Longitudinal Associations Between Early Language Input and Caregiver–Infant Neural Synchrony

***Ajmal Irshaad Mohammed (amoha277@asu.edu)[1], *Aditya Mutharasu[1], Casey Lew-Williams[2], Jessica E. Kosie[1]**

[1]School of Social and Behavioral Sciences, Arizona State University

[2]Department of Psychology, Princeton University

Abstract

Language acquisition is shaped by infants' engagement in socially embedded, synchronized communicative interactions. At a neural level, this is instantiated as neural synchrony. Extant literature has focused on in-the-moment predictors of neural synchrony, yet little is known about how early language environments shape neural coordination across development. The present study investigated the joint and independent effects of language quantity (i.e., number of adult words) and interaction quality (i.e., caregiver-infant reciprocal exchanges) on neural synchrony. We used day-long audio recordings collected between 12-24 months to characterize speech in infants' everyday environment and examined effects on caregiver-infant neural synchrony during play at 24 months. We found that greater conversational turn-taking at 12 months significantly predicted neural synchrony at 24 months, suggesting that early reciprocal interaction may be central in shaping neural attunement over time. These findings suggest that early reciprocal language experiences may scaffold the development of caregiver–infant neural attunement.

Keywords: adult word count; conversational turn-taking; neural synchrony; caregiver-infant interaction; fNIRS

Introduction

Language acquisition is among the earliest and most consequential developmental achievements, emerging through infants' participation in complex, socially embedded interactions with caregivers (Ferguson & Lew-Williams, 2016; Kuhl, 2006; Soderstrom, 2007). Extensive evidence indicates that variation in caregivers' linguistic input shapes infants' language learning across development (Hoff, 2006; Masek et al., 2021; Rowe, 2012; Rowe & Snow, 2020; Weisleder & Fernald, 2013). Research has primarily operationalized caregiver-infant verbal communication in terms of both the quantity and quality of linguistic input in an infant's environment, frequently indexed, respectively, by measures of the amount of language that the infant hears from adults (i.e., adult word count or AWC; Hoff, 2006; Romeo et al., 2018a) and how language is exchanged between the infant and caregiver (i.e., conversational turn count or CTC; Nguyen et al., 2023; Romeo et al., 2018). Variation in both AWC and CTC during early development has been linked to later language outcomes, including language processing efficiency, vocabulary growth, and grammatical development (Masek et al., 2021; Rowe, 2012; Weisleder & Fernald, 2013). In recent years, researchers have increasingly examined the neural mechanisms through which early language environments may influence development, focusing on how caregiver–infant interactions are instantiated in coordinated neural activity across dyads (Hasson et al., 2012; Hoehl et al., 2025; Piazza et al., 2020). Importantly, this work builds on long-standing approaches to characterizing infants' language environments, which have operationalized variation in linguistic input using well-established measures of the quantity and structure of caregiver speech.

Adult word count (AWC) is frequently used to approximate the "quantity" of speech that infants are exposed to (Rasanen, 2021; Romeo et al., 2018a). AWC is the measure of the number of adult words that are spoken in the proximity of the infant, or the aggregate of the language that an infant is exposed to in their everyday interactions. A wide body of empirical research has supported the notion that exposure to a greater "quantity" of language is associated with increased opportunities to build phonological representations and acquire new words (Hart & Risley, 1995; Hoff, 2006; Kuhl, 2006; Soderstrom, 2007). These results are further supported by longitudinal studies, which demonstrate that variation in the quantity of caregiver speech that infants hear predicts later language outcomes, with higher levels of input in the early stages of development being associated with larger vocabulary and language efficiency during the second year of life (Rowe, 2012). For example, Weisleder and Fernald (2013) showed that infants exposed to more child-directed speech at 19 months not only developed larger expressive vocabularies by 24 months but also processed spoken language more efficiently in real time. These findings suggest that the first two years of life may be a sensitive window during which exposure to language has lasting effects on language learning. To that end, AWC seems to serve as a meaningful index that captures the extent of infants' exposure to language during a stage of cognitive and linguistic growth.

