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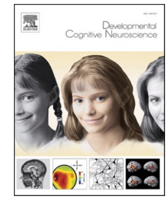

Within arms reach: Physical proximity shapes mother-infant language exchanges in real-time

Catalina Suarez-Rivera [a,b], Nicole Pinheiro-Mehta [c], Catherine S. Tamis-LeMonda [a,*]

[a] New York University, United States
[b] University College London, United Kingdom
[c] Illinois Institute of Technology, United States

A R T I C L E I N F O

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A B S T R A C T

During everyday interactions, mothers and infants achieve behavioral synchrony at multiple levels. The ebb-and-flow of mother-infant physical proximity may be a central type of synchrony that establishes a common ground for infant-mother interaction. However, the role of proximity in language exchanges is relatively unstudied, perhaps because structured tasks—the common setup for observing infant-caregiver interactions—establish proximity by design. We videorecorded 100 mothers (U.S. Hispanic $N = 50$, U.S. Non-Hispanic $N = 50$) and their 13- to 23-month-old infants during natural activity at home (1-to-2 h per dyad), transcribed mother and infant speech, and coded proximity continuously (i.e., infants and mother within arms reach). In both samples, dyads entered proximity in a bursty temporal pattern, with bouts of proximity interspersed with bouts of physical distance. As hypothesized, Non-Hispanic and Hispanic mothers produced more words and a greater variety of words when within arms reach than out of arms reach. Similarly, infants produced more utterances that contained words when close to mother than when not. However, infants babbled equally often regardless of proximity, generating abundant opportunities to play with sounds. Physical proximity expands opportunities for language exchanges and infants' communicative word use, although babies accumulate massive practice babbling even when caregivers are not proximal.

Mother-infant synchrony takes many forms. Dyads coordinate gaze as they interact with objects during play (Deák et al., 2014; Yu and Smith, 2013), take turns when speaking (Hilbrink et al., 2015), and follow one other around play rooms (Hoch et al., 2021). Likewise, dyads display synchrony in physiological (e.g., heart rate and respiratory sinus arrhythmia; Feldman, 2007) and neural domains (e.g., neural responsitivity to infant attention; Wass et al., 2018). Here, we focus on the synchrony of bodies in space during everyday activities, and test the real-time effect of such physical proximity on the language exchanges between mothers and their infants.

Physical proximity—a form of synchrony that may frame social interactions—is rarely studied in the context of language interactions. Two people in an elevator may drum up a conversation, whereas they may be unlikely to interact when down the hall from one another. For infants and caregivers, proximity likewise may meaningfully structure social interactions by expanding opportunities for conversation. Indeed, language is an embodied and social tool that facilitates the sharing of experiences, particularly when people are nearby. Accordingly, we test the hypothesis that mothers' talk increases in frequency and diversity when they are within arms reach to their infants compared to out of arms reach. Likewise, we test the hypothesis that infants' babbles and words increase in frequency in the context of proximity. We expect findings to generalize across cultural communities, and so test the effects of proximity in two distinct samples.

1. Introduction

Studies of proximity draw from a rich variety of methods: Animal studies (e.g., Brett et al., 2015), observations of atypical human experiences and development (e.g., Bakermans-Kranenburg et al., 2011), caregiver-infant interactions in the laboratory (e.g., Hoch et al., 2021; Rheingold and Eckerman, 1970) and at home (e.g., Chen et al., 2023; Negayama and Trevarthen, 2022; Yamamoto et al., 2019); and experimental studies (e.g., Tanaka et al., 2021; Williams and Turner, 2020). Indeed, operational definitions of proximity and research questions involving proximity are highly heterogeneous (Barnett et al., 2022).

* Corresponding author.
E-mail address: catalina.rivera@ucl.ac.uk (C.S. Tamis-LeMonda).

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Nonetheless, all methodological and theoretical approaches converge on the idea that proximity is core to survival and healthy development.

Humans need proximal caregiving throughout infancy and early childhood (Barnett et al., 2022). Human infants, specifically, remain dependent on their parents for prolongued periods compared to non-human primate species (Humphrey, 2010). As a result, humans ensure proximity to babies by using baby carriers and slings among other artifacts (Barnett et al., 2022) and by staying close to their infants in potentially dangerous situations, such when babies are on elevated platforms (Harrist and Waugh, 2002; Tamis-LeMonda et al., 2007). Infants from Europe and North America under 1 year of age spend approximately 2 hr of the day in close contact with their caregiver (Dotti Sani and Treas, 2016); infants in many parts of Africa, Asia, and Central and South America spend up to a full day in close contact (Barnett et al., 2022). Infants themselves also engage in a rich variety of behaviors—vocalizing, gesturing, and locomoting—to maintain proximity to primary caregivers (Anderson et al., 1978; Brown, 2001; Chen et al., 2023; Hay, 1980; Negayama and Trevarthen, 2022). Thus, proximity allows caregivers to meet their babies' needs for food, shelter, and safety.

Presumably, proximity to caregiver yields many benefits for infants. While at their mother's chest, infants more effectively regulate their temperature and the production of stress hormones than when alone (Beckes and Coan, 2011). When carried, infants stop crying and reduce their movements (Esposito et al., 2013). Furthermore, proximity to a loved caregiver supports the development of secure attachment, a fundamental ingredient to healthy social and emotional functioning (Bowlby, 1969). In experimental contexts, infants increase their object exploration and reduce their wariness of strangers if they receive high physical contact from their mothers relative to low physical contact (Barnett et al., 2022).

Proximity may present ideal moments for language learning as well. Language is a hallmark of human cognition and it takes several years to master. Being proximal to caregivers may offer infants heightened opportunities to be exposed to speech and vocalize themselves. A data-rich, intensive study of mother-infant physical proximity in two dyads showed that mothers and infants spent 4–16 % of the 12 h recorded time within touching distance. Notably, the time spent in proximity in 5-min segments was associated with the number of conversational turns and number of adult words to which infants were exposed (Salo et al., 2021). Furthermore, infants better learned words that were accompanied by caregiver physical touch than words not accompanied by touch (Seidl et al., 2015), and touch itself requires proximity. Proximity may therefore be a form of synchrony that serves as a springboard for infant learning.

1.1. Proximity, survival, and healthy development

Understanding the role of proximity in infant learning and development requires documenting the temporal distribution of proximity bouts over time; examining moment-to-moment connections between proximity and other critical behaviors, such as language; and testing the robustness of findings across samples.

1.2. Unanswered questions

Behaviors unfold over time. Yet the common scientific tradition is to focus on averages rather than the temporal rhythm of behavior. Indeed, the timing of events is an understudied feature of infant experience and behavior, despite a long history in psychology of highlighting the importance of temporal parameters for learning (e.g., Ebbinghaus, 1885; Fogel, 1992; Stern, 1971; Thelen and Smith, 1994). If proximity is foundational to infants' socioemotional and cognitive development, then careful description of its temporal structure is needed—namely, the duration of bouts, length of breaks between bouts, and how bouts unfold over time.

1.3. Current study

Communication is a dyadic process that requires infants to be exposed to speech if they are to learn how to participate in conversations. In this regard, proximity may establish a common ground for talking about and acting on shared referents. Mothers talk with their infants about images in books, foods during mealtime, and clothes during dressing (Tamis-LeMonda et al., 2019), and such talk may be more likely to occur when nearby than distant. Additionally, mothers can more readily touch and gesture to objects of infant attention when close to their babies (Suarez-Rivera et al., 2022a, 2022b), coordinate visual attention to objects (Yu and Smith, 2013; Yamamoto et al., 2019), and touch infant's body while speaking (Seidl et al., 2015). Indeed, a case study of 2 families (Salo et al., 2021) indicated associations between proximity and mothers' language input.

Likewise, proximity may facilitate infants' vocal productions. To the extent that caregivers scaffold infants' real-time behaviors (e.g., Schatz et al., 2022; Yu and Smith, 2016), infants may be more likely to vocalize and produce advanced vocalizations in the context of reciprocal interactions that allow for caregiver touch and talk (Goldstein and Schwade, 2008). For example, infants may name objects they hand to their mothers (e.g., "cookie") or vocalize in response to mothers' speech, gestures, and actions on objects (Kuchirko et al., 2018).

