

INFANT-ADULT VOCAL INTERACTION AND IMPLICATIONS
ON EARLY LANGUAGE DEVELOPMENT

by

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The process of infant language acquisition is well documented. The vocalizations produced by infants develop from simple “cooing” in the first weeks, to recognizable words by the end of the first year. While they produce many of these earlier vocalizations endogenously, rapid phonological development is facilitated by their social interaction with adult caregivers. When infants vocalize, adults are inclined to respond with infant-directed speech. Adult responses appear to be dependent upon characteristics of infant vocalizations like directedness and complexity. Subsequently, infant vocalizations appear to be dependent on the quality and quantity of feedback from their caregivers. Together, these processes form a social feedback loop between infant and adult that supports early language acquisition.

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Chapter 1: Introduction

A large body of research exists on infant vocalizations, early language development, and dyadic interaction with a caregiver. In more recent years, the reciprocal relationship between infants and adults has been examined as it pertains to early vocal development. The exact nature of this relationship remains undetermined. In this thesis, I will review the existing literature to construct clearer picture of the role of the infant-caregiver dyad as it pertains to early language development. I will conduct a wide literature search of empirical papers and books. From this collection, I will extract the publications that are most informative for my project and perform a close reading of each. Then, I will establish connections between the concepts and findings across my evidence base. By the end of this project, I will answer my research questions with a narrative depiction of the current field knowledge.

To best understand the interaction between infant vocalizations and adult behavior, I will attempt to answer three main questions. First, I will investigate how infant vocalizations affect adult behavior. It is necessary to determine what information adults can discern from infant vocalizations such as the nature of the precipitating stimulus, urgency, identity of the infant, and complexity of the utterance. Each of these pieces could influence how an adult will respond to an infant. For example, adults use simpler and fewer words when providing a contingent response to an infant (Elmlinger et al., 2019). It is important to understand this process before addressing the higher order processes because adult caregivers provide an accessible source of information for infants through their behavior. In this thesis, I will discuss the types and functions of infant vocalizations, the attributes that adults can attend to, and how this input influences adult behavior.

Once the effects that infant vocalizations have on adult behaviors have been established, I will then examine how adult behaviors influence infant vocalizations. At this point in the infant-adult vocal interaction, infants now have the opportunity to extract statistical information from their caregiver's responses. As adults consistently respond to infant vocalizations, infants are able to use that information to produce more vocalizations, increasing in both total number and complexity. Over time, infants produce a greater number of complex vocalizations when they received contingent responses to earlier vocalizations (Gros-Louis et al., 2014). This vocal transaction occurs on repeat as infants rapidly acquire phonological abilities.

Finally, I will address the implications of this feedback loop on early language development. As infants begin to produce more speech-related vocalizations, adults begin to provide more syntactically complex responses, which in turn increases the likelihood of an infant producing a speech-like vocalization (Warlaumont et al., 2014). This creates a feedback loop which provides infants with increasing auditory material to learn from, allowing them to continue developing their vocalization abilities. Furthermore, adult responses that are contingent on infant vocalizations promote infant attention, which then offers more opportunity to learn from adult speech (Masek et al., 2021). Further studies are required in order to determine a causal relationship between the infant-adult feedback loop and early language development, although there is strong correlational evidence on several levels that will be addressed later in this thesis.

Chapter 2: Infant Vocalization

Infant vocalizations, also referred to as *protophones*, appear shortly after birth and continue to develop throughout infancy (Oller, 2000). By two months of age, infants have typically mastered the phonation stage of vocal development, producing comfort sounds like cooing. These phonations are often described as *quasivowels*, as they sound similar to vowel sounds but lack the level of maturity required of a true vowel sound. Between two and three months of age, infants achieve the primitive articulation stage. They begin producing slightly more advanced protophones like “gooing”. At around four months, infants enter the expansion stage. Infants begin to produce marginal babbles at this point, including squeals, growls, raspberries, and marginal syllables. Marginal syllables are characterized by a slow transition between consonant and vowel, often with distortion of the vowel sound. When read aloud, these vocalizations may sound like “ooo” and “uh”. By seven months, many infants are able to produce more advanced protophones known as canonical babbles. At this stage, infants are capable of canonical syllables, with a faster transition between consonant and vowel with a fully-formed vowel sound (Oller, 2000). For example, a canonical babble may sound like “bababa”, or “dah”.

