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How Do Infants Eat at Home? A Preliminary Study of Complementary Feeding Skills in the Naturalistic Environment

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ABSTRACT

Purpose: Understanding feeding development is essential for improving the targeted management of pediatric feeding disorder (PFD), but information is scarce on how infants develop complementary feeding skills in their natural environments. This cross-sectional observational study was a first step toward (a) assessing the feasibility of characterizing infant feeding experiences in the home environment and (b) determining the concurrent predictors of infant complementary feeding skills using a dynamic systems approach.
Method: Thirty-six 6- to 8-month-old infants and their caregivers participated; this sample was loaded with 11 infants considered "at risk" of developing feeding disorders due to experience in the neonatal intensive care unit. Feeding was assessed with the Oral Feeding Skills Scale (OFS-S) and an eating efficiency measure, extracted from caregiver-recorded videos of typical meals at home. Caregivers completed surveys and interviews to qualitatively characterize the infants' typical home feeding environment and infant experiences. Developmental covariates were assessed via standardized tests, and analyses included hierarchical logistic regressions.
Results: All enrolled families completed all components of data collection, and data analysis was found to be valid and reliable using caregiver-recorded methods in the home setting. Infants demonstrated a wide range of feeding experiences and variable complementary feeding skills (OFS-S scores of 15.67–52.67), with significant differences between risk groups ($t = 4.39$, $p < .001$); infants in the at-risk group demonstrated less skills and more variability. Risk group ($p < .00015$) and weeks of feeding experience ($p < .0026$) were the best concurrent predictors of infant oral–motor complementary feeding skills at 6–8 months of age.
Conclusions: This study provides new evidence that it is feasible to observe infant complementary feeding skills in the home environment, and infants at risk for feeding disorders demonstrate complementary feeding skills different from those of low-risk peers. Future studies should include more infants in a longitudinal design to tease out influences on development, with the aim of early identification and treatment of PFD.
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An infant's ability to chew and swallow nonliquid food facilitates growth, health, and well-being in the first year of life and beyond. Successfully transitioning to complementary feeding is associated with improved growth, obesity prevention, and food acceptance (e.g., Fewtrell

et al., 2017; Moding et al., 2014). Difficulty transitioning from reliance on breast- or bottle-feeding to complementary (i.e., solid and/or puree) foods for nutrition and hydration is associated with pediatric feeding disorder (PFD; Goday et al., 2019). Infants with PFD may experience serious health consequences, such as undernutrition and respiratory infections (Arvedson, 2008; Prasse & Kikano, 2009), as well as reduced quality of life for children and increased family stress (Estrem et al., 2018; Simione et al., 2023).

Despite the importance of complementary feeding, relatively little is documented about how an infant acquires all the oral–motor skills needed to independently chew and swallow complementary food. Understanding how these skills develop would be useful for understanding when and how to intervene for infants who are at increased risk of developing PFD.

Current feeding literature in this area largely focuses on tracking the average age of attainment of fine-motor feeding milestones and texture intake across populations in U.S. and European contexts (Campeau et al., 2021; Carruth & Skinner, 2002; Carruth et al., 2004; Delaney, 2010; Wright et al., 2011). Studies evaluating oral–motor complementary feeding skills often focus on difficulties in specific populations such as Down syndrome and preterm birth (Guimarães et al., 2024; Hielscher et al., 2023; Liotto et al., 2020). Some early efforts to characterize oral–motor feeding skills include (a) Delaney's (2010), who took a first step toward categorizing oral feeding skills and feeding experiences in typical development, and (b) the establishment of norm-referenced values for some assessments of oral feeding skills and coordination (e.g., Pados et al., 2018).

Taken together, these studies provide a broad foundation regarding average complementary feeding initiation timelines and deficits in specific diagnoses, but they do not provide a detailed characterization of oral–motor complementary feeding development in the infants' natural environment. Feeding experience and cross-system interactions were recently examined in relation to a separate but related early skill—bottle-feeding. Ibrahim et al. (2024) found that being born earlier, having longer hospital stays, and having more complex medical diagnoses are associated with a greater risk for bottle-feeding skill deficits at term-equivalent age. However, it is still unknown if this risk persists for later feeding skills including complementary feeding.

Recent developmental theories posit that development is dynamic, that is, influenced by infant experiences and cross-system interactions (Adolph, 2019; Hadders-Algra, 2010; Thelen, 2005; Zimmerman et al., 2020). Thus, in order to understand the development of a specific skill, it is necessary to evaluate this skill in context and relative to each infant's own experiences and bodies (Adolph et al., 2003; Karasik & Robinson, 2022), as well as within the culture in which they exist (Karasik & Robinson, 2022). Using a dynamic approach to study the development of feeding is crucial, not only because the approach has growing evidence in the literature but also because it explains why interventions can influence skill development in different domains (Thelen & Adolph, 1992) and supports the use of cross-system interventions to maximize function in infants with disorders.

Despite these important reasons for using a dynamic systems approach to study feeding development, research using a dynamic systems framework is only just beginning to accumulate for the study of feeding (Goldfield et al., 2017; Thompson et al., 2023; Zimmerman et al., 2020). Looking at the broader literature, it is possible that the quantity (i.e., weeks) of complementary feeding experience (Thelen, 2005); the development of related body functions/systems (i.e., vocalizations/aerodigestive system; Wolthuis-Stigter et al., 2015); and early-life disruptions, specifically spending time in the neonatal intensive care unit (NICU; Dodrill et al., 2004; Ibrahim et al., 2024), could be related to feeding skill development. To our knowledge, no published studies have systematically examined oral feeding skills in the natural environment, relative to an infant's experiences and other body systems.

