Nonlinear development of speaking rate in child-directed speech

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Abstract

This study investigates the role of child-directed speech (CDS) in language acquisition by re-evaluating the old claim that mothers adapt their speech over the course of child language development. The specific hypothesis tested is that there may be quantal changes in certain properties of CDS such as speaking rate around the time children reach major linguistic milestones. The developmental path of CDS speaking rate was analyzed in 25 mother–child pairs from longitudinal corpora in CHILDES database (MacWhinney, 2000). A parallel analysis was also made on the development of speaking rate in the child as well as the mean length of utterance (MLU) in mother and child. The total number of utterances analyzed approximates one million. The findings reveal that CDS speaking rate changes nonlinearly with a shift occurring early in the multiword stage. There is also some indication that another breakpoint might be present around the onset of child speech production. A parallel pattern of nonlinearity is also observed in the speaking rate of the child and the MLU of both mother and child. The results support the notion that CDS is adapted to the changing needs of the language-learning child, which could reflect its facilitative role in child language acquisition.
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1. Introduction

It is well-known that speech addressed to young children (CDS; child-directed speech) is produced with distinct characteristics such as higher and more variable pitch, simpler syntax, slower tempo, and clearer articulation than speech addressed to another adult. However, the extent to which these characteristics of CDS facilitate language acquisition, by serving as a specialized language model for the language-learning child, is controversial. Some studies present findings that seem to suggest that CDS directly serves as a language-model for the child listener (Fernald, 2000; Werker et al., 2007; Liu et al., 2007, among others). Others suggest that the facilitative role of CDS in a child's language learning might work in a rather indirect way. That is, the prosodic characteristics of CDS mainly function to convey affection or modulate the child's level of arousal, which could serve as a hook to the linguistic structure for the children (Kitamura and Burnham, 2003; Singh et al., 2002). Still others suggest that the characteristics of CDS are largely due to the simple semantic nature of CDS, often limited to the events occurring *here* and *now*, and the mother's desire for her child to act as told rather than any motivation to help the child's language acquisition (Newport et al., 1977; Snow, 1972).

This paper investigates the role of CDS in language acquisition by analyzing the developmental pattern of CDS over the child's course of language development. If CDS carries a "tutorial" function for the language-learning child, one expectation that can be claimed is that CDS will "grow syntactically more complex in a fine-tuned correspondence with the

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child's growing linguistic sophistication (Newport et al., 1977)''. Many previous studies exploring this hypothesis have focused on finding correlations between properties of CDS and child speech (e.g. Newport et al., 1977; Sokolov, 1993) or analyses of variance at different developmental stages (e.g. Snow, 1972; Phillips, 1973). If CDS is finely tuned to the developmental changes in the child's language, however, a crucial prediction is made beyond a mere correlation with child speech. That is, CDS may demonstrate a quantal change around the time the child begins to respond to adults' speech differentially, e.g. around the time the child begins to speak (Snow, 1977b; Phillips, 1973) or when they begin to combine words. The idea is that mothers may not feel the need to adapt their speech when the child seems too young to understand speech, but they begin to provide characteristics of CDS once the child speaks or appears to process syntax. Thus, this study tests the hypothesis that there is a sudden shift in the developmental changes of CDS around the time a child reaches major linguistic milestones. The investigation focuses on the change in CDS speaking rate, and the data draws on large-scale corpora of both CDS and child speech in the CHILDES database (MacWhinney, 2000). Analyses will be made on the developmental trajectories and the dynamics of the characteristics of CDS and child speech for *individual* mother–child dyads within the first few years of life.

Interest in CDS was at its peak in the 1970s, partly as a response to the influential claim by Chomsky (1965) that the linguistic input available to children is ''fairly degenerate in quality'' thus we could not look to the structure of the input to account for the question of how children induce the rich grammatical knowledge that they attain in a remarkably short time span (Saxton, 2010). Early studies investigating CDS typically worked with measures in discourse and grammar. As mentioned earlier, one of the key questions asked was whether there was any evidence of adaptation in maternal speech in response to changes in child language. These studies, however, yielded mixed results. For example, studies such as Snow (1972) and Phillips (1973) found some evidence of mothers' adapting the syntactic complexity in their speech depending on the age of the child interlocutor. In addition, Cross (1977, 1978) and Sokolov (1993) found that discourse features in mothers' speech were adapted to the child's level of comprehension ability. Few studies, however, were able to find any shifts in CDS patterns during the child's transition from the preverbal to the verbal stage (e.g. Snow, 1977a). In addition, Newport et al. (1977) reported, based on roughly 1500 CDS utterances from 15 mother–child pairs, that there was no significant correlation between the MLU (Mean Length of Utterance) of the mother and child, or other measures of syntactic complexity. Subsequently, more weight has been given toward the claim that properties of CDS such as simplified syntax are not essential in language acquisition, with increasing emphasis placed on the innate linguistic ability that the child brings to the task of language learning. Although the debate was never clearly resolved, interest in the role of CDS in language acquisition declined in the field, possibly because of a lack of new ideas for questions to test regarding the debate.

Compared to the measures in grammar or discourse, there has been less effort made to investigate the change of phonological or phonetic features in CDS (although see Stern et al., 1983; Liu et al., 2009). Nonetheless, a few reports point to the dynamic nature of CDS in phonological and phonetic dimension. For example, mothers tend to articulate clearly and carefully when the child listener is at the very early stage of speech production, but there is greater variability in CDS pattern when speaking to a child at the preverbal or the multi-word stage (Bernstein Ratner, 1984a, 1987). Similarly, prosodic characteristics in CDS change with the child's age or linguistic development. For example, Stern et al. (1983) found that the CDS pitch range was more exaggerated when infants were 4 months old compared to when they were younger (newborn) or older (1;0 & 2;0; see also Kitamura and Burnham (2003) for a report on differences in the relative frequency of prosodic tunes with child's age and sex). None of these studies, however, tested the correlation between the speech of mother and child or the overall developmental shape in the change of CDS based on densely sampled data.

Recently, there has been a resurgence of interest in the nature and role of input in language acquisition. With technological advances, more studies are using high-density longitudinal corpora of mother–child speech (e.g. Brent and Siskind, 2001; Englund and Behne, 2006; Demuth et al., 2006; Soderstrom et al., 2008; Roy et al., 2009). Armed with an unprecedented amount of data enabled by the consortium of the child language data via the CHILDES database and new methodological approaches, this study revisits the old ''fine-tuning'' hypothesis and tests for any evidence of quantal changes in CDS around the time the child attains major linguistic milestones, e.g. the onset of speech production or combination of words. The methodological approach in this paper is thus slightly different from most of the early studies in that the focus of investigation is on the *shape* of the longitudinal changes in CDS rather than merely testing any correlations between CDS and child speech. It is worth emphasizing that it is the density of the data set that makes it possible to investigate the developmental shape of CDS in this study. At the same time, the current approach also allows us to move beyond the main difficulty with the correlational analysis, which is the uncertainty in determining how much correlation is necessary in order to make a claim of a meaningful relationship between variables.

