Child language experience in a Tseltal Mayan village

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Abstract

We analyzed 9–11-hour at-home audio recordings from 10 Tseltal Mayan children between 0;2 and 3;0 to investigate how often they engaged in verbal interaction with others and whether their speech environment changed with age, time of day, household size, and number of speakers present. We found that Tseltal children are not often directly spoken to, that most directed speech comes from adults, and that directed speech does not increase with age. Most of children's directed speech came in the mornings or early evenings, particularly for younger children, and high interactional peaks tended to occur in ~1-minute bursts of turn taking. These findings only partly support previous characterizations of Mayan caregiver-child talk. An initial analysis of children's vocal development suggests that, despite relatively little directed speech, these children develop early language skills on a similar timescale to American English-learning children. Given the present findings, we discuss multiple proposals for how Tseltal children might be efficient learners.

Keywords: Child-directed speech, linguistic input, non-WEIRD, vocal maturity, turn taking, interaction, Mayan

Word count: X

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Introduction

A great deal of work in developmental language science revolves around one central question: what linguistic evidence is needed to support first language acquisition? In pursuing this topic, many researchers have fixed their sights on the quantity and characteristics of speech addressed to children (e.g., Golinkoff, Can, Soderstrom, & Hirsh-Pasek, 2015; Hoff, 2006). In several languages, child-directed speech (CDS[1]) has been demonstrated to be distinct from adult-directed speech (ADS) in that it is linguistically adapted for young listeners (Cristia, 2013; Soderstrom, 2007), interactionally rich (Bruner, 1983; Butterworth, 2003), preferred by infants (Cooper & Aslin, 1990; ManyBabies Collaborative, 2017; Segal & Newman, 2015), and appears to facilitate early word learning (Cartmill et al., 2013; Hoff, 2003; Hurtado, Marchman, & Fernald, 2008; Rowe, 2008; Weisleder & Fernald, 2013). However, ethnographic reports from a number of traditional, non-Western communities suggest that children easily acquire their language(s) even when they are only infrequently directly addressed (Brown, 2011). If so, frequent CDS may not be essential for learning language; just useful for facilitating certain aspects of language development. In this paper we investigate the language environment and early vocal development of 10 Tseltal Mayan children growing up in a community where caregivers have previously been reported to infrequently directly address speech to young children (Brown, 1998b, 2011, 2014).

Child-directed speech

Prior work in Western contexts has shown that the amount of CDS children hear influences their language development; more CDS is associated with faster-growing receptive and productive vocabularies (e.g., Hart & Risley, 1995; Hoff, 2003; Ramírez-Esparza,

[1]Throughout this article, we use "child-directed speech" and "CDS" in the most literal sense: speech designed for and directed toward a child recipient.

García-Sierra, & Kuhl, 2014; Shneidman & Goldin-Meadow, 2012), faster lexical retrieval (Hurtado et al., 2008; Weisleder & Fernald, 2013), and faster syntactic development (Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010). Given that CDS is designed for a child hearer, it is more likely than ADS or other-directed speech to align with the child's attention, and may thereby comparatively facilitate early language development. There are, however, a few significant caveats to this body of work relating CDS quantity and language development.

First, while there is overwhelming evidence linking CDS quantity to vocabulary size, links to grammatical development are more scant (but see Brinchmann, Braeken, & Lyster, 2019; Frank, Braginsky, Marchman, & Yurovsky, in preparation; Huttenlocher et al., 2010). While the advantage of CDS for referential word learning is clear, it is less obvious how it facilitates syntactic learning (see also Yurovsky, 2018). On the other hand, there is a wealth of evidence that syntactic knowledge is lexically specified (e.g., Goldberg, 2003; Lieven, Pine, & Baldwin, 1997), and that, crosslinguistically, children's vocabulary size is one of the most robust predictors of their early syntactic development (Bates & Goodman, 1997; Frank et al., in preparation; Marchman, Martínez-Sussmann, & Dale, 2004)—what is good for the lexicon may also be good for syntax. For now, a direct link between CDS and grammatical development still needs further exploration .

Second, most work on CDS quantity uses summary measures that average over the ebb and flow of the day (e.g., average proportion CDS). In reality, verbal behaviors are highly structured during interaction: while some occur at regular intervals , others occur in shorter, more intense bursts separated by long periods of inactivity . Infants' and adults' vocal behavior is clustered across multiple time scales of daylong recordings (Abney, Smith, & Yu, 2017) and noun and verb use is bursty across languages (Blasi, Schikowski, Moran, Pfeiler, & Stoll, in preparation). Even in experimental settings, two-year-olds have been shown to learn novel words better from a massed presentation of object labels versus a distributed one (Schwab & Lew-Williams, 2016; but see Ambridge, Theakston, Lieven, & Tomasello, 2006).

The existence of multi-scale temporal structure in children's language experience implies new roles for attention and memory in development; more work is needed to know how CDS is distributed over children's daily experiences (Soderstrom & Wittebolle, 2013).

Finally, prior work has typically focused on Western (primarily North American) populations, limiting our ability to generalize effects of CDS quantity (Brown & Gaskins, 2014; Henrich, Heine, & Norenzayan, 2010; Lieven, 1994; M. Nielsen, Haun, Kärtner, & Legare, 2017). While we gain valuable insight by looking at within-population variation (e.g., different socioeconomic groups), we can more effectively find places where our assumptions break down by studying new populations. Linguistic anthropologists working in non-Western communities have long reported that caregiver interaction styles vary immensely from place to place, with some caregivers using little child-directed speech (Brown & Gaskins, 2014; Gaskins, 2006; Lieven, 1994; Ochs & Schieffelin, 1984). Children in these communities reportedly acquire language with "typical"-looking benchmarks. For example, they start pointing and talking around the same time we would expect for Western middle-class infants (Brown, 2011, 2014; Brown & Gaskins, 2014; Liszkowski, Brown, Callaghan, Takada, & De Vos, 2012; but see Salomo & Liszkowski, 2013). These findings have had little impact on mainstream theories of language development, partly due to a lack of directly comparable methods (Brown, 2014; Brown & Gaskins, 2014). If, however, children in these communities do acquire language without delay, despite infrequent CDS, developmental language science would need to re-work current ideas about the precise role of CDS quantity in early language development.

Developmental language research using modern psycholinguistic methods has supported the idea that children in some indigenous, non-Western communities hear very little CDS. Scaff, Cristia, and colleagues (2017; in preparation) estimate based on daylong recordings that Tsimane children, growing up in a forager-horticulturalist population in the Bolivian lowlands, hear maximally ~4.8 minutes of CDS per hour between 0;6 and 3;0 (Cristia et al., 2017; Scaff et al., in preparation; see also Mastin & Vogt, 2016; Vogt, Mastin,

& Schots, 2015).

Shneidman and colleagues (2010; 2012) analyzed speech from one-hour at-home video recordings of children between 1;0 and 3;0 in a Yucatec Mayan and a North American community. Their analyses yielded four main findings: compared to the American children, (a) Yucatec children heard many fewer utterances per hour, (b) a much smaller proportion of the utterances they heard were child-directed, (c) the proportion of utterances that were child-directed increased dramatically with age, matching U.S. children's CDS proportion by 3;0, and (d) most of the added CDS came from other children (e.g., older siblings/cousins). The lexical diversity of the CDS Yucatec Mayan children heard at 24 months—particularly from adult speakers—predicted their vocabulary knowledge at 35 months, suggesting that CDS characteristics still played a role in that non-Western indigenous context.

The current study

We examine the early language experience of 10 Tseltal Mayan children under age 3;0. Prior ethnographic work suggests that Tseltal caregivers do not frequently use CDS until the children themselves begin to actively initiate verbal interactions (Brown, 2011, 2014). Nonetheless, Tseltal children develop language with no apparent delays (Brown, 2011, 2014; Brown & Gaskins, 2014; Liszkowski et al., 2012).[2] We provide more details on the community and dataset in the Methods section. We analyze five basic measures of Tseltal children's language environments including: (a) the quantity of speech directed to them, (b) the quantity of other-directed speech they could potentially overhear, (c) the rate of contingent responses to their vocalizations, (d) the rate of their contingent responses to others' vocalizations, and (e) the duration of their interactional dyadic sequences. We then also roughly estimate the number of minutes per day children spent in "high turn-taking" interaction and outline a basic trajectory for their early vocal development.