To understand how moment-to-moment changes in proximity connect to language interactions requires annotating infant and mother location relative to one another with high temporal precision. Frame-by-frame analysis of infant and mother behaviors provides the necessary test of how changes to body location align with changes in infant vocalizations and mother speech.

1.4. Scientific replication

Developmental theory rests on understanding whether phenomena generalize to different samples with different characteristics. Similar to developmental science generally, the scarce research on proximity is limited to educated English-speaking, middle-to-upper socio-economic status families. An open question is whether findings on the importance of proximity for language exchanges generalize to families that differ in culture, education, and socioeconomic status, factors associated with proximal touch (e.g., Kelle, 2007) and language exchanges (e.g., Kuchirko et al., 2020). Mothers from different cultural communities differ in how frequently they engage in different modes of communication with their infants, such as proximal touch, speech, and gestures; (e.g., Cychosz et al., 2021; Kärtner et al., 2010; Tamis-LeMonda et al., 2012). At the same time, they show similarities in how their responses temporally align with what babies are doing. Mothers from 11 cultures around the world responded to their babies' behaviors within a few seconds (Bornstein et al., 2015), suggesting that the temporal coordination of bodies in space and language interactions may apply to distinct samples.

1.5. Current study

We expand inquiry into infant-caregiver synchrony broadly and proximity specifically by quantifying the temporal structure of proximity in infant-mother dyads and testing how moments of proximity coincide with speech in mothers and vocal productions in infants. We videorecorded two samples of infants and mothers in the ecologically valid home setting, for 1–2 h per observation: English-speaking Non-Hispanic mother-infant dyads from middle-to-upper socioeconomic status homes (N = 50), and Spanish-speaking Hispanic mother-infant dyads from low socioeconomic status homes (N = 50). Three aims guided our analyses.

First, we documented the characteristics of proximity—how often and for how long mothers and infants were within arms reach, and how bouts of proximity were distributed over time. We expected mothers and infants in both samples to frequently enter and exit arms reach over the course of the observation, but to show inter-individual variation in the time spent in proximity (Chen et al., 2023). Additionally, we tested whether proximity followed a periodic, random, or bursty temporal structure (Goh and Barabási, 2008).

Second, we asked whether the quantity (i.e., frequency of word tokens) and lexical diversity (i.e., frequency of word types) of mothers' speech to infants changed with proximity. We hypothesized that mothers in both samples would increase the amount and diversity of words they direct to infants when within arms reach compared to out of arms reach. Alternatively, we recognized that proximity is not a necessary condition for infant-directed speech. Language travels over space, and mothers may talk to infants regardless of location—such as calling to their infants who are out of reach (e.g., "come here", "don't do that", "bring it over"), talking about their own actions when afar ("one minute, I'm getting your lunch"), and talking about the actions of their locomoting infants ("where are you going?"; West et al., 2022, 2023).

Finally, we asked whether infant vocal production changes with proximity. We considered two possibilities. In line with the social nature of language, proximity may induce increased infant vocalizations. Alternatively, in line with the exuberant nature of infant behavior (Herzberg et al., 2022), babies may be equally vocal when within arms reach of mother as when out of arms reach. That is, infants may not yet be socialized to produce vocalizations narrowly in social context. Finally, the effects of proximity may differ for infant babbles versus words. Day-long recordings of infant speech showed that infants generated vast practice vocalizing during independent vocal play, but produced more sophisticated vocalizations during turn-taking exchanges than during vocal play (Long et al., 2022). Infants may similarly practice babbling regardless of mothers' location, but produce more advanced vocalizations (i.e., words) when within arms reach.

2. Method

2.1. Participants

Non-Hispanic (N = 50, 24 girls) and Hispanic (N = 50, 17 girls) infants were recruited through hospitals, referrals, and brochures. Infants' ranged from 13 to 23 months (19 13-month-olds; 16 18-month-olds; and 15 23-month-olds) in the Non-Hispanic sample, and from 12 to 26 months in the Hispanic sample ($M = 16.82$, $SD = 3.72$). We focused on infants' second year as a period of marked language learning. Non-Hispanic mothers ranged from 26 to 49 years of age ($M = 35$, $SD = 5.23$); 91 % had earned college or higher degrees; 62 % worked part or full time; and 81 % were White, 7 % Asian, and 12 % mixed race. Hispanic Mothers ranged from 21 to 43 years of age ($M = 32.40$, $SD = 4.84$); averaged an 8th grade education (SD = 5.1 years), and the majority were Mexican (with two from Guatemala, one from Ecuador, and one from Spain). Most Non-Hispanic mothers spoke only English and most Hispanic mothers spoke only Spanish. Mothers received $50 to $75 gift cards for the visit (depending on their time investment). All procedures involving human subjects were approved by the Institutional Review Board (Protocol BLINDED) at BLINDED University and titled BLINDED.

2.2. Procedure

Mother-infant dyads were video-recorded in their homes by a female researcher. Visits lasted on average 119.50 min ($SD = 2.97$, $M\,dn = 120.02$, $Range = 103.36$–121.62) for Non-Hispanic dyads, and 90.04 min ($SD = 15.12$, $M\,dn = 90.45$, $Range = 58.96$–155.18) for Hispanic dyads. A handheld digital camera (30 fps) with an external microphone was used to record mother-infant interaction. Visits were scheduled between 8 am and 6 pm, according to mothers' availability, and mostly on weekdays. Participants were asked to go about their everyday activities as if the researcher was not present, and to remain inside the home. The researcher kept focus on the infant with minimal interference, following the baby when the dyad was separated.

2.3. Coding

Videos were transcribed and coded in Datavyu (datavyu.org), a coding tool that time locks user-defined behaviors and utterances to video frames. Inter-observer reliability was determined by comparing the primary coder's data to an independent secondary coder's data on 25 % of a randomly selected portion of each video. Processed data, analysis scripts, and study materials are openly shared on Databrary https://BLINDED; with participants' permission, videos are shared with authorized investigators of Databrary at https://BLINDED.

2.3.1. Mother-infant proximity

Physical proximity was coded continuously from the video recordings, defined as mother being within arm's length of the infant or arm's length of the object of infant manual action (Fig. 1). For example, if the infant was playing with blocks, and the mother could touch the infant or the same blocks that the infant was touching, proximity was coded. Proximity ended the first frame that mother was no longer within arms reach. Proximity was not coded when the infant was sitting on the floor and the mother was standing next to the infant, because the infant was not within arm's reach unless the mother bent down. Mothers and their infants did not have to be interacting with each other to be considered proximal (e.g., a mother watching TV on the couch while the infant plays with a set of toys next to her). Thus, there was no reason for language to increase in the context of proximity. This definition of proximity has precedent, with prior researchers crediting instances when infant was within arm's reach, less than 3 feet, or 5 m from mother (Chen et al., 2023; Salo et al., 2021). Cohen Kappa's ranged from 0.65 to 0.99 across dyads, and averaged 0.90, reflecting high inter-observer reliability.

2.3.2. Language transcription

Trained bilingual researchers transcribed mother language and infant vocal production at the utterance level following guidelines developed in our lab and implemented for a national multi-site project of child home activities (https://www.play-project.org/coding.html#Transcription). Transcription guidelines were adopted from conventions of the Codes for the Human Analysis of Transcripts (CHAT) (CHILDES; MacWhinney, 2000). An utterance was defined as a meaningful unit of information that contained grammatical closure or a discernible pause. Speech from electronic toys and media was not transcribed. Infant utterances were further classified as "babbles" (i.e., when the utterances contained a consonant + vowel combination such as 'ba'), or "words" (i.e., when the utterance contained an English or Spanish word such as "ball" or "si" [yes]). Other vocalization types (i.e., cries, grunts) were not analyzed given our interest in advanced vocal forms.

