GA plus postnatal age. Cycled light was provided in an 11-hour-on, 11-hour-off pattern. Start times for each phase were allowed to vary between 6:30 a.m.–7:30 a.m. and 6:30 p.m.–7:30 p.m. based on the change-of-shift nursing care needs. In the original study, infants without a history of congenital anomalies associated with neurological or visual problems (e.g., Down syndrome, congenital glaucoma) were recruited from a Level IV intensive care unit and received ongoing care in one of three transitional care nurseries in a medical center in the Southeastern United States. All transitional care nurseries were staffed by the same neonatology team, and the convalescent neonatal nursing care practices were standardized across all settings. The standard of care for all study nurseries was a clustered, developmentally appropriate, care model that aims to minimize environmental stimulations. Infants included in this analysis had at least two sleep observations (on average, the infants had six observations with a range of two to 10), complete feeding progression data, and no structural anomalies involving face, mouth, or gastrointestinal tract that might interfere with oral feeding, such as, cleft plate or tracheoesophageal fistula.

Procedures and Measures

Institutional human subjects review boards for Duke Medicine and Boston College approved this secondary analysis. Data on sleep and wake states were drawn from the original study data. Data on feeding progression were determined from the original data as well as confirmatory retrospective medical chart reviews conducted by the first author. Nine randomly selected charts (approximately 10% of the total sample) were reviewed again

separately three weeks later and full agreement was obtained between the first and second reviews of the nine charts.

Sleep and wake states.—The three major sleep and wake states (*active sleep*, *quiet sleep*, and *waking*) were included in this study. Sleep and wake states were collected beginning at 30 weeks PMA and approximately three weeks thereafter until discharge by observing two 2-hour interfeeding periods each for daytime (between 8 a.m. and noon) and nighttime (between 8 p.m. and midnight) when infants were not receiving hands-on care. Because the interfeeding periods of preterm infants in the NICU were typically 3–4 hours apart, we chose two-hour recordings for each daytime and nighttime period. The two-hour timeframe was sufficient to capture the typical 60-minute sleep-cycle length of preterm infants (Borghese, Minard, & Thoman, 1995), which allows for the capturing of changes in the proportion of sleep and wake states over time, and examining differences between the daytime and nighttime periods of their sleep and wake state development.

To be eligible to begin sleep assessments, infants needed to be stable, not acutely ill, and no longer require invasive respiratory support, such as mechanical ventilation or nasal continuous positive airway pressure (CPAP). Sleep assessments commenced between 30–31 weeks PMA for 81% of the infants, between 33–34 weeks PMA for 17%, and between 35–36 weeks PMA for 2%. Mean postnatal age at the beginning of sleep assessments was 4.5 days ($SD = 2.4$). Sleep and wake states were determined based on digitized waveforms of the infant's body movements, respiration patterns, and eye movements acquired through a piezoelectric pad and electrooculography (EOG) leads. This method was validated with direct behavioral observation (a standard and practical approach to measure sleep-wake states in the preterm population) (Brandon & Holditch-Davis, 2005), which has demonstrated concordance with other objective measures, such as actigraphy and EEG scoring (Sahni, Schulze, Stefanski, Myers, & Fifer, 1995; Sung, Adamson, & Horne, 2009). The specific definitions of each state for coding were described elsewhere in detail (Brandon et al., 2017). During observations, sleep and wake states were recoded every 10 seconds and the percentage of the observation time in each of three states was calculated. Three raters completed coding and every 20th observation was double coded to assess interrater reliability. Overall Kappa coefficient was 0.72 with 0.70 for active sleep, 0.77 for quiet sleep, and 0.70 for waking, which are considered an acceptable level of the interrater reliability (Bakeman & Gottman, 1997; McHugh, 2012).

Feeding progression.—Feeding progression was defined as the infant's PMA in weeks (i.e., GA at birth plus postnatal age) at each of five milestones:

- first enteral feeding;
- first full (100cc/kg/day) enteral feeding;
- first attempt at oral feeding at breast or bottle;
- first half (50% of total nutritional intake) oral feeding; and
- first full (100%) oral feeding followed by two consecutive days of full exclusively oral feeding.

Infant illness characteristics.