Based on prior work, we predicted that Tseltal Mayan children would be infrequently

[2] For a review of comparative work on language socialization in Mayan cultures see Pye (2017).

directly addressed, that the amount of CDS and contingent responses they heard would increase with age, that most CDS would come from other children, and that, despite this, their early vocal development would be on par with Western children. We additionally predicted that children's language environments would be bursty—that high-intensity interactions would be brief and sparsely distributed throughout the day, accounting for the majority of children's daily CDS.

Methods

Corpus

The children in this dataset come from a small-scale, subsistence farming community in the highlands of Chiapas (Southern Mexico). The vast majority of children grow up speaking Tseltal monolingually at home. Nuclear families are typically organized into patrlinieal clusters of large, multi-generation households. More than forty years of ethnographic work by the second author has supported the idea that Tseltal children's language environments are non-child-centered and non-object-centered (Brown, 1998b, 2011, 2014). During their waking hours, infants are typically tied to their mother's back while she goes about her work for the day. When not on their mother's back, young children are often cared for by other family members, especially older siblings. Typically, CDS is limited until children themselves begin to initiate interactions, usually around age 1;0. Interactional exchanges, when they do occur, are often brief or non-verbal (e.g., object exchange routines) and take place within a multi-participant context (Brown, 2014). Interactions tend to focus on appropriate actions and responses (not on words and their meanings), and young children are socialized to attend the events taking place around them (see also de León, 2000, 2011; Rogoff, Paradise, Arauz, Correa-Chávez, & Angelillo, 2003). By age five, most children are competent speakers who engage in daily chores and the caregiving of their younger siblings. The Tseltal approach to caregiving is similar to that described for other Mayan communities (de León, 2011; Gaskins, 1996, 1999; e.g., León, 1998; Pye, 1986; Rogoff et al., 1993, 2003; Shneidman

& Goldin-Meadow, 2012).

The current data come from the Casillas HomeBank Corpus (Casillas, Brown, & Levinson, 2017a; VanDam et al., 2016), which includes daylong recordings and other developmental language data from more than 100 children under 4;0 across two indigenous, non-Western communities: the Tseltal Mayan community described here and a Papua New Guinean community described elsewhere (Brown, 2011, 2014; Brown & Casillas, in press). This Tseltal corpus, primarily collected in 2015, includes recordings from 55 children born to 43 mothers. The participating families typically only had 2–3 children (median = 2; range = 1–9), due to the fact that they come from a young subsample of the community (mothers: mean = 26.3 years; median = 25; range = 16–43 and fathers: mean = 30; median = 27; range = 17—52). On average, mothers were 20 years old when they had their first child (median = 19; range = 12–27), with a following inter-child interval of 3 years (median = 2.8; range = 1–8.5).[3] As a result, 28% of the participating families had two children under 4;0. To our knowledge at time of recording, all children were typically developing. Note that all ages should be taken with a grain of salt because documentation of birthdates in the village is not rigorous. Household size, defined in our dataset as the number of people sharing a kitchen or other primary living space, ranged between between 3 and 15 people (mean = 7.2; median = 7). Although 32.7% of the target children are first-born, they were rarely the only child in their household. Most mothers had finished primary (37%) or secondary (30%) school, with a few more having completed preparatory school (12%) or university (2%; 1 mother); the remainder (23%) had no schooling or did not complete primary school. All fathers had finished primary school, with most completing secondary school (44%) or preparatory school (21%), and two completing a university-level training (5%). While 93% of the fathers grew up in the village where the recordings took place, only 53% of the mothers did because of the way clan membership influences marriage and land inheritance.

We used a novel combination of a lightweight stereo audio recorder (Olympus WS-832)

[3]These estimates do not include miscarriages or children who passed away.

and wearable photo camera (Narrative Clip 1) fitted with a fish-eye lens to track children's interactions over the course of a 9–11-hour period at home in which the experimenter was not present. Ambulatory children wore both devices at once (see Figure 1) while other children wore the recorder in a onesie while their primary caregiver wore the camera on an elastic vest. The camera was set to take photos at 30-second intervals and was synchronized to the audio in post-processing to generate snapshot-linked audio.[4] We used these recordings to capture a wide range of the linguistic patterns children encounter as they participate in different activities over the course of their day (Bergelson, Amatuni, Dailey, Koorathota, & Tor, 2018; Greenwood, Thiemann-Bourque, Walker, Buzhardt, & Gilkerson, 2011; Tamis-LeMonda, Kuchirko, Luo, Escobar, & Bornstein, 2017).

Data selection and annotation

We chose 10 children's recordings based on maximimal spread in child age (0;0–3;0), child sex, and maternal education (see Table 1; all had native Tseltal-speaking parents). We selected one hour's worth of non-overlapping clips from each recording in the following order: nine randomly selected 5-minute clips, five manually selected 1-minute top "turn-taking" clips, five manually selected 1-minute top "vocal activity" clips, and one, manually selected 5-minute extension of the best 1-minute clip (see Figure 2). We created these different subsamples to measure properties of (a) children's *average* language environments ("Random"), (b) their most *input-dense* language environments ("Turn-taking"), and (c) their most *mature vocal behavior* ("Vocal activity").

The turn-taking and high-activity clips were chosen by two trained annotators (the first author and a student assistant) who listened to each recording in its entirety at 1–2x speed while actively taking notes about potentially useful clips. The first author then reviewed the list of candidate clips and chose the best five 1-minute samples for each of the two activity types. Note that, because the manually selected clips did not overlap with the initial

[4] Documentation and scripts for post-processing are available at and https://github.com/marisacasillas/Weave.

Figure 1. The recording vest included an audio recorder in the front horizontal pocket and a camera with a fisheye lens on the shoulder strap.

"random" clip selection, the "true" peak turn-taking and vocal-activity clips for the day could have possibly occurred during the random clips. High-quality turn-taking activity was defined as closely timed sequences of contingent vocalization between the target child and at least one other person (i.e., frequent vocalization exchanges). High-quality vocal activity clips were defined as clips in which the target child produced the most and most diverse spontaneous (i.e., not imitative) vocalizations (see full instructions at https://git.io/fhdUm).

The first author and a native speaker of Tseltal who knows all the recorded families personally jointly transcribed and annotated each clip in ELAN (Wittenburg, Brugman, Russel, Klassmann, & Sloetjes, 2006) using the ACLEW Annotation Scheme (Casillas et al., 2017b). Utterance-level annotations include: an orthographic transcription (Tseltal), a loose

Table 1

Demographic overview of the 10 children whose recordings we sampled.

