THE NATURE AND NURTURE OF CANONICAL BABBLING IN NEURODEVELOPMENTAL DISORDERS

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ABSTRACT

Katie M. Belardi: The Nature and Nurture of Canonical Babbling in Neurodevelopmental Disorders
(Under the direction of Linda R. Watson)

An infant's language develops significantly during the first year of life. Language development is facilitated by an interaction between genetics and environment. Measures of vocalization development, such as canonical babbling and volubility, and the language environment (i.e., how parents respond) are important to study because they are affected by the interaction between biology and environment and may differentiate disordered populations from typical development. This dissertation includes two empirical studies. The purpose of study 1 is to determine whether there are differences in the canonical babbling and volubility (i.e., total syllables) between infants with fragile X syndrome and infants who are typically developing. Study 2 aims to determine whether parents of infants with fragile X syndrome, autism spectrum disorder and typical development respond to infant vocalizations with the same frequency and linguistic complexity. The information from these studies has the potential to inform our understanding of the early differences in language development in neurodevelopmental disorders.

To the young ones--never lose your sense of wonder.

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CHAPTER 1: INTRODUCTION

Language is a skill necessary for daily functioning. Thus, individuals with language impairment are at high risk for compromised functioning due to their deficits. The ultimate goal of this research is to identify areas and timing of intervention in order to improve individual's language skills and functioning.

Language development is impacted by three factors: (1) nature: the biological capacity for learning and using language, (2) nurture: the environment's role in facilitating growth in language skills, and (3) the interaction between nature and nurture (Lenneberg, Chomsky, & Mark, 1967; Landry, Smith, & Swank, 2002). This dissertation will examine a biologically driven and environmentally shaped aspect of language, canonical babbling, and the influence of canonical babbling on parent's responses in populations with language impairments.

Infants advance through stages of babbling in the first year of life. By 8 - 10 months the majority of infants enter the canonical babbling stage. Canonical babbling is significant for several reasons. First, canonical babbles mark the time when infant's babbles have the properties of adult-like speech. Second, these babbles are strongly predictive of later language skills (Oller, 1998). Finally, canonical babbles influence the language environment.

Theme and Purpose

This dissertation consists of two empirical studies. The studies are connected by their focus on infant vocalizations, especially canonical babbling. The first study focuses on the nature of canonical babbling in infants with fragile X syndrome (FXS), with the assumption that biological factors in FXS impact the emergence of canonical babbling. FXS is a neurodevelopmental disorder associated with language impairment (Abbeduto and Hagerman, 1997). There are multiple studies describing the speech and language deficits in school-age children and adolescents with FXS, but to the author's knowledge, only one other study on the communication skills in infancy (Marschik et al., 2014). There is evidence suggesting canonical babbling is delayed in neurodevelopmental disorders such as autism spectrum disorder (ASD) and individuals at-risk for ASD (Patten, Belardi, Baranek, Watson, Labban & Oller, 2014; Paul, Fuerst, Ramsay, Chawarska & Klin, 2011). Study 1 aims to contribute to the literature by providing information on the emergence of canonical babbling in infants with another neurodevelopmental disorder, FXS, and examining whether measures of babbling are strong predictors of whether infants will later be diagnosed with FXS or will exhibit typical development.

The second study focuses on parent responses to canonical babbling. According to the transactional model of development (Sameroff and Chandler, 1975), parent and infant behaviors mutually impact each other. Parental language is one aspect of the environment that facilitates language development (Girolametto, 1988; Wilcox, 1992). There is information suggesting canonical babbles elicit more advanced language input from parents compared to non-canonical babbles (Papoušek, 1994). For example, prior to the canonical babbling stage, parents often respond to infants' sounds with praise or encouragement to continue vocalizing. During the canonical babbling stage parents respond with more referential language (e.g., "A ball--you want your blue ball"). This type of advanced language input is thought to guide word learning. Study 2 addresses questions of whether the frequency and type of responses of adults with infants with ASD and FXS are different compared to parents of infants with typical development. Determining if and how parents of infants with neurodevelopmental disorders respond to canonical babbles provides important information about the differences in the environment during this formative time for language development. Together, these studies will address meaningful gaps in the literature about the role of biology and the environment in language development and could inform clinical practice and future research.

Rationale

These studies will use the developmental phenomena of canonical babbling to extend our understanding of neurodevelopmental disorders in two novel directions. The first study aims to examine the utility of canonical babbling and volubility as behavioral biomarkers for distinguishing infants with FXS from those with typical development. The importance of this aim is that, in the absence of universal genetic screening of newborns for FXS, easily recognized behavioral markers of communication delays associated with this syndrome could facilitate earlier identification of infants with FXS than occurs in current practice. Currently, diagnosis of FXS is not typically made until the age of three years or later (Bailey, Raspa, Bishop, & Holiday, 2009). An easily recognized behavioral marker that appears in infancy could dramatically lower this relatively late age of diagnosis. Canonical babbling and volubility are measures whose utility is promising for accurately identifying typical from atypical babbling patterns. The goal is to find a measure parents can use to identify delayed babbling so they can report concerns to their pediatrician. Canonical babbling and volubility require counting syllables, which parents could use. The primary purpose of earlier identification is earlier intervention. The brain is malleable in the first few years of life, and early behavioral intervention, such as speech and language therapy, has the potential to alter the extent of the communication delays later in life for individuals with disorders (Dawson et al., 2010).

The second study aims to examine whether parents of infants with varied neurodevelopmental disorders respond with differentially complex linguistic forms to the emergence of canonical babbling in their infants. Addressing this aim will enhance our understanding of transactional processes in interactions between parents and their infants that may exacerbate or ameliorate the communication delays associated with these disorders. The transactional model of communication recognizes the facilitating role interactions have on incrementally supporting a child's communication development (Greenberg & Crnic, 1988). The emergence of canonical babbles signifies an infant's readiness to learn to use language. Infants with neurodevelopmental disorders may not have as many opportunities for these transactions due to late onset and reduced frequency of babbles. This particular study controls for the number of babbles in order to compare and describe the types of responses parents use to respond to canonical babbling in infants with FXS and infants later diagnosed with ASD compared to infants with typical development.

Studying differences in a foundational skill of language development could inform our understanding of the timing and extent to which language-learning processes derail in neurodevelopmental disorders. This information is important for considering the timing and type of early intervention that may be most effective, with the aim to improve later language skills. The two studies of this dissertation are directed toward this end goal.

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CHAPTER 2: RETROSPECTIVE VIDEO ANALYSIS OF CANONICAL BABBLING AND VOLUBILITY IN INFANTS WITH FRAGILE X SYNDROME AT 9 – 12 MONTHS OF AGE

The first few years of life are a time of remarkable brain growth and behavior development (National Center for Infants, Toddlers, and Families, 2012). Throughout the first twelve months, infants begin exploring and using sounds of their native language. These sounds are the foundation for language production development. Research on the early language foundation differences in neurodevelopmental disabilities is underway, but many aspects of early language learning remain unexamined. Early vocalization differences, such as volubility (frequency of vocalizations) and the use of canonical babbles (i.e. a consonant-vowel syllables with a rapid transition between the sounds that cannot be perceived), have the potential to differentiate atypical language development from typical development. Moreover, the differences may serve as behavioral biomarkers in the first year of life. Reliable and valid behavioral biomarkers are important for early identification and earlier intervention.

Fragile X syndrome (FXS) is a neurodevelopmental disorder resulting from a genetic mutation on the X chromosome, specifically the fragile X mental retardation 1 (*FMR1*) gene (Einfeld, Tonge, & Turner, 1999). *FMR1* is responsible for producing a protein, the fragile X mental retardation protein (FMRP), which plays a significant role in brain development (Greenough, Klintsova, Irwin, Galvez, Bates & Weiler, 2001). FMRP is either reduced or absent in individuals with FXS, and this deficiency is thought to result in a specific profile of deficits across cognitive, motor, physical and language domains. Language skills are severely affected compared to chronological age peers. Since a hallmark of FXS is intellectual impairment, part of the focus of language research is to determine if the severity or quality of impairments in language is different than what would be expected based on individuals' cognitive levels of functioning. Individuals with FXS have deficits in all aspects of language, including comprehension, expression and pragmatics (Finestack & Abbeduto, 2010; Brady, Skinner, Roberts, & Hennon, 2006; Roberts, Mankowski, Sideris, Goldman, Hatton, Mirrett, et al., 2008) and the deficits persist throughout the lifespan.

There is a substantial body of literature documenting the language deficits in school-aged children and adolescents with FXS (Maes, Fryns, Ghesquiere, Borghgraef, 2000), but a dearth of information concerning deficits in infancy. The limited research about early development is not due to absence of signs and symptoms. In fact, parents report noticing first symptoms of FXS around 12 months for males and 16 months for females (Bailey, Raspa, Bishop, & Holiday, 2009). One study with seven 9 – 12 month old infants with FXS (Marschik et al., 2014) suggests this population may exhibit limited forms of social-communication behaviors for their age based on the Inventory of Potential Communicative Acts (IPCA; Sigafoos, Arthur-Kelly, & Butterfield, 2006). Despite infants with FXS showing symptoms early, confirmation of a developmental delay is not typically provided until about 20 months for males and 26 months for females (Bailey, Raspa, Bishop, & Holiday, 2009). More alarming is about 16 months pass between a physician confirming a developmental delay and a child receiving a diagnosis of FXS (Bailey, Raspa, Bishop, & Holiday, 2009). One method of earlier diagnosis, universal genetic newborn screening, remains controversial for several reasons. The reasons include issues of the cost-to-benefit ratio of universal newborn screening for FXS, particularly a lack of evidence for treatments that can be initiated in the newborn period to improve outcomes for this population (Tassone, 2014). There continue to be important reasons for earlier identification, such as reducing the amount of services a child needs over time and informing family planning (e.g., determining whether having more children is financially or emotionally feasible; Ouyang, Gross, Raspa, & Bailey, 2010; Ouyang, Grosse, Riley, Bolen, Bishop, Raspa, & Bailey, 2013). Therefore, some argue that earlier diagnoses of FXS have concomitant benefits for children (i.e., early intervention) and their families (e.g., reduced financial and emotional burden; Center for Diseases Control and Prevention, 2015).

One cost-effective method for earlier diagnoses and intervention could be a valid and reliable behavioral biomarker that parents and healthcare providers can use to determine whether a child is developing similarly to their typically developing (TD) peers. The purpose of this study is to test the utility of two measures of early language development as behavioral biomarkers for distinguishing infants with FXS from infants with TD. To the authors' knowledge, this is the first study comparing the language behaviors of infants with FXS to TD peers in the first year of life. There is substantial evidence documenting the effectiveness of early intervention services in improving children's language deficits in neurodevelopmental disorders like autism spectrum disorder (ASD; Dawson et al., 2010). A validated behavioral biomarker that promotes earlier identification of infants with FXS would provide opportunities to evaluate whether early intervention has similar benefits for this population as for young children with ASD. This study is the first step toward understanding the differences in the language trajectory of children with FXS compared to their TD peers. Below I review the literature on babbling development and two robust measures of babbling.