The Current Study

As a first step toward filling this scientific gap, the purpose of this preliminary cross-sectional study was to characterize feeding experiences and oral feeding skills in a cohort of infants in their home environments. We aimed to recruit a representative sample of the United States, considering race and geography and inclusive of children who may go on to develop feeding disorders. Our goal was to reflect the heterogeneity of the infant population, which includes a small but meaningful proportion of those who go on to develop PFD. In order to ensure our findings incorporated those infants, we recruited a group of "at-risk" infants with early-life experience in the NICU, who we hypothesized would be at risk for oral feeding deficits (Ibrahim et al., 2024).

Our first aim was to assess the feasibility of characterizing infant feeding experiences in the home environment; we hypothesized that it would be feasible to reliably assess infant feeding experiences at home via remote assessment, regardless of the risk of feeding disorder (Kelleher et al., 2022), and infants would demonstrate a wide range of complementary feeding experiences (such as the number of unique foods and consistencies offered to the infant and customary feeding location; Delaney et al.,

2024). Our second aim was to determine the concurrent predictors of infant complementary feeding skills using a dynamic systems approach, considering multiple factors. We hypothesized that the duration (i.e., weeks) of complementary feeding experience (Thelen, 2005); the development of vocalization skills (Wolthuis-Stigter et al., 2015); and early-life disruptions, specifically spending time in the NICU (Dodrill et al., 2004; Ibrahim et al., 2024), would be better predictors of feeding skills than general developmental status, as measured by standardized assessment.

Method

Participants

We recruited infants suspected of having typical development with typical early-life feeding experiences (low-risk infants) and infants at increased risk of developing feeding disorders secondary to NICU admission (at-risk infants). We included both groups to reflect the overall heterogeneity in the infant population; at-risk infants were specifically included to create a "loaded" group of participants, with more variability in feeding skill development than you might see in a group of all typically developing infants. Defining risk factors in any infant is difficult due to the variable combinations of detrimental and protective factors, involving genetics, prenatal care, events at or around birth, and care decisions made within the first months and years of life, among a multitude of other factors (Grunberg et al., 2019; Schemer & Sexton, 1991). Infants hospitalized in the NICU is one group that is consistently found at risk for disorders, is readily available, and crosses cultures and communities (Bieleninik & Gold, 2014; Dodrill et al., 2004; Ibrahim et al., 2024; Lee & Lee, 2018; McCormick, 1989). These infants all experience early-life disruptions and a hospital environment distinct from infant home settings during their early feeding experiences. For this preliminary study, we used NICU admission as a broad but measurable categorization of risk.

A power analysis was completed using PROC POWER in SAS (Plets & Strominger, 2013); in order to achieve greater than 0.80 power at a .05 significance level to detect the hypothesized full-model R^2 of .388, we needed 22 participants. We recruited additional participants (over 22) to account for attrition and difficulties with infant data collection at home.

Inclusion criteria for the low-risk group included 6–8 months of age at enrollment; full-term birth; no medical diagnoses (including no referrals for feeding concerns); no siblings with speech, language, or hearing issues; English learning (> 80% of input is English); and introduction to complementary food (i.e., puree and/or solid) at least one time prior to study initiation. Exclusion criteria for the low-risk group included preterm birth, medical diagnoses (cardiac deficit, laryngomalacia, etc.), non-English learning, and no prior introduction to puree and/or solid food. Inclusion criteria for the at-risk group were 6–8 months of age at enrollment (adjusted age for prematurity), inpatient stay in the NICU for any length of time, English learning, and introduction to complementary food at least once, whereas exclusion criteria were non-English learning and no prior introduction to puree and/or solid food. There were no medical/feeding diagnoses that led to exclusion from the at-risk group. The "English learning" inclusion criterion was included for the vocalization analyses.

In addition to infant participants, one corresponding adult caregiver was included with each infant. The inclusion criteria for caregivers were regular internet and computer access, daily time spent with their infant, and conversational English ability, via caregiver report. Exclusion criteria were being younger than 18 years, non-English learning, and not spending time daily with the infant.

Recruitment began in 2023, and all data collection was completed in the same year, with analysis concluding in 2024. We recruited participants from all seven geographic regions of the United States using physical flyers; e-mails to families who had opted in to internal research participant databases at the university; and social media platforms, including Instagram and Facebook.

Data Collection

A remote, cross-sectional data collection design was used to facilitate naturalistic observations of the infants (Herzberg et al., 2022; Smith et al., 2018; see Supplemental Material S4). Caregivers and infants participated in this prospective, remote data collection over the course of 2 weeks. Ethical approval was obtained from the Purdue University Institutional Review Board (No. 2022-626).