However, the quantity of language input alone does not influence language acquisition; social contingency is also thought to play an important role. Research shows that infants who receive timely, socially contingent feedback from their caregivers demonstrate accelerated phonological learning (Goldstein & Schwade, 2008), increased attention to relevant features of language (Kuhl, 2007), and understanding the structure of conversation (Rowe & Snow, 2020), thus underscoring the importance of the quality of linguistic input. Although language quality can be operationalized in many different ways, extensive research has examined the "quality" of linguistic input by examining the frequency of conversational turns.

Conversational Turn Count (CTC) is defined as the reciprocal vocal exchanges within a caregiver-infant dyad, where one partner's vocalization is followed by a response from the other and indexes the "discourse" between infants and caregivers (Nguyen et al., 2023; Romeo et al., 2018a). Also, it has been conceptualized as a form of interactional attunement, where caregivers and infants coordinate their attention and expectation during a conversation (e.g., Alonso et al., 2024; Masek et al., 2021). Bruner (1981) and Tomasello and Farrar (1986) stipulate that turn-taking provides infants opportunities to learn not only about the form of language, but also the meaning behind it. Studies using long-form speech environment recorders show CTC to be a robust predictor of later language acquisition and outcomes (Rowe & Snow, 2020). In particular, Romeo and colleagues (2018a) found that higher numbers of conversational turns in infants' everyday environments is associated with stronger language skills, even after socioeconomic status is accounted for. Moreover, CTC has also been linked with other language outcomes (e.g., grammar abilities (Nguyen et al., 2023; Rowe, 2012), suggesting that reciprocal exchanges are likely a central mechanism in supporting children's language learning.

Though AWC and CTC are central to language learning, how these factors influence the development of communication at a neural level is still not well understood. With respect to AWC, two recent studies explored links between the number of adult words in infants' everyday input and the strength of activation and diffusion in language-related brain regions respectively, but found no significant relation (Romeo et al., 2018a; Romeo et al., 2018b). To our knowledge, these are the only investigations linking AWC to neural measures. In contrast, a growing body of work suggests that CTC may be more closely tied to neural systems supporting language. For example, in the same study, Romeo and colleagues (2018a) reported that higher CTC in the everyday input of pre-school aged children (4-6 years old) was associated with stronger activation in left inferior frontal regions during language processing tasks, indicating that reciprocal language experiences can shape neural systems supporting language. Similarly, Romeo and colleagues (2018b) also examined the relationship between children's language environment and structural organization of white-matter pathways. They found that greater CTC is related to the structural organization of language areas in the brain, specifically connectivity of the left arcuate fasciculus. Collectively, these findings highlight the importance of turn-taking in the early language environment for neurocognitive development. However, this work has relied primarily on single-brain measures, limiting insight into how communication unfolds dynamically between interaction partners.

One promising approach for addressing this limitation is hyperscanning, a neuroimaging method that enables the simultaneous measurement of neural activity across two or more interacting individuals (Montague, 2002). Hyperscanning makes it possible to examine neural synchrony, which has been proposed as a neural index of successful communication (Stephens et al., 2010). Neural synchrony refers to the temporal alignment of neural activity across members of a dyad, including between infants and caregivers, and is thought to reflect shared attention and coordinated engagement during communicative interactions (Hamilton, 2021; Hasson et al., 2012; Hoehl et al., 2025). Hyperscanning studies of caregiver-infant dyads have shown that greater neural synchrony is associated with higher-quality interaction, more efficient communication, and increased engagement during joint tasks (Hirsch et al., 2017; Leong et al., 2017; Nguyen et al., 2023; Piazza et al., 2020). Notably, neural synchrony is strongest during interactional contexts that closely resemble conversational exchange, including turn-taking and child-directed speech (Hirsch et al., 2017; Piazza et al., 2020). From a developmental perspective, these findings suggest that neural synchrony provides a neural marker of learning to communicate, capturing how joint engagement and reciprocal interaction shape neural processing within a dyad.

