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A Naturalistic Home Observational Approach to Children's Language, Cognition, and Behavior

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Although early life experiences of language and parenting are critical for children's development, large home observation studies of both domains are scarce in the psychological literature, presumably because of their considerable costs to the participants and researchers. Here, we used digital audio-recorders to unobtrusively observe 107 children, aged 2.03 to 3.99 years ($M = 2.77$, $SD = 0.55$), and their families over 3 days ($M = 15.06$ hr per day, $SD = 1.87$). The recording software estimated the total number of words that a child heard over the course of a day. In addition, we transcribed six 5-min excerpts per family (i.e., 30 min overall) to extract estimates of children's and their parents' lexical diversity, positive and critical parenting, and children's internalizing and externalizing behaviors. We found that home language input (i.e., number of words and lexical diversity) was positively associated with children's cognitive ability and lexical diversity but not with their behaviors. In addition, we observed that home language input varied as much within as between families across days (intraclass correlation = .47). By comparison, parenting predicted children's behavioral outcomes but was not related to their cognitive or lexical ability. Overall, our findings suggest that home language input affects child development in cognition and language, while positive and parenting informs their behavioral development. Furthermore, we demonstrated that digital audio-recordings are useful tools for home observation studies that seek to disentangle the complex relationships between early life home environments and child development.

Keywords: home observation, language, parenting, cognitive development, lexical diversity

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Home language input and parenting behaviors are two key characteristics of the family home environment that shape children's early life experiences (Hart & Risley, 1995; Stein et al., 2013), although they are typically studied in independent research contexts and samples. Home language input refers to the quantity and quality of children's exposure to adult speech in the family home, including speech from parents and other caregivers. Home language input has been previously associated with the development of children's verbal and cognitive abilities (Hart & Risley, 1995; Hoff, 2003; Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010). Likewise, parenting behaviors, such as responsiveness, warmth, and stimulation, have been shown to be associated with children's cognitive and also their behavioral development (Merz et al., 2016; Stein et al., 2013). However, these earlier findings about the relationship between parental input and children's development were based on either brief home observations that lasted no longer than 1 hr or on observations of instructed interactions between parents and children, often in laboratory settings. The reason for the scarcity of extensive home observation studies is their extremely high costs (Mehl, 2017): Trained researchers had to visit each family home, carry out observations—often using handheld audio-recorders (e.g., Hart & Risley, 1995), transcribe and code observations, which typically takes eight times as long as the actual recording duration, and conduct reliability tests on the transcripts and coding (Margolin et al., 1998). As a result, studies that relied on home observations typically tested small samples with 50 and fewer families, who were recorded for relatively short time periods, ranging from 1.5 min to 1.5 hr at a time (Hart & Risley, 1995; Rowe, 2012; Wells, 1985; Table 1).

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Table 1
Home Observational Studies of Families' Language Use

Authors	Sample *n*	Child age at Time 1	Assessment method	Assessment duration	Mean adult word count estimates (*SD*) range
Christakis et al., 2009	329	2 to 48 months	LENA audio recordings	Daylong once a month for an average of 8 months (range, 1 to 24 months)	Per day **12,976** (6,051)
Gilkerson et al., 2017	82	36 months	LENA audio recordings	12 hours	Per day **12,990** (6,025)
Greenwood et al., 2011	30	12 to 21 months	LENA audio recordings	12 hours a day, 1 to 3 times a week, for 10 months	Per day **13,142** (5,562), range 631 to 36,563
Hall et al., 1984	39	54 to 60 months	Audio recordings	10 × 15 minutes × 2 days = 5 hours in total per child	Per hour for middle-class **2,383**; working-class **1,840**
Hart et al., 1995	42	7 to 12 months	Audio recordings	60 minutes each month, for 23 to 30 months (mean = 28 months)	Per hour for professionals **2,153**, range 1,019 to 3,504; working-class **1,251** range 143 to 3,618; welfare **616** range 231 to 947
Hoff, 2003	63	16 to 31 months	Video recordings	43 minutes at time 1; no time estimate given for follow-up assessment 10 weeks later	Per 43 minutes for high SES **2,165.12** (833); mid SES **1,570.40** (538)
Huttenlocher et al., 2007[a]	50	14 months	Video recordings	90 minutes every four months × 4 to 5 visits	Per 90 minutes, 20 mean estimates reported, range 1,563 to 4,093
Pan et al., 2005[b]	108	14 months	Video recordings	3 × 10 minutes, 10 to 12 months apart	Per 10 minutes, 3 mean estimates reported, range 505 to 638
Ramírez-Esparza et al., 2014	26	10 to 24 months	LENA audio recordings	8 hours a day, for 4 consecutive days	Across 4 days **31,111.51** (9,886), range 16,591 to 56,224
Rowe, 2008	47	31 months	Video recordings	90 minutes	Per 90 minutes **3,768** (1,936), range 696 to 7,673
Rowe, 2012	50	18 months	Video recordings	90 minutes, once a year for 3 years	Per 90 minutes **3,523** (1,951), range 360 to 9,227
Zimmerman et al., 2009	275	2 to 48 months	LENA audio recordings	12 hours a day, once a month for 6 months	Per day **12,800** (4,400)

Note. Home observational studies were identified that included a monolingual English child aged 60 months or under, used unstructured activities and reported adult word counts. Average adult word count estimates (i.e., means) are shown in bold, and refer to periods of observations reported in original papers (e.g., per day). *SD*s (shown in parentheses) and range of adult word counts are reported where available. In papers where mean word counts were reported only for subsamples (e.g., working-class), the table lists the available estimates for all groups.
[a] Huttenlocher et al. (2007) reported adult word counts for 5 child ages (14-, 18-, 22-, 26- and 30-months) and 4 education classes. [b] Pan et al. (2005) reported adult word counts for 3 child ages (14-, 24- and 36-months), to maintain accessibility of the table these are not reported in full.

Furthermore, the physical presence of a researcher to operate the audio or video equipment may trigger observer reactivity, with the recordings not being truly representative of families' natural language and behavior (Dudley-Marling & Lucas, 2009; Gardner, 2000).

Here we overcome these limitations of traditional home observation studies with a digital recording technology, known as the Language Environment Analysis (LENA) system (LENA Research Foundation, 2012). The LENA system is comprised of digital language processors (DLPs) that are worn in custom-made children's clothing and record all sounds within a 6-ft radius. This technology facilitated observing language and parenting in 107 families across 3 full days, which is the largest family home observational study to date.

Quantity of Home Language Input

The quantity of adult speech (i.e., the number of words spoken) that children experience is one important factor in their own language acquisition (Hoff, 2003; Rowe, 2012). Table 1 provides an exhaustive list of studies that were (a) observational; (b) conducted in the family home; (c) collected naturalistic observations, without instructed activities or play; (d) with monolingual English children aged up to 5 years; and (e) reported adult word counts. Overall, seven studies relied on traditional video- ($n = 5$) and audio-recordings ($n = 2$), while five studies used LENA's digital audio-recordings. Across studies, sample sizes varied from 26 to 329, and recording durations ranged from 10 min to 12 hr per observation. Average reported adult word counts per hour ranged from 972 to 3,021 words. In addition, a public repository of day-long naturalistic audio-recordings exists (Home Bank; Vandam et al., 2015), as does an extensive corpus of early language experience from a single child (Human Speechome Project; Roy, Frank, DeCamp, Miller, & Roy, 2015), which are not reviewed here.