The current study investigated the developmental changes in CDS with particular attention to speaking rate. Previous research of CDS speaking rate has shown that CDS is spoken with a slower tempo than ADS (Swanson et al., 1992; Morgan, 1986; Ko and Soderstrom, 2011; cf. Church et al., 2005). We can think of several reasons why slower speaking rate might be relevant to language development. The most straightforward explanation is that mothers might slow down their speaking rate simply to help the child's processing of the linguistic information by allowing more time (Foulke, 1968;

McCroskey and Thopson, 1973). In addition, slower CDS speaking rate may reflect an effort to deliver enhanced phonetic cues for phonological categories. There is also report that slow speaking rate enhances younger infants' attention to emotion (Panneton et al., 2006). However, it has been proposed more specifically that the lengthening of the utterance-final syllable (Klatt, 1976) is implemented in a more exaggerated form in CDS, which can provide infants with important information about syntactic constituents in the speech they hear (Hirsh-Pasek et al., 1987; Morgan et al., 1987; Soderstrom et al., 2005). According to this hypothesis, part of a theory known as the Prosodic Bootstrapping Hypothesis (Pinker, 1984; Morgan, 1986), we would predict that mothers might change their speaking rates with the syntactic development in the child's language to modulate the level of enhancements for the syntactic boundary cues. A longitudinal tracking of CDS speaking rate provides an opportunity to observe the potentially changing use of the boundary cues for syntactically relevant units in speech.

The choice of speaking rate as the main response variable of investigation also provides methodological advantages in measuring speech characteristics compared to discourse or syntactic variables. When working with variables of discourse or grammar, there is difficulty in obtaining a large amount of data because data collection relies on the occurrence of specific target constructions. Moreover, data collection on these variables often requires manual annotations, hindering studies based on large-scale data. In contrast, variables characterizing global characteristics of speech, such as speaking rate, offer a consistently large amount of data, which can be obtained based on calculations from raw data rather than observations of specific linguistic patterns.

The difficulties of the earlier studies in finding a shift or an unequivocal developmental pattern of CDS could be attributed, at least in part, to limitations in their sampling methods. For example, *frequent sampling* is important to depict the shape of developmental change most accurately (Tomasello and Stahl, 2004; Adolph et al., 2008; Roy et al., 2009). In addition, to reveal a full developmental story the data should cover an extensive individual child age range from the pre-verbal to multi-word stage. However, most of the early studies testing for any developmental changes based their findings on cross-sectional data or longitudinal data with observations made from several temporal points in a limited developmental window. Another important factor that may contribute to the variability in findings across studies is the insufficient attention to *individual differences*. Mothers and children vary not just in the timing of their developmental changes, but also in the specific implementation of their speech. Thus some mothers may display more typical characteristics of CDS whereas others may use a different style. In a typical cross-sectional study, however, data are collapsed across the subjects, thereby masking individual differences and omitting the intermediary changes within the development of an individual speaker (Ruhland, 1998).

Each of the potential methodological pitfalls discussed above are illustrated in the examples in Fig. 1, based on the data to be fully presented later in this article. The left panel is a plot based on a densely sampled longitudinal data of one mother–child pair, where we can observe an abrupt change in the developmental pattern of the response variable. The middle panel is based on the samples taken at every tenth time point in the data of the left panel. The regression modeling on this sparse subset of the data produces a spurious linear relation between age and speaking rate, failing to detect the sudden shift observed in the first panel. This highlights the importance of dense sampling in investigating the

Fig. 1. Analysis of developmental trends in CDS Speaking Rate based on high-density longitudinal data (left), sparse data sampled from the original Naima data (middle), and aggregated longitudinal data from 6 mothers, with the Naima data represented as a red circle (right). The breakpoint is obscured in the sparse and aggregated data. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

developmental trajectory. The right panel shows a plot of the data aggregated from densely sampled 6 mother–child pairs in the Providence corpus, including the one plotted in the left panel (indicated with red circles). Again, we observe that fitting the regression analysis over the data merged across the speakers seems to indicate a spurious linear correlation between the CDS speaking rate and child age. This illustrates the importance of examining individual dyads across a large-scale longitudinal sample to detect the relationships we wish to examine.

To date, there is no large-scale quantitative analysis of CDS speaking rate based on longitudinal data. As it must be the case that CDS speaking rate is accelerated in some ways before the child interlocutor becomes an adult, we are motivated to investigate the developmental trajectory of CDS speaking rate. The simplest hypothesis is that CDS speaking rate might steadily accelerate from the child's preverbal period through a stage when an adult-like competence in speech is accomplished. As discussed in the beginning of this paper, however, changes in CDS speaking rate might reflect mothers' sensitivity to the changing needs of a child's language development, in which case we would expect to see quantal changes around the child's major linguistic milestones. Specifically, we might expect the shifts in CDS speaking rate to be tied with certain shifts in the child's stages of syntactic development such as the emergence of one-word or multi-word utterances.

The availability of electronically accessible longitudinal corpora, such as those from the CHILDES database, can dramatically facilitate the research of the sort conducted in this study. Below, we describe a study testing the hypotheses laid out above using the high-density longitudinal data of mother–child verbal interactions. The particular hypotheses to be tested through the data analyses are summarized as follows: Are there any developmental changes in CDS speaking rate, and, if so, are the changes gradual or abrupt? If abrupt, are those shifts related to reaching any milestones in child language development? In particular, are those milestones related to syntactic development, the most commonly used measure to demonstrate the child's language development?

2. Methods

2.1. Data

The following corpora were chosen for analysis from the CHILDES database: Thomas (Lieven et al., 2009), Providence (Demuth et al., 2006), Brent (Brent and Siskind, 2001), and Soderstrom (Soderstrom et al., 2008). The number of mother–child pairs in the corpora ranged from 1 in Thomas to 16 in Brent corpus. Participants in the Thomas corpus speak British English and participants in the remainder of the corpora speak American English. Since the focus of the research was on the developmental trajectory *within* a speaker over the course of a child's language development, the differences in English dialects and individual variations in the age at which children reached a given milestone (e.g. onset of speech production) were not issues.