Age	Sex	Mot age	Mot edu	People in house
0;01.25	M	26	none	8
0;03.18	M	22	preparatory	9
0;05.29	F	17	secondary	15
0;07.15	F	24	primary	9
0;10.21	M	24	secondary	5
1;02.10	M	21	none	9
1;10.03	F	31	preparatory	9
2;02.25	F	17	primary	5
2;08.05	F	28	secondary	5
3;00.02	M	28	primary	6

translation (Spanish), a vocal maturity rating for each target child utterance (non-linguistic/non-canonical babbling/canonical babbling/single words/multiple words), and the intended addressee type for all non-target-child utterances (target-child/other-child/adult/adult-and-child/animal/other-speaker-type). Intended addressee was detemined by using contextual and interactional information from the photos, audio, and preceding/following footage; utterances with no clear intended addressee were marked as "unsure". We annotated lexical utterances as single- or multi-word based on the word boundaries provided by the single native speaker who reviewed all transcription; Tseltal is a mildly polysynthetic language so, on average, there is more than one morpheme per word.[5]

[5]Full documentation, including annotation training materials can be found at https://osf.io/b2jep/wiki/

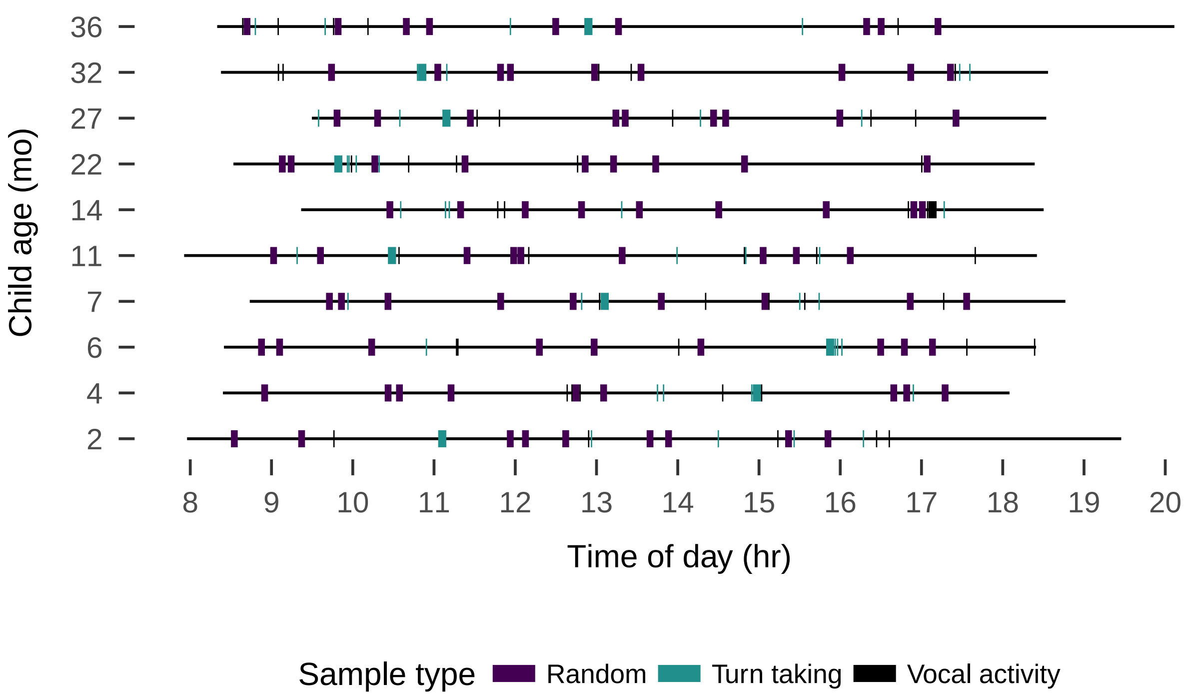

Figure 2. Recording duration (black line) and sampled clips (colored boxes) for each of the 10 recordings analyzed, sorted by child age.

Data analysis

In what follows we first describe Tseltal children's speech environments based on the nine randomly selected 5-minute clips from each child, including: the rate of target-child-directed speech (TCDS min/hr) and rate of other-directed speech (ODS min/hr), the rate of target-child-to-other turn transitions (TC–O transitions/min) and other-to-target-child turn transitions (O–TC transitions/min), and the duration of the target child's interactional sequences. We investigate the effects of child age, time of day, household size, and number of speakers present on each of these five measures. We next repeat these analyses, only this time looking at the high turn-taking clips. We then wrap up with two descriptive analyses: an initial estimate of the amount of time Tseltal children spend in high turn-taking interaction over the course of an entire day and a basic trajectory for early Tseltal vocal development.

home/.

Results

Statistical models

All analyses were conducted in R with generalized linear mixed-effects regressions using the glmmTMB package, and all plots were generated with ggplot2 (M. E. Brooks et al., 2017a; R Core Team, 2018; Wickham, 2009).[6] Notably, all five dependent measures are restricted to non-negative (0–infinity) values. This implicit boundary restriction at zero causes the distributional variance of our measures to become non-gaussian (i.e., with a long right tail). We handle this issue by using a negative binomial linking function in the regression, which estimates a dispersion parameter (in addition to the mean and variance) that allows the model to more closely fit our non-negative, overdispersed data (M. E. Brooks et al., 2017b; Smithson & Merkle, 2013). When, in addition to this, extra cases of zero were evident in the distribution (e.g., TCDS min/hr was zero because children were alone), we also added a zero-inflation model to the regression. A zero-inflation negative binomial regression creates two models: (a) a binary model to evaluate the likelihood of none vs. some presence of the variable (e.g., no vs. some TCDS) and (b) a count model of the variable (e.g., "3" vs. "5" TCDS min/hr), using the negative binomial distribution as the linking function. Alternative analyses using gaussian mixed-effects regressions with logged dependent variables are available in the Supplementary Materials, but are qualitatively similar to the results we report here.

Our primary predictors were as follows: child age (months), household size (number of people), and number of non-target-child speakers present in that clip, all centered and standardized, plus time of day at the start of the clip (as a factor; morning: up until 11:00; midday: 11:00–13:00; and afternoon: 13:00 onwards). We also added two-way interactions between child age and: (a) number of speakers present, (b) household size, and (c) time of day. We also included a random effect of child. For the zero-inflation models, we included number of speakers present. We only report significant effects in the main text; full model

[6] Data and analysis code can be found at https://github.com/marisacasillas/Tseltal-CLE.

outputs are available in the Supplementary Materials.

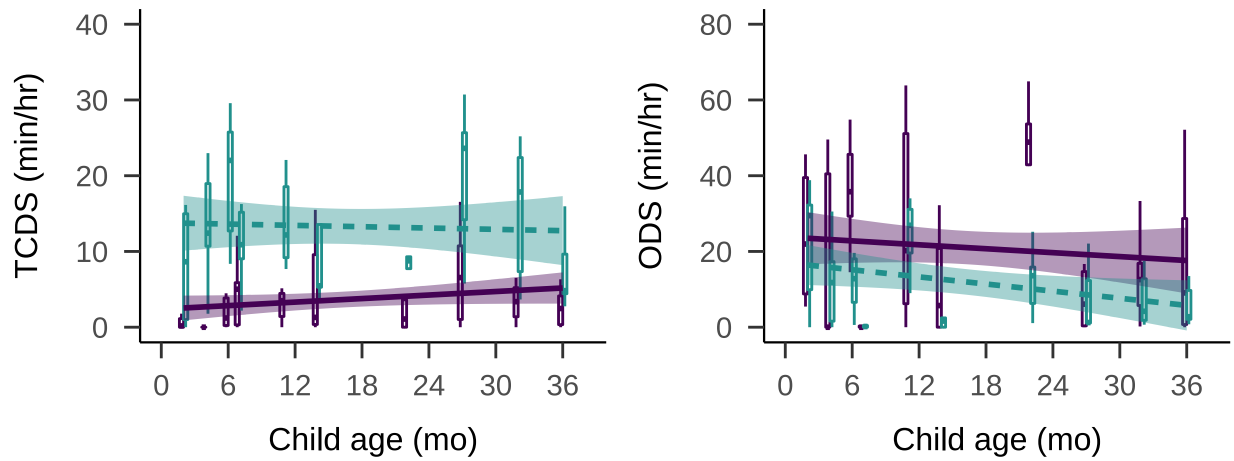

Figure 3. By-child estimates of minutes per hour of target-child-directed speech (left) and other-directed speech (right). Data are shown for the random (purple; solid) and turn taking (green; dashed) samples. Bands on the linear trends show 95% CIs.