The best-known study on the effect of the linguistic home environment for child development is Hart and Risley's (1995), in which trained researchers visited the homes of 42 families once a month for 28 months, starting when the focal child was aged 9 months. The families were audio-recorded, with a researcher following the study child for 1 hr per month at a time that was convenient for, and selected by, the parents, using a hand-held tape recorder and microphone. Data from the hour-long recordings was then extrapolated under the assumption that verbal communication within families is fairly consistent across 14 hr per day. Based on these estimates, Hart and Risley (1995) proposed that children from welfare families hear just over 8,600 words per day, while working class children hear 17,500 words and high-class children over 30,000. If we translate these daily estimates into yearly ones, the so-called "30 million word gap" emerges (Hart & Risley, 1995; Radesky, Carta, & Bair-Merritt, 2016): By the age of 4 years, children from welfare families hear just under 13 million words from adults, while high socioeconomic status (SES) children hear over 52 million words during the same time period. Although associations between family background and home language input had also been reported elsewhere (e.g., Hall, Nagy, & Linn, 1984), the dramatic disparities in adult word counts documented by Hart and Risley (1995) carried the gravitas to reach the general public, as well as clinicians, charities, and teachers, and to inspire numerous interventions (e.g., Radesky et al., 2016). However, an attempt to replicate Hart and Risley's findings of the vast differences in language environments by SES group was not successful and instead highlighted the large variation in adult word counts within SES groups (Sperry, Sperry, & Miller, 2018).

More recent studies have used the LENA system to observe language in samples of 30 to 329 American families (Christakis et al., 2009; Gilkerson et al., 2017; Greenwood, Thiemann-Bourque, Walker, Buzhardt, & Gilkerson, 2011; Zimmerman et al., 2009), who were representative in SES of the United States, specifically of the population in Kansas, where Hart and Risley (1995) had also collected their data. The families' word counts ranged from 12,800 to 13,142 words over the course of a 12-hr day (Christakis et al., 2009; Gilkerson et al., 2017; Greenwood et al., 2011; Zimmerman et al., 2009). These figures suggest that Hart and Risley (1995) overestimated the quantity of daily adult speech that children experience in the family home, if we assume that family language interactions have not substantially changed since the 1980s. Comparable data from other countries, including the United Kingdom, are currently not available to clarify how much adult speech children actually experience.

Previous studies have concluded that the quantity of adult speech that children are exposed to is positively associated with their own language skills. For example, Hart and Risley (1995) found that adult word counts per hour correlated .62 with the number of different words children uttered per hour at 34 to 36 months of age. Corroborating this finding, Hoff (2003) reported a correlation of .21 between the quantity of mothers' and children's words, after adjusting for children's previous vocabulary, by analyzing video-recordings of 63 mother–child dyads during their morning routines when children were aged 16 to 31 months. In another set of video-recordings of daily interactions in 50 families, Rowe (2012) reported correlations of .33, .42, and .37 between the quantity of parents' words and children's vocabulary, assessed by the Peabody Picture Vocabulary Test (PPVT-III; Dunn & Dunn, 1997), at the children's respective ages of 30, 42, and 54 months. The results of studies using the LENA system also support the benefits of the quantity of adult speech for children's linguistic development. In a sample of 275 families with children aged 2 to 24 months, who were audio-recorded for 12 hr once a month for 6 months, Zimmerman et al. (2009) found that a 1,000-word increase in adult speech was associated with a 44% gain in children's language ability, assessed by the Preschool Language Scale (PLS-4; Zimmerman, Steiner, & Pond, 2002). By contrast, Greenwood and colleagues (2011) failed to detect a significant correlation between the quantity of parents' and children's words in a much smaller sample of 30 toddlers aged 12 to 20 months. Likewise, a study involving 10-min video-recordings of 108 mothers with children aged 14 months, observed once annually for 3 years, did not find an association between maternal word quantity and children's growth in the number of different words spoken (Pan, Rowe, Singer, & Snow, 2005), suggesting that the quality rather than the quantity of language input may be more important for children's language growth. This notion was corroborated in a sample of 60 children aged 24 months; the quality of communication accounted for 16.4% whereas the quantity of language input only accounted for 1% of the variance in children's language development 1 year later (Hirsh-Pasek et al., 2015).

The quantity of adult speech is thought to not only benefit children's verbal development but also that of other cognitive abilities. For example, Hart and Risley (1995) reported a positive association between the quantity of adult speech and children's IQ, assessed by the Stanford-Binet Intelligence Scale at 36 months of age. In another study of 26 preterm infants, differences in the quantity of adult speech that the infants experienced at 36 weeks accounted for 26% of the variance in their cognitive scores 10 months later (Caskey, Stephens, Tucker, & Vohr, 2014). Overall, however, the empirical evidence for the link between the quantity of adult speech and children's cognitive abilities is limited and at times contradictory (e.g., Greenwood et al., 2011).

Quality of Home Language Input

The quality of language refers to the diversity, complexity, and richness of speech and is marked by lexical diversity that reflects the number of different words used in a sample of speech—so-called "word types." Words that are morphologically inflected variants (e.g., *car* and *cars, run* and *running*) are considered to be the same word type, whereas different words for the same object (e.g., *bike* and *bicycle*) are treated as different word types (Pan et al., 2005). Other measures of language quality include word sophistication (e.g., rarity of words), word-classes (e.g., verbs, adjectives or nouns), syntactical structure, or even intonation and prosody (Head Zauche, Thul, Darcy Mahoney, & Stapel-Wax, 2016; Malvern, Richards, Chipere, & Durán, 2004; Rowe, 2012). However, lexical diversity is the most valid marker of children's spoken language ability, especially in the context of naturalistic home observations (Durán, Malvern, Richards, & Chipere, 2004; Lai & Schwanenflugel, 2016).

Previous studies suggest that the exposure to lexically diverse adult speech is an important determinant of children's language and cognitive outcomes (Pan et al., 2005; Rowe, 2012). Rowe (2008) video-recorded naturalistic interactions of 47 parent–child dyads at children's age of 30 months. A composite of parental speech, including word counts, word types, mean length of utterance, proportion of directive utterances and D-scores, predicted gains in children's vocabulary size over a 12-month period, accounting for 9.5% of the variance. Huttenlocher et al. (2010) corroborated this finding when they observed 47 families in the home environment for 90 min every 4 months for a total of nine visits that commenced when the child was 14 months old. They concluded that caregivers' word types predicted children's word types 4 months later, although they did not report a standard effect size to make the magnitude of their results comparable. Likewise, a recent integrated review concluded that adult lexical diversity was significantly associated with children's language skills across five prospective cohort studies, but no effect sizes were reported (Head Zauche et al., 2016).