2.4. Data analysis plan

2.4.1. Quantifying temporal structure of proximity

Our first research aim pertains to the ebb-and-flow of proximity

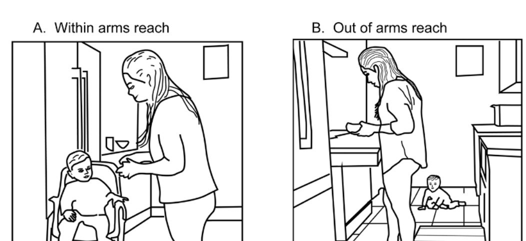

Fig. 1. Illustration of a participating mother-infant (A) within arms reach (i.e., proximal) and (B) out of arms reach (i.e., not proximal).

between mother and infant. Beyond reporting the number of proximity episodes, we characterized the temporal structure of proximity bouts. The natural rhythm of proximity may resemble that of a periodic clock, a random series of events, or a bursty structure with peaks and lulls. We used Goh and Barabási (2008) burstiness formula and the adaptation of the formula developed for finite timeseries (Kim and Jo, 2016) to distinguish between these possibilities (Fig. 2). The formula (Fig. 2B) is based on the time distance between the offset of each proximity bout (Fig. 2A, shown in red) and the onset of the adjacent proximity bout (shown in green) to produce a B value (i.e., the burstiness parameter) ranging from −1 to +1 for each dyad's timeseries (Fig. 2C). For each dyad, the mean and standard deviation of the distribution of offset-to-onset timespans was calculated to apply the formula for burstiness. Burstiness values close to −1 correspond with *periodic* timeseries, in which timespans between events are equal; values around 0 with *random* timeseries, in which timespans are independent of one another and do not follow a predictable sequence; and values close to +1 with *bursty* timeseries, which combine "lulls" (i.e., timespans between proximity events that are long, defined as equal or longer than the 75th percentile of timespans[1]) and "bursts" of proximity (i.e., timespans between events that are short, defined as shorter than the 75th percentile of timespans). We tested the degree to which proximity bouts were *not random* by comparing observed B values against randomly generated timeseries matched on the frequency for each timeseries using traditional linear models.

2.4.2. Quantifying changes to mother-infant language exchanges during proximity

Measures of mother speech to infants (i.e., word tokens and word types per hour) and infant vocal production (i.e., babbles per hour and word utterances per hour) were calculated for each dyad when within arms reach and out of arms reach and normalized by dividing the raw number of events by the time spent (in an hour unit) within and out of arms reach, respectively. For example, if an infant was within arms reach for 60 min out of the 90-minutes-long observation and the infant produced 80 utterances containing a word during the observation (50 while within arms reach and 30 while out of arm reach) the frequency of infant word utterances per hour was 53.3 (i.e., 80/1.5 hr) overall; 50 (50/1 hr) when within arms reach; and 60 (30/0.5 hr) when out of arms reach. Descriptive statistics summarized unadjusted measures of mother speech and infant vocal productions occurring when dyads were proximal to each other and when not.

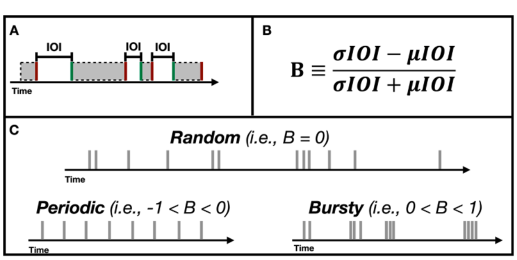

Fig. 2. Quantifying the temporal structure of proximity. (A) The first four episodes of proximity depicted over time (x-axis) with onsets represented by green lines and offsets represented by red lines. The length of the episodes (dotted lines) represents the duration of episodes. Timespans (denoted with IOI) measure the time distance between the offset of each proximity bout and the onset of the next proximity bout. (B) The mean and standard deviation of the distribution of timespans (i.e., IOIs) between proximity episodes are used in Goh & Barabasi's formula of Burstiness. (C) Burstiness values help to distinguish between "Periodic", "Random", and "Bursty" temporal structures, depicted by the onsets-offsets of proximity bouts in each timeline.

Linear mixed models examined the effect of proximity on mother and infant language while adjusting for infant age and sociocultural group. Model assumptions (i.e., linearity, no outliers, no multicollinearity, random normally distributed residuals) were validated for all models predicting mother language measures. Measures of infant language were transformed with the square root to meet assumptions for linear mixed models (i.e., linearity, no outliers, no multicollinearity, random normally distributed residuals). All analyses were conducted in R, version 4.1.0. Alpha was set to.05 for all analyses.

Model selection was carried out using likelihood ratio tests between nested models (Yu, 2015), and we report the best-fitting, most parsimonious model. Models with maximal random structure were fit (Barr et al., 2013) by specifying first random intercepts for infants and then random slopes for proximity if the model converged. Furthermore, an interaction term between proximity and sociocultural group was specified for all models to examine whether the effects of proximity on mother speech or on the two types of infant vocal productions differed between groups. Likewise, an interaction term between proximity and infant age was specified for all models to examine whether the effects of proximity differed by infants' age. Each term was retained in the final model if it improved model fit relative to a model without the term (as described in Results).

The relative change in mother speech/infant vocal production when within reach versus when out of reach was calculated by dividing each normalized measure of language when within arms reach by the same measure when out of reach. For example, if the frequency of mother word tokens was 3000 per hour when within arms reach and 1500 per hour when out of arms reach, the ratio was 2 (i.e., 3000/1500). This ratio quantified the degree to which language measures changed proportionately for both groups (i.e., a relative change with respect to language when out of arms reach for each group). Linear regression models were specified to predict the ratios from the sociocultural groups after adjusting for infant age. These analyses tested whether the relative change in mother speech/infant vocal production differed between sociocultural groups. The outcome (i.e., ratio) was log-transformed to meet assumptions for the model.

3. Results

3.1. Proximity at home is variable and bursty across samples

Both samples showed a dynamic ebb-and-flow of proximity. Fig. 3A and B illustrate 20 randomly selected timelines of Non-Hispanic and Hispanic dyad's proximity bouts over the course of the visit respectively, with each block representing a proximity bout. Proximity occurred in short bouts. On average, Non-Hispanic dyads entered proximity 38.79 times per hour ($SD = 12.19$, $Range = 18.5–66.17$) and the duration of proximity bouts followed a right-skewed distribution (Fig. 4A); Hispanic dyads on average entered proximity 36.02 times ($SD = 16.98$, $Range = 7.85–89.32$) and the duration of proximity bouts followed a right-skewed distribution (Fig. 4B). Most bouts of proximity were short ($Mdn = 16.86$ s for Non-Hispanic and $Mdn = 13.72$ s for Hispanic dyads), with longer bouts pulling the average proximity bout to a duration of 61.95 s for Non-Hispanic and 52.34 s for Hispanic dyads. For example, the longest bout in the Non-Hispanic sample lasted 37 min in which a mother fed the baby, changed the baby's diaper, and played with books and toys. The longest bout in the Hispanic sample lasted 26 min, in which the mother fed the baby, watched television, and played with toys. Aggregating across the visit, Non-Hispanic dyads were proximal 65 % of the visit ($SD = 12$ %, $Range = 32–95$ %) and Hispanic dyads were proximal 52 % of the visit ($SD = 22$ %, $Range = 3–91$ %).

Delving deeper into the timing of proximity events, timespans from offset-to-onset between bouts of proximity followed a right-skewed

[1] According to the 75th percentile split of timespans used in the literature (e.g., Slone et al., 2023), "long" timespans were defined as lasting 39 s or more, whereas "short" timespans as lasting less than 39 s

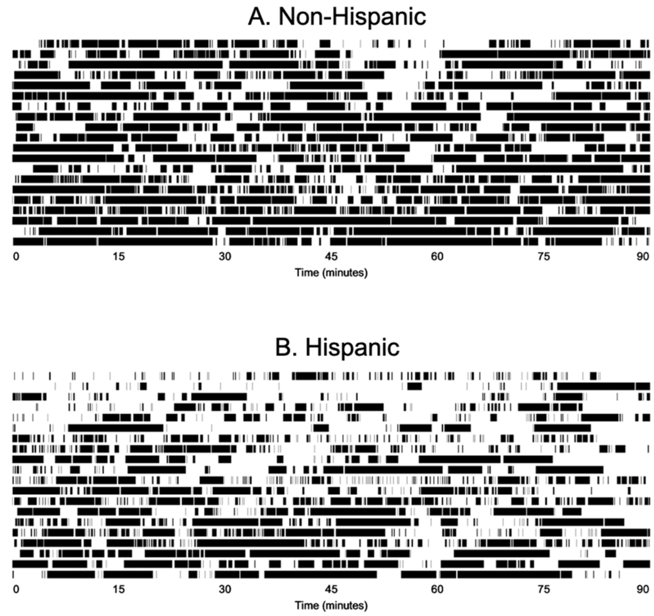

Fig. 3. Proximity timelines in two samples depicting bouts of proximity across time for randomly selected individual dyads. (A) timelines for twenty Non-Hispanic dyads, (B) timelines for twenty Hispanic dyads. Black bars denote bouts of physical proximity between the mother and the infant. Timelines in each panel are ordered from least to most time spent in proximity.