Due to the similarities between marginal and canonical syllables and early words, caregivers sometimes attribute semantic meaning to protophones where none exists (Oller, 2000). Infants typically begin to understand semantic information and produce their first single word vocalizations between ten and thirteen months (Bates et al., 1987). Many infants produce the word “no” most often during this stage. At this stage, infants still produce many non-word vocalizations intermittently with a growing repertoire of proper words. Speech develops rapidly

from this point throughout the next several years as infants make bounds in receptive and semantic communicative abilities.

Endogenous and Social Vocalizations

From birth to approximately ten months, infant vocalizations typically do not carry semantic value (Bates et al., 1987). Infants produce a wide variety of sounds along the trajectory of early vocal development with varying levels of social and endogenous origin. Among these are vegetative sounds, which encompass reflexive productions such as burps and sneezes (Oller, 2000; Stark, 1980). These vegetative sounds may carry some value for a caregiver in terms of evaluating an infant's wellbeing, although they should not be conflated with vocalization; social or endogenous. Vocalizations known as *fixed vocal signals* exist in between vegetative sounds and protophones in terms of communication (Oller, 2000). Productions such as crying and laughing are considered fixed vocal signals. While these signals are not evidence of intentional social communication, they can still be recognized by a caregiver. Fixed vocal signals differ from endogenous vocalizations in that they are often unintentional or elicited by an external stimulus.

As infants enter the second and third stages of vocal development and begin to produce marginal syllables, these early non-cry vocalizations are often instances of endogenous vocalizations known as *vocal play* (Oller, 2000; Stark, 1980), wherein infants explore the range of their vocal abilities independently. Most early protophone production can be characterized as vocal play (Oller, 2000). Through vocal play, infants strengthen their non-semantic vocalization skills as they approach the subsequent stages of vocal development (Stark, 1980).

Endogenous vocalizations may also be celebratory or complaintive, but are not directed towards nor prompted by a caregiver. Long et al. (2020) found that the majority of vocalizations

by infants ages three to ten months were endogenous, even during periods of caregiver interaction. The proportion of social vocalizations to endogenous was significantly higher during trials when caregivers interacted with infants compared to trials when they did not. Social vocalizations were determined using infant gaze and other contextual information. The proportion of social vocalizations to endogenous was not significantly different between age groups. The increase in social vocalizations during engaged periods may serve as a scaffold in the development of communicative phoneme production as infants begin to produce more and more advanced vocalizations (Oller, 2000; Stark, 1980). The increase in speech-related vocalization over the first ten months may be facilitated by higher rates of social feedback that infants receive as they increase rates of canonical babbling (Albert et al., 2018; Gros-Louis et al., 2014).

Adult Perception of Infant Vocalizations

Adult listeners can extract several pieces of useful information from infant vocalizations despite the absence of semantic information (Beyak et al., 2022; Bouchet et al., 2020; Lindová et al., 2015; Oller et al., 2001). For example, adult listeners were able to identify their “own” baby by recorded cries independently of parenthood or gender (Bouchet et al., 2020). In this study, mothers and other adult listeners were familiarized with cries of either their own infant in the days following birth or recorded cries of an assigned infant. In a recognition test, there was no significant difference in the success rates between mothers and other adults when identifying the recorded cries of the target infant. Exposure to the target infant’s cries was the strongest predictor of successful identification, indicating that infant cry recognition is influenced by time spent with an infant more so than motherhood alone.

With little or no training, adults can understand enough from an infant's vocalization to provide proper care, identify urgent needs, and respond with a developmentally appropriate level of verbal complexity. The ability to extrapolate situational information from an infant vocalization is a highly advantageous aspect of infant-adult communication. If an adult listener can tell that an infant is vocalizing due to a potentially unsafe stimulus they may respond with more urgency. Lindová et al. (2015) found that adults with no training perceived infant vocalizations elicited by a negative stimulus such as pain as more urgent than those elicited by positive situations such as play. The adult listeners in this study were largely successful at differentiating between vocalizations prompted by positive and negative stimuli and at accurately determining the urgency of a vocalization. This may confer an evolutionary advantage if an infants' vocalization is elicited by a negative stimulus. It may be more urgent or even life-threatening and therefore more imperative to recognize and respond quickly compared to a positive stimulus. Adult listeners were less successful at identifying the specific stimulus (Lindová et al., 2015), although in a naturalistic setting they would likely be able to use other contextual clues to elucidate the situation (Beyak et al., 2022).