Infant illness characteristics were described by immaturity at birth and five common medical comorbidities (neurological risk, severity of lung disease, and the diagnoses of necrotizing enterocolitis [NEC], patent ductus arteriosus [PDA], and gastroesophageal reflux disease [GERD]). *Immaturity* was measured as GA in weeks at birth. *Neurological risk* was based on the presence of periventricular leukomalacia (PVL) and grade of intraventricular hemorrhage (IVH) (no risk = no PVL or IVH grade 1–2; risk = PVL or IVH grade 3–4) (Payne et al., 2013). *Severity of lung disease* was identified using diagnostic criteria for bronchopulmonary dysplasia (BPD; none, mild, moderate, or severe), depending on the duration and degree of supplemental oxygen required when the infant reached 36 weeks of PMA (Jobe & Bancalari, 2001). *Diagnosis of NEC* was identified; *PDA* was classified as no PDA, PDA with medical treatment, or PDA with surgical treatment. *GERD* was based on need for antireflux medications as determined by the physician.

Analysis

Data were analyzed using SAS version 9.3. Descriptive statistics were computed to detail the sample characteristics and outcomes. Nondirectional statistical tests were conducted, with statistical significance set at 0.05 for all tests. Given the exploratory nature of this study, findings with p -values of ≤ 0.10 were identified to inform future studies with a larger sample size and greater statistical power for detecting relationships. In the original study, there were significant effects of the early cycled light intervention on developmental patterns of some sleep and wake states (Brandon et al., 2017); therefore, the cycled light intervention group was included as a covariate for outcome analyses.

To examine the developmental trajectories for sleep and wake states, available sleeping and waking data were grouped into two-week intervals: 30–31, 33–34, 35–36, 37–38, 39–40, 41–42, and 45–46 weeks PMA; three PMA intervals (37–38, 41–42, and 45–46 weeks PMA) were excluded from the analysis due to missing data exceeding 50% of the sample. Random coefficients regression models (RRM, a type of hierarchical mixed-effects model for longitudinal data) were used to examine the developmental trajectories of sleep and wake states over four PMA intervals (30–31, 33–34, 35–36, and 39–40 weeks PMA) after accounting for the effect of cycle light group. Six separate models were examined for waking, active sleep, and quiet sleep each for day and nighttime. Each model was tested based on the fixed effects of time (PMA intervals) and cycled light group along with the random effects of infant and infant-by-time. All models were tested for nonlinear temporal effects and model fit criteria such as Akaike information criterion (AIC) and Bayesian information criterion (BIC) were used to select the final model parameters (Knafl, Beeber, & Schwartz, 2012).

A latent class trajectory analysis approach for longitudinal data was applied to identify different patterns or classes of feeding progression. Each infant was placed in the feeding progression group that corresponded to his/her rate of progression across the feeding milestones. Time was represented by the five successive feeding milestones (1 = first enteral feeding to 5 = full oral feeding), and the outcome was infant PMA week in which each milestone was achieved. The fixed effect was feeding milestone, while random effects were

infant and infant-by-milestone. The best fitting model was determined by comparing BIC scores for each model (Jones, Nagin, & Roeder, 2001) and confirmed by the average posterior probability assigned to each feeding progression group identified by the model. Average posterior probability values exceeding 0.70 indicated good statistical basis which differentiates a group of individuals with and without similar patterns of change based on the modelled trajectories (Andruff, Carraro, Thompson, Gaudreau, & Louvet, 2009). The resulting feeding progression groups were compared in terms of infant illness characteristics using Wilcoxon two-sample tests for continuous measures and Fisher's exact tests for categorical measures due to the small size ($n < 30$) of one of the trajectory groups identified.

Trajectory analysis was then conducted to examine the relationship between the feeding progression groups and sleep and wake state trajectories. A separate RRM was conducted for each of the six sleep and wake state developmental trajectories. Each model included the fixed effects of time (PMA intervals), feeding group, feeding group-by-time, and cycled light group as a covariate, and random effects were infant and infants-by-time. Significant nonlinear temporal effects were incorporated in the model, as needed. Each full RRM was evaluated and the model was reduced to increase statistical power by removing the interaction term (feeding group-by-time) only if (a) the term was statistically nonsignificant and (b) AIC and BIC scores improved.

Results

Infant Characteristics

Among 94 preterm infants, 55.3% were male, and 72.3% were African American. Infants were almost evenly divided between the cycled light groups: early cycled (47.9%) and late cycled light (52.1%). Specific infant illness characteristics are presented on Table 1.