Target-child-directed speech (TCDS)

The children in our sample were directly spoken to for an average of 3.63 minutes per hour in the random sample (median = 4.08; range = 0.83–6.55; Figure 3). These estimates are close to those reported for Yucatec Mayan children (Shneidman & Goldin-Meadow, 2012), as illustrated in Figure 4 (see Scaff et al. (in preparation) for more detailed cross-language comparisons).[7] We modeled TCDS min/hr in the random clips with a zero-inflated negative binomial regression. The rate of TCDS in the randomly sampled clips was primarily affected by factors relating to the time of day (see Figure 5). The count model showed that the children were more likely to hear TCDS in the mornings than around midday (B = 0.82, SD = 0.40, z = 2.06, p = 0.04), with no difference between morning and afternoon (p = 0.29) or midday and afternoon (p = 0.19) TCDS rates. Time of day effects varied by age: older children were significantly more likely to hear TCDS at midday (B = 0.73, SD = 0.36, z =

[7]We convert Shneidman (2010)'s utterance/hr estimates to min/hr with the median Tseltal utterance duration for non-target child speakers: (1029ms) because Yucatec and Tseltal are related languages.

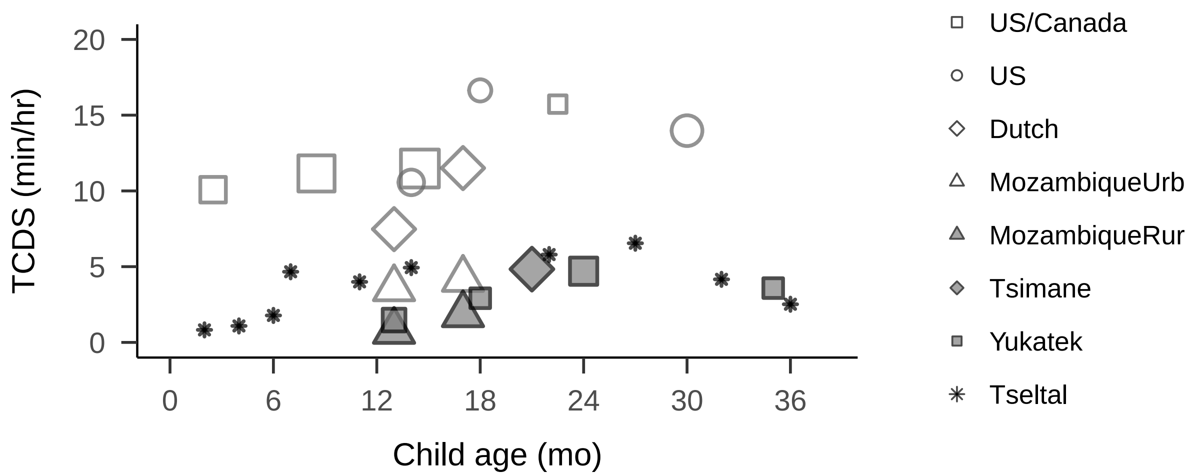

Figure 4. TCDS rates reported from at-home recordings in different populations, including both urban (empty shape) and rural/indigenous (filled shape) samples. Each point shows the average TCDS rate at the indicated age, while size indicates the number of children sampled (range: 1–26). Data sources: Bergelson et al. (2019) US/Canada; Shneidman (2010) US and Yucatec; P. Vogt, Mastin, and Schots (2015) Dutch, Mozambique urban and rural; Scaff et al. (in preparation) Tsimane.

2.04, p = 0.04) and marginally more likely to hear it in the morning (B = 0.46, SD = 0.28, z = 1.65, p = 0.10) compared to the afternoons. Older target children were also significantly more likely to hear TCDS when more speakers were present, compared to younger children (B = 0.61, SD = 0.20, z = 3.06, p = 0.00). There were no significant effects of target child age or household size, and no significant effects in the zero-inflation model.

In contrast to findings from Shneidman and Goldin-Meadow (2012) on Yucatec Mayan, most TCDS in the current data came from adult speakers (mean = 80.61%, median = 87.22%, range = 45.90%–100%), with no evidence for an increase in proportion of TCDS from children with target child age (Spearman's *rho* = -0.29; *p* = 0.42).

Other-directed speech (ODS)

Children heard an average of 21.05 minutes of ODS per hour in the random sample (median = 17.80; range = 3.57–42.80): that is, nearly six times as much speech as was

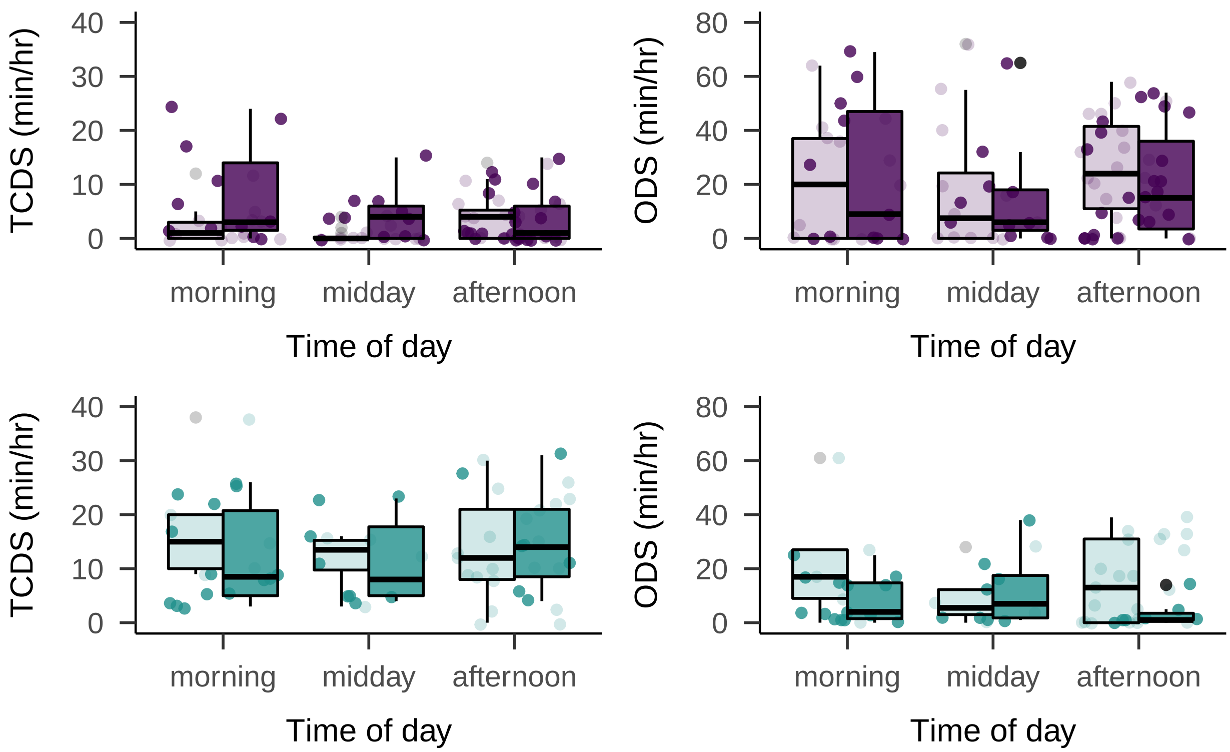

Figure 5. TCDS (left) and ODS (right) rates heard at different times of day in the random (top) and turn-taking (bottom) clip samples by children age 1;0 and younger (light) and 1;0 and older (dark).

directed to them, on average. We modeled ODS min/hr in the random clips with a zero-inflated negative binomial regression. The count model of ODS in the randomly selected clips revealed that the presence of more speakers was strongly associated with more ODS (B = 0.65, SD = 0.09, z = 7.32, p < 0.0001). There were an average of 3.44 speakers present other than the target child in the randomly selected clips (median = 3; range = 0–10), more than half of whom were typically adults. Older target children were also significantly more likely to hear ODS in large households, compared to younger children (B = 0.32, SD = 0.13, z = 2.41, p = 0.02).