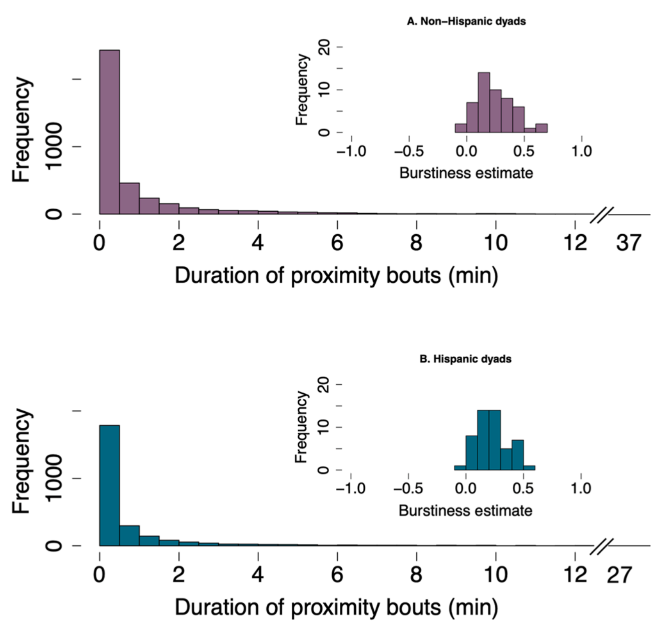

Fig. 4. Duration of proximity bouts and Burstiness estimates for Non-Hispanic (A) and Hispanic dyads (B). The x-axis breaks in A and B after 12 min and extends until the end of each distribution (i.e., 37 and 27 min, respectively).

distribution in both samples; the median timespan between proximity bouts was 12.53 s and 19.43 s for Non-Hispanic and Hispanic dyads, respectively. Few long breaks pushed the mean up to 31.84 s and 49.06 s for Non-Hispanic and Hispanic dyads, respectively. Finally, the frequency of "long breaks" per hour (i.e., timespans $\geq$39 s, the 75th percentile) varied among Non-Hispanic dyads from 0.50 to 17.6 bouts ($M = 7.94$, $Mdn = 8.28$, $SD = 3.41$), and among Hispanic dyads from 2.42 to 20.97 bouts ($M = 10.04$, $Mdn = 9.52$, $SD = 4.59$).

The temporal structure of proximity in Non-Hispanic and Hispanic dyads was bursty, with many short timespans between proximity bouts being separated by several lulls (i.e., long timespans between proximity bouts). For Non-Hispanic dyads, the average burstiness estimate was 0.24 (Fig. 4A) for bouts of proximity ($SD = 0.16$, $Mdn = 0.22$, $Range = -0.08$ to 0.63), which significantly differed from burstiness estimates of simulated random temporal structures ($M = 0.00$, $SD = 0.07$), $t(49) = 10.5$, $p < .001$, 95 % CI [0.20, 0.30].[2] For Hispanic dyads, the average burstiness estimate for proximity bouts 0.22 (Fig. 4B) ($SD = 0.15$, $Mdn = 0.21$, $Range = -0.08$ to 0.59), which also differed from burstiness estimates of simulated random temporal structures ($M = -0.01$, $SD = 0.09$), $t(49) = 10.49$, $p < .001$, 95 % CI [0.19, 0.28][2].

3.2. Proximity is associated with high and lexically diverse infant-directed speech

We next tested whether mothers' speech differed in amount and lexical diversity when within arms reach to the infant compared to when out of reach. Overall, mothers produced hundreds of word tokens and types per hour, although mothers in both samples varied greatly (Table 1). The last column of Table 1 shows the focus of this analysis: change (i.e., difference scores) in the language production of each individual mother when within arms reach compared to when out of reach.

3.2.1. Proximity amplifies mothers' total words across samples

We tested the absolute difference in the frequency of mother word tokens per hour in the context of proximity in a linear mixed model (Table 2, Fig. 5A). A main effect of sociocultural group revealed that Non-Hispanic mothers produced more word tokens per hour than did Hispanic mothers ($B = -663.45$, $p = .004$, large effect size, 95 % CI [-1102.87 to -224.03]). Infants' age did not significantly predict mother word tokens per hour ($p = .052$).[3] As hypothesized, mothers in both samples directed more speech to their infants when within arms reach ($M = 2633.73$) compared to when out of arms reach ($M = 1444.90$; M difference within mother = 1188.83). The average increase in mother word tokens per hour in the context of proximity was $B = 1488.58$ after adjusting for infant age and sociocultural group ($p < .001$, large effect size, 95 % CI [1263.50 – 1713.65]).

A significant interaction between proximity and sociocultural group indicated that the association of proximity and mother word tokens per hour differed between groups ($B = -599.50$, $p < .001$, medium effect size, 95 % CI [-917.81 to -281.19]). To further interpret the interaction, we compared the absolute change (i.e., difference scores) in mothers' word tokens per hour (i.e., word tokens within arms reach per hour minus word tokens beyond arms reach per hour) by sociocultural group (Fig. 5B). The vast majority of Non-Hispanic (N = 49, 98 %) and Hispanic (N = 47, 94 %) mothers produced more word tokens per hour when within arms reach compared to out of arms reach per hour. However, Non-Hispanic mothers produced on average 1488.58 ($SD = 893.26$) more word tokens per hour when close to the infant than when not, whereas Hispanic mothers produced on average 889.08 ($SD = 722.55$) more word tokens per hour when close to the infant than when

[2] A sensitivity analysis investigated if patterns in the full sample of Non-Hispanic and Hispanic dyads replicated in Non-Hispanic and Hispanic participants with at least 50 proximity bouts, respectively, since the recommended minimum number of proximity events to apply the burstiness formula for finite timeseries is 50 (Kim and Jo, 2016). Results replicated in both samples. Average B value for 70 % of Non-Hispanic participants who had at least 50 episodes of proximity was 0.26 ($SD = 0.17$, $Mdn = 0.25$, $Range = -0.07$ to 0.63) and it also differed significantly from the frequency-matched random temporal structures, $t(34) = 9.81$, $p < .001$. The average B value for 46 % of Hispanic participants who had at least 50 episodes of proximity was 0.17 ($SD = 0.13$, $Mdn = 0.17$, $Range = -0.08$ to 0.48) and it also differed significantly from the frequency-matched random temporal structures, $t(22) = 5.74$, $p < .001$.

[3] The interaction between infants' age and proximity (tested separately) was not significant ($p = .100$).

Table 1
Quantity and Lexical Diversity Mothers' Language.

	Measure	Overall	Within arms-reach	Out of arms-reach	Difference score (Within-Out)
Non-Hispanic sample					
Frequency of word tokens	Mean (SD)	2775.69 (1202.88)	3313.80 (1363.09)	1825.22 (1067.76)	1488.58 (893.26)
Frequency word types	Mean (SD)	372.15 (131.68)	512.52 (192.39)	455.03 (194.80)	57.49 (187.03)
Hispanic sample					
Frequency of word tokens	Mean (SD)	1461.11 (1017.16)	1953.65 (1113.27)	1064.57 (858.99)	889.08 (722.55)
Frequency word types	Mean (SD)	244.74 (111.92)	427.04 (247.99)	298.10 (203.61)	128.94 (301.53)

Note. Table shows frequencies per hour at the participant level during the visit (labelled overall), during moments when the infant was within arms reach, and during moments when then the infant was out of arms reach. The last column reports the difference score calculated within participant (i.e., paired data).