Upon eligibility established via a phone screening, the caregivers and their infants were invited to schedule an initial session via a secure videoconferencing platform (Zoom Healthcare). In this session, first, caregivers completed consent procedures and case history interviews/documentation (documents submitted securely via Docusign). During this case history time, the researcher asked the caregivers standard questions, and they provided information on the number of foods tried, the types of food tried, and weeks of experience with complementary food. They were also coached on how to complete study procedures on their own time, with the aim of completion within 1 week of the initial consent and instructional session. Specifically, they were asked to take video recordings of

two naturalistic full mealtimes on their own devices and one daylong audio recording of the infant's language environment via a Language Environment Analysis (LENA; Gilkerson et al., 2017) device. The device was shipped to them in a package that included visual step-by-step guides to all study procedures. In the same session, they were provided with detailed verbal and visual instructions for completing the recordings, completed knowledge checks of the procedures, and were given the opportunity to troubleshoot and ask questions. In addition to recording specifications, they were told how to submit their videos via a secure file-sharing platform (Purdue Box) and return the LENA device. About 1 week after the initial session, caregivers completed a Follow-up and Survey session (i.e., a second live video session), where researchers confirmed that files had been successfully submitted or troubleshot file uploading, administered standardized caregiver report measures about feeding, and obtained qualitative data about feeding experiences.

Measures

Characterizing Feeding Environment and Experience

Our first goal was to characterize infants' feeding environment and experiences. To do this, we first had to determine if this characterization was feasible using our remote data collection scheme. After collecting caregiver-recorded files from their own devices, all videos were reviewed and deidentified by research assistants before analysis. They ensured that (a) the infant's whole head was visible throughout the recording, (b) the infant's upper body and hands were visible, (c) over 80% of bites of food were visible via a nonobstructed view, (d) the video included the entirety of the mealtime, and (e) the lighting and video quality were adequate to view all infant facial structures. The research assistants also objectively coded infants' feeding environment, including position/seating, foods presented, observed feeding methods (e.g., self-feeding with the hand or a spoon), and consistencies presented. They also categorized if the presented complementary food included purees (smooth/blended) and/or chewable solids. They were trained to track these variables by the first author, and they completed a set of infant training videos before coding study videos. Intra- and interrater reliability were calculated for these quality measures (described below). We also collected caregiver reports of their infants' feeding experiences via written case history forms, which were discussed and clarified with the researchers in the teleconferencing survey session.

Feeding Skill Measures

Two observational coding schemes were used to assess feeding skills from the mealtime videos. First, we utilized the Oral Feeding Skills Scale (OFS-S), a measure that characterizes oral behaviors during feeding (Delaney, 2010). This observation scheme includes a binary assessment of 52 feeding skills observable during infant feeding videos. These 52 skills were systematically identified from a larger pool of behaviors identified in the literature and selected through expert validation procedures for their salience to comprehensive feeding development (Delaney, 2010). For example, one of the 52 scored behaviors is described as "No bolus loss during bolus manipulation," which is scored as *observed* or *not observed* for each bite. The first author (R.H.A.) was trained in infant-feeding coding analysis in person by an expert rater and specific to the OFS-S through discussion and guidance from the creator of the tool. As described in the original scheme, we scored all 52 feeding skills as *present* or *absent* for three bites of each consistency (puree and chewable solid) using the OFS-S. We selected the second, third, and fourth bites of each eating instance to be consistent across infants. To account for intra-individual variability, we used a sum score method, where each consistency consumed (i.e., puree, solid) had a maximum score of 156.

In addition to the OFS-S, normalized mealtime duration (nMD) was calculated from the recorded mealtimes. Raters were trained through a standardized training protocol in the lab of the nMD's creator (last author). This is a measure of eating efficiency adapted from Mishra et al. (2018) by Malandraki et al. (2022), which allows comparison of average time per bite/sip between participants. This is calculated by dividing the total duration of the meal by the total number of bites/sips. We define the onset of a bite as when a food or liquid crosses the anterior border of the lips, and we define the offset as the beginning of the next bite. This method of bite timing was based on the original method and refined for application to infants.

Predictors of Oral Feeding Skill

Our second goal was to examine predictors of infant feeding skills using a dynamic systems framework. We utilized (a) previously described data on feeding environment and experience, (b) measures of general development, and (c) more detailed measures on the development of a related system—infant prespeech behaviors/vocalizations.

First, we obtained a measure of general development across systems as a control covariate using a "Problem Solving skills" subset as a proxy of general development. This was the Ages and Stages Questionnaire (ASQ; Bricker et al., 1999), completed by the caregivers, which is a developmental screener that has good psychometric properties of concurrent validity and internal consistency (e.g., Fauls et al., 2020; Hornman et al., 2013).

We also obtained data on children's vocalizations because speech/vocalization is a physiologically related

system to oral feeding skills (Fehrenbach & Herring, 2015; Hahn Arkenberg et al., 2023), and we were particularly interested in the predictive value of clinically feasible cross-system measures. Although feeding and speech/vocalizations have distinct purposes, producing intentional prelinguistic vocalizations relies on similar anatomical features and shares some neurophysiological processes with swallowing, including inferior frontal gyrus activation (Fehrenbach & Herring, 2015; Malandraki et al., 2009; Saarinen et al., 2006). There is also some evidence that vocalization and feeding development may be linked in specific populations, such as cerebral palsy (Hahn Arkenberg et al., 2023; Malandraki et al., 2022). To evaluate the relationship between vocalizations and feeding skills, vocalizations were collected via daylong audio recordings (Gilkerson et al., 2017). The LENA system includes proprietary analysis software, which is utilized for the diarization (speaker tagging) of the recordings and the analysis of quantity of vocalizations. However, in this study, only one such variable—child vocalization count (CVC)—was utilized, because it has been shown to be one of the most valid and reliable measures from the LENA software (Cristia et al., 2021). CVC is the number of speech-related vocalizations produced by the infant, calculated automatically by the LENA algorithm when infant speech is surrounded by 300 ms of silence (Gilkerson et al., 2017), with a minimum length of 600 ms. We normalized the number of vocalizations by the length of audio recordings, which may vary based on awake hours. We also used the raw LENA .its files to run a bespoke Python script to calculate the duration of each infant utterance extracted.