Like TCDS, ODS was also strongly affected by time of day (see Figure 5). Compared to midday, target children were significantly more likely to hear ODS in the mornings (B = 0.36, SD = 0.17, z = 2.09, p = 0.04) and marginally more likely to hear it in the afternoons (B =

0.29, SD = 0.16, z = 1.89, p = 0.06), with no significant difference between ODS rates in the mornings and afternoons (p = 0.63). As before, ODS rate varied across the day by target child age: older children were significantly more likely to hear ODS in the afternoon than at midday (B = 0.38, SD = 0.17, z = 2.21, p = 0.03), with no significant differences between afternoon and morning (p = 0.10) or midday and morning (p = 0.63). There were no other significant effects on ODS rate, and no significant effects in the zero-inflation models.

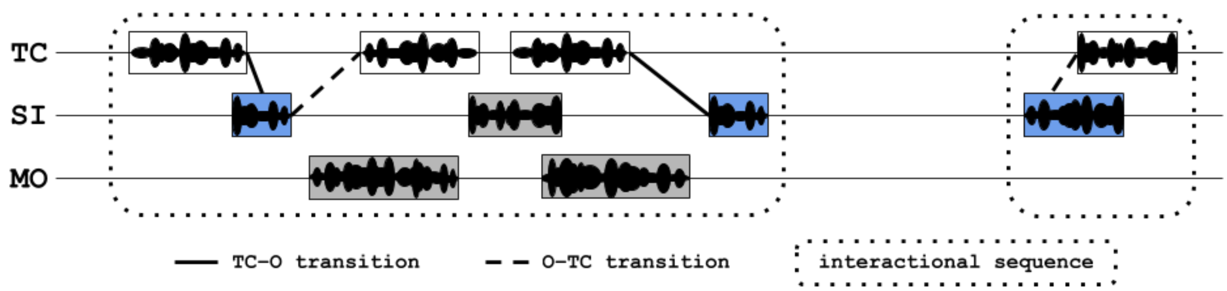

Figure 6. Illustration of an annotated audio clip including the target child (TC), an older sister (SI), and mother (MO). Transitions between the target child and others are marked with solid and dashed lines. Interactional sequences are boxed in with dotted lines. Box color indicates TCDS (blue) and ODS (light gray).

Target-child-to-other turn transitions (TC–O)

Contingent responses by or to the target child are likely to occur at moments in which the child and another speaker are attentionally aligned; the rate at which these responses is an index of the frequency of these joint moments of high-quality linguistic evidence. We measured two types of contingent responses: target-child-to-other and other-to-target-child. We detect these contingent turn transitions based on utterance onset/offset times and the annotations of intended addressee for each non-target-child utterance (Figure 6). If a child's vocalization is followed by a target-child-directed utterance within -1000msec to 2000msec after its end (Casillas, Bobb, & Clark, 2016; Hilbrink, Gattis, & Levinson, 2015), it is counted as a contingent response (i.e., a TC–O transition). We use the same idea to find other-to-target-child transitions (i.e., a target-child-directed utterance followed by a target child vocalization with the same timing restrictions). In our analysis, each target child vocalization can have maximally have one prompt and one response, and each target-child-directed utterance can maximally count once as a prompt and once as a response (e.g., in a TC–O–TC sequence, the "O" is both a response and a prompt). These timing restrictions are broadly based on prior studies of infant and young children's spontaneous turn taking (e.g., M. H. Bornstein, Putnick, Cote, Haynes, & Suwalsky, 2015; T. Broesch, Rochat, Olah, Broesch, & Henrich, 2016; Casillas et al., 2016; Hilbrink et al., 2015).

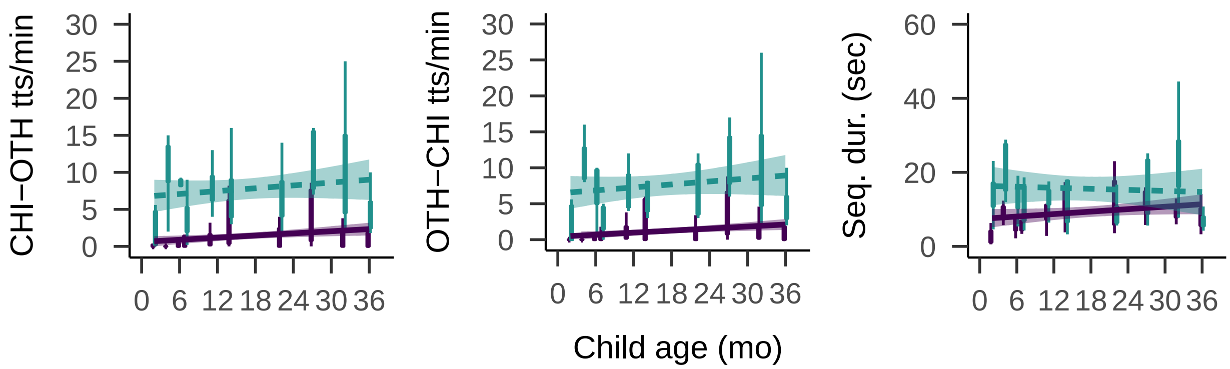

Figure 7. By-child estimates of target-child-to-other contingent responses (left), other-to-target-child contingent responses (middle), and the average duration of interactional sequences (right). Each boxplot represents the variance across clips within the random (dark purple; solid) or turn taking (light green; dashed) samples for each child. Bands on the linear trends show 95% CIs.

Other speakers responded contingently to the target children's vocalizations at an average rate of 1.38 transitions per minute (median = 0.40; range = 0–8.60; Figure 7). We modeled TC–O transtions per minute in the random clips with a zero-inflated negative binomial regression. The rate at which target children heard contingent responses from others was primarily influenced by factors relating to target child age. The rate of contingent responses to target child vocalizations varied across the day by target child age: older children heard significantly more contingent responses around midday (B = 1.08, SD = 0.44,

$z = 2.44$, $p = 0.01$) and in the morning ($B = 0.94$, $SD = 0.37$, $z = 2.51$, $p = 0.01$), compared to the afternoon, with no significant difference between morning and midday ($p = 0.77$). Older target children also heard significantly more contingent responses then younger ones when there were more speakers present ($B = 0.56$, $SD = 0.23$, $z = 2.48$, $p = 0.01$).There were no further significant effects in the count or zero-inflation models.

Other-to-target-child turn transitions (O–TC)

The children in our sample responded contingently to others' target-child vocalizations at an average rate of 1.17 transitions per minute (median = 0.20; range = 0–8.80; Figure 7). We modeled O–TC transtions per minute in the random clips with a zero-inflated negative binomial regression, excluding by-child intercepts of time of day to achieve convergence. The rate at which target children responded contingently to others (O–TC turn transitions per minute) was similarly influenced by child age and time of day: older children responded contingently to others' utterances significantly more often around midday ($B = 1.46$, $SD = 0.46$, $z = 3.13$, $p = 0.00$) and in the morning ($B = 1.33$, $SD = 0.42$, $z = 3.19$, $p = 0.00$), compared to the afternoon, with no significant difference between morning and midday ($p = 0.81$). Overall, older children responded to others' utterances at a marginally higher rate ($B = 1.14$, $SD = 0.66$, $z = 1.74$, $p = 0.08$). Older target children also gave significantly more contingent responses then younger ones when there were more speakers present ($B = 0.52$, $SD = 0.22$, $z = 2.30$, $p = 0.02$).There were no further significant effects in the count or zero-inflation models.

Sequence duration

We defined sequences of interaction as periods of contingent turn taking with at least one target child vocalization and one target-child-directed prompt or response from another speaker. To detect sequences of interaction, we used the same mechanism as before to detect contingent TC–O and O–TC transitions, but also allowed for speakers to continue with multiple vocalizations in a row (e.g., TC–O–O–TC–OTH; Figure 6). We bounded sequences by the earliest and latest vocalization for which there is no contingent prompt or response, respectively. In our analysis, each target child vocalization can only appear in one sequence. We modeled these sequence durations in the random clips with negative binomial regression alone (i.e., with no zero-inflation model). We detected 311 interactional sequences in the 90 randomly selected clips, with an average sequence duration of 10.13 seconds (median = 7; range = 0.56–85.47; Figure 7). The average number of child vocalizations within these sequences was 3.75 (range = 1–29; median = 3). None of the predictors significantly impacted sequence duration (all *p* &ge 0.21).