Table 2
Frequency of Mother Word Tokens by Proximity, Sociodemographic group, and Age.

	Estimate	SE	df	t	*p*	95 % CI
Intercept	867.41	512.05	99.47	1.69	.094	−130.43 to 1865.25
Proximal (0 =no, 1 =yes)	1488.58	114.89	98.00	12.96	<.001	1263.50 to 1713.65
Hispanic (0 =no, 1 =yes)	-663.45	255.79	125.25	-2.94	.004	−1102.87 to −224.03
Age (months)	54.42	27.72	97.00	1.97	.052	0.40 to 108.44
Proximal: Hispanic	-599.50	162.48	98.00	-3.68	<.001	−917.81 to −281.19

Note. Model specification of fixed and random effects: mother_tokens ~ proximity + Hispanic + infant_age + proximity*Hispanic +(1|infant_id). Beta coefficients represent the estimated change in the frequency of mother word tokens per hour.

not. Thus, there was a greater absolute difference in the sheer number of word tokens per hour in the context of proximity for Non-Hispanic dyads compared to Hispanic dyads.

However, the relative change in words while in proximity per hour (compared to out of arms reach per hour) did not statistically differ between groups. Specifically, Non-Hispanic mothers produced 2.15 times ($SD = 0.91$, $Mdn = 1.93$, $Range = 0.94 – 5.81$) more word tokens per hour when within arms reach ($M = 3313.80$) compared to when out of arms reach ($M = 1825.22$). Hispanic mothers produced 3.04 times ($SD = 4.26$, $Mdn = 1.95$, $Range = 0.65 – 27.01$) more word tokens per hour within ($M = 1953.65$) compared to out of arms reach ($M = 1064.57$). The ratio of increase in word tokens per hour of Non-Hispanic and Hispanic mothers did not differ according to a linear regression model predicting the natural logarithm of the ratio and after adjusting for infants' age ($R^2 = .02$, $F(2, 97) = 1.03$, $B = 0.07$, 95 % CI [−0.15, 0.29], $p = .547$).

3.2.2. Proximity amplifies lexical diversity in mothers across samples

We examined the absolute difference in the frequency of mother word types per hour in the context of proximity in a linear mixed model (Table 3, Fig. 5C). A main effect of sociocultural group revealed that Non-Hispanic mothers produced more word types per hour overall than Hispanic mothers ($B = −104.44$, $p = .003$, medium effect size, 95 % CI [−171.30 to −37.58]). A main effect of infants' age ($B = 9.39$, $p = .040$, medium effect size, 95 % CI [0.59 – 18.18]) indicated that the frequency of mother word types per hour increased with infants' age.[4] As hypothesized, mothers in both samples produced more word types when within arms reach ($M = 469.78$) compared to when out of arms reach ($M = 376.57$; M difference within mother = 93.21). The average increase in mother word types per hour in the context of proximity was $B = 93.21$ after adjusting for infant age and sociocultural group ($p < .001$, medium effect size, 95 % CI [43.56 – 142.87]).

Notably, the interaction between proximity and sociocultural group (tested separately) was not significant ($p = .157$).[5] Most Non-Hispanic (N = 32, 64 %) and Hispanic (N = 38, 76 %) mothers produced more word types per hour when within arms reach compared to when out of reach. Specifically, Non-Hispanic mothers produced on average 57.49 ($SD = 187.03$) more word types per hour when close than when not, and Hispanic mothers produced on average 128.94 ($SD = 301.53$) more word types per hour when close than when not (Fig. 5D).

The relative change in mother word types per hour in the context of proximity differed between sociocultural groups. Non-Hispanic mothers produced 1.26 times ($SD = 0.47$, $Mdn = 1.12$, $Range = 0.49 – 2.69$) more word types per hour when within arms reach ($M = 512.52$) compared to when out of arms reach ($M = 455.03$), whereas Hispanic mothers produced 2.59 times ($SD = 4.59$, $Mdn = 1.40$, $Range = 0.47 – 33.43$) more word types per hour when close ($M = 427.04$) than when not ($M = 298.10$). Thus, the ratio of change in the context of proximity was significantly greater for Hispanic mothers compared to Non-Hispanic mothers according to a linear regression model predicting the natural logarithm of the ratio and adjusting for infants' age ($R^2 = .06$, $F(2, 97) = 3.27$, $B = 0.32$, 95 % CI [0.07, 0.57], $p = .014$).

To delve deeper into the language that mothers produced in the context of proximity, we analyzed the degree of overlap between the word types produced when within arms reach versus out of arms reach. Most word types that appeared out of arms reach also appeared within arms reach in both groups (Fig. 6). In contrast, a large proportion of word types that mothers said when within arms reach were not said when beyond arms reach. Thus, infants were exposed to more new (unique) word types when close than when not close.

3.3. Proximity is associated with frequent infant utterances containing words

We examined whether two types of infant vocal production—the frequency of utterances that contained babbles and the frequency of utterances that contained words—differed when within arms reach of mother compared to when out of reach. Overall, infants produced hundreds of utterances and vocalizations per hour, although infants in both samples varied greatly (Table 4). The last column of these tables shows the focus of analyses: change (i.e., difference scores) in vocal production (calculated separately for babbles and words) at the level of individual infants when proximal versus not proximal.

[4] The interaction between infants' age and proximity (tested separately) was not significant ($p = .597$).

[5] A sensitivity analysis examined the effect of an outlier in the Hispanic group with a frequency of word types per hour of proximity of 1754. Results demonstrated that the main pattern of results reported with the full sample remained the same when the outlier was removed.