Canonical Babbling Status

Early developmental stages unique to humans lay the foundation for language development and support the child's ability to produce adult-like syllables (Oller and Griebel, 2006). During the first few stages, infants explore moving their articulators and using their resonance, respiratory and phonatory systems. Around five to ten months, all of the systems are coordinated. The synchronization of speech systems is evident in the well-formed syllables an infant produces. The syllables are called canonical babbles. More specifically, canonical babbles are fully articulated sound sequences with full resonance and rapid transitions between articulator movements (Oller, 2000). These syllables are often reduplicated (e.g., /dada/) and they resemble adult-like speech. Universally, infants produce canonical babbles before producing words. Then, between eight to ten months, infants typically reach the canonical babbling stage, as marked by the production of a ratio of .15 canonical babbles per total syllables (Eilers and Oller, 1994). This stage is robust in that no delay in onset of canonical babbling is seen in infants at-risk for communication deficits due to premature birth or low socioeconomic status (SES; Eilers et al., 1993; Oller, Eilers, Basinger, Steffens, & Urbano, 1995). Infants with Down syndrome show slight delays in canonical babbling onset of about two months at the group level (Lynch et al., 1995). Infants who are tracheostomized at birth also produce age-appropriate canonical syllables shortly after decannulation (Bleile, Start, & McGowan, 1993; Locke & Pearson, 1990). The evidence strongly suggests canonical babbling is part of the natural course for learning language. Populations with substantial delays in canonical babbling onset include infants with profound hearing impairment (Eilers & Oller, 1994), Williams syndrome (Masataka, 2001), later diagnosed with ASD (Patten et al., 2014) and at genetic risk for ASD (Paul, Fuerst, Ramsay, Chawarska, & Klin, 2011). The robustness of this developmental milestone demonstrates its importance to language learning. Moreover, infants without previously identified disorders whose canonical babbling onset is after ten months are at-risk for later language delay or other developmental disabilities (Oller, Eilers, Neal, & Schwartz, 1999; Stark, Ansel, & Bond, 1988; Stoel-Gammon, 1989). Clinically, this milestone has the potential to serve as a reference point for identifying and possibly differentiating neurodevelopmental disorders. Two types of evidence support the potential utility of this marker for early identification: (a) parents are reliably able to identify when their child reaches the canonical babbling stage (Lewedag, 1995; Oller, Eilers, Neal, & Schwartz, 1999), and (b) canonical babbling status at 9-12 months emerged as a strong predictor of diagnostic group in a study of infants with ASD versus typically developing infants (Patten et al., 2014).

Volubility

The quantity of infant vocalizations is also a significant measure of vocal development. This quantity can be indexed by volubility, defined as the rate of vocalizations regardless of whether a vocalization represents a canonical or non-canonical babble (Nathani, Oller, & Neal, 2007). Oller and colleagues suggest lower volubility may be due to environmental factors, given that children from low SES households vocalize less frequently than middle or high SES peers (Eilers et al., 1993; Oller et al., 1995). Although infants later diagnosed with ASD have demonstrated low volubility (Patten et al., 2014; Warlaumont et al., 2014; Warren et al., 2010), infants with severe or profound hearing loss and infants with cleft palate have not shown differences in volubility compared to peers with typical development (Oller, Eilers, Basinger, Steffens, & Urbano, 1995). To date, no study sought to investigate volubility in infants with Down syndrome, but in one study (Steffens, Oller, Lynch, & Urbano, 1992), the means for total vocalizations for infants with Down syndrome at 12 months look similar numerically to those of infants with typical development (TD = 1.41 per minute; Down syndrome = 1.25 per minute), suggesting small to no differences. Findings suggest volubility in infants with hearing loss and possibly infants with DS are not remarkably different compared to TD. Lower volubility in infants from low SES homes may be attributed to a smaller amount of adult-directed communication to infants (Hart & Risley, 1995; Snow, 1995). Patten et al. (2014) found infants with ASD had lower volubility than TD infants at 9 - 12 months, and proposed the idea that lower volubility may be due to less social motivation among infants with ASD. Lower volubility among infants with ASD may result in these infants eliciting fewer adult responses and thus not setting the stage for infant-caregiver reciprocal vocalizations as well as their TD peers.

The existing research provides a strong rationale for using canonical babbling and volubility as behavioral biomarkers. There is accumulating evidence supporting their use in differentiating between infants with TD and those who are later diagnosed with ASD. Particularly relevant to the search for behavioral biomarkers, the combination of canonical babbling status and volubility accurately predicted diagnostic group (ASD versus typically developing) for 75% of infants—82% for those with ASD and 64% for TD peers (Patten et al., 2014). Therefore, it is a reasonable next step to explore their utility as behavioral biomarkers in another neurodevelopmental disorder, FXS. Another important factor to consider when examining vocal development is motor development, because coordination between vocal and manual system development is postulated (Iverson & Thelen, 1999) and in TD populations there is a positive relationship between canonical babble onset and increased production of upper limb movements (e.g., waving and swinging; Cobo-Lewis, Oller, Lynch, & Levine, 1996). One novel component of the current study is the examination of the relationship between onset of walking, vocal measures, and FMRP level. Since there is speculation about the motor system playing a role in canonical babbling development (Iverson, 2010; Masataka, 2001; Cobo-Lewis, Oller, Lynch, & Levine, 1996), it was important to complete an initial investigation of the relationship in FXS compared to TD.

Specifically, this study aimed to address five research questions:

1. Are there differences in the likelihood infants with FXS and infants with TD will meet or exceed the .15 criterion for the canonical babbling stage by 9-12 months?

Hypothesis: Fewer infants with FXS will meet the criterion for canonical babbling stage by 9-12 months, indicating a delay in the development of canonical babbling.

2. Are there differences in the canonical babbling ratio between infants with FXS and those with TD?

Hypothesis: Infants with FXS will have a lower mean canonical babbling ratio compared to infants with TD.

3. Are there differences in volubility among infants with FXS and TD at 9-12 months?

Hypothesis: Infants with FXS will have lower volubility compared to infants with TD.

4. Does volubility and canonical babbling status predict group membership?

Hypothesis: These two variables together will significantly predict group membership.

5. Is there a relationship between onset of walking and (a) volubility and (b) total canonical babbling?

Hypothesis: There will be an inverse relationship between onset of walking and (a) volubility and (b) canonical babbles.

Methods

It is challenging to study early communication behaviors in infants with neurodevelopmental disorders like FXS because diagnoses are not typically made until three or four years of age (Bailey, Raspa, Bishop, & Holiday, 2009). Retrospective interviews or surveys with parents are not ideal methods for studying early communication development, as there is likely bias and lack of detail in recall. Prospective designs similar to Paul et al. (2011) offer advantages of standardization of data collection procedures and elimination of the need to depend on parent recall of their children's early behaviors, but are expensive and challenging to implement for studying infants with FXS due to the small numbers of children with FXS who are identified in infancy. An alternative method to study infant behaviors is retrospective video analysis. Retrospective video analysis is a method where researchers collect home videos of infants recorded during infancy from families when their children are older; this method offers the opportunity to study infant videos of children later diagnosed with a neurodevelopmental disability, or later confirmed to have typical development. Thus, retrospective video analysis is a cost-effective way to study the early behavioral manifestation of developmental phenomenon and describe patterns of behaviors prior to diagnosis in the FXS population. The current study used retrospective video analysis to compare canonical babbling and volubility of 9- to 12-month-old infants with FXS to age-matched infants later confirmed to be developing typically.

Participants

There were a total of 24 participants in this study. Ten participants had a diagnosis of FXS confirmed by medical records and 14 met criteria for the TD group. Given the sample sizes and assuming a Type 1 error rate of 5%, we had 80% power to detect an effect size of 1.06, which by Cohen's d standards (Cohen, 1988) is large. Previous research (Patten et. al., 2014) with 37 9 - 12 month old infants with ASD and TD demonstrated effect sizes ranging from 1.09 - 2.07. Thus, it is reasonable to assume the current sample is sufficient to detect effect sizes in a range comparable to those found for infants with ASD. There was one female in the FXS group and three in the TD group. Parents of nine infants with FXS and 13 with TD identified them as Caucasian. The other FXS and TD participants were identified as Asian. Participants included children enrolled in previous studies at the University of North Carolina-Chapel Hill (UNC) and one child newly recruited for the current study. Children with TD were recruited through research efforts spanning a 15-year time period. Recruitment criteria for children with TD in the previous studies included: (1) child age at recruitment between two and seven years, (2) available home video footage of the child between birth and two years that the parents were willing to share; and (3) enough footage for at least one five-minute codeable segment of the child at 9 - 12 and/or 15 - 18 months of age. Children in the TD group were excluded if they demonstrated one or more of the following: significant hearing, vision, or motor impairments; symptoms of ASD as measured by the Childhood Autism Rating Scales (CARS; Schopler, Reichler, & Renner, 1988); and/or positive test for FXS or other genetic syndrome per parent report. The group of children with TD also had no history of developmental or learning difficulties per parent report and received scores in the average range for overall developmental maturity on the Vineland Adaptive Behavior Scales, Interview Edition, Survey Form (VABS; Sparrow, Balla, & Cicchetti, 1984). The sample chosen for the current study was based on the availability of two five-minute edited videos at 9 – 12 months; using this selection criterion, 14 infants were chosen at random from all eligible infants with TD in the larger sample.

This study was specifically designed to examine babbling in infants with FXS who did not later meet criteria for ASD. Nine of the 10 participants with FXS were drawn from extant data collected in a longitudinal study of children with FXS (Bailey, Hatton, & Skinner, 1998), which required participants with FXS to be older than 12 months at the time of recruitment. The children with FXS needed to have a full-mutation confirmed by DNA analysis and not meet the cut-off score for ASD as measured by the CARS (Schopler, Reichler, & Renner, 1988). Available records for potential participants with FXS were screened for reports indicative of ASD (e.g., CARS scores >30 or ASD clinical diagnosis), and four potential infants with FXS were excluded due to documentation suggesting they later met criteria for an ASD diagnosis.

Additional participants with FXS were recruited for this study via flyers posted on social media and distributed to Fragile X community groups, a mailing from the North Carolina Fragile X Registry, and by word of mouth. Recruitment criteria for new participants included being at least three years of age, full-mutation, below threshold for ASD as measured by CARS scores less than 30 or parent report that no ASD diagnosis had been received by age three years, and available video footage of the child at 9 – 12 months. This recruitment effort yielded one more participant meeting inclusion criteria. Parents were asked to share other demographic information such as the child's intelligent quotient (IQ) and adaptive behavior skills if available. FMRP levels were available from medical reports of 8/10 participants with FXS. Table 1 provides descriptive information on the study participants.

Assessment Measures.