With regard to children's cognitive outcomes other than language, parental lexical diversity has been associated with children's IQ (Hart & Risley, 1995). Substantiating this finding, as part of a larger Family Life Project, researchers measured the lexical diversity of 1,292 mothers during 10-min home observations reading with their children (Burchinal, Vernon-Feagans, Cox, & Key Family Life Project Investigators, 2008). Maternal lexical diversity when children were aged 6 months correlated .16 with children's cognitive skills assessed 9 months later with the Mental Developmental Index (MDI) of Bayley Scales of Infant Development (BSID-II; Bayley, 1993; Burchinal et al., 2008). Overall, previous studies reported positive associations between the lexical diversity of adult speech and children's cognitive and lexical outcomes, with effect sizes that range from small to modest.

Early Life Parenting

Parenting is the process of nurturing a child's socioemotional, physical, and cognitive development from birth onward (Belsky, 1984; Brooks, 2012). Positive parenting is characterized by warm, responsive, and encouraging behaviors (Bennetts, Mensah, Westrupp, Hackworth, & Reilly, 2016), while critical parenting describes an independent second dimension that is defined by negative attitudes and feedback to the child, expressions of disapproval and even threatening behavior (Sher-Censor, Shulman, & Cohen, 2018). Through the interactions with their parents, children are thought to develop their own behavioral styles, which are typically differentiated into internalizing behaviors that refer to symptoms of depression, anxiety, social withdrawal, and psychosomatic problems, and externalizing behaviors that imply anger, frustration, irritability, and aggression (Achenbach, 1991; Eisenberg et al., 2001).

Positive parenting has been shown to benefit children's adjustment in observational studies of the family home. For example, 320 mother–child dyads were visited at home at 10, 18, and 36 months and assessed for maternal caregiving, which accounted for up to 5% of the variance in children's prosocial behavior and hyperactivity, and for 9% of the variance in their peer problems (Stein et al., 2013).

Critical parenting has also been shown to be associated with child development, for example it accounted for 9% of the variance in externalizing behaviors in 5-min speech samples from 55 mothers and their toddlers aged 19 to 47 months (Sher-Censor et al., 2018). This and other studies in this area relied on parental reports or visiting researchers' reports to assess parenting behaviors (e.g., van Prooijen, Hutteman, Mulder, van Aken, & Laceulle, 2018). We identified only one previous study that used audio recording equipment to document naturalistic parenting behaviors over time in the family home (Holden, Williamson, & Holland, 2014): In 33 families with a child aged 2 to 5 years, the mother wore a digital voice recorder in a sports pouch that was attached to her upper arm for 4 to 6 consecutive evenings, between 5 p.m. and the child's bedtime (Holden et al., 2014). The recordings (on average 13 hr per family) were coded for parental incidences of corporal punishment (e.g., slapping, hitting) and children's behavior, for example aggressive transgressions (Holden et al., 2014). The authors found meaningful associations between parenting and children's behaviors, and they concluded that audio-recordings were an effective method for studying family interactions in the home. Accordingly, audio-recordings have also been used to examine the effectiveness of parenting intervention programs (e.g., Johnson, Christensen, & Bellamy, 1976). Within the personality literature, naturalistic audio-recordings have been coded for participants moods (e.g., occurrence of laughing, crying, sighing) which correlated with some aspects of self-reported personality (Mehl, Gosling, & Pennebaker, 2006). Also, Wu, Sheppard, and Mitchell (2016) found that participants made accurate judgments about target person's empathy from audio-recordings, interpreting

voice characteristics like tone and pitch. Overall, these findings support the suitability of audio-recordings for collecting naturalistic observations of parenting.

The Current Study

We sought to undertake the largest and most comprehensive investigation to date of how home language input and parenting are related to children's language, cognition, and behavior. To this end, we used LENA to unobtrusively audio-record 107 children and their families in the home environment over the course of 3 days. Using LENA pro automatic speech processing software, we determined the number of adult spoken words that our sample of British children were exposed to and then assessed the stability of adult speech within-families across hours and days. We also computed D-scores to assess the lexical diversity of adults' and children's speech, based on transcriptions of six 5-min excerpts per family, equivalent to 30 min of recordings overall. The D-score is based on the probability of introducing new words into progressively longer language samples (see online supplemental materials for more information). In contrast to other indices of lexical diversity, for example word types or type-token ratios, D-scores are extremely robust against sample size effects and thus constitute reliable markers of lexical diversity (Malvern et al., 2004; McKee, Malvern, & Richards, 2000; Owen & Leonard, 2002). To quantify parenting and children's behavioral outcomes, we coded relevant behaviors from six audio excerpts per family. Previous studies have reported that SES and birth order affect adult speech and children's vocabulary acquisition (Hart & Risley, 1995; Hoff, 2003; Morgan, Farkas, Hillemeier, Hammer, & Maczuga, 2015; Oshima-Takane & Robbins, 2003), which we consider in our analyses although they are not foci.

We hypothesized that adult speech, including the quantity and quality of adult spoken words that children experienced within their families, would be positively associated with children's lexical diversity and cognitive ability. For parenting, we hypothesized that positive parenting behaviors would be associated with lower incidences of children's internalizing and externalizing behaviors, whereas critical parenting behaviors were likely to coincide with higher occurrences of children's internalizing and externalizing behaviors. We had no specific hypotheses regarding the predictive validity of SES and birth order for children's behaviors in our sample.

Method

Sample

Overall 225 parents (236 children) from Southeast London responded to study advertisements displayed in nurseries ($N = 59$), on Facebook ($N = 141$), through word-of-mouth ($N = 15$) or the authors' lab website ($N = 10$). Of the 210 families (220 children), who met the eligibility criteria (i.e., monolingual English-speaking families with a typically developing child aged 24 to 48 months), 131 parents with 137 children completed a 1hr online survey, and received the study materials, including LENA recording devices, LENA clothing and testing booklets (Figure 1). Out of these, 107 families completed digital audio-recordings on three different days for more than 5 hr each. In six families, two children (i.e., two fraternal siblings and four twin pairs) participated in the study; to ensure the independence of observations, one sibling was randomly selected to be included in the current analyses. The final analysis sample consisted of 105 mothers (mean age in years = 37.11, $SD = 4.56$, range = 22.48 to 51.57), 73 fathers (mean age = 39.49, $SD = 5.16$, range = 25.24 to 55.09), and 107 children (51 girls; mean age in years across recordings = 2.77, $SD = 0.55$, range = 2.03 to 3.99). On average, parents had spent 33.42 years in the United Kingdom ($SD = 10.92$, range = 0 to 55), with the vast majority being born in Britain and native speakers of English (86% and 99%, respectively). Of the mothers, 28 were full-time parents; 58 were in part-time and 11 in full-time employment; 4 identified as students, and 4 were on maternity leave. Of the fathers, 59 were in full-time and 10 in part-time employment; 4 were full-time parents. Most parents in the sample held university degrees (86% of mothers and 78% of fathers) and were married coparents (96%), most whom had been living together for 4 or more years (92%). About half of the children in the sample had siblings that lived in the same household (54%). Although families varied in sociodemographic background, they were on average of high SES.

