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Preverbal communication complexity in infants

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Abstract

The development of prelinguistic communication in typically developing infants is marked by changes in complexity as well as frequency, yet most measures focus on frequency. In the current study, we used the Communication Complexity Scale (CCS) to measure prelinguistic complexity of typically developing infants in a cross-sectional sample of 6-, 8-, 10-, and 12-month-olds ($N = 204$) during semi-structured play interaction. For each toy/interactive episode, infants' highest level of communication complexity (ranging from 0 for no response to 12 for multi-word verbalization), for both joint attention (i.e., social) and behavior regulation (e.g., requesting) functions, was scored. In addition, the same interaction was coded for frequency of all prelinguistic communication acts. Results of multivariate models indicated age-related differences in prelinguistic complexity. Measures of prelinguistic complexity and frequency evidenced moderate to strong correlations, with age-related differences by function (joint attention and behavior regulation). Significant associations with parent-report communication questionnaires were observed for both complexity and frequency measures. Results indicate that evaluating complexity of infant preverbal communication skill with the CCS is a valuable approach that can meaningfully index developmental differences in prelinguistic and early linguistic communication.

1 | INTRODUCTION

Children communicate with gestures, vocalizations, and eye gaze long before they learn to communicate with spoken words. For young children, developmental and individual differences in the frequency (or rate) of these preverbal communication behaviors have been well characterized (e.g., Carpenter, Nagell, & Tomasello, 1998). Research has focused on the emergence of specific communication forms, such as gesture (Iverson & Goldin-Meadow, 2005; Tomasello, Carpenter, & Liszkowski, 2007), triadic eye gaze (e.g., Bakeman & Adamson, 1984; Striano & Rochat, 1999), or vocalizations (Hsu & Fogel, 2001; Nathani, Ertmer, & Stark, 2006). Importantly, this literature has established frequency of preverbal communication as a key indicator of later language outcomes (e.g., Morales, Mundy, & Rojas, 1998; Mundy et al., 2007; Mundy & Gomes, 1998).

In contrast, less attention has been given to age-related changes in *complexity* of a child's early communication acts and how this may (or may not) be related to frequency of communication and/or language outcomes. Complexity refers to the use of different forms (i.e., eye contact, gestures, vocalizations, words) of communication and how these forms are directed to communication partners (i.e., the degree of multi-modal coordination). For example, higher levels of complexity can be defined by the use of more advanced communication forms (e.g., words are more advanced than vocalizations) and the degree of coordination of communication (e.g., vocalization with gesture would be more advanced than gesture alone). In the current study, we systematically examine the continuum of preverbal and early linguistic communication complexity in a cross-sectional sample of infants (age 6, 8, 10, and 12 months). We also consider associations among measures of prelinguistic complexity, prelinguistic frequency, and parent-report communication questionnaires. Our purpose in examining communication complexity is to identify developmental benchmarks within typically developing infants (including complexity of communication for social/joint attention and requesting/behavior regulation functions).

1.1 | Prelinguistic development

Prelinguistic communication refers to non-word vocalizations and gestures that infants produce during interactions with caregivers. During the first year, infant vocalizations progress from crying to vowel-like productions and eventually consonant–vowel productions that increasingly sound like words (Nathani et al., 2006; Oller, Eilers, Neal, & Schwartz, 1999). During this same time, infants also begin to use gestures to communicate (Crais & Day, 2000; Crais, Douglas, & Campbell, 2004). For example, they reach for things, they show things, and eventually they point to things (Butterworth & Morissette, 1996; Tomasello et al., 2007). Infants' gesture use increases during the second half of the first year of life; in particular, pointing gestures dramatically increase between the ages of 8 and 12 months (Reilly et al., 2006). By the end of the first year, typically developing infants reliably combine gestures and vocalizations within communicative acts (e.g., when an infant says /da/ while pointing to a referent), and these productions occur more frequently in response to contingent caregiver social feedback (Bates & Dick, 2002; Miller & Lossia, 2013). Thus, the 6- to 12-month-old age period offers an optimal opportunity to consider individual variability within emerging prelinguistic communication acts (Adamson & McArthur, 1995; Mundy & Gomes, 1998; Tomasello, 1995).

Prelinguistic behaviors are judged to be intentionally communicative when they are clearly directed to another individual (Carpenter et al., 1998; Crais et al., 2004). For example, at or before 6 months of age a child may reach toward a toy that is out of reach, but if the child's attention was singularly focused on the toy, the reach would be considered as *perlocutionary* communication (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979). By 8 months of age, infants begin to reach for objects that are unattainable when another person is present, but not when they are alone (Ramenzoni & Liszkowski, 2016). Later in that first year, when the child now reaches toward the toy while also looking up at her mother, or looks back and forth between the toy and mother, these behaviors are considered intentional or *illocutionary*, because the child is clearly trying to engage or "communicate to" her mother. Other means to demonstrate attention toward the communication partner include gesturing directly toward the mother, as when giving a toy (Brady et al., 2012; Trevarthen & Aitken, 2001). This coordination of attention between communication partners and referent objects or events is the hallmark of intentional communication (Bates et al., 1979).