Over time, caregivers' ability to identify infant vocalizations becomes increasingly more functional beyond deciphering basic wellness cues. Caregivers appear to intuitively differentiate early protophones from cries (Yoo et al., 2018). This study found that adults responded differently to infants depending on the type of vocalization they produced. In addition to crying, infants ages zero to three months primarily produce quasivowels (Oller, 2000). Yoo et al. (2018) found that adults interrupted these early protophones significantly less compared to cries. The adults in this study responded to infant vocalizations in a turn-taking pattern, typically responding within one second after the offset of an infant vocalization. As protophones are still

very far from adult-like speech, this turn-taking structure may serve as more of a conversational framework than an opportunity for vocal development. By engaging in turn-taking in response to protophones, infants may be able to familiarize with the structure of dyadic vocal interaction, allowing them to develop their vocal abilities in a clearer framework. As evident by the differential response pattern between cries and protophones, adults are able to identify each as unique vocalizations.

Caregivers' ability to provide developmentally useful contingent feedback is dependent on their ability to recognize developmental stage. As infants progress from early protophones to canonical babbling, caregivers are able to identify those more advanced productions (Oller et al., 2001). Parents in this study were able to identify their infants' canonical babbles with upwards of 90% accuracy compared to laboratory evaluation. Caregivers also respond with more imitative speech to canonical babbles and more narrative speech to non-canonical babbles (Albert et al., 2018), indicating that they can distinguish between the two. As infants progress, their developmental stage becomes more apparent.

Chapter 3: Infant Vocalizations Influence Adult Responses

An extensive body of empirical evidence documents the first instance of exchange in the infant-adult social feedback loop; the effects of infant vocal behavior on adult behavior.

Intentional or not, infants exercise significant influence on adults through their vocal behavior.

When infants vocalize, adults tend to respond in a manner that is advantageous to early language acquisition known as infant-directed speech (Albert et al., 2023; Elmlinger et al., 2019; Pretzer et al., 2019). Several characteristics of infant vocalizations can impose nuanced effects on adult responses, such as “speechiness”, among others. Over time, infants develop a more active role in vocal exchange, shifting from incidental influence to intentional bids for adult speech input (Elmlinger et al., 2023; Goldstein et al., 2009).

Infant-Directed Speech

Infant-directed speech (IDS) is characterized by its higher pitch (Fernald, 1991; Fernald & Mazzie, 1991; Pretzer et al., 2019; Trainor et al., 2000), drawn out vowel sounds (Kuhl et al., 1997), and slower pace compared to adult directed speech (ADS). These characteristics remain stable across infancy (Kalashnikova & Burnham, 2018). The contour of IDS provides a more accessible stream of speech to novice listeners which may facilitate early language acquisition (Thiessen et al., 2005). Compared to ADS, word segmentation in IDS is more distinct. IDS is also simpler compared to ADS, with most instances of contingent IDS containing significantly fewer unique words and shorter words (Elmlinger et al., 2019; Newport et al., 1977). When adults caregivers respond contingently to infant vocalizations, the mean length of utterances in words (MLUw) is shorter compared to non-contingent adult speech, indicating that caregivers simplify their speech when directing their speech towards infants (Elmlinger et al., 2019).

Overall, adult speech input to infants is less cluttered and includes fewer novel pieces of information, which is likely beneficial for early language acquisition.

When producing IDS, adults are more likely to place additional prosodic emphasis on novel words (Fernald & Mazzie, 1991). The prosodic elements, simplified language, and slow rate of IDS may be advantageous for early word learning, even as infants begin to lose preference for IDS over time (Singh et al., 2009; Song et al., 2010). Among the benefits to early language acquisition is the accessibility of word boundary information. Using fewer novel words with more prosodic emphasis can make the beginning and end of a word clearer to a novice listener. Infants are then able to segment language by identifying word boundaries, leading to exponential language learning. Infant directed speech may also communicate situational information, such as emotion, to infants who do not yet understand semantic input from speech (Trainor et al., 2000).

Infant Vocalizations Prompt Infant-Directed Speech

Adult caregivers' responses to infant vocalizations are influenced by a number of factors, including directedness, complexity, and type (Albert et al., 2018; Gros-Louis et al., 2014; Pretzer et al., 2019; Warlaumont et al., 2014; Yoo et al., 2018). In general, infant vocalizations are likely to be followed immediately by IDS, indicating that infant vocalizations prompt adults to engage in IDS (Albert et al., 2023; Elmlinger et al., 2019; Pretzer et al., 2019). Conversely, other-directed speech (ODS), which is any adult utterance not directed to an infant, is negatively associated with infant vocalization. Considering evidence that infants learn to “bid” for adult responses (Albert et al., 2018; Goldstein et al., 2009), this may indicate that adults stop producing ODS when they hear infant vocalizations.