Data Analysis

All videos and assessments were reviewed, deidentified, and blinded for subject ID, age, and risk group. Feeding skills were assessed from the two caregiver-recorded videos of naturalistic mealtimes. Coders were required to reach 90% intra- and interrater reliability with an expert coder prior to analyzing data. Assessment measures included the OFS-S (Delaney, 2010) and nMD (Malandraki et al., 2022), as described above. For both measures, coders played the video frame by frame and marked behaviors or timing events in an Excel spreadsheet.

Statistical Analysis

We compared demographic data using *t* tests with Bonferroni correction. We utilized *t* tests with Bonferroni correction to characterize the feeding environment and experience, as well as hierarchical multiple regression models to examine the predictors of feeding skills. In this method, variables are added in a stepwise manner, building upon the initial hypothesized model, and each subsequent model is compared to determine if they fit the data significantly better than previous models. Scores for the feeding skill outcome variable were transformed into a logit value because the residuals were skewed and from a relatively small sample. Independent hypothesized variables were entered first in Regression 1 (utterance duration, weeks of feeding experience, and problem-solving skills as a proxy for general developmental level), and a group variable was added in Regression 2, due to the observed differences between groups. Finally, interaction terms were added in Regression 3 to verify that the predictors could stand independently, rather than the combination impacting the model. The R^2 value indicates how much variability in the outcome (feeding skills) can be predicted by the model. The significance of R^2 change indicates if the model is significantly different from the previous model. All statistical analyses were completed in R (R Core Team, 2021).

Results

Demographics of Participants

Forty-seven individuals were screened for participation, of which 38 qualified for the study; of the 38 who qualified, 36 caregiver–infant dyads—from 15 unique U.S. states representing all quadrants of the United States—were consented and completed the study (11 at-risk and 25 low-risk). Demographics and the developmental history of the participants are depicted in Table 1. Infants' gestational age at participation was an average of 7.04 months for low-risk infants and 6.37 months of adjusted age for at-risk infants. The sample included 16 girls and 20 boys, and 12 of the 36 infants were non-White. Across both groups, this sample was economically homogeneous, with all families having relatively high socioeconomic status (21 of 36 mothers had a graduate degree, and all had some college experience). The at-risk infants had smaller birth weight, lower Apgar scores, and younger gestational age at delivery compared to low-risk infants, but after Bonferroni correction, only gestational age at delivery was significantly different (see Table 1). Caregiver-reported reasons for NICU admission included the following: prematurity, low birth weight and/or intrauterine growth restriction, low blood glucose, and/or pregnancy and/or delivery complications.

Characterizing Feeding Environment and Experiences

The first aim was to characterize infant feeding experiences in the home environment. We found that it was feasible to reliably assess infant experience via remote

Table 1. Demographics and birth history.

Variable	Low-risk infants	At-risk infants
n (female:male)	25 (11:14)	11 (5:6)
Gestational age at participation (months), *M* (*SD*)	7.04 (0.69)	6.37 (0.55)
Race and ethnicity, *n* (%)		
White, non-Hispanic	17 (68)	7 (67)
Hispanic	3 (12)	
Asian	2 (8)	
Multiracial	2 (8)	4 (36)
Did not disclose	1 (4)	
Mother's education, *n* (%)		
Graduate degree	12 (48)	9 (82)
Bachelor's degree	12 (48)	2 (18)
Some college	1 (4)	
Birth weight (lb), *M* (*SD*)	7.61 (1.28)	6.32 (2.34)
5-min Apgar scores, *M* (*SD*)	9 (0)	8.5 (0.76)
Gestational age at delivery (weeks)		
M (*SD*)	39.17 (1.46)	36.27 (2.89)*
Mdn		35
Range		33–41
Parent-reported reason for NICU admission*		
Prematurity		6
Low birth weight and/or IUGR		4
Low blood glucose		3
Pregnancy and/or delivery complications		3
Did not report		1

Note. Unless otherwise indicated, results are reported as average (standard deviation). Caregivers had the option of reporting more than one reason for NICU admission, which is reflected in the above totals. NICU = neonatal intensive care unit; IUGR = intrauterine growth restriction.

*$p < .05$ with Bonferroni correction.

assessment in our sample, and infants demonstrated a wide range of feeding experiences.

Technical Feasibility and Reliability

This study was designed to be completed remotely to facilitate naturalistic measurement and to enable the recruitment of racially and geographically diverse participants. Because remote data collection has not been commonly used in the clinical feeding assessment literature, feasibility data were collected, and additional quality checks were completed on all data. Of the 36 participants who completed the study, 100% of caregivers attended all scheduled videoconferencing sessions, and 97.22% (35/36) of caregivers returned all fully completed online surveys and forms. One caregiver declined to complete some sections of the case history, reflected in missing values in Table 1. Furthermore, 94.44% (34/36) of caregivers followed all recording instructions reliably. All uploaded videos were taken on caregivers' personal devices, and all (100%) of the submitted videos passed the quality check.