The development of prelinguistic communication also provides early evidence for the transactional and social nature of language development (McLean, 1990; Sameroff & Fiese, 2000; Warren, Brady, Sterling, Fleming, & Marquis, 2010). Reciprocal associations are consistently observed between infants' prelinguistic productions and parents' responsive communication behaviors (Fernald, Marchman, & Hurtado, 2008; Goldstein & Schwade, 2008; Tamis-LaMonda, Bornstein, & Baumwell, 2001). For example, when mothers are responsive to their infants' vocalizations (e.g., by imitating or expanding), this predicts an increase in the frequency and quality of their infants' communication (Gros-Louis, West, & King, 2016). When infants receive contingent caregiver feedback, they are more likely to use coordinated gesture + vocal productions (Bates & Dick, 2002; Miller & Lossia, 2013). Because of these well-established links, caregivers' responsive communication behaviors are a frequent target for parent-directed language interventions (Roberts & Kaiser, 2011).

Importantly, as intentional prelinguistic communication emerges, infants communicate for two distinct functions—for social (joint attention) and requesting (behavior regulation) purposes. An example of joint attention is when a child points with coordinated eye contact to share enjoyment when something exciting or interesting happens. An example of behavior regulation is when a child points with coordinated eye contact and vocalization to access/request something.

The term joint attention has been used to refer to active sharing of attention between the infant, another person, and an object or event (Bakeman & Adamson, 1984). Behaviorally, joint attention can be demonstrated through gaze and point following, showing, and pointing. Prelinguistic joint attention is particularly important, because it establishes fundamental learning opportunities for the young child and predicts later language and social developmental outcomes, even after controlling for cognitive ability (Morales et al., 1998; Mundy et al., 2007; Mundy & Gomes, 1998; Mundy, Kasari, Sigman, & Ruskin, 1995; Mundy & Sigman, 2006). In addition, poor joint attention skills may signal atypical development. A significant body of research has documented the atypical developmental profile observed for children with autism, which is characterized by core deficits in joint attention compared to typically developing counterparts (Watt, Wetherby & Shumway, 2006; Mundy, Sigman & Kasari, 1994).

To date, developmental and individual differences in prelinguistic communication have primarily been captured by measuring frequency. Indeed, frequency of preverbal communication has been well-established as an indicator of later language outcomes. Even after controlling for cognitive level, infants who produce more frequent preverbal communication acts have significantly larger vocabularies in toddlerhood, relative to those with lower rates of preverbal communication (e.g., Morales et al., 1998; Mundy et al., 2007; Mundy & Gomes, 1998). Alongside gains in communication and language, there are predictable increases in the rate of communication for typically developing children: for 11- to 14-month-olds, those at the prelinguistic stage communicate average about 1 act/min; those at the one-word stage average about 2 acts/min; and those at the multi-word stage average about 5 acts/min (Wetherby, Cain, Yonclas, & Walker, 1988). However, although measures of frequency (or rate) capture a critical feature of prelinguistic development, this does not necessarily reflect the skill or complexity with which infants are communicating, which is also key for understanding developmental progress and outcomes. A complementary approach for capturing individual and developmental differences would be measuring prelinguistic complexity of communication. Although frequency, or rate, of prelinguistic acts is a well-established indicator of early communicative development, complexity of prelinguistic acts has been much less examined.

1.2 | Why consider complexity?

Characterizing development in prelinguistic communication is relevant for both research and clinical purposes. Complexity can be defined as the use of different communication forms (i.e., eye contact, gestures, vocalizations, words) and the degree of coordination (i.e., between people and referent objects and different forms) directed to communication partners. Complexity offers an index of the quality of communicative skill, which may add sensitivity to understanding and defining developmental level and/or skill acquisition. The complexity with which young children begin to communicate may be a sensitive early indicator of individual differences, as well as a predicator of later developmental trajectories. Precise measurement of complexity requires a tool that captures the continuum of prelinguistic skills and coordination. However, a potential deterrent to studying early communication complexity may be the difficulty in accurately measuring subtle, yet important, differences in early communication (Cates, 2013).

Many early communication measurement tools involve some combination of informant report and/or direct observation. Informant approaches offer the benefit of efficiently obtaining information from caregivers about age-related milestones of early communication. For example, the Communication and Symbolic Behavior Scales Infant Toddler Checklist and Caregiver Questionnaire (CSBS; Wetherby & Prizant, 2002) and the MacArthur–Bates Communicative Development Inventory (MCDI; Fenson, Marchman, Thal, Reznick, & Bates, 2006) contain items about prelinguistic communication, but only a limited number and they are not differentiated according to complexity. Clinician-administered standardized assessments of early development, such as the Mullen Scales of Early Learning (MSEL; Mullen, 1995) and Bayley Scales of Infant Development (BSID-III; Bayley, 2005), include items about sound production (e.g., “produces consonant-vowel combinations”) and use of gesture (e.g., “uses word and gesture combination”), but these are broad items aimed at capturing the presence or absence of delay and do not yield specific information about level of prelinguistic complexity. Observational paradigms such as the Early Social Communication Scales (ESCS; Mundy et al., 2003) provide specific opportunities for direct measurement of prelinguistic communication, including quantification of the form and type communicative functions (i.e., acts for joint attention and behavior regulation purposes); however, results are reported in terms of frequency of communication acts. These existing measurement tools are not designed with a focus on obtaining measures of complexity in early communication.