Participants in the TD group were assessed at initial recruitment for descriptive purposes (Baranek, 1999; Poon, Watson, Baranek, & Poe, 2012; Watson, Crais, Baranek, Dykstra & Wilson, 2013). Measures included the VABS for developmental/adaptive ability. The VABS scores for nine participants in the FXS group were available from the longitudinal study (Bailey, Hatton, and Skinner, 1998). The parents of the newly enrolled child did not provide VABS scores. Because the children's chronological ages varied at the start of the study, the VABS composite standard score was used as an index of developmental/adaptive status at the time of recruitment to describe and compare the groups. A one-way ANOVA was used to test for differences between the two groups on the VABS. As expected, the group with TD had significantly higher scores than the group with FXS ($F\ (1, 20) = 85.50$, $p < .01$).

Since level of intellectual impairment is also of interest for descriptive and comparison purposes, standardized scores (overall IQ) on cognitive assessments were gathered from psychological reports/assessments. All children with FXS in the earlier longitudinal study were assessed with the Battelle Developmental Inventory (BDI; Newborg, Stock, Wnek, Guidubaldi, & Svinicki, 1984). For the newly recruited child with FXS, parents were asked to share any developmental assessment reports, but none were available. The assessments for the TD group varied. Consistent with previously published infant video data (Baranek, 1999), the overall level of intellectual disability for both groups was coded as 0 = Average/Above Average Intelligence (standard scores above 85); 1 = Borderline (70-84); 2 = mild (55-69); 3 = moderate (40-54); 4 = Severe/profound (39-30). A chi-square confirmed the expected statistically significant differences on level of cognitive scores between the two groups (χ^2 (2, n = 24) = 12, p <.01)) with the FXS group having lower scores.

As part of the larger studies, parents provided the age their child walked (in months) during an initial phone call. The newly recruited family completed a demographic form with this information. Parents were asked to retrieve this information multiple years after the milestone, but since it is a major developmental milestone, it is reasonable to assume parents accurately remembered.

Procedures

Procedures included those for videotape editing and behavioral coding. This study was approved by the UNC Institutional Review Board.

Videotape editing. The procedures for videotape editing were established by a previous retrospective video analysis study (Baranek, 1999) and applied to newly recruited participants to maintain consistency. Families provided home videos of their child between birth and two years. The videotapes included a variety of events such as family vacations, mealtimes, special events such as birthday parties, and play routines. The footage for each child varied in the recorded events, as expected in family video footage (see Table 2 for percentage of activity type). All videotapes were copied, transcoded into digital formats and then original videotapes were returned to families. The newly recruited participant shared digital footage using a password-protected flash drive. Only footage for which parents could confidently identify the child's age was used.

In the Baranek (1999) study, the investigators chose the 9 - 12 month age range for two reasons. First, it is the earliest age range at which most parents had enough footage for at least one five-minute codeable segment. Second, it represents a time period when a variety of important early social and communication behaviors typically emerge. The age range is appropriate for the current study because it represents a time period when infants with TD should be in the canonical babbling stage. Research assistants, blind to study purpose and research questions, edited the videos. Instructions for editing tapes included (a) to focus on the footage during which the child was consistently visible, and (b) to compile two five-minute video segments for each child. The assistants were further instructed to quasi-randomly select a cross-section of scenes and to include scenes from each one-month age interval for which video footage was available. To ensure videos were similar in contexts, research assistants coded each scene included in the edited video segments for the following variables: (a) age of infant; (b) number of people present; (c) level of physical restriction on child's freedom to move; (d) amount of social intrusion another person was using to engage the child in interaction; and (e) number of events (Baranek, 1999). Level of intrusion and level of restriction were rated on a three-point scale (i.e., low-, medium-, high-intensity). These parameters were compared between groups with chi-square tests (See Table 3 for means and standard deviations), which yielded no significant between group differences in mean interaction per second, χ^2 (42, n = 24)

= 47.98, p = .24, or mean restriction per second, χ^2 (45, n = 24) = 52, p = .22. One-way ANOVAs were used to measure the difference in mean age per second, FXS = 11.18 (1.22) months, TD = 10.63 (.53) months, $F(1, 50) = 4.68$, p = .04; mean people per second, FXS = 3.204 (1.30), TD = 3.28 (1.24), $F(1, 50) = .47$, p = .50; and mean total events FXS = 4 (.82), TD = 5 (1.02), $F(1, 50) = 12.23$, p = .01. Thus, the FXS group was slightly older and had fewer total events than the TD group.

Coding Procedures. Each video segment was coded for infant-produced canonical babbles and non-canonical syllables by the first author of this study. In the coding scheme, syllables are defined as rhythmic speech-like vocalizations (excluding raspberries, effort sounds, ingressive sounds, sneezes, hiccups, crying and laughing) within one vocal breath group (Lynch, Oller, Steffens, & Buder, 1995). A canonical babble is defined as having consonant-like sound and a vowel, and a rapid transition between them. The transition timing is too rapid to be tracked by ear (Buder, Warlaumont, & Oller, 2013). Examples of canonical syllables are /ga/ and /mama/. No vocalizations were coded when an infant had an object or food in their oral cavity or on their lips. The reason for excluding these vocalizations is because an object can affect the articulator placement, which could result in a vocalization not representative of the child's true vocalizations. A naturalistic listening approach was used to code the syllables. This procedure was used in previous studies (Patten et al, 2014; Ramsdell, Oller, Buder, Ethington, & Chorna, 2012). Naturalistic listening has proven to a reliable technique for identifying canonical versus noncanonical syllables when compared to phonetic transcription with repeated reviews of audio recordings (Ramsdell, Oller, Buder, Ethington, & Chorna, 2012). The key of the naturalistic technique is listening as a caregiver would hear their child, listening to each utterance once. Parents are reliably able to identify when their child is in the canonical babbling range.

Therefore, this technique was utilized in the current study due to its clinical utility (i.e., parents could accurately evaluate whether or not their child is in the canonical babbling stage and share that information with their pediatrician when concerns arise).

The videotapes were randomly ordered and coded by a certified speech-language pathologist, the first author on this study, blind to participants' group status. The first author was experienced with this particular coding scheme. An undergraduate research assistant with a focus in communication sciences and disorders and pediatrics was trained in coding vocalizations using home videos separate from the project videos. The research assistant and first author achieved reliability on three training videos by agreeing on whether or not the infant was in the canonical babbling stage, and agreeing at least 80% of the time on the occurrence of any syllables and canonical babble syllables. Then, the research assistant coded a random sample of 20% of the study videos. The agreement of the reliability coder with the primary coder was checked after each reliability video was coded. The reliability for coded videos was computed as (a) the percentage of video segments for which the coders agreed that the infant was or was not in the canonical babbling stage (with the goal being an agreement of 90% or higher), and (b) the intraclass correlation coefficients (ICCs) for the frequency of all syllables and frequency of canonical babble syllables (with the goal of ICCs of .80 or higher). The percentage of video segments for which the coders agreed the child was in the canonical babbling stage was 87.5% (7/8). ICCs were .94 and .89 for frequency of all syllables and frequency of canonical babbles, respectively.

Data analysis strategy. Given the small sample sizes, unequal variances for canonical babbling ratio (t (19.50) = 3.19, $p > .00$) and volubility (t (20.61) = 3.12, $p > .00$) and nonnormally distributed data (i.e., skewness greater than 1.0), non-parametric statistics were warranted. Groups were compared on maternal education ($U = .42$), race ($U = .63$), and sex ($U = .67$) using Mann-Whitney analyses, with nonsignificant differences on these variables. Data were analyzed using SPSS 21 and SAS 9.4.

Results

Research Question 1

Are there differences in the likelihood infants with FXS and infants with TD will meet or exceed the .15 criterion for the canonical babbling stage by 9 - 12 months?

For our participants, 8 of 14 infants with TD met the criterion for being in the canonical babbling stage at 9-12 months, whereas 0 of 10 infants with FXS did so. According to an exact Pearson chi-square test, there was a significant between group difference, χ^2 (1, n = 24) = 8.57, $p < .01$, with infants with FXS less likely to be in the canonical babbling stage at 9 – 12 months than infants with TD.

Research Question 2

Are there differences in the canonical babbling ratio between infants with FXS and TD?

The median canonical babbling ratio for FXS was .03 (range = 0 - .13) and .16 for TD (range = 0 - .27). A Wilcoxon signed-ranks test was used to test for a between group canonical babbling ratio difference. The test was statistically significant ($Z = -2.27$, $p = .02$) with infants with FXS producing a smaller canonical babbling ratio. See Figure 1 for between-group canonical babbling ratios by participant.

Research Question 3

Are there differences in volubility (total vocalizations) among infants with FXS and TD at 9-12 months?

The median volubility totals across the 10-minute samples were 31.5 for infants with FXS (range = 4 – 47) and 54 for infants with TD (range = 33 – 82). A Wilcoxon signed-ranks test showed that infants with FXS produced fewer total vocalizations than infants with TD (Z = -2.49, p = .01). See Figure 2 for participant volubility totals.

Research Question 4

Does volubility and canonical babbling status (i.e., whether a child met the .15 criterion) predict group membership?

Because the overall sample for this project was small, unbalanced, and contained a cell with no observations, an exact logistic regression (Hirji, Mehta, & Patel, 1987; Mehta and Patel, 1995) was performed to determine whether the variables (canonical babbling ratio of .15 or higher and total volubility) could predict group membership. In the instances of small and unbalanced samples, where the asymptotic properties of maximum likelihood-based estimators and inferential methods are likely to fail, exact logistic regression can still provide valid parameter estimates and statistical tests (Stokes, Davis, and Koch, 1995). The canonical babbling data had a quasi-separation of data points since canonical babbling status perfectly predicts membership in the FXS group, but not the TD group (see Table 4). Results from the exact logistic regression tests suggest that (1) as total volubility increases the predicted likelihood of FXS decreases by a factor of -.09 logits per unit increase in total volubility (conditional score test = 6.24; exact 2-sided $p \leq .048$); and (2) As an infant goes from not being in the canonical babbling stage to being in the stage, the predicted likelihood of being in the FXS group decreases by a factor of -2.1 logits (conditional score test = 4.60; exact 2-sided $p \leq .027$). When examining each predictor variable in the model independently, total volubility accurately predicted (was concordant with) the group assignment of 80% of the infants, whereas canonical babbling accurately predicted the group assignment of 57%. Although it seems counterintuitive, total volubility was a stronger predictor of group compared to canonical babbling status. It is important to note that concordance is an index of the degree to which predicted values matched observed values, adjusted for the number of ties. For this sample, the number of ties reduced the percent concordant, which is a measure of the association between observed responses and predicted responses.

Research Question 5

Is there a relationship between onset of walking and (a) volubility and (b) total canonical babbles at 9 – 12 months?

Spearman correlations, appropriate for small sizes, were run within groups. There were weak correlations for both groups for volubility, TD: $r_s = -.17$, n = 8, $p = .69$; FXS: $r_s = .17$, n = 10, $p = .63$). There was a strong inverse relationship for canonical babbles in the TD group ($r_s = -.78$, n = 8, $p = .02$) but no meaningful level of association for FXS ($r_s = .03$, n = 10, $p = .94$). Although only one of the results is statistically significant, results indicate a moderately strong inverse relationship for the TD sample only, such that TD infants who walk at a younger age have higher canonical babbling ratios.