Inter- and intrarater reliability were calculated for all measures involving raters. There was excellent intrarater (intraclass correlation coefficient [ICC] = .9890) and interrater (ICC = .9577) reliability for nMD and for the OFS-S (intrarater $\kappa = .82$, with 92.69% agreement; interrater $\kappa = .81$, with 90.62% agreement). There was 100% inter- and intrarater agreement for the scores of video quality and feeding environment.

Infant Feeding Experiences

A summary of infant feeding history and experience is depicted in Table 2. Low-risk and at-risk infants, on average, demonstrated similar age of complementary food introduction and months of experience with complementary food, with no statistically significant differences between groups (about a month and a half; $t = 0.095$, $p < .925$), but there was higher variability in the at-risk group. Two infants in the at-risk group had an unusually long experience with complementary food compared to the other participants; both were born preterm and started

Table 2. Participant feeding history, by risk group.

Variable	Low-risk infants (*N* = 25)	At-risk infants (*N* = 11)
Feeding history, *n* (%)		
Exclusively breast-fed	2 (8)	0
Breast- and bottle-fed	21 (84)	7 (64)
Tube-, breast-, and bottle-fed	0	3 (27)
Exclusively bottle-fed	0	0
Decline to answer	2 (8)	1 (9)
Problematic feeding history, *n* (%)		
Yes	5 (20)	6 (55)
No	20 (80)	4 (36)
Decline to answer	0	1 (9)
Age of complementary food introduction (months), *M* (*SD*)	5.33 (0.63)	5.45 (1.2)
Experience with complementary foods (months), *M* (*SD*)	1.68 (0.92)	1.64 (1.72)
Consistency of complementary foods introduced first, *n* (%)		
Mashed/soft solid "mashed table food"	11 (44)	5 (45)
Regular solid "table food"	8 (32)	4 (36)
Puree	5 (20)	2 (18)
Method of complementary feeding introduced first, *n* (%)		
Caregiver spoon-fed	14 (56)	9 (82)
Self-fed with hands	5 (20)	1 (9)
Self-fed with spoon	5 (20)	1 (9)
Decline to answer	1 (4)	0
Number of foods tried, *n* (%)		
40+	5 (20)	3 (27)
20–40	6 (24)	2 (18)
10–20	9 (36)	1 (9)
5–10	3 (12)	2 (18)
3–5	0	3 (27)
Decline to answer	2 (8)	0
Observed feeding method during study, *n* (%)		
Mix of caregiver-fed and self-fed	20 (80)	8 (73)
Only caregiver-fed	0	3 (27)
Only self-fed	3 (12)	0
Reported feeding location, *n* (%)		
High chair only	14 (56)	8 (73)
More than one location (high chair, lap, floor, couch, standing, infant seat)	7 (28)	3 (27)
Infant seat only	2 (8)	0
Lap only	1 (4)	0
Decline to answer	1 (4)	0

purees at 4 months of chronological age, which was about 2 months of adjusted age. All participants had experienced breast-feeding at some point in their life, with the majority (31/36) having a history of receiving a mix of breast- and bottle-feeding, whereas three at-risk infants experienced breast-, bottle-, and tube-feeding. Twenty percent of caregivers of low-risk infants (5/25) reported generally "problematic feeding," most frequently described as difficulties with breast-feeding. Sixty-four percent of caregivers of at-risk infants (7/11) reported problematic feeding, including difficulties with breast-feeding, the necessity for tube-feeding in the NICU, and bottle refusal. For more information, individual feeding profiles are included in Supplemental Material S1.

Caregivers reported a wide variety of infant experiences with food. Caregivers were asked to describe their infants' experiences with purees, mashed/soft solids, and regular solids (i.e., chewable solids). Most infants were introduced to mashed/soft solids first (n = 16; see Table 2), followed in frequency by regular solids, that is, "table food" (n = 12), and, least commonly, purees (n = 9). The distribution of first foods was similar in the two risk groups (see Table 2). Most caregivers reported that their

infant ate food exclusively in a high chair (n = 22), followed in frequency by feeding in "more than one location" (n = 10). Caregivers estimated the number of unique foods their infants had tried; in both groups, about half the infants tried a wide variety of unique foods: 44% of low-risk infants and 45% of at-risk infants had tried more than 20 foods. However, the groups differed in the proportion of infants with very few unique foods: only 12% of low-risk infants had tried fewer than 10 foods, whereas half (45%) of at-risk infants reportedly tried fewer than 10 foods.

In addition to caregiver report, we also completed observations of feeding experiences during the recorded meals. Nineteen infants were observed eating both purees and chewable solids (four of whom were at risk), 12 ate only purees (five of whom were at risk), and five ate only solids (two of whom were at risk). Most infants had a mix of self-fed and caregiver-fed bites. Zero infants in the low-risk group demonstrated no self-feeding, whereas 27% of at-risk infants had no self-feeding.

Predictors of Infant Feeding Skills

Our second aim was to determine the best predictors of infant feeding skills and eating efficiency during complementary feeding. We hypothesized that the duration of complementary feeding experience (Thelen, 2005), the developmental level of related systems (i.e., infant vocalizations; Wolthuis-Stigter et al., 2015), and early-life disruptions (i.e., spending time in the NICU; Dodrill et al., 2004; Ibrahim et al., 2024) would be best predictors of feeding skills.