However, the literature assessing the independent and joint contributions of AWC and CTC to neural synchrony remains limited. Addressing this gap is important, as caregiver–infant language experiences are shaped through repeated reciprocal exchanges within the dyad. In this context, neural synchrony may serve as a useful marker of later dyadic neural attunement, capturing the extent to which caregiver–infant pairs become neurally aligned during naturalistic interactions. Notably, much of the existing research linking early language experience to interpersonal neural synchrony has focused primarily on moment-to-moment predictors of synchrony. For instance, hyperscanning studies demonstrate that neural synchrony fluctuates dynamically as a result of momentary interaction such as mutual gaze and infant vocalizations (Hirsch et al., 2017; Piazza et al., 2020). In relation to CTC in particular, Nguyen et al. (2023) found that, during a play session between mothers and their 4- to 6-month-old infants, more frequent conversational turn taking was positively related to mother-infant neural synchrony. While this highlights how turn-taking relates to neural synchrony during real-time social interaction, the question of how CTC and AWC impact neural synchrony longitudinally (e.g., across the second year of life) has not yet been explored.

The present study aims to provide a developmental account of the joint and independent effects of quantity of caregivers' words (operationalized as adult word count; AWC) and caregiver-infant reciprocal verbal interactions (operationalized as conversational turn count; CTC) on neural synchrony during infants' second year of life. We focus on this developmental window because infancy and early childhood mark a period of sizable change for linguistic and neurocognitive development). Although prior work has demonstrated robust links between infants' everyday language input and neural outcomes, little research has examined how quantity and reciprocal vocal exchanges jointly and independently contribute to neural synchrony over developmental time, particularly as a marker of successful communication within caregiver-infant dyads. We conducted a longitudinal, naturalistic observational study measuring AWC and CTC at 12, 18, and 24 months and using these measures to predict caregiver-infant neural synchrony at 24 months. By integrating long-form speech environment recordings with hyperscanning measures, this study bridges prior work focused on in-the-moment predictors of neural synchrony with a developmental account of how early language environments may shape neural attunement between infants and caregivers.

Methods

Participants

We recruited 63 English-speaking caregivers–infant dyads (40 female infants) from a predominantly White, middle- to upper-middle-class community in Northeastern United States. All infants were full-term (> 37 weeks' gestation) and had no reported auditory, visual or developmental impairments. Recordings of home environments were collected longitudinally in three waves: at infant age 12 months (M = 11.9, SD = 0.51, range = 11.1-13.2), 18 months (M = 17.8, SD = 0.78, range = 16.2-20.2), and 24 months (M = 24.0, SD = 0.66, range = 23.1-26.0). In-lab fNIRS data was collected when infants were 24 months old. Additional data on infants' vocabulary size were collected via parent report but are not reported here due to space limitations. Seven dyads were excluded for failure to complete all portions of the study (e.g., all three waves of home language recordings and the in-lab visit) 15 were excluded due to the inability to acquire reliable fNIRS data because the child did not tolerate the fNIRS cap, and one was excluded due to experimenter error. After applying these exclusion criteria, 40 dyads are included in the following analyses.

Measures

Home language environment: Infants' everyday language environments were assessed using the Language Environment Analysis (LENA) system (LENA Foundation, 2014). At each data collection wave (12, 18, and 24 months), infants wore a small, wearable audio recorder for two days, with recordings capturing approximately 16 hours per day (mean: 15.9; range: 10.9 - 16.0). The device recorded all speech occurring in the infant's environment, and audio files were processed using LENA software.

The LENA software applies automated speech recognition algorithms trained on human-transcribed recordings to segment audio into mutually exclusive sound source categories (e.g., adult female, adult male, key child, other child, electronic sounds, noise, and silence). From these classifications, the software provides a range of quantitative metrics characterizing infants' auditory environments, including estimates of adult word count (AWC), defined as the number of words spoken by adults in the infant's environment, and conversational turn count (CTC), defined as instances of child speech-related vocalizations followed by adult vocalizations (or vice versa) separated by less than 5 seconds. For the purposes of this study, analyses focused on LENA-derived measures of AWC and CTC.