Based on previous indications that severity of FXS phenotype correlates with FMRP expression (Jacquemont, Berry-Kravis, Hagerman, vonRaison, Gasparini, Apostol, Ufer, Des Portes, & Gomez-Mancilla, 2014; Tassone, 1999; Loesch, Huggins, & Hagerman, 2004), we examined correlations between FMRP level and babbling measures and onset of walking. The correlations were negative and moderate for canonical babbling ($r_s = -.26$, n = 8, $p = .54$), volubility ($r_s = -.33$, n = 8, $p = .42$), but strong for onset of walking ($r_s = -.83$, n = 8, $p = .01$), with two participants missing FMRP levels. FMRP and age walking have a statistically significant inverse relationship whereby earlier onset of walking corresponds to higher FMRP levels.

Discussion

During the first year of life, typically developing infants make a transition from marginal syllables (i.e., syllable shapes where the transition between sounds can be perceived by ear because it is slow) to well-timed canonical babbles (i.e., /mama/; Oller, 1980). Delays in the groundwork for language development are a reasonable sign that early intervention is warranted. In order for children with FXS to receive earlier intervention, however, they must be identified earlier than three to four years of age, as occurs currently. This study examined the potential of early infant vocalizations, including volubility and canonical babbling, to serve as behavioral biomarkers that could alert parents and physicians to the need for a neurodevelopmental assessment. The usefulness of canonical babbling as a behavioral biomarker is of particular interest because previous research has demonstrated that parents readily recognize when their infant makes this transition (Oller, Eilers, & Basinger, 2001), and thus most parents could reliably report to the child's primary care provider whether the infant is using canonical syllables regularly. Results from this study support the utility of canonical babbling status (reached .15 criterion of canonical babbles per total syllables) and total volubility at 9 – 12 months as predictors for diagnostic category. This pattern is similar to the Patten et al. (2014) study that reported canonical babbling status and volubility at 9 - 12 months were relatively strong predictors of group membership for infants with ASD vs. TD, more so than these same measures at 15 – 18 months.

In the current study, infants with FXS were significantly less likely to be in the canonical babbling stage at 9 - 12 months compared to their TD peers; further, the magnitude of the differences at 9 - 12 months, and the fact that none of the 10 infants with FXS met criterion (i.e., 15% canonical babbles) for being in the canonical babbling stage, suggest this could be an important surveillance question for physicians to ask parents when seeing infants in this age range. However, it is important to point out that six of the infants with TD did not meet the criterion for the canonical babbling stage at 9 – 12 months, an unexpected result given that the literature indicates typically developing infants reach this stage by nine months (Eilers and Oller, 1990). This finding may be due to some of the videos having more footage of when the child was younger than ten months or the fact that these video samples were relatively brief (10 minutes total) and did not require that a minimum number of vocalizations be included in the samples (Molemans, 2001). Even in lab samples of as long as 20 minutes, TD infants often fail to meet the .15 ratio criterion in the samples even though they are known to be in the canonical babbling stage. This is a case in which parents may be able to provide more reliable information on an infant's typical vocalizations than can be gained through relatively brief observations, such as in these 10 minute video samples or what a physician would be able to observe in person during an office visit. There is also natural variability in these early language production skills. Nevertheless, it is striking that the majority of TD infants met the .15 criterion for being in the canonical babbling stage in these 10-minute home video samples, whereas none of the infants with FXS did, demonstrating a delay in canonical babbling similar to infants later diagnosed with ASD (Patten et al., 2014).

In our study, we also found infants with FXS had lower volubility compared to TD infants, similar to that for infants with ASD (Patten et al. 2014). These findings may be the result of impaired social skills, reduced parent input, or depressed transactional communication processes operating between infant and adult (i.e., decreased infant syllables yield fewer adult responses, in turn yielding fewer learning opportunities for the infant). Both disorders are associated with pragmatic and language deficits, but with potentially different underlying reasons (i.e., increased social anxiety in children with FXS and reduced motivation in children with

ASD; Hagerman, 2002; Chevallier, Kohls, Troiani, Brodkin & Schultz, 2012). To what extent either of these issues is present in infancy remains unknown. However, the social issues may affect the amount an infant babbles. Since the frequency of infant vocalizations is strongly associated with frequency of parent responses (Gilkerson & Richards, 2009; Goldstein et al., 2003; Gros-Louis et al., 2006), the infant may not receive as much language input. The diminished input may in turn decrease infant babble production. Thus, social impairments inherent in the infant and/or social transactions between infant and caregiver may negatively impact babbling.

A potential explanation for reduced vocalizations was explored further by looking at the relationship with another motor milestone, that is, age of walking. The trends are not the same between groups. In the TD group, there was a moderately strong negative relationship between babbling and age of walking, indicating early walkers produce more canonical babbles, consistent with previous findings for infants with TD. This finding may be important because it suggests more evidence for Iverson and Thelen's (1999) theory that motor milestones are coordinated. The story was not the same for the FXS group, where no meaningful degree of association was found. Thus, other factors above and beyond motor skills, such as cognition or sociability, may play a role in early language development in infants with neurodevelopmental disorders. One caveat of the correlations is the variability in the data and the small sample sizes, which increases the risk of sampling errors. The moderate correlations of canonical babbling and volubility with FMRP level may suggest that reduced FMRP, perhaps through its role in synaptic development and functioning (Weiler & Greenough, 1999), suppresses early language development and walking. Perhaps the low canonical babbling ratios introduce a sort of floor effect for the FXS group; that is, the limited variability in canonical babbling ratios in this group produces low correlations with any other measure.

Limitations

Home videos offer multiple advantages including a sample of children who have a confirmed diagnosis of FXS, ability to observe children before they were diagnosed, and data from the naturalistic environment where infants vocalize more freely (Lewedag, Oller, & Lynch, 1994). However, home videos have drawbacks including potentially poor video/audio quality, limited availability of footage in a given age range, and lack of experimental control. In this particular study, the videos may not be fully representative of the child's language development since we only examined 10 minutes of vocal behavior. Thus, we were likely seeing greater variability in the canonical babbling ratios compared to studies with longer sampling periods (Molemans, 2011). There were between-group differences in mean infant age and mean total events with the children with FXS being slightly older and with fewer total events. However, it is unlikely these differences biased our findings related to canonical babbles or volubility, given the lack of differences on the other contextual variables (e.g., people present, amount of restriction) that characterize the nature of the events. Another limitation of this study is the small sample sizes. Although we could have included infants with comorbid FXS and ASD to increase sample size (and be more representative of the total population of infants with FXS), the association between ASD, low volubility, and delayed transition to the canonical babbling stage has previously been demonstrated (Patten et al., 2014). Thus, our primary interest was in examining the vocal patterns in a sample of infants with FXS without ASD in order to understand the utility of canonical babbling and volubility for identifying infants with FXS who do not go on to exhibit symptoms of ASD.

Future directions

In order to test the utility of canonical babbling and volubility as behavioral biomarkers, a logical next step is to conduct a larger sample retrospective video analysis or longitudinal study incorporating the guidance from Molemans (2011). Molemans emphasizes the need to observe for longer blocks of time and use repeated measurements to reliably study the onset of canonical babbling. Longer samples and repeated samples will provide more information regarding individual variability in babbling trajectories in typical development and neurodevelopmental disorders. The challenges will be developing new ways to identify these children early and acquire data at these ages.

Given the information on canonical babbling and volubility in ASD and FXS, it would be interesting to investigate infants with comorbid FXS and ASD to determine whether the comorbidity of these disorders has an additive effect on a child's vocalization development over having only FXS or only ASD. FXS is the most common genetic cause of ASD (Hagerman and Hagerman, 2002) and the communication deficits associated with the disorders are similar, although among older children with FXS, those with comorbid ASD have more severe communication deficits than those with FXS alone, especially in pragmatic language functioning (Estigarribia, Martin, Roberts, Spencer, Gucwa & Sideris, 2011; Martin, Losh, Estigarribia, Sideris & Roberts, 2013). Additionally, using a group of infants with Down syndrome as a comparison group would provide more information regarding whether the findings are a profile associated with intellectual disability in general. This is especially important given the moderate correlation between FMRP level and canonical babbling. To further control for this issue, future studies should match on mental age or a mental age proxy to ensure cognitive impairments are not affecting outcomes. The present study demonstrated a strong relationship between babbling and the start of walking in the group with TD, but not in the FXS group. However, it is important to note the very low canonical babbling ratios in the FXS group may restrict any possible correlation. Examining babbling in the context of other important motor milestones, such as postural stability, may also provide insight into the relationship between motor and language systems (Iverson, 2010). Finally, it is a logical next step to examine the environment's role in canonical babbling. Results from one previous study support the idea that parents of children with TD intuitively begin advancing their language input when their child starts using canonical babbles (Papoušek, 1999). Whether the same is true for parents of children with neurodevelopmental disabilities remains unknown. Available literature on maternal responsivity with older children with FXS and ASD suggests frequency and contingency of maternal responses influences a child's language level (Warren, Brady, Sterling, Fleming, & Marquis, 2010; Sterling, Warren, Brady, & Fleming, 2013), supporting the idea of studying responses to canonical babbles in children with neurodevelopmental disorders. Further, testing methods for eliciting more canonical babbles, similar to treatment with a sample of children with intellectual disability (Woynaroski, Yoder, Fey, & Warren, 2014), could further inform early intervention treatments to promote language learning.

Table 1. Participant demographics

Characteristic	FXS Mean (SD)	TD Mean (SD)
	11.18 (1.22)	10.63 (.53)
Chronological age (months)		
Intelligence Quotient[1]	52.40 (3.87)	101.38 (7.25)
Maternal Education[2]	5.44 (1.13)	5.83 (.72)
Vineland Adaptive Behavior Scales Composite Standard Score	61.44 (10.11)	102.77 (13.85)
Childhood Autism Rating Scale[3]	24.16 (3.12)	16.2 (1.21)
Onset of Walking (months)	15.75 (2.84)	11.89 (1.57)
FMRP Level[4]	6.94 (6.97)	NA

[1] Missing 2; 0=Average/Above Average Intelligence (standard scores above 85); 1=Borderline (70–84); 2 = Mild ID (55–69); 3=Moderate ID (40–54); 4=Severe/Profound ID (<39).

[2] Maternal Education: 1 = 6th grade or lower; 2 = 7th to 9th grade; 3 = partial high school; 4 = high school graduate/GED; 5 = associate of arts/associate of science or technical training or partial college training; 6 = bachelor of arts/science; 7 = master of arts/science or doctorate or other professional degree completed

[3] Missing 1 FXS and 4 TD

[4] Missing 2

Table 2. Percentage of each activity type

Type	FXS; n = 10	TD; n = 14
Mealtime	10	12
Active play	62	54
Special event	17	8
Bathtime	5	12
Passive activity	4	6
Other	2	1

Table 3. Content variables for videos

Type	FXS; Mean (SD)	TD; Mean (SD)
Number of people present	3.04 (1.30)	3.28 (1.24)
Amount of physical restriction	1.77 (.62)	1.51 (.32)
Amount of social intrusion	2.03 (.42)	2.04 (.37)
Total number of different events	4.17 (.82)	5.07 (1.02)

Table 4. Exact Logistic Regression

	Statistic	Logit	Standard Error	95% Confidence Intervals		Two-sided p-value
Canonical babbling status[5]	6.24	-2.12	-	-Infinity	-.33	.05
Total volubility	4.59	-.09	.05	-.19	-.01	.03

[5] Reference group is FXS

Figure 1. Group canonical babbling ratios by participant across 10-minute sample. Error bars represent standard error.