All children were typically developing, except for Ethan in the Providence corpus, who was diagnosed with Asperger syndrome at age 5. Most data in these corpora were collected at the homes of the participants except for a few sessions in the Thomas corpus, which were video-recorded in the laboratory at the Max Planck Child Study Centre at the University of Manchester. Each session lasted about 1–1.5 h. The Brent and Soderstrom corpora mainly contained data from the preverbal stage, whereas the Providence and Thomas corpora contained data in the early speech production stage and beyond. The Brent corpus included data collected in the homes of 16 mother–child pairs, approximately every other week when the child was between 9 and 15 months old. In the Soderstrom corpus, recordings from two mothers and their children were made approximately every two weeks from 0;6 to 0;10, with an additional recording of two sessions at 1;00. The data in the Thomas corpus are denser in the earlier production stage (age 2;00.12–3;02.12), when the data were collected five days a week. The frequency of the data collection beyond this stage was then reduced to five days a month in the span of one week (age 3;03.02–4;11.20). The 6 mother–child pairs in the Providence corpus were recorded every two weeks, with two of the children having denser data from weekly recordings during 1;3–2;10 (Naima) and 2;0–3;0 (Lily).

The corpora used in this study were chosen because the utterances in their transcripts were linked to media files. From the corpora of 25 mother–child pairs that included 18 pre-verbal children, a total of 945,255 utterances were analyzed: 638,960 from the CDS and 306,295 from the speech of children. These numbers reflect the reduction from the original 1,120,076 utterances (CDS; 747,805, child-speech; 372,271) after the clean-up process described in the next section. Table 1 presents a list of the corpora and detailed information about each corpus.

2.2. Calculation of speaking rate and MLU

Speaking rate was calculated based on the transcripts (Yuan et al., 2006) rather than the actual acoustic signal in time. In the transcripts of the CHILDES corpora chosen, each utterance was marked with two time stamps that corresponded with the beginning and end of the utterance in the linked media file; the speaking rate was calculated by dividing the total

Table 1
Information on the data.

Corpus (number of children)	Child (gender)	Age range	Number of observations	Number of utterances	
				Mother	Child
Thomas (*n* = 1)	Thomas (m)	2;0.12–4;11.20	376	329,089	217,859
Providence (*n* = 6)	Naima (f)	0;11.28–3;10.10	88	35,620	22,875
	Lily (f)	1;1.02–4;0.02	80	43,129	22,567
	Violet (f)	1;2.0–3;11.24	54	16,742	8005
	Alex (m)	1;4.28–3;5.16	52	23,039	13,876
	Ethan (m)	0;11.04–2;11.01	50	22,439	9070
	William (m)	1;4.10–3;4.15	44	16,764	12,043
Brent (*n* = 16)	c1, d1, f1, f2, i1, j1, m2, q1, s1, s2, s3, t1, v1, v2, w1, w3	0;8–1;3	179	131,205	N/A
Soderstrom (*n* = 2)	Joe (m)	0;5.30–1;0.29	14	9967	N/A
	Theo (m)	0;6.15–1;0.28	44	10,966	N/A

number of words spoken in an utterance by the timed duration of the utterance. The result was a representation of the speaking rate as number of words per second. Utterances containing phonological fragments (e.g. *&t cant' you go*?) or unintelligible speech (e.g. *&*, *xx*, or *yy*) were identified by the CHAT convention (MacWhinney, 2000) and excluded from further analysis. Paralinguistic materials such as cries, transcriber comments, or omitted words recovered by transcribers were eliminated in the calculation. Further excluded from analysis were utterances with durations of longer than 10 s because they often contained long pauses or utterances from previous or subsequent turns.

All of the transcripts were created following the CHAT convention, which does not include detailed guidelines for the segmentation of utterances. Therefore, there may be some differences in the exact method aligning the utterance boundaries among the transcribers for each of the corpora. The trade-off between the accuracy of the analysis and the covered amount of data is a common issue in any study based on an automated analysis of a large-scale corpus data. The need for a densely sampled large amount of data outweighed the accuracy of the calculation in this study, as the focus was on the developmental trajectory in individual data. Another potential issue in the accuracy of the speaking rate in the current analysis is that some of the utterances coded as being spoken by the mothers could have been directed to another adult or a sibling instead of the target child. However, only 1 out of the 25 corpora (joe in Soderstrom Corpus) was recorded in some presence of a sibling, and any interactions of the mother with another adult seemed to be only sporadic and randomly distributed across the corpora. Thus no special efforts were made to filter them out. Even with some measurement errors due to such inconsistencies, however, it was expected that the Law of Large Numbers would ensure to reveal the robustness of the data given the vast number of utterances analyzed.

Measures to test the reliability of the speaking rate calculated as the number of words per second based on the transcripts, as described above, were taken in two complementary steps (see section 3.3 for details). First, the transcripts of all utterances containing five-word sentences, along with their corresponding acoustic signals, were extracted from ten sessions of the Naima data. After a cleaning process, a total of 425 tokens were manually coded at the syllable-level based on the acoustic signal. The resulting measures of speaking rate in the number of syllables per second were subjected to a correlation analysis with the speaking rates calculated based on the transcripts. As an additional safeguard, an analysis of speaking rate measured as the number of syllables per second was conducted in all eligible utterances contained in three one-hour sessions in the Naima data based on the detection of intensity peaks (De Jong and Wempe, 2009). The pauses preceding and trailing the target utterances were manually removed in these files and omitted from measurement. The total number of utterances used in this second additional supplementary analysis was 1213.

The MLU (Mean Length of Utterance) was calculated as the mean number of words in the given utterances in any session using the CLAN tools (MacWhinney, 2000). The choice of counting words, rather than the more conventional morphemes, was due to the unavailability of morphological analysis in most of the corpora selected for analyses in this study.

2.3. Statistics

The main interest in the statistical analysis was to detect any structural changes in the linear relationship between child age and CDS speaking rate. The analysis thus focused on establishing whether there was any significant change in the slope of the regression line, and if so, where this discontinuity was located. The current study adopted regression modeling of the least-square method which results in estimates that approximate the conditional mean of the response variable. This is a method commonly used to find the line that comes close to the data by finding the values for the slope

and the intercept that define the line that minimizes the sum of the square of the vertical distances between the data points and the line.

If there is a structural change in the relationship between child age and CDS speaking rate, however, the best fitting line for the data would involve discontinuity in otherwise smooth and continuous relations. To test this hypothesis, the data were plotted with a breakpoint regression model (Toms and Lesperance, 2003; Baayen, 2008) using R (R Development Core Team, 2010), which detects the turning points where the slopes of the linear functions change. The most likely breakpoint was determined using the following three-step procedure: First, a series of models were fitted, treating each of the data points as a possible breakpoint. Next, the sum of the squared differences between the observed and the fitted values was used to calculate deviance. Finally, the model with the smallest deviance establishes the breakpoint model.