Functional near-infrared spectroscopy (fNIRS): Neural activity was recorded simultaneously from the caregiver and infant using a dual-brain LABNIRS system (Shimadzu Scientific Instruments, Columbia, MD). Functional near-infrared spectroscopy (fNIRS) is a noninvasive neuroimaging technique that indexes cortical activity through changes in the oxygenated (HbO) and deoxygenated (HbR) hemoglobin concentrations. fNIRS data was recorded from 41 channels for each member of the dyad (channel separation on the scalp was 2.5cm for the infant and 3cm for the adult) at a rate of ~13.33 Hz. These 41 channels covered three patches: (1) prefrontal cortex (PFC; 7 channels total); (2) right temporal region (17 channels); and (3) left temporal region (17 channels). Data were preprocessed using the Homer2 toolbox for MATLAB (Huppert et al., 2009) following parameters outlined by Di Lorenzo and colleagues (2019). In line with prior research (e.g., Liu et al., 2017; Piazza et al., 2020), neural synchrony was computed using the deoxygenated hemoglobin (HbR) signals. These signals are closely coupled to the blood-oxygen-level-dependent (BOLD) response and are less susceptible to systemic physiological noise. To calculate inter-subject correlation (or ISC, a correlation-based measure that has increasingly been used to index neural synchrony in dyadic contexts (Boas et al., 2014; Hirsch et al., 2017)), HbR signals were averaged across all usable channels within each cortical patch at each time point, producing a single averaged HbR value per patch per time point. Pearson correlations were then computed between caregivers' and infants' averaged HbR values across all time points during the interaction period. The current study focused on the prefrontal patch, as this area tends to be related to caregiver-infant interactive behaviors (e.g., Alonso et al., 2024; Piazza et al., 2020; Reindl et al., 2018).

Procedure

Data were collected when infants were 12, 18, and 24 months of age. At each wave, families completed two days of in-home audio recordings using the LENA system (LENA Research Foundation, 2014). Caregivers were instructed to turn on the LENA device when the infant woke up in the morning and place it into a vest worn by the infant for the remainder of the day. Caregivers were informed that they could remove the vest and set it aside if they preferred not to be recorded during specific activities or notify the research team to remove any segments of the recordings upon request.

When infants were 24 months of age, caregiver-infant dyads additionally participated in a laboratory session. All dyads engaged in five minutes of free play, in which caregivers and infants were provided with a set of three familiar toys and caregivers were asked to play with their infant as they typically would at home. During free play, neural synchrony was recorded simultaneously from both members of the dyad using dual-brain functional near-infrared spectroscopy (fNIRS). Neural synchrony during the caregiver–infant free-play interaction (i.e., the degree to which caregiver and infant neural signals were temporally aligned) served as the primary neural measure in the current study[1].

Results

To examine whether early language input predicted later caregiver–infant neural synchrony, we fit multiple regression models predicting dyadic neural synchrony (ISC) at 24 months from LENA-derived adult word count (AWC) and conversational turn count (CTC) collected longitudinally at 12, 18, and 24 months. Both AWC and CTC are computed per hour of recording. Continuous predictors were mean-centered prior to analysis. All analyses were performed in RStudio (RStudio Team, 2020) using R Statistical Software (R version 4.5.1 (2025-06-13), R Core Team, 2025).

Infant language environment

We first examined AWC and CTC per hour in infants' input from 12 to 24 months. Regarding the number of adult words, a multiple regression predicting AWC from infant age (12, 18, and 24 months) was not significant, $F(2, 117) = 0.81$, $p = .45$, $R^2 = .01$. The number of adult words in infants' everyday input did not differ at 12 months ($M = 1075$, $SD = 379$), 18 months ($M = 1005$, $SD = 363$), or 24 months ($M = 1115$, $SD = 426$; $ps > .63$). In contrast, a multiple regression predicting CTC from infant age (12, 18, and 24 months) was significant, $F(2, 117) = 15.44$, $p < .001$, $R^2 = .21$. A set of Bonferroni-corrected pairwise comparisons revealed that the difference between CTC at 12 months ($M = 24.8$, $SD = 9.77$) and CTC at 18 months ($M = 33.0$, $SD = 15.4$) approached significance, $t(120) = -2.38$, $p = .056$. CTC at 12 months differed significantly from CTC at 24 months ($M = 44.0$, $SD = 19.7$), $t(120) = -5.54$, $p < .001$, and CTC at 18 months differed significantly from CTC at 24 months, $t(120) = -3.16$, $p = .006$ (see Figure 1).