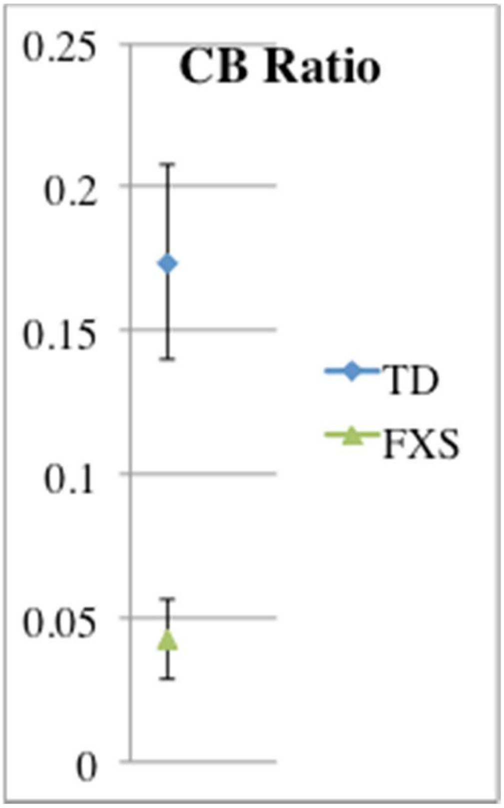
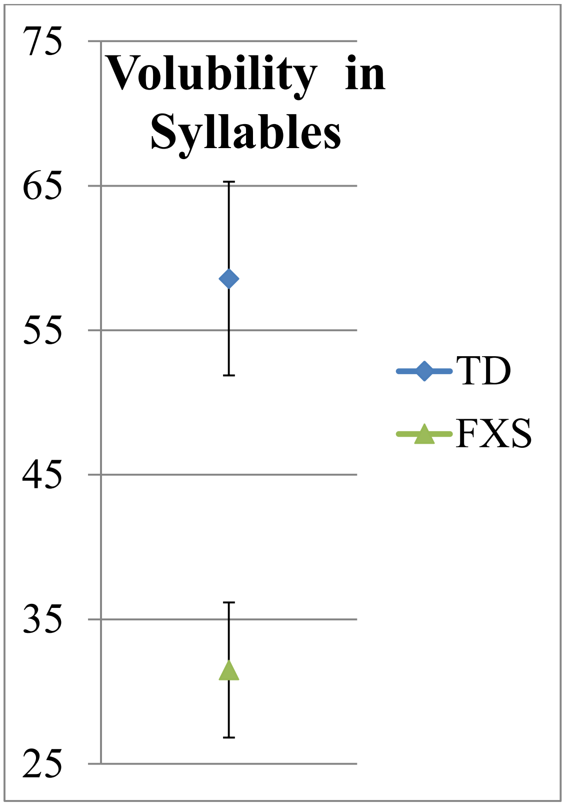


Figure 2. Group volubility across 10-minute samples. Error bars represent standard errors.



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CHAPTER 3: ADULT RESPONSES TO CANONICAL BABBLES IN INFANTS WITH FRAGILE X SYNDROME AND AUTISM SPECTRUM DISORDER

From a transactional perspective of child development (Sameroff & Chandler, 1975; McLean & Snyder-McLean, 1978), exchanges between parent and child are related to a child's cognitive and communicative growth. The central idea of the transactional theory suggests development is facilitated by a bidirectional, reciprocal interaction between child and environment. These interactions might impact when children advance from one stage to another. Reciprocal influences between parent and child seem particularly likely when an infant reaches the canonical babbling stage of language development, a stage when an infant's syllable shapes have the properties of adult speech (Oller, 2000) and elicit more advanced language from parents of typically developing (TD) children (Papoušek, 1994). Two populations of children for whom this type of change in parent language complexity could be more significant are Fragile X syndrome (FXS) and Autism Spectrum Disorder (ASD). The primary aim of this study is to determine whether parents of infants with neurodevelopmental disorders, specifically FXS and ASD, respond to non-canonical and canonical babbles at the same rate and with similar linguistic complexity as parents of TD infants. Understanding whether transactions play out differently between developmentally different groups will enhance our understanding of factors that may exacerbate or ameliorate the communication delays associated with these disorders. Clinically, this information could inform and support early parent-focused interventions.

Parent-Child Interactions

Due to methodological and statistical limitations, it is challenging to measure true bidirectional effects of communication. For example, reported correlations between parent responsivity and infant behavior (e.g., Yoder and Warren, 1999; Girolametto, Weitzman, Wiigs, & Pearce 1999) do not indicate a direction of causal effects or even whether causal effects explain the correlation; however, the conceptual frameworks within which these findings are interpreted often focus on a unidirectional assumption that parent responsivity is impacting infant behavior. Under this assumption, previous research suggests that maternal responsivity facilitates children's social, emotional, and cognitive growth (Landry, Smith, Miller-Loncar, & Swank, 1998; Landry, Smith, Swank, Assel, & Vellet, 2001), with findings paralleling the seminal Hart and Risley (1995) findings that the amount of child-directed language parents direct toward children is associated with later language outcomes. More specifically, low levels of verbal input are associated with low vocabulary skills. This body of evidence has been interpreted as showing the strong impact parents' responsivity and language has on children's language development.

Less attention has been paid to the potential role of infant behaviors in influencing the quality or quantity of parent responsivity. Examination of infant vocalizations provides an opportunity to study potential transactional influences in parent-infant relationships. For example, in infants with TD, a child's prelinguistic productions cue parent responses (Locke, 1996; McCune, 1992, McLean, 1990). In terms of verbal productions, infant vocalizations elicit immediate adult responses (Goldstein, King, & West, 2003; Gros-Louis, West, Goldstein, & King, 2006; Warlaumont, Oller, Dale, Richards, Gilkerson, & Xu, 2010) and the frequency of infant vocalizations is positively associated with the number of adult responses (Abraham, Crais,

& Vernon-Feagans, 2013; Gilkerson & Richards, 2009; Goldstein et al., 2003; Gros-Louis et al., 2006).

Studies of caregiver responsivity in neurodevelopmental disabilities suggest similar patterns to parent-child dyads involving TD children (Siller & Sigman, 2008). For example, maternal responsivity is significantly related to receptive and expressive language levels for children with FXS (Brady, Sterling, Fleming, & Marquis, 2010) and ASD (Yoder & Warren, 2004; Warren & Brady, 2007). Additionally, there is evidence suggesting mothers' responsivity to their children's prelinguistic acts may facilitate intentional and verbal communication in children with developmental disabilities (Girolametto, 1988; Wilcox, 1992). Overall, research suggests that children with disabilities with highly responsive mothers have more advanced language development compared to less responsive mothers (Yoder & Warren 1998, 2000, 2001; Yoder, Watson & Lambert, in press). In recent years, researchers have turned more attention to the question of how the behaviors of infants and young children with neurodevelopmental disabilities may impact the responses of caregivers (Green et al., in press; St. Georges et al., 2011; Vernon, 2014.

Parent Responses to Canonical Babbles

The transactional influences of communicative partners on one another are demonstrated during multiple stages of language development, particularly the canonical babbling stage. Parents naturally recognize when an infant transitions to canonical babbles, and alter their responses in ways that advance the communication negotiation (Locke, 2006; Oller, Eilers, & Basinger, 1996). For example, prior to the onset of canonical babbles, an infant may express an emotional state and the parent may respond in kind. There is a remarkable shift in the linguistic complexity of the parent response (Papoušek, 1999), and is significant as it may guide the infant toward word learning.

More recent research investigates the differential responses of adults interacting with children with disabilities. Warlaumont and colleagues (2014) examined child-adult interactions from day-long recordings of children with typical development as well as those with ASD (ages 8 - 48 months), and found adults were more likely to respond to canonical babbles compared to non-canonical sounds in both groups. However, the proportions of children's canonical and non-canonical babbles receiving responses were smaller for the ASD group, suggesting the vocalizations of children with ASD may be less effective in eliciting responsive input from adults. Further understanding the differences in (1) how parents of infants with neurodevelopmental disorders respond (i.e., the type of response) to their infants' non-canonical and canonical babbles, and (2) the frequency of responses made to non-canonical and canonical babbles compared to parents of infants who are typically developing, may inform our theories of how language develops in children with neurodevelopmental disabilities.

There is preliminary evidence on the nature of these transactions from a recent study that examined whether parent responsivity mediated the association between canonical syllable production and intentional communication among toddlers with intellectual disability (Woynaroski, Yoder, Fey, & Warren, 2014). Participant inclusion criteria required expressive language standard scores less than 20 and low-risk for ASD. Participants were randomly assigned to two groups with different dosages of the treatment, milieu communication teaching (MCT; Fey, Yoder, Warren, & Bredin-Oja, 2006). MCT uses a technique called linguistic mapping whereby adult responses to the child reflect the adult's "guess at the presumed meaning of an immediately preceding child communication act." Results suggested more intensive MCT increased infant's use of canonical babbles and was associated with larger spoken vocabularies post treatment. The relation between canonical babble communication and later spoken vocabulary was partially mediated by parental linguistic mapping. These findings were interpreted as supporting a transactional model whereby an increase in child use of canonical syllables elicited a greater use of linguistic mapping by parents. One caveat of this study is that the age range of the toddlers studied (i.e., 18 to 27 months) is a period of time when canonical babbles should be well established. Nevertheless, this is a respectable start for understanding whether increasing canonical babbles changes the quality of parent responses to the child's vocalizations, leading in turn to increased child communication in a group of young children with developmental disabilities that included delayed expressive language.

The purpose of the present study was two-fold. First, it was designed to confirm findings from previous studies, but with the novel addition of a FXS group and at a younger age than previous studies of children with developmental disabilities. The second purpose was to examine the frequency and type of response to canonical and non-canonical syllables and determine whether predictive relationships exist between these dimensions of parent responsivity and group membership. This study was guided by the following research questions:

Research Question 1

Are there differences in (a) infant volubility, or frequency of vocalizations, between groups of infants with different neurodevelopmental disorders, (b) number of adult words spoken between groups and (c) correlations between frequency of infant vocalizations and number of total adult words across groups?

Hypothesis: It is hypothesized that there will be (a) no differences in the volubility between infants with FXS and ASD; (b) no difference in the number of adult words spoken; and (c) a difference in the correlations between TD and neurodevelopmental disability groups with the TD group having stronger relationships.

Research Question 2

What is the likelihood of a caregiver response to canonical babbles compared to non-canonical babbles? Does it vary by diagnostic group?

Working hypothesis: It is anticipated that parents will be more likely to respond to canonical babbles than non-canonical babbles, and that the likelihood ratios will not vary by diagnostic group.