An ANOVA model comparison was applied as a measure of testing the null hypothesis of no structural change, whereby the fit of the more complicated equation, i.e. the one with the breakpoint, was compared with the fit of the simple linear model. In general, a model with an additional parameter will nearly always fit the data better (has a lower sum-of-squares) than a simpler one because of the greater number of inflection points. The question is whether this decrease in sum-of-squares is worth the "cost" of the additional variables, i.e. loss of degrees of freedom. If the simpler model is correct, we can generally expect the relative changes in the sum of squares to equal the relative changes in degrees of freedom. If the more complicated model is correct, then we expect the relative increase in sum-of-squares (going from a complicated to a simple model) to be greater than the relative increase in degrees of freedom. The F-test calculates the probability that the additional parameter improves the sum-of-squares by random chance, i.e. if the simple linear model is really correct, what is the chance that we would randomly obtain data that fits the breakpoint model so much better? If the p-value is low, we can conclude that the breakpoint model is significantly better than the simple linear model.

Additionally, a linear mixed-effects model (see Pinheiro and Bates, 2000) was fit to the combined data set using the lme4 package (Bates et al., 2011) of R to test the hypothesis of the breakpoint in the mother–child dyads as a group. In this model, variation among the mothers is taken into account by including the individual as a random factor. A likelihood ratio statistic was conducted to test the goodness of fit between the simple linear model and the breakpoint model. Again, a model with more parameters, i.e. the breakpoint model, is likely to fit the data better than a simpler one, i.e. the simple linear model. Whether the fit provided by the more complicated model is significantly better thus preferred to the simpler model is determined by comparing the log-likelihoods of the two models. The probability based on the chi-squared distribution of the test-statistic will show if the model with more parameters fits the data significantly better than the simpler one.

3. Results

In order to detect the abrupt shifts in an otherwise linear developmental pattern, it is essential to have data covering the moments the children reach major linguistic milestones with substantial temporal margins on both sides. The corpora containing older children, i.e. Providence and Thomas, cover a more extensive period (the onset of speech through multi-word stage) than the ones containing preverbal children, i.e. Brent and Soderstrom. Therefore, the corpora of older children are more suitable for testing the specific prediction of abrupt shifts around the major linguistic milestones discussed earlier, and thus their results will be presented first.

3.1. Analyses of data in older children

3.1.1. Breakpoint analyses

The first analysis was of CDS speaking rates in the corpora of children at an early stage of speech production (Thomas, Naima, Lily, Violet, Alex, William, and Ethan). As discussed in the introduction, the "tutorial function" hypothesis of CDS predicts an abrupt shift in the developmental pattern of CDS as mothers might change their speech style to adapt to the needs of their child at a given stage of language development. Raw average speaking rates of the utterances in each recording session were plotted as a function of age (Fig. 2). The number of utterances collectively represented by each of the data points ranges from 405 to 875. To detect any structural changes in the linear relationship between child age and CDS speaking rate, the data were plotted with the breakpoint regression model using R as described in section 2.

What is remarkable in Fig. 2 is that the change in CDS speaking rate is nonlinear, as predicted by the "tutorial function" hypothesis. ANOVA model comparisons of the breakpoint model and a simple linear regression model reveal that the extra parameter for modeling the breakpoint is justified in most mothers' speech analyzed in this study. The null hypothesis of no structural change was rejected in the CDS speaking rate of Thomas (F [1, 373] = 253.33, $p < 0.001$), Naima (F [1, 85] = 69.57, $p < 0.001$), Lily (F [1, 77] = 42.04, $p < 0.001$), Violet (F [1, 48] = 13.96, $p < 0.001$), Alex (F [1, 48] = 4.87, $p < 0.05$), and William (F [1, 39] = 7.6187, $p < 0.01$). The probability in the Ethan data narrowly missed the alpha level of 0.05 but is small enough to justify the breakpoint analysis (F [1, 47] = 3.09, $p = 0.085$). The breakpoint in his data, however, comes much earlier than the rest, i.e. at 13.5 months of age, with the smallest MLU value for both the

Effects of Child's Age on CDS Speaking Rate

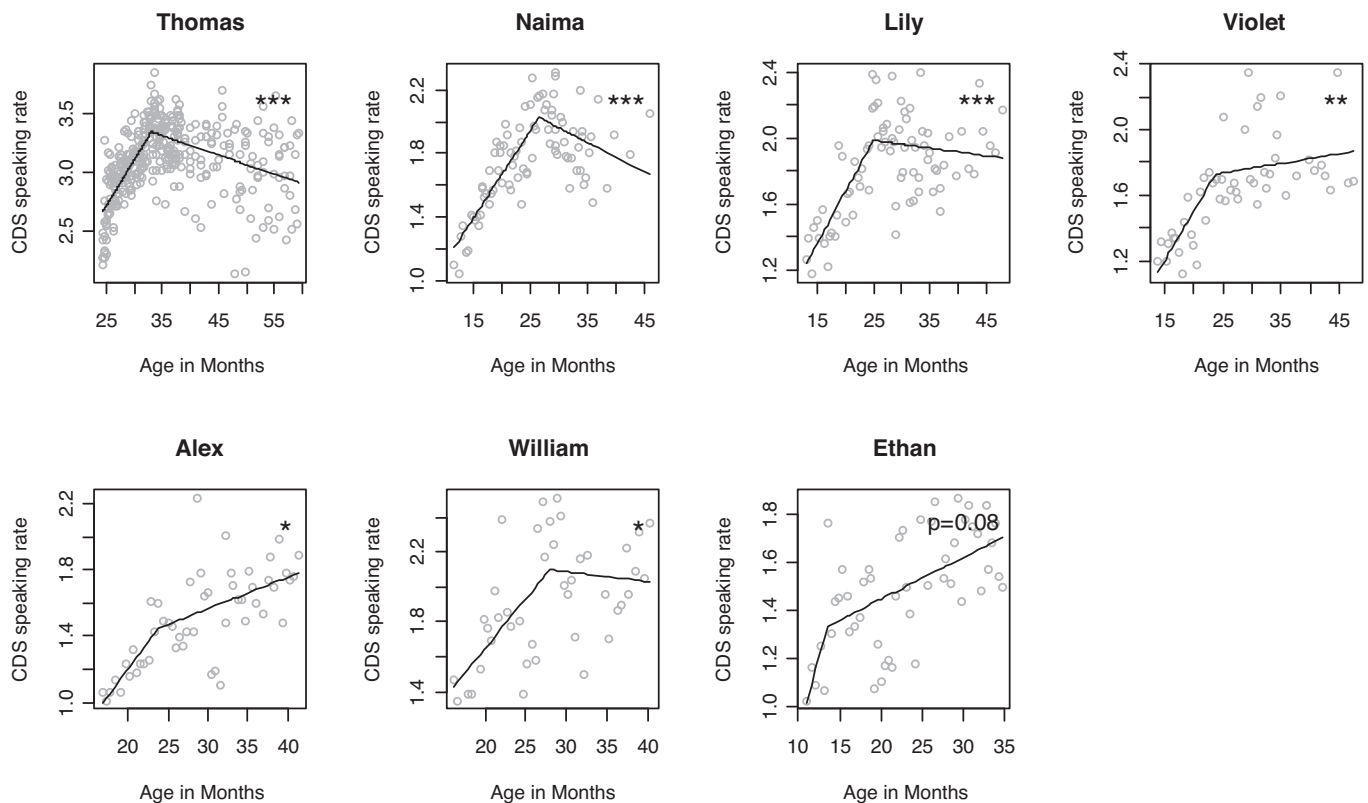Fig. 2. Breakpoint analysis of the CDS speaking rate of mothers as a function of child age. The significance codes (***$p < 0.001$, **$p < 0.01$, *$p < 0.05$) are from the ANOVAs comparing the breakpoint model with a simple linear regression model.