Feeding Skills

Feeding skills were first assessed with the OFS-S, on a scale of 0–156 (Delaney, 2010). Results are reported as mean (standard deviation), unless otherwise stated. For each infant, we recorded the number of oral feeding skills demonstrated on a single bite of food (0–52). Then, we summed scores for three bites of each consistency (purees and chewable solids). Individual results—averaged between two meals—are depicted in Supplemental Material S2, and specific meal summaries are listed in the feeding histories (see Supplemental Material S1).

t tests with Bonferroni correction revealed that feeding skills were significantly different in the two groups (t = 4.39, p < .001). Infants in the low-risk group received an average score of 88.31 (8.01), whereas infants in the at-risk group averaged 71.75 (14.88) skills. There was significant variability in the at-risk group, with scores ranging from 53 to 107 (see Figure 1a). Because groups were significantly different, a group factor (coded 0 for low-risk or 1 for at-risk) was added to the regression analysis.

Hierarchical multiple regression was completed to determine the model that best predicted feeding skills. Feeding skills were significantly and independently predicted by weeks of feeding experience and risk group in a positive direction (see Table 3). The model that included utterance duration, weeks of feeding experience, the ASQ, and risk group explained 56.61% of the variability in oral feeding skills, and the change in R^2 by the addition of the interaction was not significant. Utterance duration alone and ASQ problem solving (as a proxy for general developmental level) did not contribute significantly to the model.

Eating Efficiency

nMD also significantly differed between groups (t = 2.49, p < .01), with low-risk infants demonstrating an average time of 20.96 s (8.45) per bite/sip, compared to the at-risk average time of 14.78 s (3.93) per bite/sip (see Figure 1b). Hierarchical multiple regression was again

Figure 1. (a) Sum of oral feeding skills across consistencies, as assessed using the Oral Feeding Skills Scale (OFS-S), by group. (b) Normalized mealtime duration, by group. *p < .05.

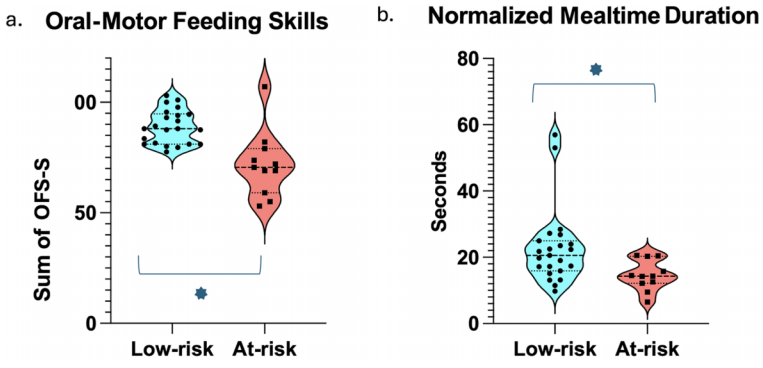

Table 3. Hierarchical regression analysis of predictors of feeding skills.

Predictor variable	Regression 1	Regression 2	Regression 3
Utterance duration	0.0122	0.0093	0.0138
Weeks of feeding experience	4.8027*	5.0558**	4.4045**
ASQ problem solving	–0.1446	–0.0171	–0.0061
Group		17.1538***	16.3231
Group × Utterance Duration			–0.0276
R^2	.2217	.5661	.6131
R^2 change		.3444***	.0470

Note. ASQ = Ages and Stages Questionnaire.
*$p < .05$. **$p < .01$. ***$p < .001$.

completed to determine the model that best predicted nMD (see Supplemental Material S3); initial variables included utterance duration, weeks of feeding experience, and the ASQ. None of the models significantly predicted nMD, and the subsequent hierarchical models did not significantly improve R^2.

Discussion

Developing independent complementary feeding skills is necessary for child and family well-being but remains relatively unstudied. As a first step toward addressing this gap, we conducted a preliminary observational study to (a) characterize infant feeding experiences in the home environment and (b) determine the best predictors of infant skills during complementary feeding. To accurately characterize infant feeding skills, we used a remote study design and quantified behaviors of interest in the infants' natural environment. We prioritized naturalistic recordings, as opposed to strictly controlled feeding protocols, because of evidence that ecologic validity is essential when examining dynamic influences on infant skills, which was a primary motivation of this study (Bergelson et al., 2019; Herzberg et al., 2022; Smith et al., 2018; Yurovsky et al., 2013). We found that infants demonstrated a wide range of feeding experiences and variable complementary feeding skills. Risk group and weeks of feeding experience were the best concurrent predictors of infant oral–motor complementary feeding skills.

Naturalistic Assessment of Infant Feeding Experiences

In this sample, it was feasible to reliably assess feeding skills in the naturalistic environment with the caregiver's own devices. Our remote design allowed us to collect naturalistic data on infants; 94.4% of caregivers completed all study tasks with 100% accuracy, including using correct camera angles and independent video uploading with their own devices.