In order to systematically characterize the continuum of complexity in prelinguistic and early linguistic communication and to identify potentially important individual differences in communication complexity, a new assessment strategy was developed by Brady and colleagues, resulting in the Communication Complexity Scale, or CCS (Brady et al., 2018, 2012). The CCS is based on developmental milestones from typical infant development, with a range of communication matching a developmental level of 1–18 months, making this assessment strategy appropriate for measuring variability in infant communication. A 12-point scale reflects a developmental continuum across three levels of communication—preintentional, intentional nonsymbolic, and beginning symbolic communication. Higher scores reflect more complex communication. For example, scores of 6–10 indicate intentional communication. However, a score of 6 indicates triadic eye gaze alone, whereas a score of 10 indicates triadic eye gaze plus two other behaviors (usually a vocalization and a gesture). The key observation within this coding scheme is the extent to which a child *coordinates* multiple forms within a single communicative act (e.g., eye gaze + vocalization + pointing). Note that a child may achieve lower scores on the CCS (e.g., less complexity) by using the same communication forms (e.g., eye gaze, vocalizations and point) without coordination. The full scale is presented in Table 1.

The CCS also captures communicative functions for intentional communicative acts. Specifically, acts used to request or protest are labeled as behavior regulation; acts used to comment or share social affect are labeled as joint attention. The CCS has undergone extensive testing with prelinguistic individuals with intellectual disabilities (Brady et al., 2018, 2012; Hahn, Brady, McCary, Rague, & Roberts, 2017). These previous studies showed that the CCS has high inter-rater reliability and test–retest reliability (Brady et al., 2018). However, the CCS has not yet been applied to characterize the full range of variability within low-risk and typically developing infants. The CCS offers the potential for precise measurement of early communication complexity, in natural interactions using standardized observational procedures.

1.3 | Present study

Two aims were pursued in the current study. The first aim was to describe age-related variability in prelinguistic communication complexity. Specifically, we examined age differences in *complexity* for joint attention and behavior regulation functions within a cross-sectional cohort of infants. We also

TABLE 1 Communication Complexity Scale (CCS) scoring

Score	Definition	Communication level
0	No response	Preintentional
1	Alerting—a change in behavior, or stops doing a behavior	
2	Single orientation (object, event, person)—using vision, body orientation, or other	
3	Single orientation only + 1 other PCB (potentially communicative behavior)	
4	Single orientation only + more than 1 PCB	
5	Dual orientation—attention shift between person and object (without PCB)	
6	Triadic orientation (e.g., eye gaze/ touch from object to person and back)	Intentional nonsymbolic
7	Dual orientation + 1 PCB (e.g., dual focus + gesture)	
8	Dual orientation + 2 or more PCB (e.g., dual focus + gesture +vocalization)	
9	Triadic orientation + 1 PCB (e.g., triadic + vocalization)	
10	Triadic orientation plus more than 1 PCB (e.g., triadic + vocalization +switch closure)	Symbolic
11	One-word verbalization, sign or AAC symbol selection	
12	Multi-word verbalization, sign or AAC symbol selection	

examined age differences in *frequency* of communicative acts for both joint attention and behavior regulation functions to allow comparison with complexity measures and examine relations between communicative functions. It was expected that frequency and complexity for joint attention and behavior regulation purposes would each evidence age-related increases across age cohorts (Mundy et al., 2007). A second aim was to examine relations among three measures (a) communication complexity derived from communication samples in the laboratory, (b) communication frequency also derived from the communication samples in the laboratory, and (c) concurrent parent-report measures of communication. Within each age cohort, it was expected that communication complexity and frequency would be positively related to each other and to parent-report measures of early communication with moderately sized correlations. We expected that correlations would be moderate because observation measures may capture more variability in prelinguistic communication than standardized parent-report measures.

2 | METHOD

2.1 | Participants

Typically developing infants were recruited to participate in a larger cross-sectional study on early language development by email and phone. All children were healthy at the time of the visit, carried full-term (more than 36 weeks), and heard 75% English or more in the home according to parent report. Infants and caregivers visited the laboratory at 6, 8, 10, or 12 months of age. This age range encompasses the period of emerging preverbal communication and joint attention behaviors (Adamson & McArthur, 1995; Mundy & Gomes, 1998; Tomasello, 1995). The sample was predominantly Caucasian. Among the infants' mothers, 2.3% had a high school education, 14.0% had attended community college, 45.3% had a college education, and 38.5% had graduate education. From the initial $N = 222$ infants who were enrolled in the study, a final sample of $N = 204$ infants had available data on all measures of interest. Infants were excluded due to fussiness (4), and experimenter/video recording error (14). Other cohort and demographic characteristics are provided in Table 2.

2.2 | Procedures and measures

The study was approved by the Human Subjects Committee at the University of Kansas (HSC #20265), and written informed consent was obtained from parents. The present study was conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from

TABLE 2 Study cohort characteristics (sample $N = 204$)

			Gender		Ethnicity			Race		
Age cohort	*n*	Age in days *M* (*SD*)	Boy	Girl	Hispanic	Non-Hisp.	Caucasian	Afr. Amer.	Multi-Race	Other
6-month*	25	189 (7)	44%	56%	16%	64%	84%	4%	12%	0
8-month	62	246 (8)	45%	55%	2%	68%	89%	5%	7%	0
10-month	54	305 (8)	48%	52%	15%	59%	89%	2%	9%	0
12-month	63	367 (11)	57%	43%	8%	76%	84%	3%	10%	3%

Note: The 6-month sample was a smaller cohort recruited separately from the larger study.

a parent or guardian for each child before any assessment or data collection. During the visit to the laboratory, assessment began when the infant was calm and alert. Infants' prelinguistic communication behaviors were assessed during semi-structured, play-based interaction with an experimenter designed to elicit opportunities for communicative acts (described below), along with other tasks as part of a larger study, with parents present at all times. Parents completed questionnaires about their infant's communicative development at the time of the visit. Study data were collected and managed using REDCap (www.project-redcap.org), a secure web application for building and managing online surveys and databases, hosted at the University of Kansas (Harris et al., 2009).