mother and the child compared to others (Table 3). Whether or not this somewhat deviant pattern in the Ethan data has anything to do with the Asperger syndrome that he was diagnosed with at age 5 is hard to discuss given the limitations of the data. In the context of the rest of the data, the single marginal result of Ethan seems likely to be an outlier. Overall, the curvature was so distinct that the existence of discontinuity in the developmental pattern of the CDS speaking rate was evident in most corpora.

In order to test the hypothesis of the breakpoint over all the mother–child dyads analyzed in this study as a group, a linear mixed effects model was fit to the combined data set using the lmer( ) function of the lme4 package of R. In this model, variation among the mothers' speaking rates is taken into account by including the mother as a random factor. The dependent variable was the CDS speaking rate and the fixed factors were the shifted age of the children, calculated by subtracting the age at each data point from the age at breakpoint, and the indicator variable that specifies whether or not that shifted age is greater than 0. The formula[1] for constructing the model included only the term on the interaction of the shifted age with the indicator variable without the main effects. The results thus yield three coefficients: one for the intercept, one for the slope before the breakpoint, and one for after the breakpoint (see Baayen, 2008 §6.4 for details). The significance testing in the linear mixed model is not implemented in the lme4 package thus a p-value is not available. However, we can infer from the t-values that the interactions are highly significant both before ($b = 0.064$, $t = 20.52$) and after the breakpoint ($b = -0.007$, $t = -5.3$) because an absolute t-value of 2 or greater indicates a significance level of $\alpha = 0.05$ (Gelman and Hill, 2007). A likelihood test comparing the breakpoint model with a simple linear model showed that the breakpoint model provides a better fit than the linear model ($\chi^2(1) = 265.59$, $p < 0.001$). This confirms that the individual differences in the developmental pattern of CDS do not overrule the underlying similarity of the presence of the inflection point.

Returning to the discussion of the data in the individual dyads, the speaking rate of CDS rapidly increased in the early stage of child speech production, up to a certain point in a child's age, in all mother–child pairs (see Table 2).

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[1] Formula: MOT_SpeakingRate ~ ShiftedMonths:PastBreakPoint + (1 | mother).

Table 2
Statistics of the breakpoint regression analysis for CDS speaking rate as a function of child age in Thomas, Naima, Lily, Violet, Alex, William, and Ethan corpus. Regression coefficients with significant p-values are bold-faced.

Target child	F-statistics	R^2	Coefficients before breakpoint	Coefficients after breakpoint
Thomas	F [2, 373] = 132.4, $p < 0.001$	0.42	**$b = 0.08$, $p < 0.001$**	**$b = -0.02$, $p < 0.001$**
Naima	F [2, 85] = 73.63, $p < 0.001$	0.63	**$b = 0.06$, $p < 0.001$**	**$b = -0.02$, $p < 0.01$**
Lily	F [2, 77] = 26.44, $p < 0.001$	0.41	**$b = 0.04$, $p < 0.001$**	$b = -0.01$, $p = 0.25$ (n.s.)
Violet	F [2, 48] = 25.58, $p < 0.001$	0.52	**$b = 0.61$, $p < 0.001$**	$b = 0.01$, $p = 0.23$ (n.s.)
Alex	F [2, 48] = 28.71, $p < 0.001$	0.55	**$b = 0.07$, $p < 0.001$**	**$b = 0.02$, $p < 0.01$**
William	F [2, 39] = 11. 3, $p < 0.001$	0.37	**$b = 0.06$, $p < 0.001$**	$b = 0.01$, $p = 0.65$ (n.s.)
Ethan	F [2, 47] = 16.86, $p < 0.001$	0.41	**$b = 0.12$, $p < 0.05$**	**$b = 0.17$, $p < 0.001$**

The F-statistic in Table 2 is an overall test of whether the breakpoint linear model as a whole succeeds in explaining a significant portion of the variance. Given the small p-values in all of the corpora, there is no question about the significance of the fitted model. The regression coefficients before and after the breakpoint presented in Table 2 are for the slope of the regression line. The null hypothesis is that the slope is equal to zero, in which case there is no linear relation between the child age and the CDs speaking rate. Alternatively, a positive coefficient value indicates an acceleration of CDS speaking rate with an increase in child age, whereas a negative coefficient indicates the opposite, i.e. a decrease in CDS speaking rate with an increase of child age. In all of the dyads, the slope before the breakpoint was positive with the p-value less than the significance level, which means that CDS speaking rate steadily increased with the increase in child age up until the breakpoint. Past the breakpoint, however, some mothers continued to accelerate their speaking rate, i.e. Alex and Ethan, whereas others began to slightly slow down their speaking rate, i.e. Thomas and Naima. The rest of the mothers did not have a clear pattern in the direction of the change in the speaking rate beyond the breakpoint.

The estimated breakpoint of the linear-fitted function occurred at different ages among the children. The age and the corresponding MLU of child and mother at the breakpoint are summarized in Table 3. The determining factor for the breakpoint is not immediately clear. The child age range where the breakpoint occurs seems to be quite broad. If we eliminate the smallest value from Ethan and the largest value from Thomas, the age range for the breakpoint in the rest of the children becomes more uniform at 24–29 months. The child MLU and the mother MLU at breakpoint, expressed in terms of the mode, i.e. the value that most frequently occurs in the data set, was approximately around 2.4 and 5.5, respectively. We could then roughly say that the breakpoint tends to occur in the child's early multi-word stage, soon after the child begins to put the words together. Note that both of the two children with continued acceleration of CDS speaking rate past the breakpoint, i.e. Alex and Ethan, had a substantially smaller MLU of both the child and the mother at the breakpoint compared to other mother–child pairs.