Research Question 3

Does the type of response parents give to non-canonical babbles predict group membership?

This research question is exploratory rather than hypothesis driven. We will report descriptive information of the data.

Research Question 4

Does the type of response parents give to canonical babbles predict group membership?

This research question also is exploratory. We will report descriptive information on the data.

Methods

Participants

Participants were 14 children with TD, 10 with FXS and 10 with ASD. Assuming a Type 1 error rate of 5%, a large odds ratio of 2.7 and 80% power, a total sample of 62 participants would be needed. With 34 participants we are powered to detect an effect size, as measured by Cohen's d, of .84 (OR = 4.6). Moderate to large effect sizes (Cohen's d of .55-1.00) are reported in the literature comparing maternal responses to children with ASD and Down syndrome with maternal responses to children with typical development (Venuti, de Falco, Esposito, Zaninelli, & Bornstein, 2012). Thus, this study may be underpowered for detecting differences between groups with different neurodevelopmental disabilities, but sufficient to detect differences between infants with different neurodevelopmental disorders and infants with TD.

There was one female in the FXS and ASD groups and three in the TD group. Thirteen infants with FXS, nine with ASD, and 10 with TD were identified by their parents as Caucasian. See Table 1 for more information on participant demographics.

Participants in this study were selected from archived data collected in previous studies (e.g., Baranek, 1999; Baranek et al., 2005; Watson et al., 2013), except for one child with FXS who was newly recruited. The UNC Institutional Review Board approved this study. Children with TD and ASD were recruited through research efforts spanning a 15-year time period. Recruitment criteria for these children included the following: (1) child age at recruitment between two and seven years, (2) available home video footage of the child between birth and two years that the parents were willing to share; and (3) enough footage for at least one five-minute codeable segment of the child at 9-12 months of age.

Children in the TD group were screened at the time of recruitment and excluded if they demonstrated one or more of the following: significant hearing, vision, or motor impairments; symptoms of ASD as measured by the Childhood Autism Rating Scales (CARS; Schopler, Reichler, & Renner, 1988); positive genetic test for FXS or another genetic syndrome. The group of children with TD also had no history of developmental or learning difficulties per parent report and received scores in the average range for overall developmental maturity on the Vineland Adaptive Behavior Scales, Interview Edition, Survey Form (VABS; Sparrow, Balla, & Cicchetti, 1984).

All participants in the ASD group received a clinical diagnosis of ASD from a licensed psychologist and/or physician; symptoms were confirmed by research staff using Diagnostic and Statistical Manual of Mental Disorders-IV criteria (American Psychiatric Association, 2000), and each participant received scores of 25 or above on the CARS. The files of participants with ASD were reviewed and none of the participants had a documented diagnosis of FXS. Children in the ASD group were screened at the time of recruitment and excluded if they demonstrated significant hearing, vision, or motor impairments. Participants for the current study were selected based on diagnosis and the availability of at least one five-minute edited video at 9 - 12 months of age (see below for information on video editing). Sets of twins and siblings were excluded from this study since their language environment is likely very similar.

Nine of ten participants with FXS were drawn from archived data from a longitudinal study of children with FXS (Bailey, Hatton, & Skinner, 1998; Baranek et al., 2005), which required participants with FXS to be older than 12 months at the time of recruitment. These children were required to have full-mutation FXS confirmed by DNA analysis and to fall below the cutoff score for ASD on the CARS. Available medical records for participants with FXS were screened and resulted in no reports of ASD. All CARS scores were less than 30, the recommended cut-off score for ASD. Additional participants with FXS were recruited for this study via flyers posted on social media and distributed to Fragile X community groups, the North Carolina Fragile X Registry as well as by word of mouth. Recruitment criteria for new participants included at least three years of age, full-mutation FXS, CARS scores less than 30 or parent report of no ASD diagnosis, and available video footage of the child at 9 – 12 months. Out of three newly recruited families, only one child met the inclusion criteria.

Assessment Measures.

Participants in the ASD and TD groups were assessed at initial recruitment for descriptive purposes (Baranek, 1999; Poon, Watson, Baranek, & Poe, 2012; Watson, Crais, Baranek, Dykstra & Wilson, 2013). Measures included the VABS for developmental/adaptive ability and CARS for ASD symptom severity. VABS scores for 9/10 participants in the FXS group were available from Bailey, Hatton, and Skinner (1998) but were not available from parents of the one newly recruited participant. A one-way ANOVA was run to evaluate between group differences on the VABS. The omnibus test was significant (F (2, 28) = 45.57, p < .01). As expected, the Tukey post-hoc test revealed the TD group had significantly higher scores compared to the clinical groups; however, there was no difference between the ASD and FXS groups (p = .22). CARS scores were also compared with a one-way ANOVA; the omnibus was significant (F (2, 23)= 20.62, p <01) and post-hoc tests revealed differences between TD and both disability groups (p = .01) and between FXS and ASD (p = .02) with the ASD group having a higher mean, as one would expect on an autism measure.

Because level of cognitive impairment for the three clinical groups is also of interest for interpreting findings, standardized scores (overall IQ) on cognitive assessments were gathered from extant psychological reports/assessments. Children with FXS who were part of the longitudinal study (Bailey et al., 1998) were assessed with the Battelle Developmental Inventory (BDI; Newborg, Stock, Wnek, Guidubaldi, & Svinicki, 1984). The newly recruited family was unable to provide the child's IQ scores. The cognitive assessment instruments for the ASD group varied. Consistent with previously published studies where varied cognitive assessment instruments were used (Baranek, 1999), the overall level of cognitive impairment was coded as 0 = Average/Above Average Intelligence (standard scores above 85); 1 = Borderline (70-84); 2 = mild (55-69); 3 = moderate (40-54); 4 = Severe/profound (39-30). A chi-square test was used to determine if there were statistically significant differences on level of cognitive impairment across the two clinical groups. The test showed no differences (χ^2 (2, n = 14) = 3.05, p = .22). It is important to note, however, that four participants with FXS and one with ASD were missing IQ scores. See Table 1 for means and standard deviations.

Procedures for editing videotapes

The procedures for videotape editing were established in an early retrospective video analysis study that initiated this program of research (Baranek, 1999) and applied to subsequently recruited participants to maintain consistency. Families provided home videos of their child between birth and two years. The videotapes included a variety of events such as family vacations, mealtimes, special events such as birthday parties, and play routines. The footage for each child varied in the recorded events, as expected with home videotapes. All videotapes were copied, transcoded into digital formats and then original videotapes were returned to families. The newly recruited family shared their digital videos with a password-protected flashdrive. Only footage for which parents could confidently identify the child's age (in months) was used.

The larger study identified the 9 - 12 month age range as a time of interest for two reasons. First, it is the earliest age range most parents could provide enough footage for at least one five-minute codeable segment. Second, it represents a time period when important early behaviors typically emerge. The age range is appropriate for the current study because it represents a time period by which infants with typical development should be in the canonical babbling stage, as marked by the production of .15 canonical syllables per total syllables (Oller, 2000). Research assistants, blind to study purpose and research questions, edited the videos. Instructions for editing tapes included to (a) focus on the footage during which the child was consistently visible and (b) compile two five-minute video segments for each child if possible. The assistants were further instructed to quasi-randomly select a cross-section of scenes, and to include scenes from each one-month age interval for which video footage was available. Research assistants coded each scene included in the edited video segments for the following variables: (a) age of infant; (b) number of people present; (c) level of physical restriction on child's freedom to move; (d) amount of social intrusion another person was using to engage the child in interaction; and (e) number of events (Baranek, 1999). Level of social intrusion and level of restriction were rated on a three-point scale (i.e., low-, medium-, high-intensity; see Table 2 for means and standard deviations). Categorical data were compared between groups with chi-square tests, and continuous data were analyzed with a one-way Analysis of Variance (ANOVA). There were significant between group differences for mean total events ($F(2, 70) = 11.53$, $p = .00$) with ASD having with more total events compared to TD and FXS, and mean child age (in months; $F(2, 70) = 4.42$, $p < .05$) with infants with FXS older than TD and ASD infants (see Table 3 for pairwise comparisons). Mean number of persons per event ($F(2,70) = .32$, $p = .73$); mean amount of social intrusion (χ^2 (114, n = 34) = 130.79, $p = .14$) and physical restriction (χ^2 (122, n = 34) = 131.59, $p = .26$) were nonsignificant. The percentage of each activity type per group is presented in Table 4.

Coding infant vocalizations.

The first author, a speech-language pathologist with previous training in coding infant vocalizations, coded the canonical babbling and syllables produced in all videos. As part of Belardi et al. (in preparation) and Patten et al. (2014), each video segment was coded for infant-produced canonical syllables and total syllables. Syllables are defined as rhythmic speech-like vocalizations (excluding raspberries, effort sounds, ingressive sounds, sneezes, hiccups, crying and laughing) within an “utterance”, which is typically defined as one vocal breath group (Lynch, Oller, Steffens, & Buder, 1995). A canonical babble is defined as including a vowel-like nucleus, at least one consonant-like sound and transition between the vowel and consonant. Examples of canonical syllables are /ba/ and /kaka/. Any vocalizations occurring when an infant had an object or food in their oral cavity or on their lips were excluded. Canonical babbles and other vocalizations were coded in real time with a naturalistic listening approach. This procedure was used in previous studies (Patten et al, 2014; Ramsdell, Oller, Buder, Ethington, & Chorna, 2012) and is meaningful because it simulates how a caregiver would hear their child, listening to each utterance once. Parents are reliably able to tell when their child is in the canonical babbling range. Therefore, this procedure is justified because it simulates or resembles the perceptions of the caregivers who interact with infants about their vocalizations. Parents are the primary individuals who have the potential to influence both babbling and early speech. What caregivers understand from infants forms the basis for negotiation over words. A second observer coded a random sample of 20% of videos consisting of two 5-minute segments. Reliability for infant vocalizations was assessed in terms of coders’ agreement on canonical babbles, total babbles and whether the infant was in the canonical babbling stage (i.e., met or exceeded the .15 babbling criterion). Coders agreed on the canonical stage for 90% of the samples, and ICCs were strong (.90 for canonical babbling and total volubility .94).

Coding parent responses.

The first author of this study and two additional coders were randomly assigned a percentage of videos and completed two additional listening passes. On the first pass, coders transcribed all adult words spoken during the video. Utterances directed to the target child were marked with “C”. Coders were permitted to listen to a given utterance up to three times to determine what words were spoken; if unable to determine what was said after the third time, the utterance (or portions of the utterance) was marked as unintelligible. Twenty percent of the videos were randomly selected and coded for reliability across raters. ICCs, or correlations among raters, were calculated for each of the variables of interest with a two-way mixed effects model. ICCs for number of parent responses was .97, child directed utterances, .83, total utterances, .76, and total adult words, .99.