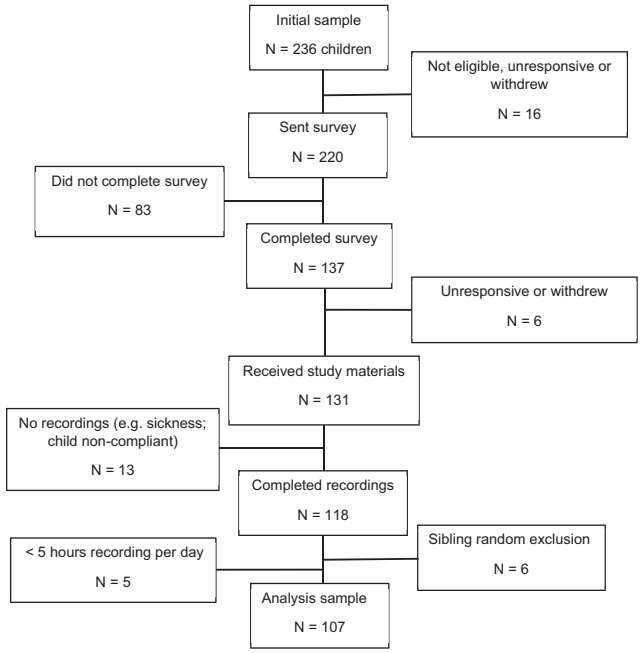

Figure 1. Flowchart of sample selection. Sample counts refer to the number of children.

Procedure

The study entitled "Advancing Data Collection for the Behavioral Sciences: The Practicability of LENA" was approved by the Ethics Committee at Goldsmiths, University of London. Data were collected between November 2014 and August 2016. Parents first completed an online survey to assess sociodemographic background information and various parent and child characteristics.

After parents completed the survey, boxes with study materials were hand-delivered to each family. Each box contained (a) 3

LENA DLPs (details in Measures below), (b) 3 items of LENA clothing, and (c) a Parent Report of Children's Abilities (PARCA) booklet (details in Measures below). Parents conducted the recordings independently on 3 separate days when their child was not attending nursery or any other formal childcare setting. Parents also completed the PARCA booklet with their child in their own time. For their participation, each family was given a child's LENA t-shirt and 79 families also received £50 in cash. Differences in compensation were because of changes in the study's funding, which only became available after the first families had participated.

Measures

Language.

Adult word counts. The LENA DLPs are small, lightweight audio-recorders that record all sounds within a six-foot radius for up to 16 hr per day. Children "wore" the DLPs in the front pockets of specifically manufactured clothes, for example t-shirts and dungarees. Audio-recordings were processed by an ASUS × 555LD laptop using the LENA Pro software version V3.4.0–143, which extracts the number of adult spoken words on each recording day (see online supplemental materials; LENA Research Foundation, 2012). LENA software, and human derived adult word counts have previously shown good interrater agreement (Cohen's *k* 0.65) in a sample of 70 12-hr recordings (Zimmerman et al., 2009).

Lexical diversity. Lexical diversity was extracted based on transcripts of two 5-min recording excerpts per day that registered the highest number of conversational turns in LENA between 8 a.m. and 11 a.m. and between 5 p.m. and 8 p.m. Conversational turns refer to the total number of conversational interactions the child engages in with an adult, in which one speaker initiates and the other responds within 5 s. We selected the excerpts with the highest conversational turns counts during the morning and evening, because they offer a rich source of data to compare language and behavior between families.

Professional typists used the Codes for the Human Analysis of Transcripts (CHAT; MacWhinney, 2000) to transcribe the excerpts (i.e., two per day for 3 days, resulting in six 5-min transcripts per family). Two trained research assistants proofread and corrected all transcripts. Across transcripts, and after excluding babbling, we computed the D-scores for the study child and all adult speakers using the VOCD command in Computerized Language Analysis (CLAN; Macwhinney, 2000).

Child cognitive ability. The PARCA assesses cognitive skills in early childhood. For the current study, items were selected from the PARCA versions for children aged 2 and 3 years (Oliver et al., 2002; Saudino et al., 1998). First, parents reported within the study's online survey if their child could perform a set of 28 activities, for example "Can your child stack seven small blocks on top of each other by him or herself?" Responses were recorded as yes, no, and I do not know. PARCA parent report ratings were then summed. Second, parents completed a PARCA testing booklet together with their child at home. The booklet consisted of three tests, including nine drawing tasks, seven copying tasks and 10 matching tasks. PARCA responses were independently scored by two research assistants, in line with the test's scoring guidelines (Oliver et al., 2002; Saudino et al., 1998), with an initial agreement rate of 92.9% and 100% after resolving differences through discussion with reference to the coding instructions. Composite scores for the three sections of the PARCA booklets tests (i.e., drawing, copying and matching), which correlated .33, .42, and .51, were calculated, *z*-transformed and summed.

The parent-report and parent-administered sections of the PARCA have been shown to correspond to scores from the BSID-II Mental Development Index in a sample of 107 2-year-olds (MDI; Bayley, 1993; $r = .39$, $p < .001$ and $r = .27$, $p < .01$, respectively; Saudino et al., 1998). In addition, the total PARCA was validated against the nonverbal component of the McCarthy Scales of Children's Abilities in a sample of 85 3-year-olds (McCarthy, 1972; $r = .54$, $p < .001$; Oliver et al., 2002). A revised version (PARCA-R) is now part of the United Kingdom's National Institute for Clinical Excellence's (2017) guidelines for developmental assessment, which substantiates the validity of parent-administered tests for the assessment of children's cognitive ability (Blaggan et al., 2014; Martin et al., 2013).

Child behavior. After reviewing two seminal assessments for childhood behavior problems—the Child Behavior Checklist for Ages 1.5 to 5 years (CBCL; Achenbach & Rescorla, 2000), and the Rutter Scale (Rutter, Tizard, & Whitmore, 1970)—we identified 10 adjectives that described internalizing (anxious, worried, tearful, depressed), externalizing (irritable, disobedient, aggressive), and hyperactive (restless, impatient, distracted) behaviors. Child behavioral analysis was conducted on the same 5-min excerpts that were previously selected for the lexical diversity analysis (i.e., six excerpts per child based on the highest number of conversational turns in LENA during the mornings and evenings). As the majority of children in our study had siblings, we included excerpts with multiple children, because this better reflected the natural home environment. Two research assistants were trained to rate the children's behaviors on the audio-recordings, not the written transcripts, using a scale from 1 to 10. A rating of 5 indicated "*normal behavior*," while deviations from 5 indicated atypical behavior. A rating of 10 indicated the behavior was extremely excessive, while 0 indicated the behavior was notably absent (see online supplemental materials, and Tables S8 and S9).