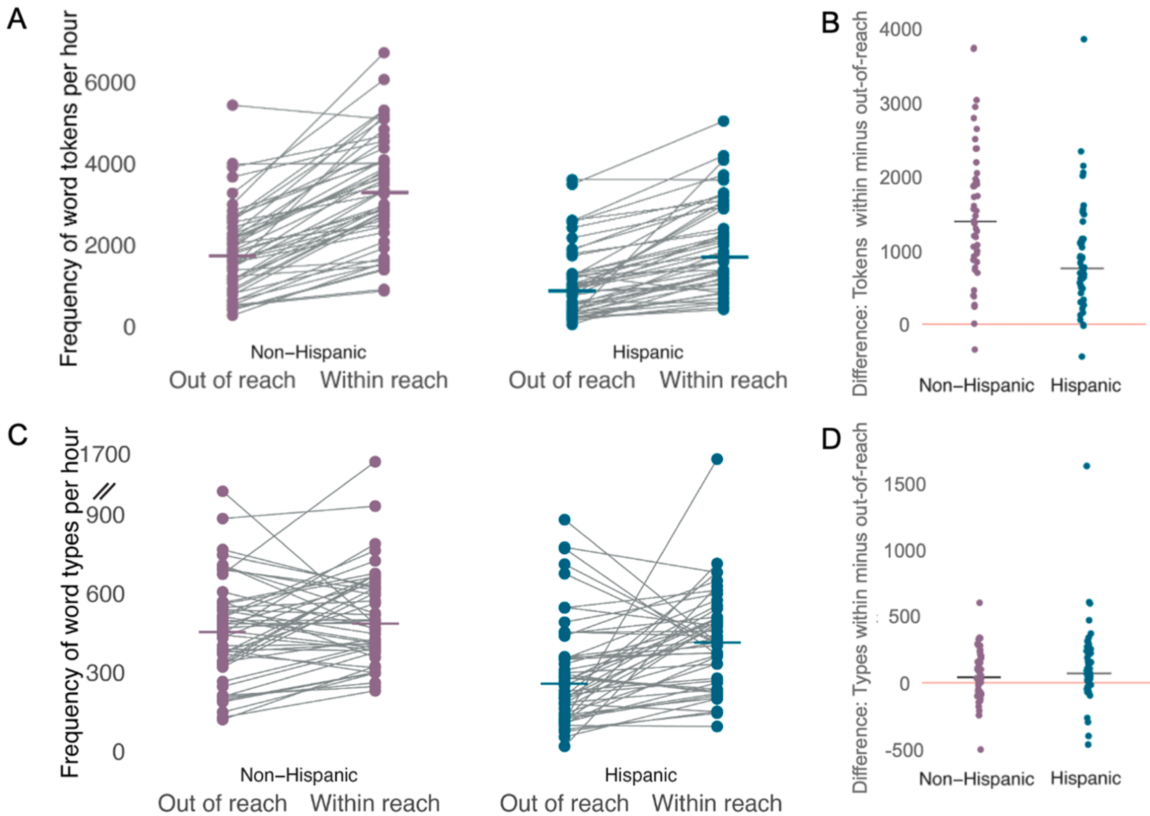

Fig. 5. Mother language when within arms reach and when out of arms reach for Non-Hispanic and Hispanic dyads. Mothers produced more word tokens per hour within arms reach than out of arms reach (A); Difference scores in word tokens per hour for Non-Hispanic and Hispanic mothers in which the zero line signifies no change (B); Mothers produced more word types per hour within arms reach than out of arms reach (C- y-axis cuts off at 900); Difference scores in word types per hour for Non-Hispanic and Hispanic mothers in which the zero line represents no change. Each pair of dots (A & C) or dot (B and D) represents one mother. A sensitivity analysis was conducted to examine the effect of the outlier in the Hispanic group with a frequency of word types per hour of proximity of 1754 on the overall pattern of results. Results remained the same when removing the outlier.

Table 3
Frequency of Mother Word Types by Proximity, Sociodemographic group, and Age.

	Estimate	SE	df	t	*p*	95 % CI
Intercept	271.97	83.81	101.49	3.25	.002	108.65 to 435.29
Proximal (0 =no, 1 =yes)	93.21	25.22	99.00	3.70	<.001	43.56 to 142.87
Hispanic (0 =no, 1 =yes)	-104.44	34.31	97.00	-3.04	.003	−171.30 to −37.58
Age (months)	9.39	4.51	97.00	2.08	.040	0.59 to 18.18

Note. Model specification of fixed and random effects: mother_types ~ proximity + Hispanic + infant_age +(1|infant_id). Beta coefficients represent the estimated change in the frequency of mother word types per hour.

3.3.1. Utterances containing babbles do not differ by proximity across samples

We tested the absolute difference in the frequency of infant babbles per hour in the context of proximity in a linear mixed model (Table 5, Fig. 7A). A main effect of sociocultural group revealed that Non-Hispanic infants produced more babbles per hour than did Hispanic infants ($B = -3.96$, $p = .002$, a small effect size, 95 % CI [−6.34 to −1.57]). Infant age was not a significant predictor of infant babbles per hour ($p = .520$). Unexpectedly, the key analysis—the difference in babbling by proximity—indicated a significant decrease in the frequency of infant babbles per hour when within arms reach ($M = 113.28$) relative to when out of arms reach ($M = 123.21$) for both groups (M difference within infant = −9.93). The average decrease in the square root of infant babbles per hour during proximity was $B = -3.10$ after adjusting for sociocultural group and infants' age ($p = .003$, small effect size, 95 % CI [−5.12 to −1.08]).

However, the association between proximity and infant babbling changed with infants' age ($B = 0.16$, $p = .008$, small effect size, 95 % CI [0.05 – 0.28]), as indicated in a significant interaction between proximity and age. To further interpret the interaction we analyzed infants' age in three mutually exclusive categories (13mo = 9–13mo; 18mo = 14–18mo; 23mo = 19–24mo) (Fig. 8A). Specifically, the mean change (i.e., difference score: within arms reach per hour minus out of reach per hour) was −19.10 for 13-month-olds; −16.69 for 18-month-olds; and 11.01 for 23-month-olds. Thus, whereas younger infants (i.e., 9-to-18-month-olds) produced more babbles when out of arms reach, older infants (19-to-24-month-olds) were more likely to babble when within arms reach compared to when out of reach.

In a separate model, the interaction between sociocultural group and proximity was not significant ($p = .098$). Similary, the ratio of infant babbles while in proximity per hour (relative to out of arms reach per hour) did not differ between groups. Specifically, Non-Hispanic infants produced on average 1.05 times ($SD = 0.37$, $Mdn = 0.94$, Range = 0.35 – 2.12) more babbles per hour when out of arms reach ($M = 158.05$) compared to when within arms reach ($M = 157.50$). Hispanic infants produced on average 1.23 times ($SD = 1.32$, $Mdn = 0.82$, Range = 0.28 – 5.92) more babbles per hour out of arms reach ($M = 88.38$) compared to

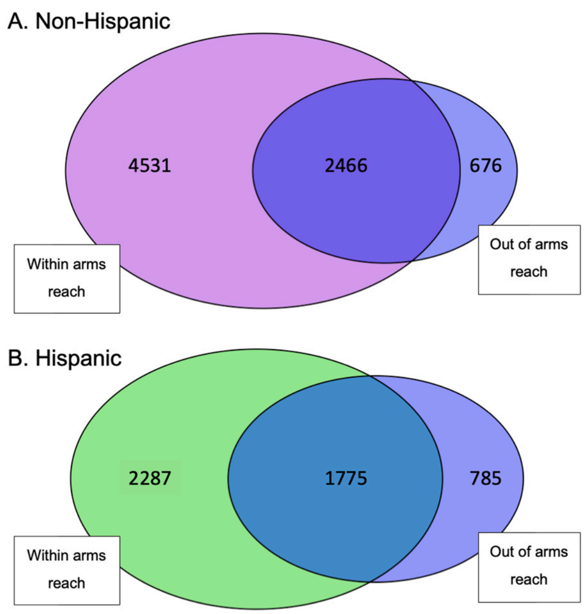

Fig. 6. Word types when within arms reach and outside arms reach aggregated across participants. (A) Number of word types that mothers produced exclusively when within arms reach; exclusively when out of arms reach; and shared words within and outside of arms reach in non-Hispanic dyads. (B) Number of word types that mothers produced exclusively when within arms reach; exclusively when out of arms reach; and shared words within and outside of arms reach in Hispanic dyads.

within arms reach (M = 69.06).[6] The ratio of decrease in babbles per hour during proximity of Non-Hispanic and Hispanic infants did not differ in a linear regression model predicting the natural logarithm of the ratio and after adjusting for infants' age (R^2 =.11, $F(2, 74) = 4.39$, $B = -0.01$, 95 % CI [−0.27, 0.25], $p = .932$).

3.3.2. *Infants produced more utterances with words during proximity across samples*

We examined the absolute difference in the frequency of infant utterances containing words per hour in the context of proximity in a linear mixed model (Table 6; Fig. 7B). A main effect of age revealed that frequency of infant words per hour increased with infants' age (B = 0.66, $p < .001$, small effect size, 95 % CI [0.41 – 0.91]). Sociocultural group did not significantly predict infant words per hour ($p = .546$). As hypothesized, infants of both groups and across all ages produced more utterances containing words when within arms reach (M = 73.39) at a per hour rate than when out of reach (M = 70.70; M difference within-infant = 2.68 per hour). The average increase in the square root of infant words per hour during proximity was $B = 0.42$ after adjusting for sociocultural group and infants' age ($p = .038$, small effect size, 95 % CI [0.03 – 0.82]). Further analysis by age group (Fig. 8B) showed that the mean change (i.e., difference score at a per hour rate) in infant utterances containing a word was −6.79 at 13mo; 5.93 at 18mo; and 8.03 at 23mo. However, the interaction between infants' age and proximity was not significant ($p = .135$).