3.1.2. Relationship between speaking rate and other variables in mother–child speech

In order to understand if there is any relationship between CDS speaking rate and other potentially related variables such as child speaking rate, child MLU, and mother MLU, the developmental patterns of these related variables were analyzed. A correlation analysis was first conducted between each paired variables in each mother–child pair, which is

Table 3
Child age, child MLU, and mother MLU at the breakpoint in each child.

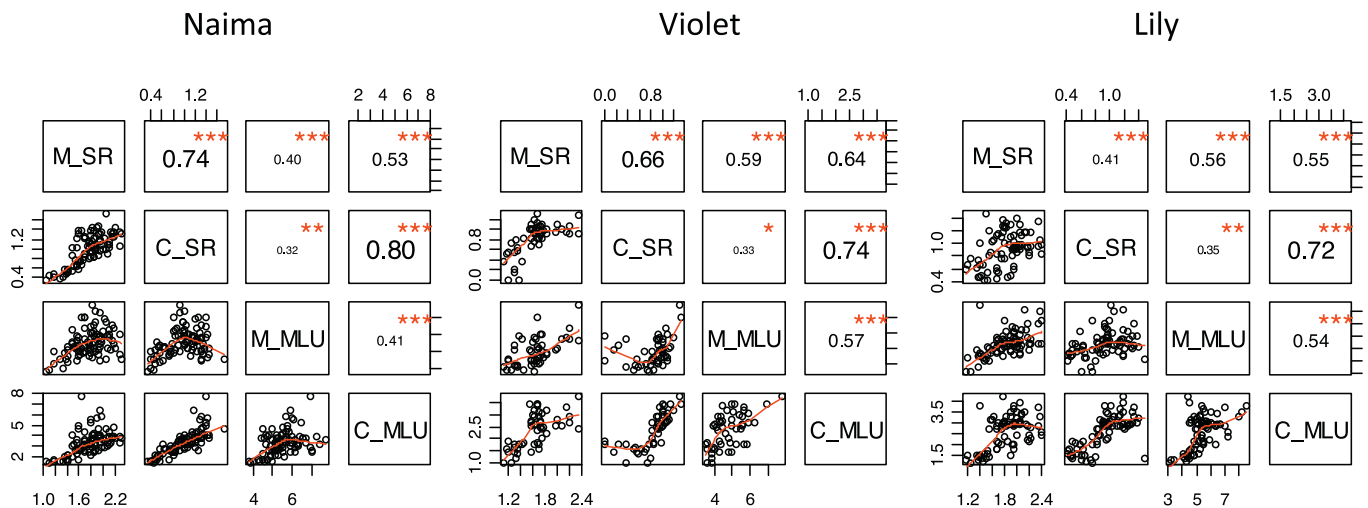| Child	Age at breakpoint in days (months)	Child MLU at CDS speaking rate breakpoint	Mother MLU at CDS speaking rate breakpoint
Thomas	1007 (33.0)	2.377	5.373
Naima	807 (26.5)	3.917	5.634
Lily	761 (29.3)	2.448	5.324
Violet	895 (23.7)	2.437	5.484
Alex	724 (23.7)	1.32	3.874
William	851 (27.9)	2.442	4.895
Ethan	412 (13.5)	1.1	2.829

Fig. 3. Visualization of a correlation matrix between Mother Speaking Rate (M_SR), Child Speaking Rate (C_SR), Mother Mean Length of Utterance (M_MLU) and Child Mean Length of Utterance (C_MLU) for Naima, Violet, and Lily. Each matrix contains three components: (1) the label for each variable (the diagonal elements), (2) the values of the correlation plus the result of the correlation test as stars (***$p < 0.001$, **$p < 0.01$, *$p < 0.05$; upper diagonal elements), and (3) the bivariate scatterplots with a fitted line (the lower diagonal elements). For example, the element at the 2nd row and 1st column of each matrix represents the scatter plot between the 2nd row (C_SR) and 1st column (M_SR) in the diagonal elements with a fitted line.

presented as a correlation matrix in Fig. 3. As we see in Fig. 3, there are high levels of correlation among CDS speaking rate, child speaking rate, child MLU, and mother MLU. Although correlation matrices were presented for only three mother–child pairs due to space limitations, correlations among the related variables are clear.

The multicollinearity among the related variables makes it hard to estimate independent contributions of each of the variables in predicting the values of CDS speaking rate, and violates the assumptions for a multivariate analysis. Therefore, we sought to describe the developmental changes operating in each variable, although it should be noted that they are likely not mutually independent. To describe the developmental patterns, an analysis of breakpoint linear regression was conducted on each of the related variables. Fig. 4 presents sample plots of the four variables for three mother–child pairs, showing only the regression lines where the extra parameter in the breakpoint model, compared to the simple linear regression model, was justified at $p = 0.05$ or smaller; Table 4 presents the child's age at the breakpoint for each variable.

The results (Fig. 4 and Table 4) suggest that the nonlinearity of the developmental pattern was present not only in the CDS speaking rate, but also in the speaking rate of the child, and in the MLU of both mother and child (cf. Brown, 1973; Scarborough et al., 1986). They also suggest that the breakpoints in the development of speaking rate and MLU do not necessarily coincide. Overall, the direction of the shift was from a rapid increase in the speaking rate and MLU, during the child's early speech, to a phase characterized by individual variations in the developmental pattern, i.e. a deceleration in

Table 4
Age in days at the breakpoint of the linear regression analysis. Significance codes are from the ANOVAs comparing the regression with a breakpoint to the simple linear regression. The minus signs presented in parentheses indicate that the coefficient values before the breakpoint were negative.

	Age at mother speaking rate breakpoint	Age at child speaking rate breakpoint	Age at mother MLU breakpoint	Age at child MLU breakpoint
Thomas	**1007*****	**1191*****	**803*****	**1165****
Naima	**807*****	**592*****	**549*****	702, $p = 0.29$ (n.s.)
Lily	**761*****	556, $p = 0.05$ (−)	**859*****	**859*****
Violet	**895****	**743*****	**627**** (−)	**926****
Alex	**724***	**1225*****	1239, $p = 0.07$	**657***** (−)
William	**851***	**864****	619, $p = 0.32$ (n.s.)	978, $p = 0.07$