The likelihood of a caregiver response to infant vocalizations is affected by the directedness of the vocalization (Albert et al., 2018; Gros-Louis et al., 2014). Caregivers are more likely to respond to object-directed (Albert et al., 2018) and mother-directed (Gros-Louis et al., 2014) infant vocalizations than undirected vocalizations. Mother-directed vocalizations (MDV) tend to be the least common produced by infants in the first few months, yet their caregivers provide sensitive responses to a significantly higher proportion of these vocalizations compared to all other vocalizations. This indicates that directedness of infant vocalizations has a significant relationship with caregiver response frequency.

Directedness also influences the type of sensitive response (Albert et al., 2018). Caregivers are more likely to provide narrative responses to undirected vocalizations compared to object-directed vocalizations. This could be influenced by the naming opportunity presented to a caregiver when an infant is engaged with an object. Rather than provide broader responses such as behavior descriptions or praise, a caregiver is able to name the object that the infant is attending to.

The likelihood of a sensitive adult response is also influenced by infraphonological complexity (Albert et al., 2018; Chen et al., 2023; Gros-Louis et al., 2014; Pretzer et al., 2019; Warlaumont et al., 2014). When infants produced canonical vocalizations, mothers are more likely to imitate the infant, compared to marginal syllables, which elicited more narrative responses (Albert et al., 2018; Gros-Louis et al., 2014). Mothers and fathers respond to infant vocalizations at similar rates (Chen et al., 2023), although the semantic complexity of IDS may be moderated by infants' communicative abilities (Quigley & Nixon, 2020) and the genders of both infant and adult (Chen et al., 2023; Lovas, 2011). This indicates that syllabic maturity of vocalizations influences the type and frequency of verbal feedback that caregivers provide. In

infants 12 to 13 months, reflexive vocalizations are the most likely to elicit IDS, followed by canonical babbles (Pretzer et al., 2019). Reflexive vocalizations were defined as laughs and cries in this study. Canonical babbles were significantly more likely to be followed by IDS compared to non-canonical. In this study, overlapping vocalizations were coded as sensitive responses if the infant vocalization had an earlier onset. It is possible that a caregiver's response to reflexive vocalizations may also be reflexive in nature.

Caregivers follow different response time patterns depending on vocalization type as early as three months (Yoo et al., 2018). Adults are significantly more likely to interrupt cries compared to protophones. Rather than interrupting, caregivers engage with protophones in a turn-taking pattern. These findings suggest that although caregivers may produce utterances most often after the onset of a reflexive vocalization, they may be largely limited to soothing rather than communicative.

Warlaumont et al. (2014) found that more complex infant vocalizations were correlated most strongly with contingent adult responses. When infant vocalizations were more speech-like, adults were more likely to respond with more mature speech. The methodological approach in this study excluded overlapping utterances, unlike the study conducted by Pretzer et al. (2019). They found that speech-related infant vocalizations were the most likely to receive contingent, speech-like feedback from adults. Infants who produced more vocalizations then received more contingent feedback from adults overall. These findings support that infant vocalization complexity influences the frequency and type of caregiver response.

Despite adults' propensity to respond to more advanced vocalizations, they still respond at significant rates to the earliest protophones (Anderson et al., 1977; Chen et al., 2023). This evidence could be influenced by the high proportion of noncanonical vocalizations during the

first year of life (Oller, 2000). Nonetheless, it is important to acknowledge that adults seem to be hard-wired to engage in vocal exchange with infants, regardless of the communicative value of their vocalizations. This intuitive urge to respond provides infants with a framework in which they acquire statistical information about adult response patterns and develop an active role in vocal exchange.

Infants Understand the Social Efficacy of Vocalization

Infants' understanding of their vocal influence on their social environment develops over time (Elmlinger et al., 2023). At two months of age, infants do not demonstrate an extinction burst in response to still face, indicating that they have not yet achieved this developmental milestone. At two months, infants typically begin to produce protophones known as quasivowels (Oller, 2000), which are usually undirected, reflexive noncry vocalizations with no semantic value. It is unlikely that infants have become aware of the communicative nature of noncry vocalization at this point in development as they do not exhibit an extinction burst when adult contingent responses cease (Elmlinger et al., 2023).