Peak interaction

As expected, the high-quality turn taking clips featured a much higher rate of contingent turn transitions: the average TC–O transition rate was 7.73 transitions per minute (~5.5x the random sample rate; median = 7.80; range = 0–25) and the average O–TC rate was 7.56 transitions per minute (~6.5x the random sample rate; median = 6.20; range = 0–26). The interactional sequences were also slightly longer on average: 12.27 seconds (~1.2x the random sample rate; median = 8.10; range = 0.55–61.22). Crucially, children also heard much more TCDS in the turn-taking clips—13.28 min/hr (nearly 4x the random sample rate; median = 13.65; range = 7.32–20.19)—while also hearing less ODS—11.93 min/hr (nearly half the random sample rate; median = 10.18; range = 1.37–24.42).

We modeled each of these speech environment measures with parallel models to those used for the random sample above, though with no zero-inflation model for TCDS, TC–O, and O–TC rates because extra-zero clips (e.g., due to no other speakers being present) do not exist in the turn-taking clips. Overall, the factors impacting the five speech environment measures look rather different when focusing on interactional peaks instead of randomly sampled clips (see Figures 3, 5 and 7). In what follows, we briefly highlight differences between the random and turn-taking samples with respect to the influence of time of day and number of speakers present. Full model outputs are available in the Supplementary

Materials.

Time-of-day effects were consistently weaker in the turn-taking sample: interactional peaks tend to be similar across different hours of the daylong recording. In the random sample, TCDS and ODS rates both showed strong time-of-day effects, including an overall dip in both speech types at midday, and interactions between time of day and age. In contrast, TCDS rates in the turn-taking sample show no time-of-day effects or interactions between time-of-day and age, and ODS rates *do* show a dip, but later in the day (i.e., afternoon, not midday; afternoon-vs.-midday: B = 0.70, SD = 0.29, z = 2.39, p = 0.02, afternoon-vs.morning: B = 0.72, SD = 0.25, z = 2.91, p = 0.00). Older children were also significantly more likely to hear ODS around midday compared to the morning (B = -0.56, SD = 0.28, z = -1.99, p = 0.05). In fact, the trend for ODS in the turn-taking sample is a dip around midday for younger children and a peak around midday for older children. Interestingly, older children also heard significantly less ODS than younger children in the turn-taking sample (B = -0.45, SD = 0.21, z = -2.19, p = 0.03), suggesting that older children may have different ODS experiences, distributed differently over the day. These findings also demonstrate that older children in the turn-taking sample had the highest TCDS:ODS ratio in our dataset. We see some shift in time-of-day effects for contingent response behavior as well. Whereas contingent response rates (TC–O and O–TC) in the random sample showed significant dips in the afternoon hours for older children, there were no time-of-day effects at all in the turn-taking sample. Running counter to this overall pattern, sequence duration in in the turn-taking sample showed significant time-of-day effects not found in the random sample: sequences were significantly longer in the afternoon compared to morning and midday (afternoon-vs.-morning: B = -0.32, SD = 0.15, z = -2.12, p = 0.03; afternoon-vs.-midday: B = 0.38, SD = 0.15, z = 2.61, p = 0.01).

Effects relating to the number of speakers present were also somewhat weaker in the turn-taking sample, though inconsistently. In the random sample, older children heard more TCDS, and participated in more contingent responses (both TC–O and O–TC) when more speakers were present, but this effect did not hold up in the turn-taking sample on any of the three measures. On the other hand, the number of speakers present was associated with significantly more ODS in both the random and turn-taking samples (random sample: B = 0.71, SD = 0.11, z = 6.63, $p < 0.001$), suggesting that the number of speakers is a robust predictor of ODS quantity across different contexts.

Peak minutes in the day. Now knowing the interactional timing characteristics of the "high" turn-taking clips, we looked for similarly temporally-contingent 1-minute sections of interaction in the random samples in order to estimate the number of high interactivity minutes in the whole day. To do this, we scanned each 60-second window (e.g., 0–60 sec, 1–61 sec, etc.) of each random clip and recorded the observed turn-transition rate. We then compared the resulting 1-minute transition rates to those typical for the high turn taking sample.

Only 6 of the 10 children showed at least one minute of their random sample that equalled or exceeded the average contingent transition rate (12.89 transitions/min), and 7 of the 10 children showed at least one minute equalling or exceeding their *own* average turn transition rate from their turn-taking sample. Across the 6 children who did show turn-taking "peaks" in their random data, peak periods were relatively long, at an average of 88.95 seconds (median = 90.67 seconds; range = 71–103 seconds). Assuming approximately 14 waking hours (Hart & Risley, 1995), we therefore very roughly estimate that the Tseltal child spends an average of 116.85 minutes (1.95 hours) in high turn-taking, dyadic interaction during their day. Importantly, however, the range in the quantity of high turn-taking interaction varies enormously across children, starting at just a few minutes per day and topping out at more than 489.69 minutes (8.16 hours) in our sample. Much more data, particularly from other Tseltal children in this age range, is required to get a stable estimate of peak minutes in the day.

Vocal maturity

Tseltal children's vocalizations appear to follow the normative benchmarks for productive speech development, as typically characterized by the onset of new production features. Decades of research in post-industrial, typically Western populations has shown that, typically, children begin producing non-canonical babbles around 0;2, with canonical babbling appearing sometime around 0;7, first words around 1;0, with first multi-word utterances appearing just after 1;6 (Fine & Lieven, 1993; Frank et al., in preparation; P. K. Kuhl, 2004; Slobin, 1970; Tomasello & Brooks, 1999; Warlaumont & Finnegan, 2016; Warlaumont, Richards, Gilkerson, & Oller, 2016). These benchmarks are mirrored in the Tseltal children's vocalizations, which are summarized in Figure 9 based on all annotated vocalizations from the random, turn-taking, and high vocal activity samples (N = 4725 vocalizations). There is a decline in the use of non-canonical babble and an accompanying increase in the use of canonical babble from 0;6 to 1;0. Recognizable words are observed for every child from age 11;0 and older. Multi-word utterances appear in all recordings at 1;2 and later, making up 45% of the oldest child's (3;0) vocalizations.

These data are also consistent with usage statistics of speech-like vocalizations by English-acquiring infants (Oller, 1980; Warlaumont & Finnegan, 2016; Warlaumont et al., 2016). Between 2 and 14 months, these Tseltal children demonstrated a large increase in the proportion of speech-like vocalizations (canonical babbling and lexical speech): from 9% before 0;6 to 58% between 0;10 and 1;2. Around age 1;0, their use of speech-like vocalizations (58%) is nearly identical to that estimated by Warlaumont et al. (2016) for American children around age 1;0 in a variable SES sample (~60%).[8]

Discussion

We analyzed 10 Tseltal Mayan children's speech environments in order to estimate how often they have the opportunity to attend and respond to speech directed to them. We also

[8]Speech-like vs. non-speech-like comparisons are limited to age 1;6 in the ACLEW Annotation Scheme.