Sleep and Wake State Development

Detailed statistical tables are available in Supplemental Digital Files 1 and 2. Figure 1 presents predicted means for the percentage of the observation time for waking, active sleep, and quiet sleep over time during day and night times, as generated by RRM after adjusting for the effect of cycled light group. As infants mature, waking increased during the night, $F(1, 52.5) = 8.76, p = .005$, but not during the day, $F(1, 64.6) = 1.54, p = .219$ (Figure 1A). Active sleep decreased over time both during the day, $F(1, 69.4) = 28.58, p < .001$, and night, $F(1, 61.9) = 30.88, p < .001$; during the day, a quadratic effect was also found as the rate of changes in active sleep over time slowed down after 35–36 weeks of PMA, $F(1, 69.3) = 11.36, p < .001$ (Figure 1B). Similarly, quiet sleep increased both during the day, $F(1, 63.2) = 15.42, p < .001$, and night, $F(1, 58.6) = 16.10, p < .001$; a quadratic effect was also found during the day as the rate of changes in quiet sleep leveled off after 35–36 weeks of PMA, $F(1, 55.5) = 5.84, p = .019$ (Figure 1C).

Feeding Progression

The latent class trajectory analysis identified two feeding progression groups:

1. typical feeding progression ($n = 70$); and

2. delayed feeding progression ($n = 24$) (Figure 2).

Average posterior probability was 1.0 for the typical feeding progression group and 0.9 for the delayed feeding progression, indicating a good statistical basis for sufficient similarity of individuals within the group as well as sufficient dissimilarity between the groups with regards to their feeding progression. Infants in both groups began enteral feedings around the same time. In contrast, infants in the delayed feeding progression group delayed achievement of full enteral feeding by 1.7 weeks, first oral feeding by 3.8 weeks, half oral feeding by 6 weeks, and full oral feeding by 6.5 weeks, compared to those in the typical feeding progression group (based on difference in mean predicted PMA between the latent feeding groups).

The infants in the two feeding progression groups were compared on demographics and severity of illness. Compared to the infants with the typical feeding progression, those with the delayed feeding progression were more immature and smaller at birth, stayed longer in the hospital, and had a greater number and severity of the medical comorbidities considered (Table 1).

Relationship Between Sleep and Wake State Development and Feeding Progression

Because factors that have a potential effect on sleep and wake state development and/or feeding progression were incorporated into the feeding groups, such as birthweight, GA, and medical comorbidity (Table 1), it was not necessary to adjust for the effects of these factors as covariates in the analyses examining the relationship between feeding progression and sleep and wake state trajectories. Detailed statistical tables are available in Supplemental Digital Files 3 and 4. Figure 3 presents means for the predicted percentage of the observation time for waking, active sleep, and quiet sleep over time by the feeding progression groups, as generated by RRM after accounting for the effect of cycled light groups. Differences between the feeding trajectory groups were found only for trajectories of active and quiet sleep during the day. For active sleep during the day, there was a significant interaction effect between time and feeding groups, $F(1, 46.2) = 46.2, p = .026$, suggesting the rate of decrease in active sleep over time was slower in the delayed feeding progression group compared to the typical feeding progression group (Figure 3B). Similarly, for quiet sleep during the day, an interaction effect between infant's PMA and feeding groups was noted, $F(1, 43.3) = 4.19, p = .047$, suggesting the rate of increase in quiet sleep over time was slower in the delayed feeding progression group compared to the typical feeding progression group (Figure 3C). Infants with delayed feeding progression tended to be more awake during the night across all timepoints compared to those with typical feeding progression, $F(1, 83.8) = 3.49, p = .065$ (Figure 3A). Waking during the day and active and quiet sleep during the night did not differ in their trajectories regarding the feeding progression groups (Supplemental Digital File 3).

Discussion

We explored the relationship between preterm infants' sleep and wake states and their feeding progression longitudinally over the course of the hospitalization. Several meaningful findings were identified in this study. We first found that with maturation, preterm infants

demonstrated changes in sleep and wake states, including a decrease in time for active sleep state and an increase in time for both quiet sleep and waking states. These changes were observed both during day and nighttime observations for active and quiet sleep, but an increase in waking state was observed only during the night with no change during the day. Our findings reinforce the results of the original study (Brandon et al., 2017), which included sleep and wake state development as one of the outcome measures evaluating the effects of the early versus late cycled light intervention groups. Both intervention groups showed developmental trajectories similar to the subsample in the current study. Our findings are consistent with the findings of previous studies that described the general patterns of preterm infants' sleep and wake state development (Holditch-Davis, Scher, Schwartz, & Hudson-Barr, 2004; Lehtonen & Martin, 2004), except for the day and night difference in waking state. Many studies noted that sleep and wake state development can vary depending on several infant factors (e.g., illness severity, GA at birth, or sex) and environmental factors (e.g., caregiving, light/noise or feeding methods) (Brandon et al., 2017; Foreman, Thomas, & Blackburn, 2008; Lan et al., 2018; Thomas, 2000). Further studies that carefully consider potential factors affecting sleep and wake development differently between the day and night would enhance our understanding on the day-night difference in sleep and wake state development.