As early as five months old, infants demonstrate an understanding that their vocal behavior influences the social responses from adult caregivers (Elmlinger et al., 2023; Goldstein et al., 2009). In each of these studies, five-month-old infants exhibited a *vocal extinction burst* while undergoing a still-face paradigm testing period. This extinction burst is often observed when a typically occurring contingent response to an infant's vocal behavior is not provided by an adult caregiver (Goldstein et al., 2009). Evidence of the vocal extinction burst at five months indicates that infants have begun to expect a contingent response to their vocalizations. This established phenomenon marks the early stages of the social feedback loop between infant and adult as infants begin to conceive of the social efficacy of their own vocalizations.

Infants also begin to change their turn-taking behavior around five months of age (Hilbrink et al., 2015). While a turn-taking pattern between infant and caregiver can be observed earlier than five months (Anderson et al., 1977; Bateson, 1975; Bloom et al., 1987), this pattern continues to develop over time as infants gain understanding of the exchange characteristics of vocalization. By five months, infants begin increasing the length of their pauses before onset of vocalization following an adult's vocalization and decreasing overlap (Hilbrink et al., 2015). Infants continue to slow their responses until nine months, possibly because they are learning how to engage in verbal exchange during this period.

At nine months of age, infants continue to demonstrate that they are aware of the perlocutionary effects of their own vocalizations. Infant vocal learning explodes around this period of development, largely due to the increase in infant-caregiver vocal interaction which provides more learning opportunities (Goldstein & Schwade, 2008). This area of inquiry has significant implications in terms of an infant-adult social feedback loop in establishing an infant's active role.

Chapter 4: Adult Behavior Influences Infant Vocalization

Infant-directed speech provides a plethora of learning opportunities for infants. Infants' acquisition of language can be influenced significantly depending on several characteristics of the speech input provided by caregivers, among other behaviors. At this point in the social feedback loop, infants can extract semantic and pragmatic information from their caregivers' utterances, allowing them to rapidly develop their own vocalizations (Masek et al., 2021). This is evident as infants produce more advanced vocalizations while receiving scaffolded verbal input from adults (Warlaumont et al., 2014). Infants also increase their engagement in turn-taking behaviors when they receive more contingent responses over time (Bloom et al., 1987; Long et al., 2022).

Proximity

Physical proximity between infant and caregiver has significant implications for vocal development. Proximity tends to be bursty over the course of the day, yet still rich with vocal interaction (Suarez-Rivera et al., 2023). Although infants tend to vocalize more when their caregiver is not in proximity, they produce more complex vocalizations when in proximity. Caregivers also produce more lexically complex utterances when in proximity with their infant (Suarez-Rivera et al., 2023). This bursty pattern of proximity combined with more complex speech implies that speech input from caregivers may also be bursty, which predicts vocabulary size in toddlerhood (Cychosz et al., 2024).

During bouts of proximity, mothers' infant-directed vocalizations are almost always accompanied by looking at the infant while infants' visual attention on their mothers was not dependent on proximity (Anderson et al., 1977; Bateson, 1975).

Contingency

One of the most salient factors in infant-adult vocal interaction is contingency in adult responses, also referred to as sensitivity or relevance. Adults' contingent responses to infant vocalizations increase the likelihood of subsequent vocalizing (Elmlinger et al., 2023; Goldstein & Schwade, 2008; Lopez et al., 2020; Tamis-LeMonda et al., 2001; Warlaumont et al., 2014). Infants vocalize more when they receive either contingent or noncontingent feedback, but the pattern of their vocalization differs (Bloom et al., 1987). When adults provided contingent responses, infants vocalized in a turn-taking pattern, pausing more often between vocalizations, compared to noncontingent responses. Infants also produce more speech-like vocalizations during bouts of contingent turn-taking despite vocalizing more often during independent play (Long et al., 2022).

Contingent responses to infants predict infants' imitation of adult vocalizations (Pelaez et al., 2018). Infants vocalized more often when adults imitated their vocalizations compared to a yoked control condition. When adults provided noncontingent vocal stimuli, infants vocalized near baseline and seldom imitated adult utterances. In this study, infants heard the same number of total responses from adults, confirming that infants' vocal behavior is influenced specifically by contingent responses.