2.2.1 | Semi-structured play interaction

Infants participated in a semi-structured play interaction with an experimenter. This interaction followed the ESCS (Mundy et al., 2003) paradigm, which is widely used to elicit preverbal social communication behaviors among infants and toddlers. This play interaction paradigm has been used in research studies to examine social communication skills in typically and atypically developing children, including those with developmental disabilities and autism spectrum disorder (ASD; Kasari, Freeman, & Paparella, 2006). For the play interaction, infants were seated on their caregiver's lap at a table facing the experimenter and presented with a series of eight toy/activity episodes (three small windup mechanical toys; three hand-operated active toys; turn-taking with car and ball). For example, the experimenter winds up the mechanical toy and allows it to move across the table (without talking or cueing the child) to allow opportunity for child vocalizations or eye contact; if the child makes a communication bid to request the toy (e.g., reach), the experimenter offers the toy and allows the child to briefly play. Parents were asked to avoid talking to their child or directing their child's play during the task (e.g., helping them to use the toys) in order to allow their child to interact with the experimenter. Parents were instructed to provide brief acknowledgment (e.g., "I see it,") when/if their child tried to engage with them, and then to direct their child's attention back to the experimenter. The entire play interaction lasted approximately 20 min.

All sessions were recorded by a digital camcorder placed so that infant behavior was recorded face-on. Recordings were coded offline twice: first for *frequency* of prelinguistic communication (following ESCS scoring) and second for *complexity* of prelinguistic communication (following CCS scoring), as described in the following sections. All coding occurred during the toy/activity episodes (i.e., beginning when toy/activity was presented and ending when the toy was removed).

For both ESCS and CCS, each coded preverbal communication act was categorized according to two functions. First was *behavior regulation,* defined as an act with the goal of requesting or eliciting assistance in obtaining an object or object-related action, such as when the infant looked from an inactive toy to the experimenter for the apparent purpose of requesting access to the toy. Second was *joint attention*, defined as an act with the goal of initiating shared attention to the objects or events, such as when the infant looked from windup toy moving across the table to the experimenter and then back at the toy for the apparent purpose of "commenting" on the interesting event.

2.2.2 | Frequency of prelinguistic communication

The play interaction was first coded for frequency following the ESCS coding scheme (Mundy et al., 2003). The following behaviors were coded for frequency of occurrence: eye contact (spontaneous looks to the caregiver or experimenter), gestures (pointing, reaching, giving, showing), and vocalizations. Each preverbal communication act was then categorized by function: either initiating behavior regulation (BR) or initiating joint attention (JA). Only child-initiated behaviors were coded. Summary scores were obtained for frequency of both joint attention (*frequency JA*) and behavior regulation (*frequency BR*). Inter-rater reliability for frequency coding was assessed for 25% of the sample across all item scores; intraclass correlation coefficients were .94 for frequency JA and .87 for frequency BR (all $p < .001$), indicating high levels of agreement.

2.2.3 | Complexity of prelinguistic communication

The play interaction was then coded a second time using the CCS scoring system (Brady et al., 2012). For each of the eight toy/activity episodes, the highest observed communication act was scored (see Table 1), ranging from 0 (no response) to 12 (multi-word verbalization or sign). For each toy/activity episode, coders identified the highest scoring communicative act for each function. Thus, we obtained a complexity score with respect to both joint attention and behavior regulation for each activity.

Communication Complexity Scale summary scores quantify the peak or maximum complexity observed by averaging the highest three scores within each function across all eight toy/activity episodes. For example, a participant's complexity JA score would be 10.33 if the three highest scores were as follows: 11 for the ball, 10 for the car, and another 10 for the windup toy. A participant's complexity BR score would be 11.00 if the three highest scores were as follows: 10 for jack-in-the-box, 11 for the car, and a 12 for the windup toy. These complexity summary scores have been used in previous studies of the CCS with atypically developing populations (Brady et al., 2018, 2012) and have been found useful to capture the most advanced level of communication displayed in the context of a discrete observation period with an interactive stranger (as is common in an evaluation situation). CCS summary scores were used in our analyses because we wanted to measure changes in peak communication across age groups. Inter-rater reliability for CCS coding was assessed for 25% of the sample across all item scores. Inter-rater reliability (ICC) was .82 for CCS scores and .94 for CCS functions (JA and BR).

2.2.4 | Parent-report measures of communication

At the visit, parents completed questionnaires about their child's development, including the Ages and Stages Questionnaires, Third Edition (ASQ-3), Communication and Symbolic Behavior Scales Caregiver Questionnaire (CSBS-DP), and MCDI.

The Ages and Stages Questionnaires, Third Edition (Squires & Bricker, 2009), a widely used developmental screener, includes items that describe behaviors observed or easily elicited by parents. For the current study, only the communication domain was of interest (e.g., When you ask, "Where is the ball (hat, shoe, etc.)?" does your baby look at the object?).