In this sample of extremely preterm infants (< 28 weeks of GA), we identified two distinct latent groups that differed in terms of the time of attainment of five early feeding milestones. All infants initiated the first enteral feeding within one week after birth; however, variability was noted for the timing of achieving the rest of the feeding milestones across the infants. Most infants reached full enteral feeding around 30 weeks of PMA, the first oral feeding around 35 weeks of PMA, and full oral feeding around 37 weeks of PMA, whereas a quarter of the infants had a considerable delay in achieving each milestone by two to seven weeks. This variability in our sample was expected because multiple studies have consistently shown the timing of achieving early feeding milestones is highly variable among preterm infants, especially for those born < 28 weeks of GA and who often exhibit several comorbidities (Hwang, Ma, Tseng, & Tsai, 2013; Van Nostrand et al., 2015). In addition, while comparing the infants' characteristics between the feeding latent groups (typical and delayed feeding progression), we found that infants with delayed feeding progression were smaller and younger at birth, stayed longer in the hospital, and had severe types of medical comorbidities, compared to those with typical feeding progression. These findings are consistent with other work that demonstrated preterm infants with younger GA at birth and medical comorbidities, such as BPD, NEC, and IVH, had significant delays in both introduction and achievement of full oral feeding compared to those without these conditions (Dodrill, Donovan, Cleghorn, McMahon, & Davies, 2008; Hwang et al., 2013; Jadcherla, Wang, Vijayapal, & Leuthner, 2010; Van Nostrand et al., 2015). Our findings further support the need for more thorough clinical assessments and incorporation of these factors into the development of feeding care to support an infant's individual needs for feeding skill development.

Finally, some relationships between sleep and wake state development and feeding progression were identified. Compared to infants with typical feeding progression, infants with delayed feeding progression showed a slower rate of development in active and quiet

sleep during the day and tended to be awake more often during the night. The association between the development of sleep and wake states and feeding progression may not be unidirectional because both aspects of development are driven by the maturation of an infant's neurologic functioning, with plausible explanations for both directions. Sleep and wake state development has a pivotal role in brain plasticity, i.e., the ability of the brain to change its structure and function in response to environmental changes and needs (Calciolari & Montirosso, 2011; Peirano, Algarín, & Uauy, 2003). In this study, the slower development in active and quiet sleep, as well as the interruption of sleep during the night, might have affected the infant's ability to regulate feeding in response to challenges that arise in the process of attaining full oral feeding. On the other hand, repeated stressful experience during feeding, which occurs more often among infants with delayed feeding progression, can provide abnormal sensory stimulations to the developing brain (Smith et al., 2011) and affect the developmental trajectories for sleep and wake states. Previous research demonstrated that infants' sleep and wake states prior to and during feeding can affect an infant's ability to feed orally (Griffith et al., 2017; McCain, 1997; McGrath & Medoff-Cooper, 2002). Our study extended these findings by demonstrating that development of sleep and wake states can be associated with an infant's emerging skills to attain full oral feeding over longer periods of time during hospitalization. Our findings highlight the importance of providing developmentally appropriate care consistently throughout hospitalization, which can promote the normal development of sleep and wake states and also improve feeding outcomes. Infants who demonstrate abnormal/delayed patterns of sleep and wake states or delays in feeding progression need more protection from environmental stimulation to further support their development in both sleep and wake states and feeding. These delays can be an indication of less developed neurobehavioral organization, which leads to limited ability to coordinate sensory, autonomic, motor, behavioral state regulation, and social interaction systems (Als, 1986, 1991).

The strengths of this study included both the extensive longitudinal data on sleep and wake development collected across the entire hospitalization and the assessment of the full range of early feeding milestones that are necessary to transition toward independent oral feeding. The study also has limitations. The sample consists of extremely preterm infants (born < 28 weeks of GA) who were primarily African American (72.3%); therefore, the findings have limited generalizability. The high incidence of African-American infants was common in the study NICUs but is not as common in other NICUs across the country. Additional studies with a more diverse group of preterm infants in terms of their GA at birth and racial background would improve the generalizability of the study findings. Additionally, we conducted separate trajectory analyses for each sleep and wake state outcome due to the exploratory nature of the study. Small sample sizes per group also prevented the application of multivariate analytic models that take into account multicollinearity among the sleep-wake state outcome measures. Lastly, this study preliminarily examined whether a relationship coexists between sleep and wake state and feeding progression, not the causal relationship between them. Additional studies examining the relationship of sleep and wake state during preterm period to later feeding outcomes would provide support for using sleep and wake states as a potential biomarker to predict long-term feeding outcomes.