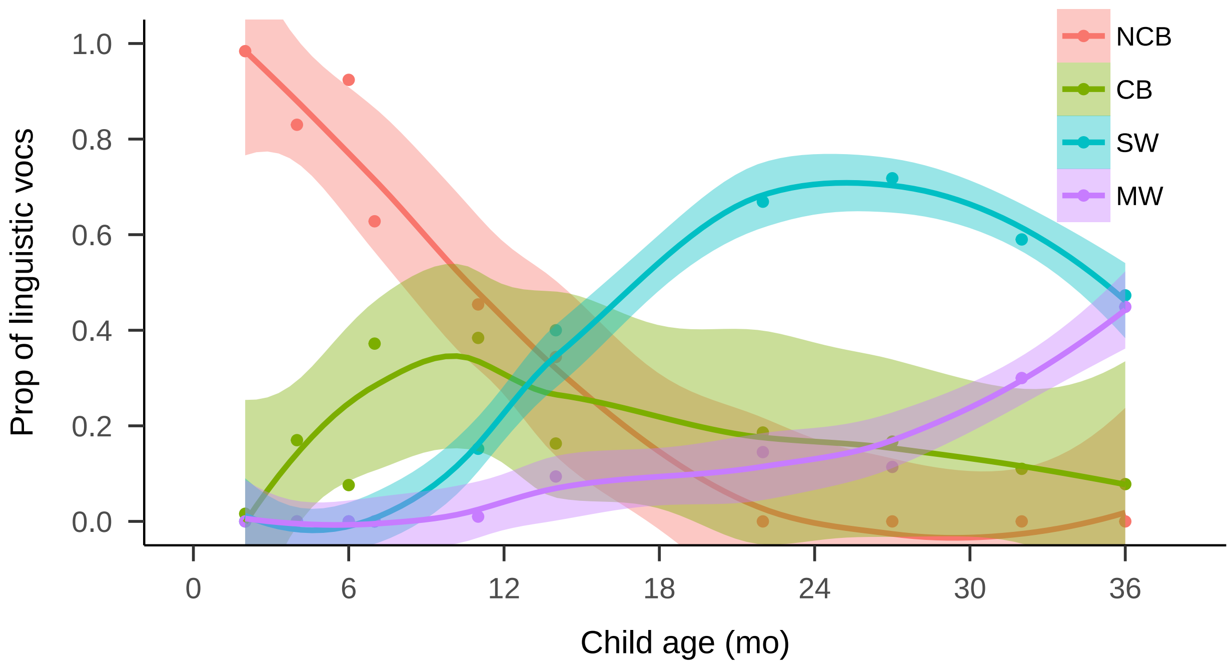

Figure 8. Proportion of vocalization types used by children across age (NCB = Non-canonical babble, CB = Canonical babble, SW = single word utterance, MW = multi-word utterance).

investigated how these speech environment characteristics changed (or stayed stable) across different ages, household sizes, time of day, and number of speakers present. To achieve representative estimates, we sampled audio segments randomly from each child's daylong recording, but we show that most of the same general patterns hold up during the "peak" turn-taking moments of the day as well. Finally, we roughly estimated the number of "high interactivity" minutes Tseltal children encounter on a typical day and demonstrated that, despite the relatively small quantity of CDS, children's early vocal development was on-par with norms built from WEIRD children's data. These findings, which use a new methodology (i.e., daylong recordings with multiple sample types), partly replicate estimates of child language input and development in previous ethnographic and psycholinguistic work on Yucatec and Tseltal Mayan communities (Brown, 1997, 1998c, 2011, Tseltal: 2014; Shneidman, 2010; Yucatec: Shneidman, Arroyo, Levine, & Goldin-Meadow, 2012). In what follows we briefly review each of the predictions made at the outset of the paper.

How much directed speech do Tseltal children hear?

The bulk of our analyses were aimed at understanding how much speech Tseltal children hear: we wanted to know how often they are directly spoken to and how often they might be able to listen to other-directed speech around them. As suggested by prior work, the children were only infrequently directly spoken to: an average of 3.63 minutes per hour in the random sample. Compared to other studies based on daylong recordings, the Tseltal average TCDS rate is approximately a third of that found for North American children (Bergelson et al., 2019), but is comparable to that for Tsimane children (Scaff et al., in preparation). The CDS estimates also fall almost precisely in-line with those based on short-format recordings in a Yucatec Mayan village (Shneidman, 2010; Shneidman et al., 2012).

A novel contribution of this study is that we also included interactive measures to describe how often children were directly engaged with an interlocutor, either as a responder or as an addressee being responded to. We found that children's vocalizations were responded to at a rate of 1.38 speaker transitions per minute and that children responded to others' child-directed vocalizations at a rate of 1.17 transitions per minute. Prior work from a number of different domains suggests that contingent interaction (and the joint attention that likely accompanies it) is an ideal context for language learning since the child and interlocutor's coordinated attentional states decrease referential uncertainty, are a source of dynamic feedback, and can spur more interactions in the near future (M. H. Bornstein et al., 2015; T. Broesch et al., 2016; Romeo et al., 2018; Warlaumont & Finnegan, 2016; Warlaumont et al., 2016). Because our measure is a novel one, we cannot directly compare Tseltal children's data with those of children growing up in other communities. That said, 1.38 and 1.17 transitions per minute suggests that contingent responses—more so than speech directly addressed to the child—are rare across children's day. Importantly, however, this may be due to the fact that children did not vocalize very often.

Preliminary analyses of children's vocal maturity showed that, on average, children only produced 472.50 vocalizations (many of which were crying, laughter, and non-canonical babble) during the entire 1-hour of clips sampled from their daylong recordings. This explanation resonates with the fact that, despite the low frequency of contingent turn-taking in the random sample, interactional sequences were fairly long: 10.13 seconds. During these long sequences, children tended to only vocalize 3.75 times, meaning that many of children's dyadic interactional sequences are marked by longer streams of directed input from another speaker, interspersed with only occasional responses from the child. Interactional peaks with contingent turn-taking *do* occur in the data, only rarely; our rough estimate is that Tseltal children participate in approximately 100.16 minutes of such interaction during a 12-hour waking day, most of which come in bursts of ~53 seconds long.

In sum, our results confirm prior claims that Tseltal children, like other Mayan children, are not often directly spoken to. When they are, much of their speech comes in interactional sequences in which children only play a minor part—directly contingent turn transitions between children and their interlocutors are relatively rare. However, we estimate that the average child under age 3;0 experiences more than one cumulative hour of high-intensity contingent interaction with CDS per day. If child-directed speech quantity linearly feeds language development (such that more input begets more output), then the estimates presented here would lead us to expect that Tseltal children are delayed in their language development, at least relative to North American children. However, our initial analyses of early vocal development suggest that Tseltal children, though they may not vocalize often, demonstrate vocal maturity comparable to children from societies in which CDS is known to be more frequent (Braine & Bowerman, 1976; Fine & Lieven, 1993; Frank et al., in preparation; P. K. Kuhl, 2004; Oller, 1980; Tomasello & Brooks, 1999; Warlaumont & Finnegan, 2016; Warlaumont et al., 2016). How do Tseltal children manage this feat?

Other-directed speech. One proposal is that Mayan children become experts at learning from observation during their daily interactions (de León, 2011; Rogoff et al., 2003; Shneidman, 2010; Shneidman et al., 2012), thereby bridging the "gap" otherwise left by the lower rate of CDS. In the randomly selected clips, children were within hearing distance of other-directed speech for an average of 21.05 minutes per hour. That is substantially more than the ~7 minute per hour heard by North American children (Bergelson et al., 2019), but comparable to the ~10 minutes per hour heard by Tsimane children (Scaff et al., in preparation). The large quantity of other-directed speech is likely due to the fact that Tseltal children (like Tsimane children) tend to live in households with more people compared to North American children (Bergelson et al., 2018).

In our data, the presence of more speakers was associated with significantly more other-directed speech, both based on the number of individual voices present in the clip and on the number of people living in the household (for younger children). In comparison, children also heard more CDS when more speakers were present, but the effect was much weaker (0.2440 vs. 1.05622 more minutes per hour per speaker unit). This finding rings true with Brown's (2011, 2014) claim that Tseltal is a non-child-centric language community; the presence of more people somewhat increases talk to the child but really primarily increases talk amongst the other speakers. However, given that this increase in the number of speakers and amount of talk is also associated with an increase in the amount of overlapping speech (Cristia, Ganesh, Casillas, & Ganapathy, 2018), we suggest that attention to other-directed speech is at least not the only learning mechanism needed to explain the robustness of early vocal development in Tseltal. Furthermore, just because speech is hearable does not mean children are attending to it. Follow-up work on the role of other-directed speech in children's speech development would need to clarify what constitutes viable "listened to" speech by the child.