The timing and content of contingent responses to infants may affect their language learning differentially based on parental gender (Chen et al., 2023). In this study, mother-infant and father-infant play-based interactions were observed during four home visits from nine months to 30 months. They found significant differences in the language acquisition effects of verbal responses between fathers and mothers during "serve and return" interactions. When fathers provided temporally contingent responses, infants' receptive skills increased. When

infants received semantically relevant responses from mothers, but not fathers, they demonstrated greater expressive abilities. Fathers' semantically relevant responses were negatively associated with expressive language skills, except when mothers also provided relevant responses. Chen et al. (2023) reported some specific instances when fathers' semantically relevant responses included more words compared to mothers' or were more complex overall. Although there was not a significant difference in MLU between mothers and fathers, fathers did produce slightly more complicated responses.

Type of Response

Maternal responsiveness between nine and thirteen months is related to acquisition of vocabulary (Tamis-LeMonda et al., 2001). Differences in the type of maternal response to infants had varying effects on infant vocalizations depending on developmental stage. For instance, infants achieved first words earlier when they received more imitative responses from their caregivers at 13 months. Affirmations and descriptions, however, were most effective in facilitating infants' language acquisition at nine months.

Verbal Complexity

In three month old infants, the effects on vocal development observed during turn-taking were determined by the presence of verbal input from adults (Bloom, 1988; Bloom et al., 1987). Infants engaged in turn-taking regardless of speech quality from adults, but only demonstrated significant differences in language acquisition when adults provided verbal, nonrandom responses.

Phonological learning in infants is facilitated by the speech-relatedness of mothers' contingent responses (Goldstein & Schwade, 2008; Warlaumont et al., 2014). Infants who heard more complex infant-directed speech produced more speech-related babbles in response.

Contingent, speech-related responses to previous speech-related infant vocalizations increases the likelihood of subsequent speech-related infant vocalizations, indicating that infants learn over time from adult responses.

Attention

Mothers initiate attentional synchrony by tuning to the object of their infant's attention and responding contingently (Tamis-LeMonda et al., 2001). By providing situationally relevant responses, infants are able to pair adult utterances to their own behaviors and objects. Over time, infants who heard more adult input that was relevant to the object of their attention scored higher on vocabulary measures.

More contingent responses lead to greater infant attention skills. With more attentional control, infants are more interested in the responses from their caregivers. Across all instances of contingent responses, which offer different information to infants, the common product is attentional skill building (Masek et al., 2021). Through contingent verbal interaction, infants are able to gain more control of their own attention. Over time, infants' ability to attend to their caregivers' utterances allow them to engage more and extract more phonological information during dyadic exchange. This is facilitated by consistent contingent feedback from adults across temporal, semantic, and pragmatic pathways. By providing responses that are relevant to an object that an infant is attending to, referential ambiguity is reduced, and infants can learn new words more effectively. Pragmatic responses can help to establish understanding of communicative intent. Overall, these pathways operate through attentional skill acquisition and result in vocabulary gains and more engagement in social interaction.

Chapter 5: The Social Feedback Loop and Implications on Early Language Development

Beginning in the first two months of life, infants and caregivers engage in increasingly reciprocal and communicative vocal interaction (Elmlinger et al., 2023; Goldstein & Schwade, 2008; Lopez et al., 2020; Tamis-LeMonda et al., 2001; Warlaumont et al., 2014). Infants vocalize, prompting adults to provide sensitive responses, rich with social and lexical learning opportunities. In turn, infants respond with progressively more advanced vocalizations and demonstrate gradual gains in understanding the social aspects of conversation. Together, these processes form the social feedback loop that facilitates language acquisition. As described in previous sections, the component parts of dyadic exchange at each turn of the feedback loop are multifarious, largely interdependent, and develop over time.

Some early instances of reciprocal interaction between infant and caregiver are known as *protoconversation* (Bateson, 1975). Infant-caregiver interactions as early as three months can resemble the core dynamics of adult conversation. These instances are marked by sustained eye contact and reciprocal vocalization between mother and infant (Anderson et al., 1977; Bateson, 1975). Although infants are still in the primitive articulation stage of vocal development (Oller, 2000), producing sounds like "cooing" and "gooing", they still appear to engage in turn-taking with their mother. Anderson et al. (1977) found that both mothers and infants were more likely to begin vocalizing when the other was already vocalizing. However, only mothers were likely to stop vocalizing when their partner, the infant, was silent. This indicates that mothers attempt to engage in a meaningful exchange while infants at this stage do not engage in intentional turn-taking. There is little to no evidence that protoconversation trains infants to respond to their mother's vocalizations, yet it may carry greater value in laying the groundwork of conversational

structure. Protoconversation appears to serve as a precursor to the social feedback loop as infants at this stage are not yet perceptive of the social aspects of dyadic exchange.