In a separate model, the interaction between sociocultural group and proximity was not significant ($p = .761$). Similarly, the ratio of infant words while in proximity per hour (relative to out of arms reach per hour) did not differ between groups. Specifically, Non-Hispanic infants produced on average 1.53 times (SD = 1.88, Mdn = 1.09, Range = 0.25 – 12.29) more words per hour when within arms reach (M = 96.86) compared to when out of arms reach (M = 95.43). Hispanic infants produced on average 1.55 times (SD = 1.51, Mdn = 1.23, Range = 0.14 – 8.47) more words per hour within (M = 49.91) compared to out of arms reach (M = 45.98)[7]. The ratio of increase in words per hour of Non-Hispanic and Hispanic infants did not differ according to a linear regression model predicting the natural logarithm of the ratio and after adjusting for infants' age (R^2 =.03, $F(2, 79) = 1.23$, $B = 0.03$, 95 % CI [−0.28, 0.35], $p = .837$).

Table 4
Frequency of Infants' Babbles and Words.

	Measure	Overall	Within arms-reach	Out of arms-reach	Difference score (Within-Out)
Non-Hispanic sample					
Frequency of babbles	Mean (SD)	157.68 (123.62)	157.50 (128.49)	158.05 (130.18)	-0.55 (63.55)
Frequency of words	Mean (SD)	94.68 (129.13)	96.86 (129.94)	95.43 (142.15)	1.43 (46.34)
Hispanic sample					
Frequency of babbles	Mean (SD)	76.12 (87.88)	69.06 (82.28)	88.38 (101.78)	-19.31 (58.55)
Frequency of words	Mean (SD)	45.94 (56.67)	49.91 (59.14)	45.98 (58.72)	3.93 (36.31)

Note. Table shows frequencies per hour at the participant level during the visit (labelled overall), during moments when the infant was within arms reach, and during moments when then the infant was out of arms reach. The last column reports the difference score calculated within participant (i.e., paired data).

Table 5
Frequency of Infant Babbles by Proximity, Sociodemographic group, and Age.

	Estimate	SE	df	t	p	95 % CI
Intercept	9.19	3.00	102.88	3.06	.003	3.34 to 15.04
Proximal (0 =no, 1 =yes)	-3.10	1.03	98.00	-3.01	.003	−5.12 to −1.08
Hispanic (0 =no, 1 =yes)	-3.96	1.22	97.00	-3.23	.002	−6.34 to −1.57
Age (months)	0.11	0.16	103.75	0.65	.520	−0.21 to 0.42
Proximal * Age	0.16	0.06	98.00	2.72	.008	0.05 to 0.28

Note. Model specification of fixed and random effects: sqrt(infant_babbles) ~ proximity + Hispanic + infant_age + proximity*age +(1|infant_id). Beta coefficients represent the estimated change in the square root of the frequency of infant babbles per hour.

4. Discussion

Synchrony in the behaviors of infants and mothers—shared gaze, shared actions, shared conversations—supports learning. We expanded the lens of synchrony to the phenomenon of bodies in space to test

[6] Calculated for 96 participants (47 Non-Hispanic) with valid, finite ratios between infant babbles within/out of arms reach.[7] Calculated for 86 participants (42 Non-Hispanic) with valid, finite ratios between infant words within/out of arms reach.

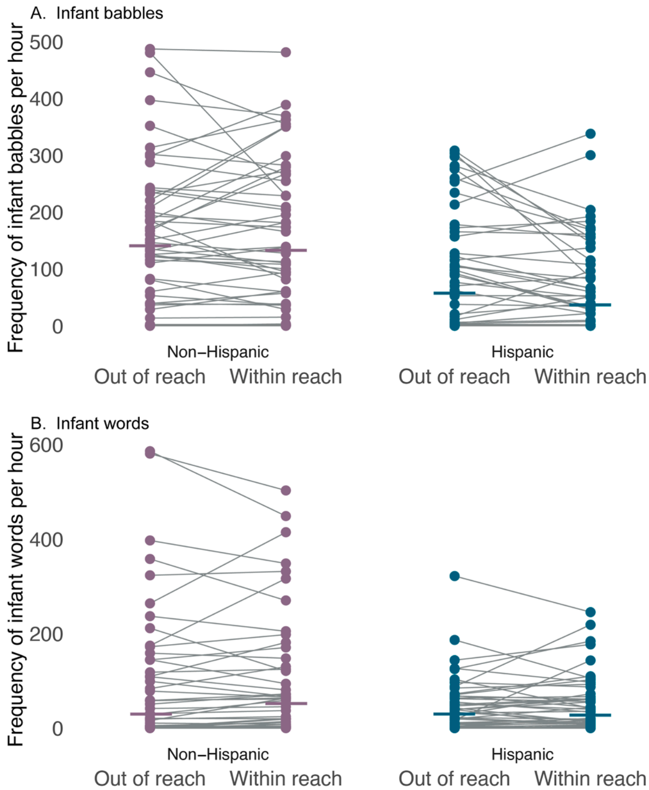

Fig. 7. Infant vocal productions within and out of arms reach for Non-Hispanic and Hispanic infants. (A) Utterances that contained babbles; (B) Utterances that contained words. Infant babbles showed a significant decrease during proximity for both groups; in contrast, infant words showed a significant increase during proximity for both groups, although effect sizes were small.

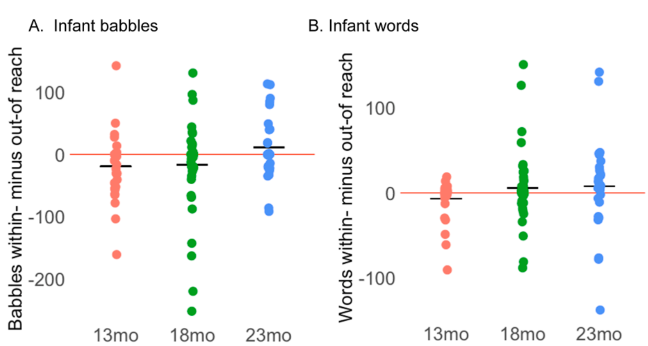

Fig. 8. Difference scores of infant vocal productions within arms reach and beyond arms reach by infant age group. (A) Difference scores for individual infants for babbles (B) Difference scores for individual infants for words. Differences were calculated by subtracting, for each infant, the frequency of word babbles and words per hour when out of arms reach from the frequency of babbles and words per hour when within arms reach, respectively. Positive scores indicate that the infant produced more babbles/words when close to the mother than when not. Scores at 0 signify no change in infant vocal production by proximity. Each dot represents an infant. Whereas younger infants (i.e., 9-to-13-month-olds) produced more babbles when out of arms reach, older infants (i.e., 14-to-18-month-olds and 19-to-24-month-olds) were equally likely to babble when within arms reach compared to when out of reach. Infants in all age groups produced more words within arms reach than out of arms reach (no interaction with age). Effect size was small for the change in infant babbles and infant words.

hypotheses on the temporal structure of proximity and its association to mother speech and infant vocal production. Observations of infants and mothers during everyday activities at home revealed proximity to be bursty, with bouts of proximity coinciding with heightened mother speech and infant word production relative to times when infants and mothers were physically apart. Notably, the role of proximity in infants' vocal productions was specific to words. That is, infants babbled at similar rates when within and out of arms reach, indicating their inclination to practice independent "vocal play" (Long et al., 2022) regardless of mothers' location. We discuss the implications of findings for behavioral synchrony and language development, and possible mechanisms that explain associations; the need to consider behavior in context; and the added value of testing the robustness of phenomena across diverse samples.

Table 6
Frequency of Infant Words by Proximity, Sociodemographic group, and Age.

	Estimate	SE	df	t	*p*	95 % CI
Intercept	-4.41	2.37	97.35	-1.86	.066	−9.03 to 0.21
Proximal (0 =no, 1 =yes)	0.42	0.20	99.00	2.11	.038	0.03 to 0.82
Hispanic (0 =no, 1 =yes)	-0.59	0.98	97.00	-0.61	.546	−2.51 to 1.32
Age (months)	0.66	0.13	97.00	5.10	<.001	0.41 to 0.91

Note. Model specification of fixed and random effects: sqrt(infant_words) ~ proximity + Hispanic + infant_age +(1|infant_id). Beta coefficients represent the estimated change in the square root of the frequency of infant words per hour.