Significance codes:
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.
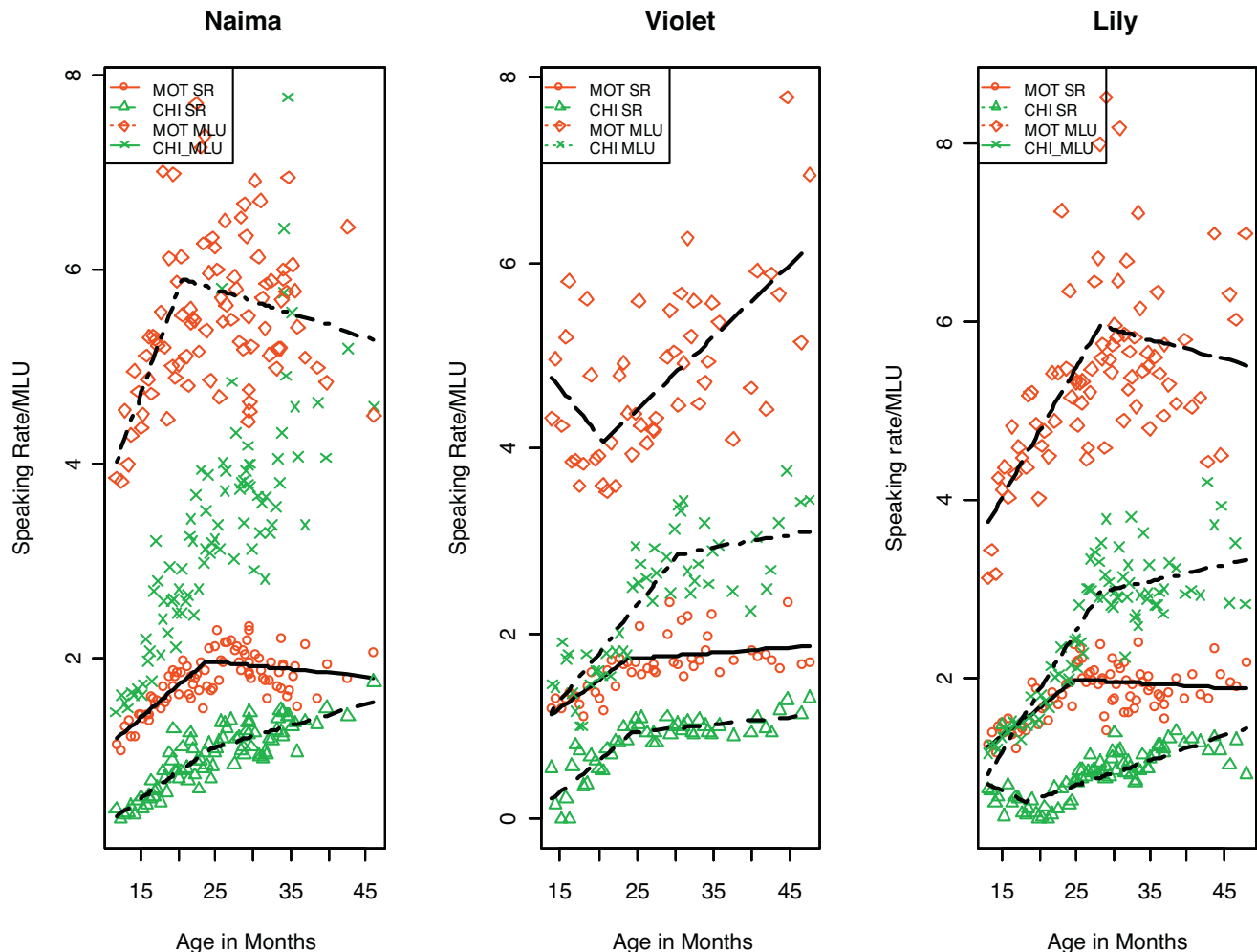
Fig. 4. Co-variate effects of child age on Mother Speaking Rate (o), Child Speaking Rate (△), Mother MLU (◇), and Child MLU (+). Only the regression lines where the parameter of breakpoint is justified at $p = 0.05$ or smaller are shown.

the rate of change or in the speaking rate, or no significant developmental pattern in speaking rates beyond the breakpoint. However, some of the breakpoints represent changes of the regression coefficients from negative to positive values, as in the mother MLU of Violet or child speaking rate of Lily. Table 4 indicates such patterns with a minus sign in parentheses. The changes of the slopes from negative to positive in the mother MLU may be associated with the transition from a pre-verbal to a verbal stage, which will be discussed in the next section.

3.2. CDS speaking rate in preverbal children

The results in the previous section indicate that a mother's speaking rate in the child's verbal period is lowest at the onset of her child's speech production. Then, do mothers start out speaking even more slowly while the child is still pre-verbal, or do they reset their speaking rates to the slowest with the emergence of speech production in the child? Unfortunately, there was no dense corpus available with duration extensive enough to address this question directly. However, CHILDES database contains data from 18 mothers interacting with their preverbal children; this study analyzed these data to detect any patterns in the CDS speaking rate in the pre-verbal stage. If the acceleration of CDS speaking rate starts during the preverbal stage, one would expect to find either evidence for positive correlation between the child's age and the mother's speaking rate, or a breakpoint where the slope of the regression line would change from negative to positive. Fig. 5 presents the results of the linear regression modeling; only the regression lines with a p-value smaller than 0.05 were plotted.

The results show that out of the 18 mothers analyzed, only 8 had a significant correlation between the child's age and the mother's speaking rate (Fig. 5). Out of these 8 mothers' data, 4 had negative, and 4 had positive regression coefficient values. The results, thus, do not provide evidence in support of the hypothesis that the CDS starts out with a lowest speaking rate and continuously accelerates through the pre-verbal period. A parallel analysis with the mother's MLU yielded similar results.
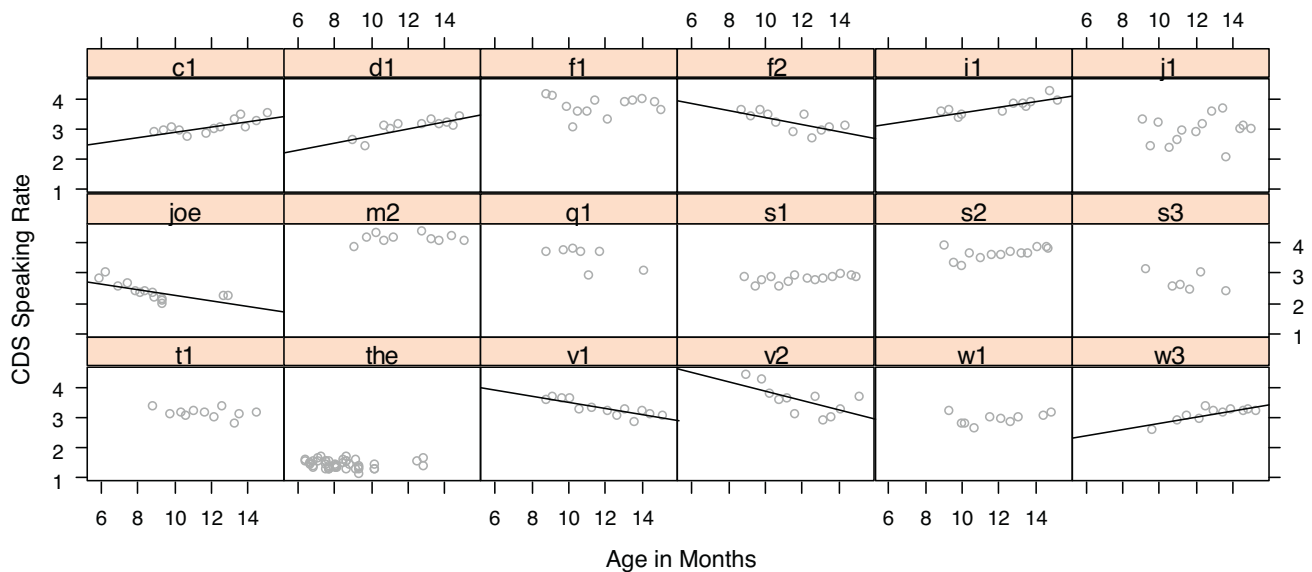
Fig. 5. Effects of child age on the CDS speaking rate in 18 mother–child pairs from Brent and Soderstrom corpora.