Parenting. We selected 8 items that referred to audible behaviors from the Parenting Styles and Dimensions Questionnaire (PSDQ; Robinson, Mandleco, Olsen, & Hart, 1995). In addition, 2 items from the "opportunities for variety in daily stimulation" subscale of The Home Observation for Measurement of the Environment (HOME, Caldwell & Bradley, 1984) were added. Trained research assistants rated how often the behavior occurred on the 5-min audio-excerpts on a 5-point scale, ranging from 1 = *never*, 2 = *once in a while*, 3 = *about half the time*, 4 = *very often*, to 5 = *always* (see online supplemental materials and Tables S1 and S2).

Socioeconomic status. Socioeconomic status was indexed by three markers, which were *z*-transformed and summed, with the emerging index score being adjusted for the number of markers available per family (e.g., information from both parents). (1) Educational Attainment: Each parent stated their highest educational qualification, ranging from school leaving certificate, national vocational qualification, undergraduate degree to postgraduate degree. (2) MacArthur Scale of Subjective Social Status (Adler, Epel, Castellazzo, & Ickovics, 2000): Parents were shown a drawing of a ladder with 10 rungs and the following instructions:

"Think of this ladder as representing where people stand in our society. At the top of the ladder are the people who are the best off, those who have the most money, most education, and best jobs. At the bottom are the people who are the worst off, those who have the least money, least education, and worst jobs or no job." Parents were then asked to indicate the rung that best represented their own SES, with 1 referring to low and 10 to high SES. The MacArthur scale has previously been validated against a composite of income, education and occupation ($r = .40$, $p < .01$, $N = 157$; Adler et al., 2000), and a composite of education and occupation ($r = .53$, $p < .01$, $N = 177$; John-Henderson, Jacobs, Mendoza-Denton, & Francis, 2013). (3) Overcrowding index: Parents reported the number of adults and children currently living in their household. Furthermore, they were asked "how many rooms, not counting bathroom, kitchen or box room, are in your home?" Each family's overcrowding score was calculated by dividing the number of rooms in the home by the number of people in the household such that a higher score represents less overcrowding.

Validation of Measures Based on Naturalistic Observations

Adult word counts. In total, 622 transcribed excerpts from 107 families were available (out of the maximum possible of 642), including 92 families with 6 excerpt transcripts and 15 families with 4 or 5 excerpt transcripts. To validate the accuracy of LENA's adult word count estimates, we randomly selected 64 excerpts (roughly 10%) from the 622 available human-transcribed excerpts for analysis in CLAN with the FREQ command, which gives the number of words for each speaker (MacWhinney, 2000). We compared the total adult word count estimate from the CLAN output to the estimate produced by LENA for the same 5-min excerpt. Adult word counts produced by LENA ranged from 35 to 690 with a mean of 245 ($SD = 128$), while the adult word counts from CLAN based on traditional transcription ranged from 41 to 603 with a mean of 275 ($SD = 120$). Differences in word counts were largely attributable to (a) the degree of distance of the speaker to the microphone and (b) mispronunciation. If the distance between speaker and DLP is greater than six feet, LENA fails to accurately record the adult spoken words (Xu, Yapanel, & Gray, 2009). However, trained typists, who can increase the volume on a recording during the process of transcription, are able to document even extremely distant and faint language. Regarding mispronunciation, LENA is more lenient in accepting "phones" as correct elements of speech, while trained typists coded mispronunciations and nonwords, which are not included in the adult word count. The correlation between LENA and CLAN based adult word counts across 64 recordings of 5 min each was $r = .79$ ($p < .001$), which increased to $r = .83$ ($p < .001$) after adjusting for recording distance.

Lexical diversity. We derived estimates of lexical diversity for each child in the study, as well as for the adult speakers in the child's environment. Because previous research showed that the complexity of adult language changes as a function of the number of children present (Huttenlocher, Vasilyeva, Waterfall, Vevea, & Hedges, 2007), we tested the consistency of D-scores in a subsample of 116 transcripts from 58 families for whom at least two excerpt transcripts of the same parent and child were available (19% of all transcripts; 54% of all families, respectively). For families with more than two eligible excerpt transcripts, two were randomly selected. For families where both parents had two eligible excerpt transcripts with their child, the two with the mother were chosen, because mothers typically spend more time with their children compared with fathers (Craig & Powell, 2012). Adult lexical diversity was adjusted for the number of excerpts available in our analysis.

Children's D-scores from the two excerpts correlated at $r = .58$, ($p < .00$), while the parents' D-scores correlated only at $r = .23$ ($p = .09$). We also computed D-scores for children and their language environment based on the two combined excerpt transcripts. Parents' D-scores intraclass correlations (ICCs) were similar between the combined transcript and transcript 1 (ICC = 0.39, $p < .001$), and the combined transcript and transcript 2 (ICC = 0.45, $p < .001$). Children's D-scores between the combined transcript with transcript 1, and transcript 2 were consistent (ICC = 0.72, $p < .001$ and ICC = 0.65, $p < .001$, respectively). These analyses suggest that children's lexical diversity is fairly stable across excerpts but that of their language environment is not.

To estimate the lexical diversity of adult and child speech, we combined data from all available transcripts per family, and a total D-score for all adults combined per family was computed along with a total D-score for each child.

Parenting behaviors. Recordings which contained only one parent and no other adult speakers (319 recordings from 104 families) were selected for parenting analysis, parenting behaviors were adjusted for the number of excerpts available for each parent. Estimates of parenting behaviors were based on ratings from two trained research assistants. For the rating process, recordings were randomized to avoid raters listening to excerpts from the same family in succession. To assess the validity of our behavior coding method, we first tested the interrater agreement for parenting ratings in a subsample of 51 families for whom there were two (or more) recordings with just the mother and child (Table S1). For those families with more than two recordings, two recordings were randomly selected. Agreement between raters was high, with an average of 73%. Therefore, we tested the interrater agreement for parenting ratings across all available recordings (Table S2), which again resulted in an average agreement between raters of 73%. Parenting ratings from the two raters' scores were then averaged.

We then tested the within-family consistency of parenting (i.e., correlation between mothers' and fathers' parenting within the same family). Absolute differences across recordings were small (see online supplemental materials, Table S4) and therefore we computed overall parenting behavior scores across both parents per family (Table S5). These summary scores were subjected to factor analysis, with varimax rotation using the R-package "nFactors" (Raiche, 2010), after excluding physical punishment (no variance) and spoils (ambiguous item). Analyses suggested retaining two factors, with the first accounting for 27% and the second for 18% of the variance. One factor represented "positive parenting" (e.g., responsive) and the other "critical parenting" (e.g., threatening; Table S7). Composite scores for positive and critical parenting behaviors were computed by summing the mean total scores for each item assigned to their respective parenting behavior. See the online supplemental materials for more details.