The CSBS-DP (Wetherby & Prizant, 2002) is a standardized parent-report screening tool designed for evaluation of communication and symbolic abilities of infants and toddlers. The CSBS-DP Caregiver Questionnaire includes questions about developmental milestones and measures skills from social (emotion, eye gaze, and communication), speech (sounds and words), and symbolic (understanding and object use) domains. Caregivers indicate whether their child is able to demonstrate a particular skill (not yet, sometimes, often) and degree of proficiency with a skill (e.g., number of words or phrases that are understood without gestures). A total score indicates risk status, with lower scores indicating higher risk. The CSBS-DP Caregiver Questionnaire has demonstrated promise as a screener that can identify children in need for further testing for ASD, language delay, or developmental delay (Pierce et al., 2011).

The MCDI, Words and Gestures (Fenson et al., 2003), has been widely used in clinical and research settings to assess vocabulary development for children 8–18 months of age and has demonstrated high internal consistency and test–retest reliability (Fenson et al., 1994). From a series of word lists ("Words Children Use"), including nouns, action lists, and animal sounds, parents choose words their child "understands" (receptive vocabulary) or "understands and says" (expressive vocabulary), and indicate whether their child is using multi-word productions (i.e., combining more than one word). The Words and Gestures version also presents questions about actions and gestures used by infants. The MCDI was completed at the laboratory visit by parents of infants in the 12-month-old cohort only; the percentile scores from the receptive, expressive, and total gestures scales were used for analysis.

2.3 | Analytic strategy

The analysis for Aim 1 (regarding age-related variability in prelinguistic communication complexity) was conducted using multivariate analyses of variance (MANOVA) models, in which age cohort was the predictor of communication complexity and frequency for both joint attention (JA) and behavior regulation (BR) functions. The MANOVA models were estimated using restricted maximum likelihood (REML) in SAS MIXED (SAS Institute, 2017). Traditional least squares estimation is equivalent to REML estimation in some restricted cases; REML was used here in order to extend the models to allow heterogeneous variances by age and function. The significance of fixed effects was evaluated with Wald tests using Kenward–Roger denominator degrees of freedom; pairwise comparisons across age groups were requested as linear combinations of the model fixed effects using ESTIMATE statements. Tests of variance heterogeneity were conducted using likelihood ratio tests (i.e., the difference in −2LL between models with the same fixed effects). Given our observed heterogeneity of variance by function, as well as by age cohort in some instances, we indicated effect size via total R^2, which is the square of the Pearson correlation between the outcome predicted by the model fixed effects and the original outcome (see Hoffman, 2015). Aim 2 (regarding concurrent relations between communication complexity and frequency; how measures of complexity and frequency relate to concurrent parent-report measures of communication) was addressed using Pearson correlations.

3 | RESULTS

3.1 | Aim 1: Age differences in complexity and frequency of communicative functions

3.1.1 | Complexity

The extent to which age cohort differences in prelinguistic complexity (as scored by the CCS) are observed in both joint attention (JA) and behavior regulation (BR) functions was examined in a MANOVA. The means for both the JA and BR functions (as shown in Table 3 and Figure 1) increased significantly across age: JA complexity, $F(3, 200) = 14.23$, $p < .001$, $R^2 = .18$; BR complexity, $F(3, 192) = 10.87$, $p < .001$, $R^2 = .14$. For JA complexity, all age cohorts differed significantly from each other (all p's < .019) except the 6- and 8-month cohorts. For BR complexity, the 12-month cohort was significantly higher than all other cohorts (all p's < .002), which were not significantly different from

TABLE 3 Descriptive statistics and pearson correlations among measures of prelinguistic communication by age cohort

Age cohort (*n* range)	Outcome	Descriptive statistics Mean	*SD*	Min	Max	Pearson correlations cJA	cBR	fJA	fBR	ASQ
6-month (20–25)	cJA	6.3	0.7	5.3	8.0					
	cBR	5.6	1.8	3.0	8.3	.17				
	fJA	5.8	3.8	1.0	17.0	**.54**	.20			
	fBR	12.1	6.4	2.0	23.0	.38	.26	**.52**		
	ASQ	45.0	11.5	15.0	60.0	.26	.33	.24	.28	
	CSBS	93.7	17.5	65.0	127.0	−.06	**.48**	.07	.10	**.62**
8-month (56–62)	cJA	6.7	1.1	5.0	9.0					
	cBR	5.7	1.6	3.0	9.0	**.30**				
	fJA	9.5	5.4	1.0	25.0	.08	.13			
	fBR	13.4	6.3	3.0	29.0	.00	.26	.19		
	ASQ	47.6	10.2	10.0	60.0	.18	.05	−.05	.16	
	CSBS	100.7	13.3	73.0	129.0	.14	−.02	−.01	.16	**.43**
10-month (53–54)	cJA	7.2	1.2	5.3	9.3					
	cBR	6.4	1.9	3.0	10.0	**.28**				
	fJA	13.3	7.0	0.0	35.0	.25	**.35**			
	fBR	17.4	9.5	4.0	51.0	.16	**.46**	.12		
	ASQ	43.7	10.3	10.0	60.0	−.17	.17	−.05	**.41**	
	CSBS	104.8	14.9	79.0	130.0	−.06	.11	−.06	**.32**	**.51**
12-month (61–63)	cJA	7.7	1.1	5.3	10.0					
	cBR	7.4	1.8	3.0	10.0	**.33**				
	fJA	17.1	8.8	2.0	46.0	**.31**	**.34**			
	fBR	21.7	8.2	5.0	47.0	**.33**	**.39**	**.28**		
	ASQ	48.8	13.2	10.0	60.0	.08	**.29**	−.01	.17	
	CSBS	101.4	12.8	76.0	130.0	.21	**.36**	.21	**.27**	**.61**

Note: Bold values indicate $p < .05$.