Increased CDS with age. Another possibility is that CDS increases rapidly with child age (and vocalization competence). Combined with the idea that very early vocalizations follow a relatively species-specific, pre-programmed path that is then modulated by caregiver response and other factors (Oller, 1980; Oller, Griebel, & Warlaumont, 2016; Warlaumont & Finnegan, 2016; Warlaumont et al., 2016), a dramatic increase in directed speech with age might be expected. In her longitudinal studies of Yucatec Mayan children, Shneidman (2012) found that CDS increased significantly with age, from 55 utterances in an hour to 209 between 13 and 35 months. Her analyses show that most of the increase in CDS comes from other children speaking to the target child. Her findings are consistent with other reports that Mayan children are more often cared for by their older siblings from later infancy onward (2011, 2014). In our data, however, age effects were limited, and CDS from children was relatively rare (~10%) all the way up through age 3;0.

Child age alone had very little overall effect on the speech environment measures. In the random sample it was, at most, associated with marginal increases in TC–O transition rate, O–TC transition rate, and sequence duration. All other significant effects involving age related to the time of day measure, which is discussed below.

The non-increase in CDS with age may be due to the fact CDS from other children was infrequent in our data (cf. Shneidman & Goldin-Meadow, 2012). The relative lack of CDS may be due to the fact that: (a) the children were relatively young and so spent much of their time with their mothers, (b) these particular children did not have many older siblings, and (c) in the daylong recording context more adults were present to talk to each other than would be typical in a short-format recording (the basis for previous estimates). We conclude, from these findings, that an increase in CDS cannot explain the robust pattern of Tseltal vocal development either.

Learning from short periods of interaction. A third possibility is that these children learn effectively from short, routine language encounters. Bursty input appears to be the norm across a number of linguistic and interactive scales (e.g., Abney et al., 2017; Blasi et al., in preparation), and experiment-based work suggests that children can benefit from massed presentation of new information (Schwab & Lew-Williams, 2016). We propose two mechanisms through which Tseltal children might capitalize on the distribution of speech input in their environment: they experience most language input during routine activities and they can consolidate experienced input during the downtime between interactive peaks. Neither of these mechanisms are proposed to be particular to Tseltal children, but might be employed to explain their efficient learning.

Tseltal children's linguistic input is not uniformly distributed over the day: all five measures of children's linguistic environment were more likely to occur in the mornings and late afternoons than around midday, though younger children showed this pattern more robustly than older children. We had predicted a dip in linguistic input around midday because household members tend to disperse after breakfast to do their daily work before returning for another late afternoon meal. Young children, who are typically carried by their mothers for the majority of the day, followed this pattern more strongly than older children, who may have been more free to seek out interactions between mealtimes. A similar midday dip has been previously found for North American children's daylong recordings (Greenwood et al., 2011; Soderstrom & Wittebolle, 2013), suggesting that non-uniform distributions of linguistic input may be the norm for children in a variety of different cultural-economic contexts. Our paper is the first to show that those time of day effects change with age in the first few years on a number of speech environment features (TCDS, TC–O transitions, O–TC transitions, and (marginally) ODS).

Our impression from having transcribed these data is that the time of day effects likely arise from the activities that typically occur in the mornings and late afternoons—meal preparation and dining times in particular—while napping could contribute to the midday dip (Soderstrom & Wittebolle, 2013). Indeed, time of day effects in daylong recordings at Canadian homes and daycares were substantially weakened when naptimes were excluded from the analysis (Soderstrom & Wittebolle, 2013). However, in the same Canadian data, the highest density speech input came during storytime and organized playtime (e.g., sing-alongs, painting), while mealtime was associated with less speech input. We expect that follow-up research which tracks activities in the Tseltal data will lead to very different conclusions: storytime and organized playtime are vanishingly rare in this non-child-centric community, and mealtime may represent a time of routine and rich linguistic experience. In both cases, however, the underlying association with activity (not hour) implies the possibility for action routines that may help children optimally extract information about what they will encounter and what they are expected to do in response, even over short periods (Bruner, 1983; Ferrier, 1978; tamis2018routine; Nelson, 1985; Shatz, 1978; Snow & Goldfield, 1983).

A more speculative possibility is that Tseltal children learn language on a natural input-consolidation cycle: the rarity of interactional peaks throughout the day may be complemented by an opportunity to consolidate new information. Sleep has been shown to benefit language learning tasks in both adults (Dumay & Gaskell, 2007; Frost & Monaghan, 2017; Mirković & Gaskell, 2016) and children (Gómez, Bootzin, & Nadel, 2006; Horváth, Liu, & Plunkett, 2016; Hupbach, Gomez, Bootzin, & Nadel, 2009; Williams & Horst, 2014), including word learning, phonotactic constraints, and syntactic structure. Our impression, both from the recordings and informal observations made during visits to the community, is that young Tseltal children take frequent naps, particularly at younger ages when they spend much of their day wrapped within the shawl on their mother's back. Mayan children tend to pick their own resting times (i.e., there are no formalized "sleep" times, even at bedtime Morelli, Rogoff, Oppenheim, & Goldsmith, 1992), and Mayan mothers take special care to keep infants in a calm and soothing environment in the first few months of life (Brazelton, 1972; e.g., de León, 2000; Pye, 1992; E. Z. Vogt, 1976). There is little quantitative data on Mayan children's daytime and nighttime sleeping patterns, but one study estimates that Yucatec Mayan children between 0;0 and 2;0 sleep or rest nearly 15% of the time between morning and evening (Gaskins, 2000), again, at times that suited the child (Morelli et al., 1992). If Tseltal children's interactional peaks are bookended by short naps, it could contribute to efficient consolidation of new information encountered. How often Tseltal children sleep, how deeply, and how their sleeping patterns may relate to their linguistic development is an important topic for future research.

Limitations and Future Work

The current findings are based on a cross-sectional analysis of only 10 children. From each child, we have manually only analyzed a total of 1 of the 9–11 recording hours. The findings only take into account verbal input; the photo-linked audio we produce is not sufficient to analyze gaze and gestural behavior (Brown, 2014). In short, more data, and more kinds of data are needed to enrich this initial description of Tseltal children's early language environments. We have also used vocal maturity as an index of linguistic development in the current study, but further analysis of these children's receptive and productive lexical, morphological, and syntactic knowledge, including experiment and questionnaire based measures that build on past linguistic work (Brown, 1997, 1998b, 1998c, 1998a, 2011, 2014; Brown & Gaskins, 2014) is needed to establish trajectory of early language development in Tseltal (Casillas et al., 2017a). To fully understand the extent to which language learning mechanisms are shared across ethnolinguistically diverse samples we cannot simply continue to compare developmental benchmarks. More promising long-term approaches include a focus on how within-community differences and/or cross-linguistic differences for related languages drive variation in learning (e.g., Pye, 2017; Weisleder & Fernald, 2013). The current analyses are based on a corpus that is under active development. As new data are added, up-to-date versions of the same analyses will be available on the same page where the current data and analysis scripts can be found: ADD-URL.

Conclusion

Based on the current data, we estimate that Tseltal children hear an average of 3.6 minutes of directed speech per hour. Contingent turn-taking is relatively rare throughout their day, and high-intensity interactive input comes in short bursts, typically in the mornings and early evenings for younger children. Despite this relatively small quantity of directed speech, Tseltal children's vocal maturity looks on-track with estimates based on WEIRD populations, in which children typically experience more child-directed speech. Our findings by and large replicate the descriptions put forth by linguistic anthropologists who have worked with Mayan communities for many decades. The real puzzle is then how Tseltal children efficiently extract information from their linguistic environments. We reviewed several proposals and outlined directions for future work. In our view, a promising avenue for continued research is to more closely investigate the activity/time-of-day effects and a possible input-consolidation cycle for language exposure in early infancy. By better understanding how Tseltal children learn language, we hope to uncover some of the ways in which human learning mechanisms are adaptive to the thousands of ethnolinguistic environments in which children develop.

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