By five months, early signs of infant participation in turn-taking with an adult partner appear (Goldstein et al., 2009; Hilbrink et al., 2015). Turn-taking in infant-caregiver dyadic vocal exchange has significant implications for language acquisition across the first few years of life (Bloom et al., 1987; Donnelly & Kidd, 2021; Long et al., 2022). From nine months on, infants who engaged in more conversational turns with an adult partner also had larger vocabularies later on (Donnelly & Kidd, 2021). This relationship was found to be bidirectional, in that larger vocabulary size also predicated more conversational turns. This indicates the existence of a social feedback loop between infant and adult.

Contingent vocal responses from adults convey a strong social component that significantly improves infants' ability to extract phonological information and produce unique vocalizations (Gros-Louis et al., 2014). Higher rates of contingent maternal responses to infants in previous months predicted increases in mother-directed vocalizations in subsequent months. Mothers also responded to mother-directed infant vocalizations more than any other type. Increases in mother-directed vocalizing was largely dependent upon receiving contingent maternal responses to those vocalizations. Infants who received greater proportions of contingent maternal responses also demonstrated larger vocabularies at 15 months. At nine months, infants who received more lexically complex contingent responses also produced more lexically complex vocalizations (Goldstein & Schwade, 2008). As infants' vocalizations prompt contingent adult responses, increasing in complexity at every turn, the result is an explosion of language acquisition. This indicates that social interaction between infant and mother facilitates early language acquisition, and that infants and mothers engage in a feedback loop.

As the feedback loop facilitates infant vocal production and language acquisition, infants who are not as responsive to adults may be at a disadvantage. In a study conducted on autistic and typically developing infants, speech-related vocalizations from infants were more likely to be followed by speech-like responses from adult caregivers, which were then more likely to be followed by speech-related infant vocalizations (Warlaumont et al., 2014). Typically developing infants produced more speech-related vocalizations and received more speech-related input from caregivers as a result compared to autistic infants. Autistic infants then received fewer verbal learning opportunities over time. As these exchanges also provide social exchange learning, autistic infants received fewer social learning opportunities. This deficit in social learning opportunities compounds upon itself over time, leading to vocabulary and other communication delays in autistic infants. For typically developing infants, however, the benefits to social learning compound, as they rapidly increase production of speech-like vocalizations with increasing adult responses.

Chapter 6: Discussion

Overall, it is abundantly clear that infant-adult dyads engage in reciprocal communication that develops over time. Through this communication, these dyads engage in a social feedback loop, which provides the necessary framework for infant language acquisition. Three main areas of evidence come together to form this feedback loop. First, it has been established that infant vocalizations wield a significant degree of influence over adult responses. In response to infant vocalizations, adults tend to engage in infant-directed speech, which follows prosodic and semantic patterns that are beneficial for language acquisition (Albert et al., 2023; Elmlinger et al., 2019; Pretzer et al., 2019). As the complexity of infant vocalizations increases over time, adults appear to follow in suit, providing increasingly diverse utterances (Albert et al., 2018; Chen et al., 2023; Gros-Louis et al., 2014; Pretzer et al., 2019; Warlaumont et al., 2014). Other characteristics of infant vocalizations such as directedness and type of vocalization influence adult responses. Adults typically respond most to speech-like, mother-directed vocalizations (Pretzer et al., 2019; Yoo et al., 2018). It is also clear that infants begin to expect contingent responses from adults over time (Goldstein et al., 2009). Together, this evidence reveals that adults are influenced to provide advantageous responses to infant vocalizations; the first cog in the feedback loop.

Second, it is evident that adult responses influence subsequent infant vocal behavior. By receiving consistent, contingent responses, infants begin to exhibit exponentially more advanced vocal behavior. When adults provide speech-like social responses, infants produce more advanced vocalizations (Bloom et al., 1987; Goldstein & Schwade, 2008). They also appear to develop stronger attentional skills as their caregivers direct their responses to the object of an infant's attention (Masek et al., 2021; Tamis-LeMonda et al., 2001). This allows infants to

continue learning from adult responses, as they are able to attend to their caregiver's utterance and extract increasingly more information day by day.

Finally, the social feedback loop between infant and adult emerges in early infancy and develops over time. Protoconversation is an early example of dyadic exchange, although infants are still passive participants at this stage (Anderson et al., 1977; Bateson, 1975). Through sustained social feedback from caregivers, infants eventually begin to engage in turn-taking exchange (Goldstein et al., 2009; Hilbrink et al., 2015). Through this reciprocal communication, infant vocal abilities explode (Gros-Louis et al., 2014). Their vocalizations increase in lexical complexity, directedness, and communicative intent, resulting in more diverse utterances from their caregivers, around and around again, forming a loop.