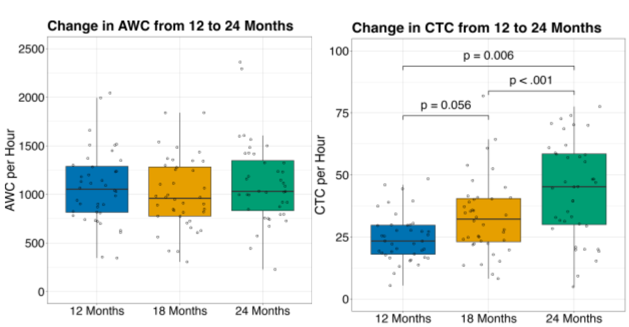

Figure 1: Per-hour measures of adult word count (left) and conversational turn count (right) in infants' input at ages 12 months (blue), 18 months (orange), and 24 months (green). Individual data points are displayed as jittered dots.

Adult word count (AWC)

The multiple regression model using AWC at 12, 18, and 24 months did not significantly predict 24-month neural synchrony overall, $F(3, 36) = 2.06$, $p = .122$, $R^2 = .15$. In this model, AWC at 12 months ($b = 0.00004$, $SE = 0.0001$, $t(36) = 0.31$, $p = .761$) and AWC at 24 months ($b = -0.0001$, $SE = 0.0001$, $t(36) = -0.89$, $p = .377$) did not predict ISC at 24 months, but AWC at 18 months did, $b = 0.0003$, $SE = 0.0001$, $t(36) = 2.15$, $p = .039$ (though see findings below suggesting lack of robustness). Thus, while the association was significant at 18 months, the overall quantity of adult speech in the home language environment did not show strong evidence of predicting caregiver-infant neural synchrony at 24 months.

Conversational turn count (CTC)

A multiple regression using CTC at 12, 18, and 24 months significantly predicted 24-month neural synchrony, $F(3, 36) = 3.40$, $p = .03$, $R^2 = .22$ (see Figure 2). Within this model, CTC at 12 months predicted greater synchrony at 24 months, $b = 0.010$ ($SE = 0.004$), $t(36) = 2.32$, $p = .026$. In contrast, CTC at 18 months ($b = 0.003$, $SE = 0.003$, $t(36) = 0.88$, $p = .385$) and CTC at 24 months ($b = -0.0001$, $SE = 0.003$, $t(36) = -0.05$, $p = .96$) did not significantly predict neural synchrony at 24 months. These results suggest that CTC at 12 months was associated with greater caregiver–infant neural synchrony at 24 months, even when controlling for turn taking at 18 and 24 months.

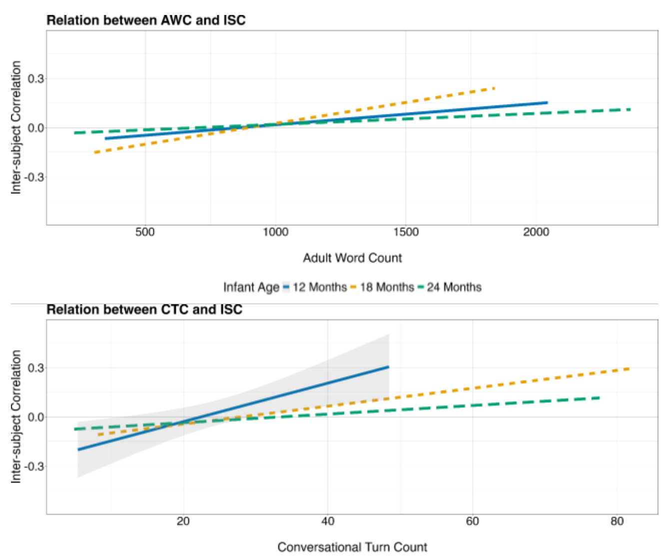

Figure 2: Relation between adult word count (top), conversational turn count (bottom) and caregiver-infant neural synchrony measured at infant age 24 months. Separate

[1] Communicative features of the interactions are currently being coded for future analysis.

lines indicate measures collected at infant age 12 months (blue), 18 months (orange), and 24 months (green). Shaded region indicates +/- 1 SE around the significant effect of CTC at 12 months.