Remote infant assessment started generating widespread research interest in the 2010s in the fields of language and gross motor development. The use of home-based daylong audio recordings has become standard practice in the study of early language input and infant/child vocalizations (e.g., Bergelson et al., 2019; Gilkerson et al., 2017; Yurovsky et al., 2013). Live videoconferencing has also been found to be valid for interview contexts (Oliffe et al., 2021), and 100% of caregivers completed our videoconferencing interviews without difficulty. Despite gaining traction in other fields, remote feeding skill assessment is rarely reported in the literature. For our behavioral feeding measures, we used caregiver-recorded videos in the infants' own homes. Home video observations have been validated for gross motor measures (e.g., Boonzaaijer et al., 2017). Live assessment and home-recorded video assessment have not yet been compared in the context of evaluating feeding skills in infants, but in the literature, live and asynchronous telehealth pediatric feeding assessments demonstrate high (> 85%) agreement with in-person clinical assessment (Clark et al., 2019; Kantarcigil et al., 2016; Raatz et al., 2021). To our knowledge, this is the first study to leverage caregiver-recorded videos for oral feeding skill assessment in infancy. In our sample, it was both feasible and reliable to use a combination of caregiver-recorded videos, daylong audio recordings, and videoconferencing interviews to obtain data on feeding experience, feeding skills, and covariates.

All infant participants were 6–8 months of age (using adjusted age for preterm infants) and had experienced at least one food. Infants in our study were introduced to complementary foods at an average of 5½ months of adjusted age, with no group differences between our low-risk and at-risk groups. This average age of introduction is close to the recommended age of introduction of 6 months from the World Health Organization and other international position statements (e.g., Fewtrell et al., 2017). However, when examining individual feeding profiles, it is clear that the at-risk group demonstrated a much wider range of complementary feeding introduction

timelines, with some infants starting complementary foods as early as 2 months of adjusted age (puree) and up to 6.5 months of adjusted age. Our sample was not adequately powered to examine individual feeding trajectories based on age at introduction, which is an important future line of research.

Caregiver reports and video observation revealed a distinct pattern of feeding experience in our sample compared to samples cited in the literature. In a nonmajority world (i.e., Western) context, it is historically assumed that infants are introduced to purees or cereals as their first complementary food (e.g., Arvedson, 2006; Carruth & Skinner, 2002; Carruth et al., 2004), but this is not consistent with complementary feeding anthropologies around the world (e.g., Singh et al., 2023; Thuita et al., 2019) or the feeding histories narratively reported by caregivers in our study (see Supplemental Material S1). The majority of participants were first introduced to regular solid table food or soft table food, with many caregivers describing a modified "baby-led weaning" method of introduction.

The popularity of this feeding practice in our sample could be why we saw a relatively high number of unique foods reported, with some infants experiencing more than 40 unique foods in their first month of complementary feeding. Caregivers who implement baby-led weaning methods typically offer whatever food is on their family plate, which often leads to more dietary variety (Morison et al., 2018), and these caregivers are systematically different from groups who use "traditional spoon feeding" (e.g., Brown, 2016), with higher levels of education, longer breast-feeding duration, and distinct personal traits from comparison groups (e.g., Brown, 2016). Our sample consisted of mostly highly educated caregivers, so their use of a baby-led approach is consistent with this body of literature (Brown, 2016).

The caregiver–infant dyads in our study also differed from the general population in breast-feeding initiation and continuation, consistent with what has been documented about educated and/or higher resourced mothers. All the infants in our study received some form of breast-feeding, which is consistent with literature showing that, in the nonmajority (i.e., Western) world, breast-feeding is more common in higher resourced families, particularly in two-parent homes with high levels of education (e.g., Carpay et al., 2021). Because breast-feeding was ubiquitous in our sample, we were unable to make inferences about the relationship between breast-feeding experience and complementary feeding skills.

Feeding problems are estimated to occur in about 25% of otherwise typically developing children (Sdravou et al., 2021), which was also evident in our sample. Moreover, 20% of caregivers of low-risk infants reported that their infants had a history of problematic feeding, whereas 67% of caregivers of at-risk infants reported problematic feeding. In the low-risk group, caregivers most often described breast-feeding problems of any variety (maternal or infant), whereas the caregivers of at-risk infants also discussed tube-feeding due to problematic feeding, bottle refusal, and more. At-risk infants not only had different feeding histories but also had heterogeneous early-life experiences in the NICU and reasons for NICU admission, including preterm birth, low birth weight, and intrauterine growth restriction. As a first step, we examined risk as a binary grouping variable, but in future studies, more participants should be recruited to examine long-term implications of variables such as NICU length of stay, the complexity of medical diagnosis, and so forth. Previous research has shown that being born earlier, having longer hospital stays, and having more complex medical diagnoses are associated with a greater risk for bottle-feeding deficits at term-equivalent age (Guimarães et al., 2024; Ibrahim et al., 2024), but it remains unclear how this relates to later complementary feeding development.

Predictors of Complementary Feeding Skills

We found that the duration of complementary feeding experience and NICU admission were the best predictors of feeding skills, whereas the developmental level of related systems that we measured (i.e., infant vocalizations, developmental status) did not significantly predict skills (Wolthuis-Stigter et al., 2015). Of note, for the related body system of vocalizations, we measured CVC and utterance duration, which are straightforward to collect and analyze reliably but give less information about vocalization complexity relative to other more time-intensive measures, such as canonical babbling ratio. Future work should consider these questions with vocalization measures that are more closely tied to infant vocalization skills.

For our first outcome measure—using the OFS-S to measure complementary feeding skills—consistent with our hypothesis, risk group was the best predictor of infant feeding skills at 6–8 months of age. Given the preliminary nature of our study and the small sample size, we must be careful with the interpretation of this finding. As previously described, the included at-risk infants were a heterogeneous group, with some being born earlier than others and experiencing more medical complications. Based on previous literature (Adams-Chapman et al., 2013; Ibrahim et al., 2024; Wolthuis-Stigter et al., 2015), it is logical that these younger and/or medically complex infants might be driving our findings, but our sample is not adequately powered to tease out individual contributions to our group statistical conclusions. Future studies should examine the influence of individual risk factors for NICU infants, such

as gestational age at birth, length of stay, respiratory complications, and more.