Implications

Although infants seem to produce vocalizations endogenously for a time, input from caregivers is critical in developing more advanced language skills. Some evidence suggests that socioeconomic status (SES) is related to the amount and quality of verbal input infants receive, affecting the amount of social and lexical information that infants can extract (Casillas et al., 2017; Suarez-Rivera et al., 2023). Caregivers seem to provide similar proportions of IDS regardless of SES, but infants from lower SES households receive less speech input overall, inherently decreasing the amount of IDS. However, SES may not in fact be a relevant predictor of language acquisition (Bergelson et al., 2023). This expansive study found that adult speech to infants was the primary predictor of language outcomes, moderated by infant age. SES was not significantly related to children's speech production. These findings indicate that it is necessary to study large populations in order to fully understand the factors that affect early language acquisition. It is also beneficial to step outside of the existing deficit lens in research, in which

we assume that a minority group lags behind WEIRD (Western, Educated, Industrialized, Rich, and Democratic) populations in a given measure due to the groups' characteristics.

Since infant vocal development is directly tied to verbal input from adults, infants who received less input may lag in language acquisition. That said, the amount of adult responses may be affected by extraneous variables that are influenced by SES, such as mental health and parental stress. Putting measures in place to reduce parental stress and increase infants' opportunities to receive sensitive responses could mitigate this difference. Implementing programs to alleviate some points of stress for low-SES families can improve children's health overall (Gennetian et al., 2024).

In light of findings that indicate possible negative impacts of the social feedback loop for autistic infants (Warlaumont et al., 2014), further investigate should be conducted into how this discrepancy could be reduced. As the social feedback loop appears to develop without external intervention, it is unlikely that parents are intentionally depriving their infants of speech-like contingent responses. Rather, they are responding to their social exchange partner's behavior. It is possible that all infants could benefit from their parents taking classes on how best to support early language acquisition. Offering no or low-cost classes to new parents where they can learn about the importance of an abundant social and verbal learning environment may result in better language outcomes for all infants.

One such intervention, the Video Interaction Project (VIP), has found success in supporting developmental outcomes for infants (Cates et al., 2018). Throughout the first three years, parents meet with an interventionist periodically. Parents engage in video-recorded play with their infants at each visit. The interventionists review these videos with parents, giving feedback and suggestions for parents to improve responses to infants. Compared to a mail-in

pamphlet program called Building Blocks and a control with no intervention, the parents who received VIP demonstrated enhanced responsiveness and provided more learning materials among other effects. This low-cost, accessible intervention showed lasting cognitive improvements for parents and offers an effective way to support early learning for low-SES families. Providing funding for programs like VIP could improve cognitive outcomes for children across all backgrounds.

Future Areas of Inquiry

While researching infant vocal development and the social feedback loop, several areas in need of further investigation became apparent. Writ large, infant research lacks data on dynamics outside of mother-infant dyads. Caregiving environments that are not infant-mother are often excluded from studies for a number of reasons. This includes infant-father dyads, single parents, same gender parents, multi-generational households, and more. Bias towards infant-mother dyads in the literature is likely related to the normative assumption that mothers are the primary caregivers (Cabrera et al., 2018).

It is important to note that the majority of research discussed in this thesis was conducted on infant-mother dyads from Western, dual parent households. Without inclusion of other dynamics, this area of research lacks generalizability. In order to develop a fully formed view on the role of social feedback in the development of infant vocalizations, it is necessary to understand the entire picture, which includes multiple diverse family environments that infants might experience.

Several more recent lines of research are working towards closing this gap by investigating the role of fathers on early language development. For instance, evidence suggests that verbal input from mothers and fathers may provide different learning benefits to infants

(Chen et al., 2023; Lovas, 2011). Furthermore, fathers appear to engage with infants similarly to mothers in terms of sensitivity and frequency (Tamis-LeMonda et al., 2004). Cabrera et al. (2018) discusses differences in the direct and indirect effects that fathers have on development. Indirect effects, such as income, appear to influence infant-mother interactions and developmental outcomes. Direct interactions, such as reading to infants, appear to improve language outcomes at similar levels compared to mothers (Malin et al., 2014). Some differences in the type of language were observed between mothers and fathers, such as labeling and referential speech. Ultimately, further investigation is necessary in order to fully understand the role of fathers, among other caregivers, during early language development.

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