Child behaviors. Child behavior analysis was performed on the full sample of 622 recordings from 107 families. As with the parenting behaviors, two trained research assistants rated child

behaviors from randomized recordings. To assess the validity of our child behavior coding method, we tested the interrater agreement for child behaviors in a subsample of 51 recordings (Table S8). After establishing good interrater agreement, on average 80%, in the subsample, we tested the interrater agreement of child behaviors across all available recordings (Table S9). Given the high level of agreement between the two raters, on average 79%, their child behavior codes were averaged for each recording. Total scores for each child behavior were then created by calculating mean child behavior scores across the available recordings for each family (Table S10).

For childhood behavior ratings, we subjected the respective summary scores (i.e., across raters and recordings) to factor analysis, in the same way as described previously for parenting behaviors. Parallel analysis suggested extracting two factors, with the first accounting for 22% and the second for 16% of the variance. One factor represented "internalizing behavior problems" (e.g., anxious, worried, tearful) and the other represented "externalizing behavior problems" (i.e., impatient, distracted, irritable; Table S13). Accordingly, an internalizing and externalizing behavior problem score was computed for each child (Table 2). Further details of the consistency and structure of child behavior are reported in the online supplemental materials, along with scatterplots of the correlations between parenting and child behavior dimensions (Figure S1).

Statistical Analysis

First, we sought to determine the total number of words that children heard from adults over the 3 recording days. Recording durations were regressed onto LENA adult word counts; unstandardized regression residuals were saved to represent adult word counts here and in all subsequent analyses. Second, we tested the stability of adult word count estimates within families across hours and days with ICCs using the R package ICC (Wolak, Fairbairn, & Paulsen, 2012). A high ICC suggests that adult word count estimates are consistent within families across time. Third, we fitted linear regression models to test associations between markers of children's early life experience, including (a) adult word counts, (b) adult lexical diversity, (c) parenting behaviors, and (d) family background (i.e., SES and birth order), and children's outcomes, including (a) cognitive ability, as indexed by PARCA booklet scores and parent report ratings, (b) child lexical diversity, and (c) child internalizing and externalizing behaviors. Models were fitted separately for each outcome (i.e., five models), which were adjusted for child age and gender, saving standardized regression residuals.

Results

Descriptive statistics for all study variables are displayed in Table 2, and their correlations are displayed in Table S15.

Adult Word Counts

The durations of all 321 recordings (i.e., 3 days of recordings from 107 families) ranged from 5.81 hr to 18.08 hr with a mean of 15.06 hr ($SD = 1.87$). The recordings continuously documented all aspects of life in the families, including times when the study child slept. After adjusting for recording duration, average daily adult word count estimates ranged from 5,471.67 to 33,476.64 across families with a mean of 17,842.50 words ($SD = 5733.98$; Table 2).

Consistency of adult spoken words across days. Across families' three days of recordings, adult word count estimates correlated .42, .46 and .56 within families. The ICC for adult word counts within families across days was .47, suggesting that about half of the variance in adult word counts occurred within, and half between, the families (Figure 2). The absolute difference of adult word count estimates within families across days (similar to *SD*) ranged from 350 to 14,433 words with a mean of 3,477 ($SD = 2,443$). Thus, the number of adult spoken words that children heard differed on average by almost 3,500 words within their families across days. After excluding families whose adult word count estimates differed by more than 8,000 words across 3 days ($N = 7$), the ICC coefficient increased to .58, with the difference of adult word count estimates averaging 3,060 ($SD = 1,714$, range = 361 to 7,847 words). Thus, excluding extremely variable families only marginally increased the consistency of language experiences within families.

Consistency of adult spoken words across hours. We selected all full hours from the available recordings (4,609 out of 5,321 hr) that registered at least one adult word (3,740 out of 4,609 hr) to exclude recording hours during which the child was most likely asleep. Adult word count estimates ranged from 1 to 7,300

Table 2
Descriptive Statistics of All Study Variables

Variable	*M*	*SD*	Minimum	Maximum	Cronbach's alpha
Adult word counts[a]	17,842.50	5,733.98	5,471.67	33,476.64	—
Adult lexical diversity[b]	46.92	13.89	−8.01	75.01	—
Child lexical diversity[c]	67.61	18.91	29.83	118.96	—
PARCA—Standardized[cd]	.13	.58	−1.22	1.63	.68
Parent report[c]	20.03	2.7	10.96	25.52	.72
Positive parenting[b]	2.68	.54	.96	4.06	.71
Critical parenting[b]	1.00	.04	.97	1.32	.53
SES Index	−.03	.57	−1.69	.95	—
Internalizing behavior[c]	4.97	.11	4.71	5.25	.70
Externalizing behavior[c]	5.08	.08	4.87	5.24	.63

Note. Descriptives are based on complete data $N = 104$ except where indicated otherwise. PARCA = Parent Report of Children's Abilities; SES = socioeconomic status. Variables corrected for [a] recording duration. [b] number of available recordings. [c] age and gender. [d] $N = 101$. Parenting was rated on a scale from 1 to 5, and child behavior on a scale from 1 to 10.

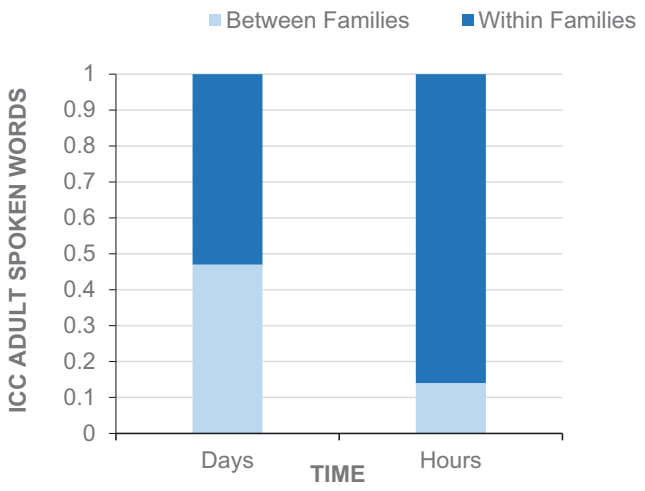

Figure 2. Intraclass correlations (ICCs) of home language input (i.e., quantity of adult spoken words) across hours and days. A low ICC suggests that home language input differs more within than between families. See the online article for the color version of this figure.

words (M = 1,458, SD = 1145) across full hours of recordings and families. The corresponding ICC was .14, suggesting that adult word counts vary greatly across hours of the day and that variance in adult word counts occurred mainly within rather than between families (Figure 2).