Joint and interactive effects of AWC and CTC

To directly test whether the longitudinal association between turn-taking and later neural synchrony depended on the overall quantity of adult speech early in development, we fit an interaction model at each time point including AWC, CTC, and their interaction. The overall (predicting 24-month synchrony from AWC, CTC, and their interaction) at 12-months was significant, $F(3, 36) = 2.97$, $p = .045$, $R^2 = .198$. CTC at 12 months was a significant, positive predictor of synchrony, $b = 0.01$, $SE = 0.004$, $t(36) = 2.470$, $p = .010$. In contrast, AWC at 12 months did not significantly predict 24-month synchrony, $b = -0.0001$, $SE = 0.0001$, $t(36) = -0.39$, $p = .698$. The AWC × CTC interaction was also not significant, $b = -0.00001$, $SE = 0.00001$, $t(39) = -0.16$, $p = .872$. The overall model predicting 24-month synchrony from AWC, CTC, and their interaction at 18 months was not significant, $F(3, 36) = 2.53$, $p = .073$, nor was any individual predictor, ps > .21. Similarly, the overall model predicting 24-month synchrony from AWC, CTC, and their interaction at 24 months was also not significant, $F(3, 36) = 0.96$, $p = .423$, nor were any individual predictors, ps > .25. Taken together, these findings support the hypothesis that early reciprocal interaction was positively predictive of later caregiver-infant neural synchrony at 24 months. The quantity of adult speech across the second life, however, was not a robust predictor of 24-month neural synchrony.

Discussion

The present study investigated relations between infants' early language experiences and their later neural synchrony with caregivers. Building on the framework that language develops through socially embedded interactions (e.g., Ferguson & Lew-Williams, 2016; Kuhl, 2006; Soderstrom, 2007), this work examined the joint and independent contributions of adult word count (AWC) and conversational turn count (CTC) on neural synchrony across the second year of life. The findings of this study, broadly speaking, support the longstanding notion that language learning is shaped by environmental factors, particularly in the early stages of life.

Conversational turn-taking and neural synchrony

Our results suggest that early conversational turn-taking may support later caregiver-infant neural synchrony. However, it was CTC at 12 months specifically that was found to be a significant predictor of neural synchrony one year later. CTC at 18 months and 24 months were not significant predictors of neural synchrony, though the relation was positive. This suggests that early interactional experiences may have the strongest impact on later neural engagement between infants and their caregivers. Additionally, our results are congruent with the existing cross-sectional literature that has established a positive relationship between CTC and neural synchrony (Nguyen et al., 2023; Piazza et al., 2020), and extend beyond existing hyperscaning studies that demonstrate that turn-taking supports neural synchrony during real-time interaction (Hirsch et al., 2017; Leong et al., 2017; Nguyen et al., 2023; Piazza et al., 2020). Although those studies show links between caregiver-infant behaviors and neural synchrony during brief live interactions, our findings further suggest that early reciprocal interaction experiences may have lasting impacts on the development of neural attunement between infants and caregivers. That is, the effects of early conversational experiences seem to extend far beyond momentary effects into longer developmental timescales.