Abbreviations: ASQ, Ages and Stages Questionnaire; cBR, Complexity of Behavior Regulation; cJA, Complexity of Joint Attention; CSBS, Communication and Symbolic Behavior Scales; fBR, Frequency of Behavior Regulation, fJA, Frequency of Joint Attention.

each other. Thus, for both JA complexity and BR complexity, age-related differences were observed, with the window of difference emerging from 8 to 10 months of age for JA, and emerging from 10 to 12 months for BR. No age differences in residual variability were found for either function of complexity.

3.1.2 | Frequency

The extent to which age cohort differences were observed in JA frequency and BR frequency (as scored during the play interaction) was examined in a MANOVA. As shown in Table 3 and Figure 1, both the mean and the variance in each function increased with age; a model including heterogeneous

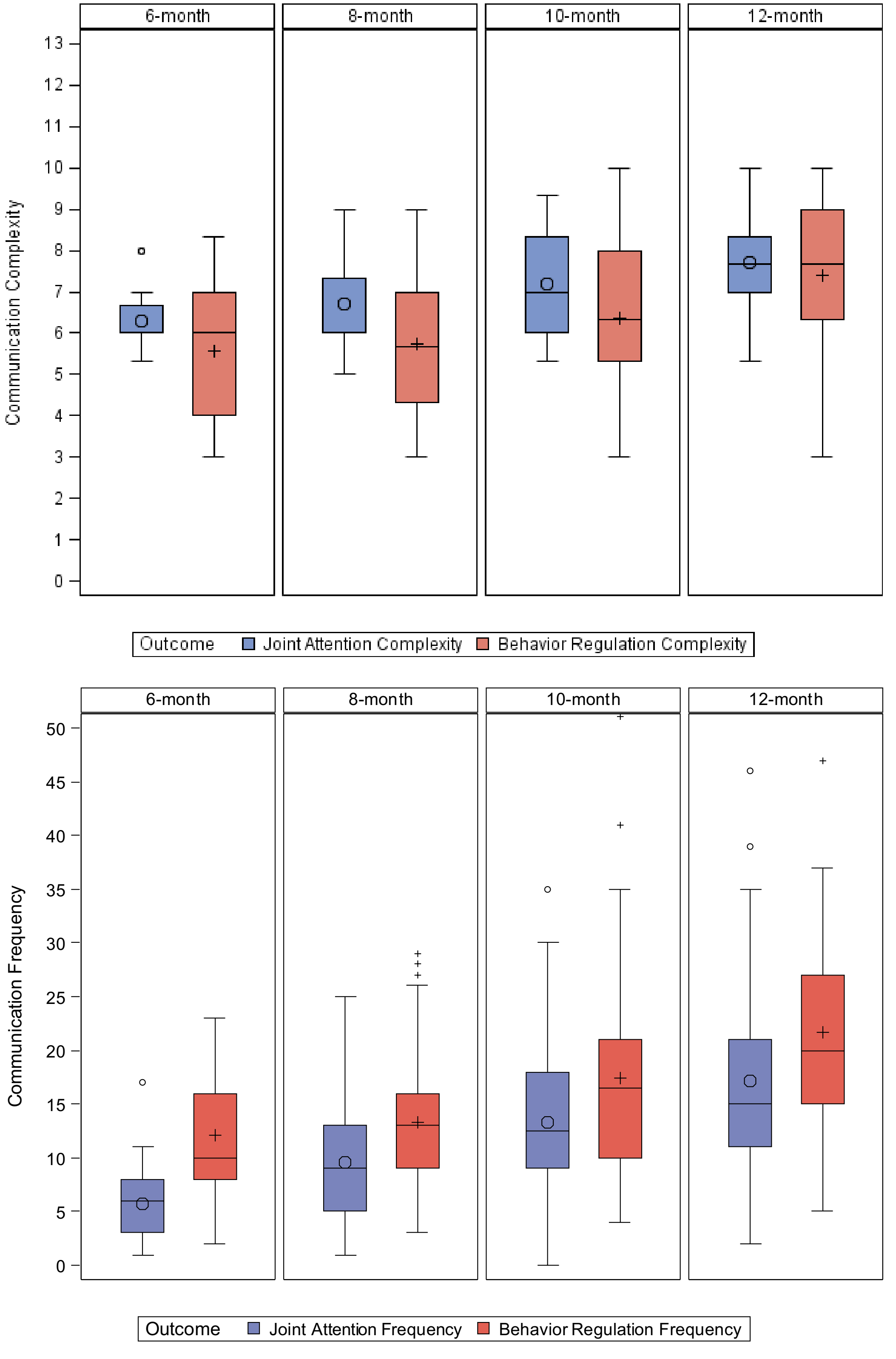
6-month
8-month
10-month
12-month
Communication Complexity
Outcome
Joint Attention Complexity
Behavior Regulation Complexity
Communication Frequency
Joint Attention Frequency
Behavior Regulation Frequency