A fourth coder and the first author on this study completed an additional listening pass of the videos. Coders were randomly assigned one half of the videos. Using the coding sheets marking intervals with child vocalization types (canonical versus non-canonical), coders identified adult responses within two seconds of an infant vocalization. Given the nature of home videos, there were other adults present during certain scenes. Any adult responses were coded and if two responses were given simultaneously, the coders used the response from the adult closest to the child. Given that the majority of time the parents were speaking, "parent" will be used in the paper to refer to all adults present. Then, the two coders coded all 187 of the parent responses for reliability of response type. Response types and definitions are in Table 5. Interobserver agreement was calculated with Cohen's kappa (Cohen, 1960). Despite being a conservative measure of reliability, the kappa reflected strong agreement ($\kappa = .90$). Discrepancies in judgments about response categories were noted when a response met criteria for two categories (e.g., "come here [child's name]"; "it's raining, hear it?"). This occurred three times.

Data Analysis Strategy

Based on visual inspection of plots of the data, it was clear the data were not normally distributed. Therefore, non-parametric analyses were warranted. Possible outliers were noted in a few of the distributions (e.g., canonical babbles and volubility). However, all cases were included in the analyses. Conceptually, this is warranted by the fact there is considerable variability in early development among TD infants, and at least in the case of children with ASD, even wider heterogeneity is reported. Analytically, it was important to retain all the participants to preserve power, given the small sample sizes. The groups were matched on maternal education because that factor is related to parent-child interactions (e.g., Hart & Risley, 1995). The specific analytic approaches will be described for each question in the results section. SPSS was used for all analyses except the conditional logistic regressions, which were performed with SAS 9.4. SALT software was used to generate the data on the adult language characteristics, to provide a description of the samples.

Results

Prior to examining the research questions posed for this study, we examined the data for group differences on the characteristics of the language transcripts in terms of total adult words, total adult utterances, and number of child-directed utterances (see Table 6 for means and standard deviations on each variable and results from Kruskal-Wallis test for group differences). The only variable for which there was a significant omnibus test was child-directed utterances, with the ASD group receiving more language directed to them.

Research Question 1

Are there differences in (a) volubility between groups of infants with different neurodevelopmental disorders, (b) number of adult words spoken between groups and (c) correlations between frequency of infant vocalizations and number of total adult words.

(a) A Kruskal-Wallis analysis, the non-parametric equivalent to a one-way ANOVA, revealed a nonsignificant difference in total infant volubility (p = .16) between FXS and ASD groups.

(b) A Kruskal-Wallis analysis revealed no significant group differences in total adult words spoken (p = .32).

(c) Spearman correlations were run between variables of interest. Then, a Fisher's r to z transformation was performed to convert within group Spearman correlations to Fisher's z statistics in order to test the significance of the difference between two correlation coefficients (Fisher, 1921). Spearman correlations are demonstrated to work as well as Pearson coefficients in the z transformation and are more robust with response to Type 1 error (Myers and Sirois, 2006). Total infant volubility was moderately and significantly correlated with total adult words for infants who were TD (r_s = .68 p = .02; n = 14); very weakly correlated for infants with FXS (r_s = .09 p = .80; n = 10), and moderately correlated for infants with ASD (r_s = .57 p = .09, n = 10). There were no differences between children with neurodevelopmental disorders compared to children who were TD (FXS vs. TD, z = .94, p = .35; ASD vs. TD, z = -0.78 p = .44)).

Research Question 2

Is the likelihood for whether there is a caregiver response or no response to non-canonical or canonical babbles similar for TD and neurodevelopmental disabilities?

The percent of parent responses for all babbles (canonical and non-canonical) was similar for all three groups (TD = 16%, FXS = 18%, ASD = 12%). There was a higher percentage of responses to canonical babbles for each group (TD = 26%, FXS = 39%, ASD = 19%) compared to responses to non-canonical babbles (TD = 19%, FXS = 23%, and ASD = 14%).

For non-canonical babbles there was a quasi-complete separation of data points (i.e., the TD and ASD groups always had at least one parent response whereas in the FXS group two participants did not have any parent responses), so a Frith's bias correction (Heinze & Schemper, 2002) was used. A logistic regression was run with a nested model (syllables nested within parent/child dyad). Total syllables for each participant was the exposure variable (i.e., a way to control for differences in the number of opportunities for parent response) and parent response, the dependent variable, was coded as a binary variable (response versus no response). Canonical babbles were 1.88 times more likely to receive a response compared to non-canonical sounds. There was no significant difference between either the ASD or FXS group compared to the TD group (see Table 7). Of note, it is common to see pairwise comparisons fail to indicate group differences, particularly with small samples and insufficient power.

Research Question 3

Does type of response parents give to non-canonical babbles predict group membership?

A logistic regression was used to answer this question. We collapsed categories to represent more linguistic responses (question, general, expansion, and directive) compared to non-linguistic responses (name call and imitation). This breakdown was determined after examining the data; the low frequencies of responses in several of the original categories required developing a rationale for merging some of them together.

Generalized linear mixed models were used to model the multivariate outcomes as a function of response type with a random effect for participant to account for the repeated measures (i.e., each participant had multiple outcomes). As demonstrated by previous literature, maternal education is one factor that may explain some of the variance in the type of responses used (Hoff, 2003), and thus was used as a covariate in the model. The exposure variable in the model, in order to account for different number of opportunities per parent-infant dyad, was total non-canonical babbles for each child (see Table 8 for response type descriptives). The type of response parents gave to non-canonical babbles did not predict group membership (F (2,127) = .02, p = .98).

Research Question 4

Does the type of response parents give to canonical babbles predict group membership?

Similar to question four, generalized linear mixed models were used to determine if type of response (linguistic versus non-linguistic) used to canonical babbles could predict group membership. It is important to note the small number of responses and multiple zeros within categories for different groups (see Table 9). The exposure variable in the model was total canonical babbles for each child. The type of response that parents gave to canonical babbles did not predict group membership (F (2,15) = .32, p = .73).

Discussion

Language competence is a major factor in communication, a skill domain needed for successful daily functioning. In the first few years of life, transactions between adults and child are important for facilitating language growth. The canonical babbling stage is a prime opportunity for parents to provide more advanced linguistic input to their infants. In the typically developing population, it is suggested that parents intuitively begin providing more complex language when infants use canonical babbles (Papoušek, 1999). The purpose of this study was to examine the types of responses parents of infants with neurodevelopmental disabilities use to respond to non-canonical and canonical babbles, and whether the responses of these parents and parents of typically developing infants are predictive of group membership. Research focusing on the transactional interplay between infants and parents early in life is important because knowing which infant behaviors elicit varied adult responses, and which adult responses support the child's development in multiple domains, could inform early intervention practices.

The first step of this study was to examine the infant and adult level characteristics independently. The purpose of this step was to determine whether there were any significant group differences in the adult and child language used in the sample. There were no significant differences in the infant's total volubility nor total adult words across the groups. The second step was to examine correlations between child level factors and adult level factors. Total infant volubility was moderately positively correlated with total adult words for the TD and ASD groups, but very weakly correlated for the FXS group. The findings for the TD group are similar to previous research suggesting frequency of infant vocalizations is associated with number of adult responses or adult words (Gilkerson & Richards, 2009; Goldstein et al., 2003; Gros-Louis et al., 2006). The weak correlations for the FXS group are largely due to the reduced infant volubility, with more limited variability in the FXS group compared to other groups.

The third step was to investigate the likelihood parents would respond to canonical babbles compared to non-canonical babbles. Canonical babbles elicited more responses compared to non-canonical babbles in all three groups, with no significant differences between groups. The final step was to explore whether the type of responses used by adults predicted group membership for the infants, in order to see if parents of infants with neurodevelopmental disabilities are responding with less linguistic complexity compared to the parents of infants with TD. Type of response did not predict group membership for non-canonical or canonical sounds, suggesting infant sounds are eliciting a similar quality of response from parents whether the infants are developing typically or have FXS or ASD.

Limitations

Retrospective video analysis has multiple drawbacks including lack of experimental control and potentially poor video and audio quality. Audio quality likely affected this study, particularly with the words spoken by adults. In multiple scenes, more than one adult was present and often talking simultaneously. In our study we had between group differences in total events. This difference should not affect the babbling patterns since the video editors were blind to study hypotheses and did not specifically select video segments to capture adult or child vocal behavior, and parents were unaware at the time they recorded the videos that they would eventually be used as part of a research study on infant vocalizations.

It is important to point out that due to small sample sizes, we would have been only able to detect large effect sizes. Thus, typical for initial studies with populations that are difficult to recruit, this study was not powered to detect small to moderate effect sizes.

Although all videos were standardized to 10 minutes, another limitation was the short length. Longer videos would allow greater opportunities for infant vocalizations and parent responses. Given the constraints on our data, we were limited in statistical analyses and in the chance to observe the target behavior, canonical babbles, in groups with documented delays in this area of language development (Patten et al., 2014; Belardi et al., in preparation). A much larger sample of children and audio recordings and longer observations may allow researchers to examine whether there are types of samples more representative of diagnostic groups with multi-level modeling. Also, the video footage was not selected based on adult-child interaction being present. Examining interactions designed to elicit child vocalizations may be a better method for sampling this type of behavior, but requires access to an adequate pool of infants who have already been identified in infancy as having a neurodevelopmental disorder or who are at high risk for being diagnosed with a neurodevelopmental disorder.

Future directions

Transactions between parents and their children are affected by a number of variables such as maternal education and child developmental level (Bornstein, 1995; Shapiro, Blacher, & Lopez, 1998), yet there is a paucity of information about how child level factors affect transactions in neurodevelopmental disorders. Characteristics of ASD (e.g., diminished responsiveness, poor eye contact, and lack of initiation) and FXS (e.g., social anxiety and atypical eye gaze) and their delay of babbling may affect the dyad negatively. These types of factors should be considered when observing communication interactions. Additionally, measuring child engagement is a factor typically missing from parent-child interaction literature. This type of information is important for considering whether a child is in tune with his or her environment. Some theories suggest an underlying issue related to limited social motivation among infants and young children with ASD (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2007), i.e., that individuals with ASD are less interested in social interactions and over time may have fewer opportunities to learn from these interactions. Therefore, early patterns of engagement may impact the types of parent responses used.

Research studies on potentially efficacious treatments for increasing canonical babbles (Woynaroski, Yoder, Fey, & Warren, 2014) should be replicated with infants and toddlers with varied neurodevelopmental disabilities. The results of Woynaroski et al. suggested that children exposed to a higher dose of intervention (delivered by research staff) involving linguistic mapping of children's vocalizations increased their use of canonical babbles, which in turn increased parental use of linguistic mapping in responding to their children. This type of treatment may be specifically valuable for young children with ASD, given that the nonsignificant trend in the current study for canonical babbles of infants with ASD to elicit fewer adult responses than the other groups (i.e., TD = 26%, FXS = 39%, ASD = 19%), along with previous evidence that the vocalizations of children with ASD are less likely than those of TD peers to elicit responses from (Warlamount et al., 2014).

In conclusion, the present study suggests adults, regardless of their infants' diagnostic group, intuitively respond to canonical babbles more often than non-canonical sounds. Finer-grained analyses of variations in the types and complexity of parental responses to the babbles of infants with neurodevelopmental disabilities will require larger samples of infants and longer samples of infant vocalizations. Also, it may also be beneficial to study responses to canonical babbles at a later age range for groups with neurodevelopmental disorders since they are delayed compared to TD peers. Despite no between group differences, understanding the role of the environment in promoting language development in the first two years of life is important for informing early intervention, specifically parent-mediated treatments.