In addition to risk group, we found that weeks of feeding experience significantly contributed to our model. This finding is aligned with the underlying theoretical model of dynamic systems theory. The key principles of dynamic systems theory are that infant skills are (a) multidetermined (i.e., influenced by many factors), (b) softly assembled (i.e., context dependent), and (c) nonlinear, with critically important variability (Thelen, 2005; Zimmerman et al., 2020). The statistical significance of infant experience in our model is consistent with the massive body of literature showing that infant experience with skills such as sitting, crawling, playing, and stepping can be an important driver for the acquisition of these skills (Adolph, 2019; Herzberg et al., 2022; Thelen, 2005). For example, an experimental study of 210 infants compared the relative contributions of body dimensions, walking experience, and age in the development walking skill (Adolph et al., 2003), and experience was the single greatest predictor of skill (Adolph et al., 2003). A study of development across cultures also provides support that experience is a key driver of onset of skill and that skill development is encultured, that is, shaped by cultural expectations of the type and amount of experience infants are given with a skill (Karasik & Robinson, 2022; Singh et al., 2023). Because we were exclusively investigating the early stages of feeding skill development, our finding that infant feeding experience is a significant predictor of skill is consistent with this larger body of work in the motor domains.

For our second outcome measure—nMD as a measure of eating efficiency—none of our models significantly predicted efficiency. nMD has been used to measure efficiency in older children (Malandraki et al., 2022; Mishra et al., 2018), but to our knowledge, this is the first time it has been applied to infants. We found significant differences in nMD between the two groups, with at-risk infants demonstrating significantly faster nMD compared to the low-risk group. On the basis of clinical data in older children, we expected at-risk infants to be slower (likely meaning less efficiency; Malandraki et al., 2022; Mishra et al., 2018). However, there are no norms for nMD, and it has been hypothesized that eating too slowly or too fast could both represent adaptive or maladaptive strategies, depending on individual and environmental factors (Malandraki et al., 2022).

Importantly, in our sample, the groups differed in the type of food they consumed. Caregivers fed infants their "typical meals and consistencies," so we could observe the most naturalistic assessment of infant feeding skills. Therefore, not every infant consumed both purees and solids, unlike in the original nMD study (Malandraki et al., 2022). Specifically, 45% of at-risk infants ate only purees during the videos, whereas 17% of low-risk infants ate only purees. In general, puree bite duration is shorter than chewable solid feeding duration, likely because purees require less oral preparation (Malandraki et al., 2022). Even though we normalized for number of bites, the discrepancy in oral processing of purees versus chewable solids may partially explain why infants in the at-risk group had shorter nMD and why we did not see the predicted relationship between nMD and vocalizations. Future studies should balance the prioritization of naturalistic assessment with the standardization necessary to compare between groups.

Limitations/Future Directions

This study demonstrated the feasibility of naturalistic assessment of infant skills, but we acknowledge that several limitations need to be considered. As previously mentioned, more robust measures of speech complexity may be necessary to compare vocalization and feeding skills. Also, although our sample was adequately powered, it was still small given the inherent variability in this population. It represents a starting point for research in this area, but the findings should be verified in larger, more diverse samples. We achieved our goal of including at least one-third non-White participants, which is representative of the recent U.S. census, and we included participants from 15 states. However, our sample was characterized by high socioeconomic status, with all caregivers having at least some college education. This is a limitation that must be ameliorated in future work. Also, caregivers largely used infant-driven approaches to introduce complementary food, which is consistent with their education level (Boswell, 2021; Brown, 2016) but does not represent the infant population as a whole. It is imperative that future research include participants who better represent a global perspective of infant development (Singh et al., 2023).

We also acknowledge that some of the measures have not been widely validated and tested in the literature. We found only one detailed measure of oral feeding skills (Delaney, 2010), and it is in the process of validation. Furthermore, future studies should use a dynamic systems approach to assess infant feeding skills in context, not only by behavioral observation but also by physiological assessment, such as the use of surface electromyography (for neuromuscular contributions) or biomechanical measures (for kinematic variables). Finally, as previously stated, defining at-risk infants is an extremely complicated proposition because there are no standard qualifications. Our classification was broad, straightforward, and reproducible, but our binary risk categorization meant that infants who had heterogeneous reasons for NICU admission, some of which may have been more relevant to feeding skills than others

(see Table 1), qualified for the study. Future research should identify who is most at risk for feeding and communication disorders in a larger longitudinal study.

Conclusions

This preliminary study provides new evidence that infants have distinct early-life experiences with feeding, and these feeding experiences can predict complementary feeding skills at 6–8 months of age. Risk group (i.e., infants who spent time in the NICU) and weeks of feeding experience were the best predictors of skill (decreased feeding skills in those who were in the NICU and increased feeding skills for infants with more weeks of experience), which provides first insights into the development of improved screening measures in the future. Future studies should include more infants in a longitudinal design to tease out influences on development, with the aim of early identification and treatment of PFD.

Data Availability Statement

The data necessary to reproduce the analyses presented here are available from the last author upon reasonable request.

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