Adult word count and neural synchrony

We did not find clear evidence that adult word count - at any age - was predictive of later neural synchrony. These findings align with previous neuroimaging research that reported no associations between quantity of language and neural measures (Romeo et al., 2018a; Romeo et al., 2018b). One probable explanation for this could be that, though AWC indexes the amount of speech in an infant's environment, it does not capture whether the speech is socially contingent or aligned with infants' attention. As demonstrated by previous research, neural synchrony reflects, among other things, shared attention and concurrent interactions (Hamilton, 2021; Hasson et al., 2012). A second possible explanation for this finding is that AWC did not change much from 12 to 18 to 24 months, unlike CTC; and if AWC does not exhibit much change over developmental time, then it is unlikely to be a driver of change in 24-month neural synchrony compared to behaviors that do change. Lastly, AWC might influence development through mechanisms that may not be captured well by neural synchrony, and future research will need to examine the effects of AWC on different neural measures. For example, Romeo and colleagues (2018a) looked at the association between AWC and functional activation in language-related brain regions using fMRI. Though they failed to find any significant effects, it is important to note that their study was a cross-section design. Future research could examine these effects longitudinally to investigate how language quantity may affect neural development over time. It is important to note our AWC measure is that it captures the overall quantity of adult speech in the infant's auditory environment. Although AWC provides a useful estimate of the overall quantity of adult speech surrounding the infant, LENA-based AWC does not distinguish between speech directly addressed to the infant and speech occurring in close proximity to the infant.

Effects of AWC and CTC on neural synchrony

When assessing the joint contribution of quantity and reciprocal exchanges (AWC and CTC, respectively) to caregiver-infant neural synchrony, we found that CTC at 12 months was the single significant predictor. Neither AWC or CTC at 18 or 24 months, nor interactions between them, significantly predicted synchrony. These results underscore the importance of early conversational turn-taking on infants' developing ability to successfully communicate with others in their environment. One possible explanation could be that reciprocal exchanges provide infants with structured opportunities to engage in social coordination. This is considered to underlie neural alignment (Hamilton, 2021). Over developmental time, there may be accumulated 'practice' effects of these interactions with caregivers, setting the stage for neurally-indexed moments of shared attention on people, objects, and/or events.

Overall, our results suggest that while the "quantity" of language may be important for vocabulary growth and processing efficiency (e.g., Rowe, 2012; Wesileder & Fernald, 2013), the "quality" of interaction (i.e., CTC in this case) is a more robust predictor of neural synchrony within dyads.

Limitations and future directions

The present study is the first longitudinal study examining how the home language environment predicts later neural synchrony between infants and caregivers. However, there are several limitations of our approach. First, neural synchrony was assessed at a single time point (24 months) in a laboratory setting, and conversational turn-taking was operationalized as an aggregated average number of turns per hour. Stronger support for the relation between input and synchrony could be acquired by examining how neural synchrony itself changes across development, especially in regard to different timescales of conversational experience, including moment-to-moment, month-by-month, and aggregate effects (see Cychosz et al., 2025; Slone et al., 2023). Second, while the LENA recording system provides an automated window into the prevalence of turn-taking, it does not provide information about the content of communicative exchanges. Caregiver-infant communication is embedded in a variety of social and activity contexts, in which multimodal cues such as gestures or facial displays of emotion (e.g., Kosie & Lew-Williams, 2024) and shared routines (e.g., Tamis-LeMonda et al., 2019) may structure turn-taking exchanges and influence the development of synchrony. Future studies incorporating longform video recordings may allow for the characterization of these multimodal and contextual features of interaction, providing a more comprehensive account of how conversational experiences support neural attunement. Third, while we found that conversational turn taking at 12 months (but not 18 or 24 months) predicted neural synchrony, the absence of significant effects at 18 and 24 months was unexpected. Though the overall pattern suggests that very early caregiver–infant interaction may play a key role in shaping later dyadic neural attunement, it will be important for future research to determine whether the null findings at 18 and 24 months reflect developmental shifts in the role of interaction, differences in measurement sensitivity, or other methodological factors. Next, although our sample is relatively large for developmental hyperscanning research, concerns about statistical power remain, and results should be interpreted cautiously. Finally, participants in the current study came from predominantly white, mid- to high-SES, English-speaking families in the Eastern United States, and all measures were based on dyadic caregiver–infant interactions. As such, further work is needed to examine the extent to which our findings generalize to more diverse populations or to interactional contexts that extend beyond the dyad.

Conclusion

This investigation provides novel insights into the predictive effects of the features of infants' everyday language environment on caregiver-infant neural synchrony. These findings lend support to interaction-based accounts of language development and suggest that neural synchrony is a meaningful marker of coordinated communication. By combining naturalistic language measures across time and neural measures of coordinate engagement at age two, this work advances our understanding of how early interactions shape the developing social brain.

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