Table 1. Participant demographics

Characteristic	FXS Mean (SD)	ASD Mean (SD)	TD Mean (SD)
Mean chronological age in infant videos (months)	11.18 (1.22)	10.49 (.60)	10.63 (.53)
Cognitive standard score at recruitment[6]	52.40 (3.87)	47.39 (15.06)	101.38 (7.25)
Maternal Education[7]	5.44 (1.13)	5.30 (.95)	5.83 (.72)
VABS Composite Standard Score at recruitment	61.44 (10.11)	70.11 (26.27)	102.77 (13.85)
CARS at recruitment[8]	24.16 (3.12)	30.70 (6.68)	16.2 (1.21)
Onset of walking	15.75 (2.84)	14.75 (3.49)	11.89 (1.57)
FMRP Level[9]	6.94 (6.97)	NA	NA
Infant Volubility	29.70 (13.88)	44.64 (13.97)	43.60 (34.21)
Number of infants with at least one canonical babble	6/10	5/10	12/14

[6] Missing 2; 0=Average/Above Average Intelligence (standard scores above 85); 1=Borderline (70–84); 2 = Mild ID (55–69); 3=Moderate ID (40–54); 4=Severe/Profound ID (<39).

[7] Maternal Education: 1 = 6th grade or lower; 2 = 7th to 9th grade; 3 = partial high school; 4 = high school graduate/GED; 5 = associate of arts/associate of science or technical training or partial college training; 6 = bachelor of arts/science; 7 = master of arts/science or doctorate or other professional degree completed

[8] Missing 4 FXS; 7 TD; 1ASD

[9] Missing 2

Table 2. Content variables for videos

Type	FXS Mean (SD)	ASD Mean (SD)	TD Mean (SD)
Number of people present	3.04 (1.30)	3.01 (1.47)	3.28 (1.24)
Amount of physical restriction	1.77 (.62)	1.95 (.38)	1.51 (.32)
Amount of social intrusion	2.03 (.42)	1.59 (.34)	2.04 (.37)
Total number of different events	4.17 (.82)	5.38 (.81)	5.07 (1.02)

Table 3. Video content post-hoc comparisons

Video Edit	FXS vs. ASD	ASD vs. TD	FXS vs. TD
Total events	F = 25.11, df = 1, *p* < .01	F = 1.3, df = 1, *p* = .26	F = 12.23, df = 1, *p* < .01
Mean age per second	F = 5.50, df = 1, *p* = .02*	F = .71, df = 1, *p* = .40	F = 4.68, df = 1, *p* = .04*

Table 4. Percentage of each activity type

Type	FXS; n = 10	ASD; n = 10	TD; n = 14
Mealtime	10	11	12
Active play	62	46	54
Special event	17	27	8
Bathtime	5	3	12
Passive activity	4	10	6
Other	2	3	1

Table 5. Parent responses

Type of response	Definition
imitation	adult imitates the infant's vocalization
expansion	adult expands the linguistic content the infant produces (e.g., infant says /ba/ and adult says "ball, you want the big ball?")
general	adult says something to confirm they heard the child (e.g., yes, yeah, oh, laughing)
question	adult asks a question (e.g. what are you doing?)
directive	adult suggests the infant do something (e.g., smile for mommy)
name call	adult says child's name or nickname (e.g., Cody, sweetheart)

Table 6 Characteristics of language transcripts

Characteristic	FXS (n=10) Mean (SD)	TD (n=14) Mean (SD)	ASD (n=10) Mean (SD)	Kruskal-Wallis Test
Total adult words	494.80 (177.05)	452.21 (232.26)	546.00 (122.68)	χ^2 = 2.29, df = 2, p = .32
Total adult utterances	122.10 (34.88)	107.00 (41.88)	131.90 (32.90)	χ^2 = 2.73, df = 2, p = .26
Child directed utterances	46.55 (22.49)	41.25 (22.24)	76.70 (27.22)	χ^2 = 10.15, df = 2, p = < .01

Table 7. Omnibus conditional logistic regression analysis of parent response to canonical versus non-canonical babbles

Independent Variable	SE	Z	*p*	β
omnibus	.18	12.79	<.01**	1.88
FXS vs. TD	1.82	.20	.66	
ASD vs. TD	2.44	.23	.63	
maternal education	.66	.21	.64	

Table 8. [Number of different respondents] Frequency (Percentage) of types of response to non-canonical babbles by group

Type of response	TD (n = 14)	FXS (n = 10)	ASD (n = 10)
Imitation	[6] 11 (9%)	[1] 3 (4%)	[3] 11 (18%)
Expansion	[1] 2 (2%)	[0] 0 (0)	[3] 5 (8%)
General	[12] 63 (53%)	[6] 25 (37%)	[9] 29 (47%)
Directive	[9] 20 (17%)	[7] 19 (28%)	[5] 10 (16%)
Question	[9] 15 (13%)	[4] 14 (21%)	[4] 6 (10%)
Name call	[4] 7 (6%)	[6] 7 (11%)	[1] 1 (2%)

Table 9. [Number of different respondents] Frequency (Percentage) of types of response to canonical babbles by group

Type of response	TD (n = 14)	FXS (n = 10)	ASD (n = 10)
Imitation	[0] 0 (0)	[1] 1 (10%)	[2] 3 (23%)
Expansion	[0] 0 (0)	[0] 0 (0)	[1] 3 (23%)
General	[11] 23 (72%)	[3] 7 (70%)	[3] 6 (46%)
Directive	[4] 4 (13%)	[1] 1 (10%)	[0] 0 (0)
Question	[1] 1 (3%)	[1] 1 (10%)	[2] 2 (15%)
Name call	[3] 3 (9%)	[0] 0 (0)	[0] 0 (0)

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CHAPTER 4: CONCLUSION

Language skills are required for daily functioning. Improving the language skills in individuals with disabilities is a priority in clinical practice. However, before intervening it is necessary to determine the differences in language behaviors in populations with disabilities compared to the typically developing population, and gain a better understanding of various factors that impact language outcomes, including genetic factors (nature), environmental factors (nurture), and the joint influences between the two. It is important to study these factors in the first few years of life when the groundwork for learning language is established for two reasons. First, if the groundwork for language is not established appropriately, later learning will be affected. Second, early differences will guide early intervention targets to help guide the language learning process. The purpose of this dissertation was to examine two factors associated with later language skills. First, we examined a subfactor of nature, canonical babbling, in a novel population, FXS. Second, we examined the potential impact of canonical babbling by the infants with FXS, ASD or TD on the environment (i.e., as measured by parent response types). Both factors were studied at 9 – 12 months with retrospective video analysis methodology. The information from these studies is important for building clinician's awareness of the early differences in the language development process, informing the argument for earlier identification, and identifying potential areas of intervention.

Canonical babbling is a universal stage of language evolution. This milestone is typically reached in the first year of life, although previous research suggests individuals with language disorders have delays (Patten et al., 2015; Paul et al., 2011). There is accumulating evidence suggesting the emergence of the canonical babbling stage combined with the total volume of sounds a child produces has the potential to reliably differentiate infants with ASD from those with typical development at 9 – 12 months (Patten et al., 2014). The possibility of detecting a behavioral biomarker in the first year of life is especially important given some neurodevelopmental disorders, such as FXS and ASD, are not diagnosed until age three or later (Bailey et al., 2009). Considering the transactional model of development, infant and caregiver behaviors mutually affect one another. In terms of early vocalization development, delayed development of child babbling is thought to impact the environment. Despite the limited information on how child behaviors affect parent behaviors, Papoušek (1994) argues parents intuitively respond more frequently and with more complex language to the child when they begin using canonical babbles. Thus, determining whether parents of infants with neurodevelopmental disorders who are delayed in canonical babbling respond as often and with different linguistic forms is important information for early identification and intervention.

Study summaries

The purpose of the first study was to examine the canonical babbling patterns in infants with FXS. Results indicated 9 – 12 month old infants with FXS were delayed in the canonical babbling stage. Zero of the ten infants with FXS met the canonical babbling criterion compared to about 60% of the TD infants who did. Infants with FXS also used a smaller number of syllables (i.e., lower volubility) compared to typically developing peers. Both the infant's status, with respect to the canonical babbling stage (i.e., whether the infant met criteria for being in this stage or not), and the infant's total volubility were statistically significant predictors of group membership. This information may have important clinical implications given the importance of early identification and intervention. Study 1 also suggested a lack of association for two motor-related skills, walking and canonical babbling, among infants with FXS whereas the association was strong, significant and negative for the TD group. That is, earlier walking was related to more canonical babbles. This finding suggests other factors above and beyond motor skills, such as cognition or sociability, may play a role in early language development in infants with neurodevelopmental disorders.

The aim of the second study was to determine whether parents of infants with neurodevelopmental disorders respond to canonical and non-canonical babbles with similar linguistic forms as parents of infants with TD. The rationale for this study was to examine how child behaviors affect parent behaviors, an understudied part of communication transactions. Results indicated canonical babbles were more likely to receive a parent response compared to non-canonical babbles. However, the lack of group differences in responses to canonical babbles may be related to fewer instances of canonical babbles than non-canonical babbles across all groups, especially the neurodevelopmental disorders with documented delays in canonical babbling.

Patterns across studies

Infants with neurodevelopmental disorders have delayed canonical babbling and reduced volume of speech productions. This delay is concerning for two reasons: (1) canonical babbles are associated with later language skills and (2) they are more likely to receive a parent response compared to non-canonical babbles. Therefore, a delay in canonical babbling may result in fewer parent responses and reduced language input. Conceptually, the canonical babbling factor is impaired by the child's biology, and the delay in emergence of babbling negatively affects the environment and the transactions. The findings of these two studies in supporting the applicability of this conceptual framework to infants with FXS and ASD are significant, especially given this foundational time of language development. One of the major reasons for conducting studies of the early behaviors is to yield information about early identification and intervention with the long-term goals of improving the language skills in children with disabilities. Together, these studies reinforce the importance of studying differences in language development during the first year of life in terms of the potential transactions between biological and environmental factors.

Future directions

The results from both studies contribute meaningful information about the similarities and differences in early language development in infants with neurodevelopmental disorders compared to infants with typical development. It is critical for future studies to use longer and larger samples for four reasons: (1) to replicate the utility of canonical babbling and volubility as reliable behavioral biomarkers of neurodevelopmental disabilities around 12 months of age (2) to understand the variability in these early language skills and (3) to have more opportunities for parent responses and canonical babbles and (4) to increase the statistical power in order to detect smaller, yet meaningful differences. Additionally, a more fine-tuned approach to studying the role of motor and cognitive abilities in language development is warranted in order to understand the potential influence of other systems. Finally, studying the effectiveness of interventions designed to increase canonical babbling among infants with ASD or FXS would be a logical next step in research, given the reduced canonical babbling in these populations. Promoting more canonical babbles may in turn promote more parent responses and opportunities for children to learn language.

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