FIGURE 1 Vertical box plot displaying communication scores by age and function (top = complexity, bottom = frequency). The vertical line indicates the median for each group and outcome, the box indicates the 25th and 75th percentiles, the lower line indicates the minimum, and the upper line indicates the maximum value below the upper fence (which is 1.5 inter-quartile range above the 75th percentile)

residual variance and covariance by age fit significantly better, $-2\Delta LL(9) = 43.31$, $p < .001$, and therefore was used to generate the results below. As expected, there were significant mean differences across age for both functions: JA frequency, $F(3, 96) = 27.86$, $p < .001$, $R^2 = 0.24$; BR frequency, $F(3, 86) = 16.92$, $p < .001$, $R^2 = .19$. For JA frequency, all age cohorts differed significantly from each other (all *p*'s < .002). For BR frequency, all age cohorts differed significantly from each other (all *p*'s < .011) except for the 6- and 8-month cohorts. Thus, for both JA frequency and BR frequency, age-related differences were observed, with significant increases in JA for all age cohorts and increases for BR beginning from 8 to 10 months of age.

3.2 | Aim 2: Concurrent relations among complexity and frequency measures and parent-reported communication

3.2.1 | Complexity and frequency associations

To examine associations between complexity and frequency of infants' communication, we examined correlations by age cohort for observational measurements. Specifically, we correlated CCS scores for JA complexity and BR complexity with ESCS scores for JA frequency and BR frequency, as shown in Table 3. Across measures of JA, complexity and frequency were significantly correlated in the 6- and 12-month cohorts. Across measures of BR, complexity and frequency were significantly related in the 10- and 12-month cohorts. When we considered associations between functions, JA complexity and BR complexity were significantly related in the 8-, 10-, and 12-month cohorts; JA frequency and BR frequency were significantly related only in the 6- and 12-month cohorts.

3.2.2 | Association with parent-report measures

To examine how observed measures of complexity and frequency of communication were related to widely used parent-report measures of communication, we examined correlations by age cohort among all measurements. Specifically, we correlated CCS scores for JA complexity and BR complexity and ESCS scores for JA frequency and BR frequency with concurrent parent-reported communication measures (i.e., ASQ and CSBS in all cohorts, the MCDI in the 12-month cohort). As shown in Table 3, all significant correlations were positive as expected, indicating that as complexity and frequencies increase, so did scores on the parent-report measures. The two parent-reported communication measures (ASQ and CSBS) were related to each other in each age cohort.

In the 6-month cohort, the only significant cross-source relationship was between BR complexity and the CSBS. In the 8-month cohort, no cross-source relationships were significant. In the 10-month cohort, BR frequency was significantly related to both the ASQ and the CSBS. In the 12-month cohort, BR complexity was related to the ASQ, and both BR complexity and BR frequency were related to the CSBS.

One additional parent-report measure was available only for the 12-month cohort, the MCDI, which included percentile scores for expressive vocabulary ($M = 57.34$, $SD = 18.90$, range = 25–99), receptive vocabulary ($M = 44.55$, $SD = 18.90$, range = 0–99), and total gestures ($M = 48.77$, $SD = 25.25$, range = 0–96). All MCDI scores were significantly correlated with each other as expected. In terms of cross-correlations, expressive vocabulary was significantly related to JA complexity ($r = .30$), BR complexity ($r = .31$), and JA frequency ($r = .35$), but not BR frequency ($r = .18$). Receptive vocabulary was significantly related to JA complexity ($r = .34$) and BR complexity ($r = .40$), but not JA frequency ($r = .20$) or BR frequency ($r = .22$). Total gestures were significantly related to BR complexity ($r = .39$), but not to JA complexity ($r = .11$), JA frequency ($r = .12$), or BR frequency ($r = .11$).

4 | DISCUSSION

A primary goal of the current study was to characterize age-related differences in infants' *complexity* of prelinguistic communication between 6 and 12 months of age. A secondary aim was to examine concurrent associations between infants' complexity and frequency of prelinguistic communication as observed in the laboratory, as well as how those observational measures related to concurrent parent-report on communication questionnaires.

4.1 | Prelinguistic communication complexity as a benchmark for developmental differences

Significant age-related increases in prelinguistic communication complexity were observed during the 6- to 12-month-old period among typically developing infants, consistent with the literature documenting developmental increases in frequency during this age range (Carpenter et al., 1998; Mundy et al., 2007). Frequency-based measures have been predominantly used to index development level and individual differences in prelinguistic communication for young children; while frequency measures allow dichotomizing higher and lower levels of communicative behaviors (e.g., Mundy et al., 2007), they do not necessarily capture *how* an infant communicates. In contrast, the CCS yields a measure of the most advanced coordination of prelinguistic forms that an infant consistently demonstrates during direct observation—that is, the *quality* of an infant's communication skill.

When we examined age-related changes in infants' complexity and frequency of communication, interesting patterns were observed. For complexity of communication, significant age-related differences were observed in joint attention beginning at the 8- and 10-month window and continuing through 12 months; for behavior regulation, age-related differences were later emerging, during the 10- to 12-month window. For frequency of communication, consistent age-related increases in joint attention were observed across all ages (6-, 8-, 10-, and 12-month cohorts); for behavior regulation, age-related differences were also later emerging, during the 8- and 10-month window and continuing through 12 months. Taken together, these overall patterns suggest a potentially important possibility for the emergence of prelinguistic communication within and across functions—that developmental increases in frequency may precede developmental gains in complexity of communication. In other words, attaining the capacity for more frequent communicative acts may be a developmental precursor to the emergence of more complex, or coordinated, forms of communication.