Conclusion

In general, preterm infants followed the expected developmental patterns for sleep and wake states during their initial hospitalization, as demonstrated by a decrease in active sleep and an increase in both quiet sleep and waking states as they mature. However, when the developmental change in sleep and wake states was compared to two different trajectories of attaining independent oral feeding, the infants with delayed feeding progression had a slower rate of active and quiet sleep development during the day and tended to be more awake during the night. While additional research is required to confirm our findings, there may be a relationship between sleep and wake development and feeding progression. Therefore, consideration to protect the preterm infant's environment during hospitalization could promote more normal developmental process of sleep and wake states and also improve feeding outcomes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Developmental Trajectory for Sleep-Wake States during the Day and Night. (A) Developmental trajectory for waking, (B) developmental trajectory for active sleep, and (C) developmental trajectory for quiet sleep. PMA = postmenstrual age. Notes. Significant findings were found for the following terms: (A) PMA in weeks during the night ($p = .005$); (B) PMA in weeks ($p < .001$), PMA in weeks² ($p = .001$) during the day and PMA in weeks during the night ($p < .001$); and (C) PMA in weeks ($p < .001$), PMA in weeks² ($p = .019$) during the day and PMA in weeks during the night ($p < .001$).

Figure 2.

Postmenstrual Age Trajectory for the Typical and Delayed Feeding Progression Groups.

Feeding milestones: (1) first enteral feeding, (2) full enteral feeding, (3) first oral feeding, (4) half oral feeding, and (5) full oral feeding. PMA=postmenstrual age. Error bars indicate 95% confidential interval.

A.

B.

C.

Figure 3.

Developmental Trajectory for Sleep-Wake States by Feeding Group. (A) Developmental trajectory for waking during night by feeding group, (B) developmental trajectory for active sleep during day by feeding group, and (C) developmental trajectory for quiet sleep during day by feeding group. PMA = postmenstrual age. Notes. Significant findings were found for the following terms: (B) PMA in weeks-by-feeding group ($p = .026$); and (C) PMA in weeks-by-feeding group ($p = .047$).

Table 1

Infant Illness Characteristics for the Total Sample and by Feeding Progression Group

Characteristic	Total (n = 94)	Typical (n = 70)	Delayed (n = 24)	p
	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	
Gestational age (wks)	26.2 (1.4)	26.4 (1.4)	25.5 (1.2)	.004
Birth weight (g)	868.1 (228.5)	920.0 (225.3)	716.7 (163.2)	.001
Length of hospitalization (days)	103.1 (37.7)	87.9 (21.7)	147.7 (39.7)	< .001
	n (%)	n (%)	n (%)	
Neurologic risk				
None	80 (86.0)	66 (95.7)	14 (52.9)	<.001
PVL or IVH 3 or 4	13 (14.0)	3 (4.3)	10 (47.1)	
Severity of BPD				
None	23 (24.4)	22 (31.4)	1 (4.2)	<.001
Mild BPD	45 (47.9)	39 (55.7)	6 (25.0)	
Moderate BPD	14 (14.9)	7 (10.0)	7 (29.2)	
Severe BPD	12 (12.8)	2 (2.9)	10 (41.6)	
Patent ductus arteriosus				
None	33 (35.5)	29 (42.0)	4 (16.7)	<.001
Medical treatment	44 (47.3)	35 (50.7)	9 (37.5)	
Surgical treatment	16 (17.2)	5 (7.3)	11 (45.8)	
Necrotizing enterocolitis				
No	67 (71.3)	55 (78.6)	12 (50.0)	.017
Yes	27 (28.7)	15 (21.4)	12 (50.0)	
Gastroesophageal reflux disease				
No	36 (38.7)	32 (46.4)	4 (16.7)	.014
Yes	57 (61.3)	37 (53.6)	20 (83.3)	
Feeding type at discharge				
Oral	85 (90.4)	69 (98.6)	16 (66.7)	<.001
G-tube	9 (9.6)	1 (1.4)	8 (33.3)	

Note: *M (SD)* = mean (standard deviation) for continuous measures; n (%) for categorical measures; Typical=typical feeding progression group; Delayed=delayed feeding progression group; PVL=periventricular leukomalacia; IVH=intraventricular hemorrhage; BPD=bronchopulmonary dysplasia.