Associations Between the Home Environment and Children's Outcomes

The regression results for children's verbal and cognitive outcomes are shown in Table 3; the results for children's behavioral outcomes are in Table 4. Differences in the PARCA booklet scores were significantly predicted by adult word counts (B = .16, 95% CI [.08, .53], $p < .001$), and child lexical diversity was predicted by adult lexical diversity (B = .42, 95% CI [.24, .60], $p < .001$), birth order (B = −.41, 95% CI [−.71, −.10], $p < .01$) and SES (B = .44, 95% CI [.12, .75], $p < .01$; Table 3). By comparison, the PARCA parent report ratings were not significantly associated with any of the predictor variables. Child internalizing behavior was predicted by critical parenting (B = .30, 95% CI [.10, .50], $p < .01$), although the model itself did not reach significance (p = .10), and child externalizing behavior was predicted by positive parenting (B = −.25, 95% CI [−.45, −.04], $p < .05$). We note that the behavioral measures in our study showed only modest variance, which may have weakened the explanatory power of our regression models, because the children in our sample were overall well-adjusted. Overall, the quantity and lexical diversity of adult speech was associated with children's cognitive and language ability, while parenting was related to children's behavioral outcomes.

Discussion

We used naturalistic observations in the family home to investigate associations between early life experiences of language and parenting, and children's cognitive, language and behavioral outcomes. We found that early life experiences of adult speech, including the quantity and quality of language that children heard over the course of three days, varied as much within as between families. This finding extends previous studies, which assumed children's language experiences to be very stable and thus, to vary mostly between families but not within. However, in line with previous research, we also found that the overall quantity of adult speech that children were exposed to was positively associated with their cognitive ability (Caskey et al., 2014; Hart & Risley, 1995). In addition, we showed that a marker of the quality of adult speech—adults' lexical diversity—was associated with children's own lexical diversity. However, the quantity of adult speech was not related to children's lexical diversity, and the lexical diversity of adult speech was also not related to children's cognitive ability. Finally, we found that positive parenting—parenting behaviors that are responsive and encourage children's self-expression and novelty seeking—was associated with lower levels of child externalizing behaviors but not with cognitive or language abilities. Likewise, critical parenting was associated with children's internalizing behaviors, such as depressive, anxious and socially withdrawn tendencies, but not with cognitive or language outcomes. We discuss our results in the context of existing literature, noting strengths, limitations and future directions.

Table 3
Regression Model Results for Predicting Children's Cognitive and Language Ability

	PARCA[cd]				Parent report [c]				Child lexical diversity[c]			
Variable	*B*	*SE* B	β	95% CI	*B*	*SE* B	β	95% CI	*B*	*SE* B	β	95% CI
Adult word counts[a]	**.16**	**.04**	**.39**	**[.08, .53]**	.01	.05	.02	[−.08, .10]	−.01	.04	−.02	[−.09, .07]
Adult lexical diversity[b]	.10	.09	.10	[−.09, .25]	−.07	.10	−.07	[−.28, .13]	**.42**	**.09**	**.42**	**[.24, .60]**
Positive parenting[b]	.12	.10	.12	[−.08, .31]	−.02	.11	−.02	[−.23, .20]	.10	.09	.10	[−.08, .29]
Critical parenting[b]	.14	.09	.14	[−.05, .32]	.06	.10	.06	[−.15, .26]	−.07	.09	−.07	[−.25, .11]
Birth order	−.01	.16	−.00	[−.33, .31]	−.34	.18	−.21	[−.69, .01]	**−.41**	**.15**	**−.25**	**[−.71, −.10]**
SES Index	.13	.18	.07	[−.22, .48]	.32	.18	.18	[−.04, .68]	**.44**	**.16**	**.25**	**[.12, .75]**
R^2			.22				.08				.28	
F			4.43				1.34				6.31	
p			<.001				.25				<.001	

Note. PARCA = Parent Report of Children's Abilities; SES = socioeconomic status; CI = confidence interval. Variables corrected for [a] recording duration. [b] number of available recordings. [c] age and gender. [d] N = 101. Predictors significant at $p < .01$ are shown in bold.

Table 4
Regression Model Results for Predicting Children's Behavioral Outcomes

Variable	Internalizing behavior[c]				Externalizing behavior[c]			
	B	*SE* B	β	95% CI	*B*	*SE* B	β	95% CI
Adult word counts[a]	−.04	.04	−.09	[−.13, .05]	.03	.04	.06	[−.06, .11]
Adult lexical diversity[b]	−.12	.10	−.12	[−.32, .08]	.14	.10	.14	[−.06, .33]
Positive parenting[b]	.01	.10	.01	[−.20, .22]	**−.25**	**.10**	**−.25**	**[−.45, −.04]**
Critical parenting[b]	**.30**	**.10**	**.30**	**[.10, .50]**	.18	.10	.18	[−.02, .37]
Birth Order	.04	.17	.02	[−.30, .38]	.07	.17	.04	[−.27, .40]
SES Index	−.00	.18	.00	[−.35, .35]	−.05	.17	−.03	[−.39, .30]
R^2			.10				.14	
F			1.85				2.73	
p			.10				.02	

Note. SES = socioeconomic status. Variables corrected for [a] recording duration. [b] number of available recordings. [c] age and gender. Predictors significant at $p < .01$ are shown in bold.

Home Language Input

Several previous studies that used LENA to collect naturalistic observations of American families have reported that children heard on average between 12,800 and 13,142 adult spoken words over the course of a 12-hr day (Christakis et al., 2009; Greenwood et al., 2011; Zimmerman et al., 2009). Our estimate of the average daily word count of 17,843 words for a 15-hr day is only slightly higher and this discrepancy is likely to result from samples' differences in educational attainment. In our study, 86% of mothers held university degrees compared with 26% reported in both the studies described above (Christakis et al., 2009; Zimmerman et al., 2009). Similarly, fathers were more educated in our sample with 78% possessing university degrees compared with 23% and 24% reported by Christakis et al. (2009) and Zimmerman et al. (2009), respectively. We note that our estimates were considerably lower than those noted by Hart and Risley's (1995), who estimated daily adult word counts to be 30,100 in professional families and 17,500 words in working-class families. Hart and Risley's (1995) overestimations are likely to result from extrapolating data from hour-long recordings, under the assumption that children's exposure to adult speech is stable across hours in the day.

Our findings suggest that adult speech varies considerably across hours and days. Previous studies have shown that the quantity of adult speech peaks during the morning and early evening but is reduced around midday (Greenwood et al., 2011), and we replicate this finding in Figure 3. It has been proposed that certain daily activities yield more adult speech than others, for example book reading, which often occurs at bedtime, produces more adult speech per unit time than mealtimes or toy-play activities (Weizman & Snow, 2001). Across the 3 recording days, we observed that almost as much of the variance in the amount of adult speech occurred within as between families. Our results are comparable to Gilkerson et al.'s (2017) reports of a correlation of .66 between adult word counts on consecutive days, however this correlation reduced to around .40 when the time span between observations increased to between 4 and 16 weeks. Taken together, these findings suggest that there is a vast amount of within family variance in adult speech.

Although our sample's restriction of range in SES may have emphasized the within-family differences, the observation of substantial variance in adult speech within families appears not to be sample specific but generally underreported in the literature (Greenwood et al., 2011). Nevertheless, it is typical to observe large within SES group variation in adult speech, even within low SES samples (e.g., Weisleder & Fernald, 2013).