Measurement of complexity offers several potential benefits, including added description of developmental level and/or age-related differences in skill acquisition. Another benefit is the potential for enhancing measurement of individual differences by capturing more nuanced data on quality of communication. While typically developing children move relatively quickly through the prelinguistic stage, children with a language delay or disorder (and individuals with global developmental delays or intellectually disability) demonstrate divergent patterns of early communication that often require more fine-grained assessment. For these latter groups, assessment of patterns of prelinguistic communication is important for diagnostic determination (Eadie et al., 2010), as well as for treatment planning (Goods Stickles, Ishijima, Chang, & Kasari, 2013; Vivanti, Dissanayake, Zierhut, & Rogers, 2013). In recent work, the CCS demonstrated promise for capturing communication changes among preschoolers with autism (Thiemann-Bourque, Brady, & Hoffman, 2019), which also highlights the benefit of measuring complexity of communication for clinical populations.

4.2 | Observational and parent-report measures of communication

When we examined associations between observational measures of complexity and frequency (CCS and ESCS), we found moderate correlations within each age cohort. Compared to younger ages (6-, 8-, and 10-month cohorts), at 12 months there were significant correlations between complexity and frequency across both functions. This suggests that the constructs of complexity and frequency may be capturing unique aspects of emerging prelinguistic complexity. In addition, correlation data indicate that there may be differing developmental trajectories for joint attention and behavior regulation. This is supported by the longitudinal work of Mundy et al. (2007), which reported distinct developmental trajectories for each function among typically developing infants: Frequency of communication for behavior regulation demonstrated a linear increase with age during the prelinguistic period (at 9, 12, 15 and 18 months of age), while communication for joint attention demonstrated a cubic increase during the same period (Mundy et al., 2007). Improving our understanding of developmental associations between frequency and complexity of communication will be critical, given the potential implications for early identification of delays and intervention.

To understand results of parent-report measures utilized in this study, it is important to consider that these measures index related, but different aspects of early communication. The CSBS and ASQ query early communication behaviors that may be more directly aligned with the kinds of social communication acts elicited during a play interaction. In comparison, the MCDI indexes vocabulary and early gesture use, which is important for linking to language development. However, none of these measures query about complexity or frequency of prelinguistic communication. As a result, it is not surprising that in the current study only seven of the 32 tested associations between complexity, frequency, and concurrent parent-report measures of communication were significant. Furthermore, differences between parent-report measures and direct observations are not uncommon (e.g., Feldman et al., 2000; Thal, O'Hanlon, Clemmons, & Fralin, 1999).

Parent-report measures demonstrated few associations with observational measures, prior to 12 months of age. For the CSBS and ASQ, parent report was correlated with infant's communication for behavior regulation (complexity and/or frequency, depending on age). These results suggest the possibility that parents' report of their child's communication during this developmental period may more strongly rely on their observation of child communication for requesting or protesting (behavior regulation) purposes. It is worth noting that both expressive vocabulary and receptive vocabulary (MCDI scores) for the 12-month cohort were significantly correlated with communication complexity, for joint attention and behavior regulation. In line with results discussed above, measuring complexity may have added value for defining early communication development in young children.

5 | CONCLUSIONS AND FUTURE DIRECTIONS

In sum, the present results show age-related differences in prelinguistic communication as indexed by both frequency and complexity of communicative acts. Current results make several important contributions to the literature. First, they add to the existing work characterizing change in typically developing infants during the prelinguistic stage, a period which is critical for identifying potential delays and deficits in language and social communication (Brady, Marquis, Fleming, & McLean, 2004; Brooks & Meltzoff, 2008; Carpenter et al., 1998; Iverson & Goldin-Meadow, 2005; Mundy et al., 2007). In addition, the pattern of developmental increases in frequency before increase in complexity opens up new questions about the nature of early emerging communication in typical development. Perhaps of most practical value, the CCS shows promise for indexing age-related differences in prelinguistic communication in typically developing infants. Taken together, these results offer an important addition to our understanding of developmental differences in prelinguistic skills during the second half of the first year of life.

In this study as in others (Brady et al., 2018; Fleming & Brady, 2019), we summarized the complexity of the three most complex communication acts. While this summary matched our purpose of documenting developmental changes in peak complexity during a relatively short play observation, other types of summary measures may be appropriate for other purposes. For example, examining an overall mean score or the range of complexity scores may be useful on an individual basis, to document how an infant typically communicates or the range within a particular observation.

Our cross-sectional sample limits the extent to which we can make predictions about developmental trajectories. Therefore, an important next step will be to capture repeated measures of emerging communication complexity in a longitudinal sample of infants, which will allow mapping language outcomes through toddlerhood (when prelinguistic development is consolidated and verbal communication expands). This will be critical to fully characterize individual differences in developmental trajectories and language outcomes. Future work should also document how communication frequency and complexity—for both joint attention and behavior regulation—develop and change over time. Given the pivotal influence of caregiver responsiveness for communication development (e.g., Miller & Lossia, 2013), it will be important to consider how the caregiver/social partner influences communication complexity. Finally, future work should directly assess the developmental course of prelinguistic complexity in delayed and atypically developing populations. In sum, systematically considering complexity, along with frequency, has the potential to yield important and nuanced information about developmental patterns of early communication.

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