4.1. The location of bodies in space sets the stage for language input

In two distinct samples, mothers and infants entered and exited proximity in a time-distributed, bursty pattern. Temporal parameters are as critical as other features of experience that are typically studied (i.e., frequencies and durations of events, the proportion of time taken up by an event), and they promise to reveal key insights into mechanisms of learning and development (e.g., Mendoza and Fausey, 2022). The temporal signature of proximity observed here in 100 dyads resembled the bursty temporal structure that characterizes spoken and written human language (Altmann et al., 2012; Altmann et al., 2009; Church and Gale, 1995; Katz, 1996) and infant-directed caregiver speech during play (Slone et al., 2023). This temporal structure may provide infants with ideal levels of uncertainty required for learning (Kidd et al., 2012). Indeed, bursty patterns are particularly helpful for word learning in infants (Slone et al., 2023). Infants could learn to predict the systematic combination of short and long periods between proximity events and adapt by developing a flexible memory capacity that benefits from repetition of a referent or context in bursts before moving into lulls of no proximity to a caregiver.

As hypothesized, mothers talked more and produced richer language when within arms reach of their babies than when out of arms reach. Specifically, the frequency of total words and unique words that mothers produced within arms reach was 1.26–3.04 times greater than the frequency of word tokens and types they produced when out of arms reach. Notably, we replicated the finding that caregiver language increases during proximity in two families (Salo et al., 2021) in a diverse and large sample. Moreover, exploratory analysis of the content of mothers' words when close to their infants indicated that mothers introduced new words that they had not used when beyond arms reach. Such words referred to infant-relevant items and activities (i.e., animals, colors, body parts, whole body verbs, and manual verbs). Closeness of bodies in space may be an ideal platform for language learning.

What mechanism might account for the facilitative effects of proximity on language interactions? Proximity is a form of synchrony that may establish a common ground for mothers to talk about and act on shared referents. By being proximal, mothers may easily share the focus of infant attention and action, and thus enter bouts of joint engagement. Joint engagement is a critical experience for infant learning in which caregivers use multimodal behaviors to engage with the object of infant action (Suarez-Rivera et al., 2019). In this way, proximity supports increased mother language input and thus, infant learning. Future research may inform on the mechanisms through which proximity supports language interactions by delving deeper into the activities and types of interaction that occur during proximity.

Of course, proximity is only a small aspect of infant-caregiver interactions and coordination at other levels also supports human learning. Dyads achieve synchrony at multiple levels—physiological, neural, behavioral—all of which support smooth and coordinated social interactions. Rather than privileging certain types of synchrony over others, synchrony can be viewed as an emerging, dynamic, and multimodal phenomenon between the developing infant and responsive caregiver. Moreover, far from a mother-to-baby effect, proximity is achieved by the dyad. Infants may "lead the dance" by actively creating moments of proximity (Hoch et al., 2021). For example, as infants transition from crawling to walking, they go farther and faster (Adolph and Tamis-LeMonda, 2014) and bring objects to caregivers (Karasik et al., 2011), thereby establishing the physical closeness that facilitates triadic interactions.

4.2. Proximity differentially coincides with infant words versus babbles

Although the association between proximity and language was robust for mothers in both samples, the effect sizes for infant vocal productions were smaller and differed by type of vocal production and infant age. In both samples, infants produced more utterances with words when within arms reach of mother compared to when out of reach, although the small bump to number of words was likely due to the limited vocabularies of infants. The effect translated to an average increase of 2.68 infant utterances containing words per hour when close to mother than when not. With age, the median difference in words per hour increased to over 8 words (albeit a non significant change), perhaps reflecting the intersection between developmental growth in infants' vocabularies and their growing use of language as a communicative tool.

Infants were surprisingly vocal even when they were out of arms reach of mother. In fact, consistent with the view that infants are active learners who self-socialize by generating immense practice with behaviors of all forms (Tamis-LeMonda and Masek, in press), infants in both samples produced as many babbles when nearby versus distant from their mothers. In fact, younger infants produced more babbles per hour when out of arms reach, and older infants were equally likely to produce babbles within and out of arms reach. Notably, infants produced hundred of utterances per hour, which accumulates to massive practice over the course of a day, and aligns with the high prevalence of infant vocal play documented from day-long audio recordings (Long et al., 2022).

4.3. Understanding behavior in context

This study follows the widespread and growing initiative of researchers to move beyond structured tasks into natural contexts to examine real-world, everyday infant behavior. Observations of infants at home lasting from 1 to 2 h (i.e., this study) to up to 13 h (e.g., Salo et al., 2021) yield discoveries not possible in laboratory-based studies. For example, structured tasks fix the proximity of bodies and thus prevent systematic inquiry of the phenomenon. In contrast, in the ecologically-valid home environment, mothers and infants enter and exit proximity dozens of times in a single hour and across two days (Salo et al., 2021). And the location of their bodies in space—that is being within arms of each other—cascade to new opportunities for language input and in turn, infants' production of conventional words. Thus, a complete understanding of learning and development—including how social partners synchronize behaviors from actions to words to location in space—requires studying behavior in the contexts in which it unfolds. The inseparable nature of behavior and environment extends to studies of both humans and animals (Gomez-Marin and Ghazanfar, 2019).

4.4. Testing the robustness of findings

The role of proximity in language interactions replicated in two samples, with rare exception. Although proximity effects were sometimes larger in one group than the other, directions were highly consistent. And although main effects were seen in the amount of language used by mothers and infants, mean levels are independent of patterns of associations. That is, mothers and infants from different cultural communities may differ in the time spent in proximity and amount of language, but the connection between proximity and language maintained across samples, as seen in multiple domains of parenting (Prevoo and Tamis-LeMonda, 2017). Robustness of findings, at least in the families we observed, suggests a distinct feature of human communication. A critical test of learning theories requires moving beyond homogenous samples common to most developmental studies.

4.5. Limitations

Research is needed to validate whether the timescale captured here is representative of proximity seen throughout the day. The length of natural activity in the current study (i.e., 1–2 h) is longer (i.e., 12–24 times) than the standard duration of free-play observations (i.e., 5 min). Nonetheless, 1–2 h may not be representative of a given hour in a 10-hour day. Despite differences in the duration of observations, this study replicated the prior finding that proximity is associated with the quantity of caregiver language and conversational turns between caregivers and infants (Salo et al., 2021). However, proximity may change over the course of a day and dyads may spend up to 100 % of time in proximity during one hour but only 30 % in the next hour. Indeed, dyads fluctuated in bouts of proximity over the course of a day (Salo et al., 2021), as might be expected given longer durations include naps and other types of separation. Thus, future research is needed to empirically test the relevant timescales at which proximity changes and the extent to which individual differences measured within 1–2 h map to individual differences across longer time frames.

Furthermore, Non-Hispanic and Hispanic samples differed in culture, mothers' education, socioeconomic status, and immigration status; thus it is not possible to attribute any differences between samples to a single factor. Future research should consider the cultural and socio-demographic factors that affect different aspects of infant-caregiver interaction. Where possible, samples matched in socioeconomic status, education, and immigration status could be observed to test the effects of cultural differences on proximity and its connections to mother and infant language.

Finally, infant vocalizations were coded to differentiate babbles from words. Nonetheless, other aspects of infant vocal production such as phonological sophistication of babbles and lexical diversity of words (e.g., Goldstein and Schwade, 2008; Oller, 2000; Suarez-Rivera et al., 2022a, 2022b) could yield a deeper understanding of changes to infant language production in the context of proximity to a caregiver.

5. Conclusions

We observed the synchrony of bodies in space in mothers and infants during everyday activities in the home. The natural rhythm of proximity revealed a bursty pattern that amplified infants' exposure to language and production of words—a pattern that replicated across distinct sociocultural groups. As infants move within and beyond arms reach of their mothers, they spontaneously generate opportunities to hear new words and to practice producing words themselves. Nonetheless, infants do not need to be proximal to caregivers to vocalize: Infants engaged in immense, time-distributed practice with babbling, regardless of their location. Independent vocal play, together with heightened language exposure when nearby caregivers, present infants with unique opportunites: They gain extensive practice articulating sounds and producing words while learning about the social affordances of physical proximity for joint engagement and shared language exchanges.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

We have uploaded materials, data, and scripts to Databrary: https://nyu.databrary.org/volume/1445.

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