We also observed that lexical diversity varied considerably among adults across recording excerpts, so that the majority of variance occurred within rather than between families. By contrast, children's lexical diversity was fairly stable across assessments. Future research must explore if our findings are specific to times of high conversational turns.

Finding large within-family differences in adult speech suggests that between-family differences may have less dramatic effects on the development of children's language abilities than previously thought. On a particular day, two families may produce similar quantities of adult speech, but on the next day, they may differ vastly in speech. Our findings emphasize that early life experiences, especially with regard to language, are dynamic processes

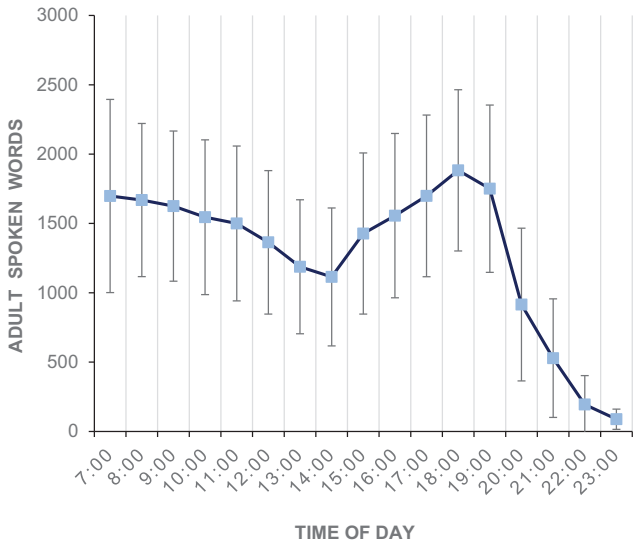

Figure 3. Home language input (i.e., quantity of adult spoken words) over the duration of a day, averaged across families. Bars reflect *SD*. See the online article for the color version of this figure.

that change and evolve over time, rather than static environmental determinants.

Home Language Input and Children's Cognitive and Language Ability

Confirming our hypothesis, we found that the quantity of adult spoken words that children heard was positively associated with their cognitive ability as indexed by the PARCA booklet. However, the mechanisms that underlie this association remain speculative. It is possible that a greater exposure to language provides greater learning opportunities for children, or that children's cognitive ability may actively influence adults' spoken language (Song, Spier, & Tamis-Lemonda, 2014). As an alternative, it may be that a third factor explains why the quantity of adult speech and children's cognitive ability are associated, for example shared genetic predispositions (i.e., gene–environment correlations; Ayorech, Krapohl, Plomin, & von Stumm, 2017).

We found no meaningful association between adult word counts and parent reports of their children's cognitive ability. One explanation might be that parent reports were completed at study enrollment whereas the PARCA booklet was administered later on in the study, when the recordings were also done. The difference in the time of assessment may have affected the validity of the parent reports. As an alternative, parents may be less accurate in assessing their child's abilities through a rating scale compared with when the child actually demonstrates cognitive skills in a test. In any case, the correlation between parent reports and children's booklet test scores in the current study was comparable to previous reports (e.g., Saudino et al., 1998).

In the current study, we differentiated the quantity and quality of adult speech and observed specific associations for both markers with children's lexical diversity, in line with previous research (Hart & Risley, 1995; Hoff, 2003; Huttenlocher et al., 2010; Pan et al., 2005). Specifically, the lexical diversity of adult speech but not the quantity was related to children's lexical diversity, so that children who experienced more lexical diversity in their home environment also produced language of greater lexical diversity themselves. However, our estimate that adult lexical diversity predicted 17.6% of the variance in children's language ability is notably higher than the 9.5% previously reported (Rowe, 2008). An obvious explanation for this finding is that estimates of adult and child lexical diversity were not independent in the current study but extracted from the same conversational interactions. By contrast, the number of words that a child heard was estimated over the course of the day and not based on one interaction. An alternative, substantive explanation is that estimates of lexical diversity reflect child-directed speech that facilitates adequate parental scaffolding, which enables children to learn and practice word meanings (Hirsh-Pasek et al., 2015). This interpretation is supported by the observation of significant effects of SES and birth order on children's lexical diversity, which were not evident for any other outcome variable suggesting that early life circumstances are mirrored more closely by children's lexical diversity than by their cognitive ability. An important avenue for future research is to explore the relationship between the quantity of adult speech and the amount of child-directed speech as they occur in the family home, and how they respectively relate to children's cognitive and language outcomes.

Parenting and Child Behaviors

We found here that using audio-recordings was a feasible method for assessing real-life parenting and child behaviors, free from the limitations of observer reactivity (Gardner, 2000). Finding concurrent associations between parenting and child behaviors in the theoretically expected direction confirms the validity of our assessment method. More explicitly, we found that positive parenting was inversely associated with children's externalizing behavior, in that parents, who were more responsive to their child's needs and encouraged exploration and self-expression, had children that showed fewer restless, attention-deficit, irritable, or disobedient behaviors. This finding is in line with studies using traditional parent-reports methods (Barnes et al., 2010; Stein et al., 2013). There was also an association between critical parenting and children's internalizing behaviors in our study, with children of parents who engaged more often in critical parenting being more often anxious, worried, and tearful. Because the overall regression model did not reach significance, this result is somewhat untenable.

Strengths and Limitations

Our study has several notable strengths: We are, to our knowledge, the first to report typical daily adult word counts in a comparatively large British sample obtained through naturalistic daylong audio-recordings. In addition, these recordings were of substantial durations to capture real-life interactions in the family home. Thus, the current study is the largest naturalistic observation study of early life home environments to date.

Nevertheless, our study also suffers limitations. First, our sample had a restricted SES range and therefore, it was not representative of the general population. However, the associations between adult speech and child outcomes should exist irrespective of SES, although we encourage future research to test more economically diverse families. Second, our cross-sectional design precludes conclusions of causality. Longitudinal studies are needed to clarify whether, for example, more intelligent children evoke more words from adults in their environment or vice versa. Third, our study children ranged considerably in age capturing a wide window of development, which reduces the validity of age-specific inferences. Fourth, we relied on 30 min of audio recordings per family to analyze their lexical diversity and behaviors, which may be too short to derive valid measures, although our reliability analyses suggest otherwise. Finally, we used interrater agreements to indicate the validity of our behavior codings, but future research must test the extent to which data on parenting from audio-recording matches that from self- and observer-report questionnaires.

Conclusions

Using unobtrusive daylong naturalistic audio-recordings, we show that the quantity of adult speech that children are exposed to varies greatly across days and within families. We also showed that early life language and parenting experiences are differentially associated with children's cognitive, language, and behavioral outcomes. We suspect that distinct developmental processes underlie these associations, which can only be understood if early life

experiences are conceptualized as the dynamic, changing phenomena that they are, rather than as static entities. Such approaches will help elucidate the interplay between environmental experience and children's differences in development.

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