The alternative hypothesis, that mothers' speaking rates are reset at their lowest values around the time their children begin to produce their own speech, was hard to evaluate due to the lack of data covering both before and after the onset of speech with enough temporal margin. Note, however, that an independent study also based on a dense corpus (Roy et al., 2009) found that the MLU of caregivers systematically decreased until about the time the child began combining words, around 16 months, followed by an increase in their MLU's. Given the lack of comparable data in the CHILDES database, the average speaking rate in the entire data from the 18 mothers in the Brent and the Soderstrom corpus were compared with that of the data from the 6 mothers in the Providence corpus. The result of a Welch's t-test indicated that the CDS speaking rate during the pre-verbal period (2.89 words/s) was higher than that in the early speech production period before the breakpoint (1.46 words/s), $t(297.3) = 24.88$, $p < 0.001$.[2] This suggests a possibility of another breakpoint around the time the child begins to produce his/her first words, which is worthy of further investigation in future research.

3.3. Testing the reliability of the speaking rate measure

Speaking rate is affected by a number of factors such as sentence length, emotion, and information status of the utterance. For example, the sentence ''Where did the armadillo go?'' was uttered four times in the same session (nai21), interleaved with other utterances. The duration of the four instances of the same sentence, however, varied greatly: 1.89, 1.34, 1.64, and 1.96 s, respectively. Given the susceptibility of speaking rate to many different factors, a proper estimation of the speaking rate in spontaneous speech would require either factoring out all influences on duration, or analyzing a large enough random data set which would represent the population statistics according to the Law of Large Numbers. Due to the great number of possibilities that would need to be controlled and the complexities of performing such a control on spontaneous speech, the current study has adopted the latter approach.

As mentioned earlier, the calculation of speaking rate in this study was based on the number of words in transcripts and the corresponding time stamps rather than on the actual acoustic signals. Therefore, the validity of the results based on such a method may need some confirmation. We could find indirect support for the findings in the nonlinear developmental patterns replicated in multiple variables in many mother–child pairs (Table 4), which suggests that the nonlinearity found in CDS speaking rates was not an artifact of the methodology. Note that the nonlinearity in the MLU, which replicates the findings in Scarborough et al. (1986), is based on firm word counts. The parallel patterns shared between the CDS speaking rates and the MLU thus point to the validity of the findings in this study. Nevertheless, the findings made under

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[2] The CDS speaking rate before the breakpoint in Thomas corpus was somewhat higher (3.01 words/s) than the ones in the Providence corpus, which could be due to the older age range of its data. It could also be due to the differences in the segmentation practice, which could have left smaller pauses around the utterances in the Thomas corpus than the data in the Providence corpus. Still another possibility is the different dialectal characteristics between the Thomas and the Providence corpus. A further investigation would be necessary to pin down the source of this divergence.

the current methodology would benefit from a supplementary analysis based on the acoustic signals. In this section, two supplementary analyses of speaking rates based on acoustic signal are presented to validate the results based on the transcripts.

First, a selection of utterances were taken to calculate CDS speaking rates based on a manual syllable count, and then compared to the speaking rates generated by the automatic analysis based on word count. The sample utterances for analyses were taken from 10 out of the 83 sessions in the Naima data. The 10 selected sessions included two sessions at the very beginning (nai01, nai03), two sessions at the breakpoint (nai49, nai50), two sessions at the very end (nai82, nai83), and two sessions in between each of the periods generated by those three points (nai21, nai22, nai65, nai66). As mentioned earlier, speaking rate is contingent upon the number of words contained in the sentence, i.e. the more words in a given sentence, the higher the speaking rate. More specifically, there is an abrupt rise of speaking rate for utterances containing from one to seven words in adult–adult speech (Yuan et al., 2006). To control for sentence length, therefore, only the utterances containing five words were selected in this analysis. The selected speech segments went through a clean-up process. The reasons for eliminating segments from analyses included the following: speech containing disfluencies, interjections or playful vocalization; unsatisfactory signal quality due to noise or overlapping voices; speech where not all five words were pronounced as in '[Are you] being a horse?'.

Out of the total of 552 utterances extracted, 425 utterances were manually coded for the number of syllables contained in the utterance as well as utterance boundaries for calculating speaking rate. Information on the number of utterances and the mean number of syllables as well as speaking rates in each session is presented in Table 5. A Pearson correlation analysis indicated that there was a high correlation between the speaking rate manually calculated based on the acoustic signal, i.e. syllable/s, and the machine-generated speaking rates based on the transcript, i.e. words/s ($r = 0.93$, $n = 10$, $p < 0.001$).

In the second supplementary analysis, speaking rates were calculated based on a semi-automated method using the acoustic characteristics of the speech signal. The samples were selected at three critical periods of the Naima data, i.e. at the beginning (age 0;11.28), breakpoint (age 2;1.10), and end (age 3;10.10) of the age range contained in the corpus. Each session lasted for 81, 82 and 82 min, and contained 887, 833, and 643 utterances, respectively. Out of these, we manually selected 343, 632, and 238 utterances after removing utterances that were not appropriate for automated calculation of speaking rate due to the inclusion of overlapping speech, vocal play, or background and static noise. The boundaries of these utterances were manually annotated with the exclusion of the preceding and trailing pauses. The speaking rates were then calculated using a Praat script that automatically detects syllable nuclei based on intensity and voicing of the acoustic signals (De Jong and Wempe, 2009).

A one-way ANOVA was performed to test the differences in mean speaking rates at the three temporal points of Naima data. The mean speaking rates significantly differed across the three temporal points (F [2, 1210] = 16.62, $p < 0.001$). Tukey post hoc comparisons of the three groups indicated that the speaking rates at age 0;11.28 were significantly lower ($M = 3.13$ syllables/s) than those at age 2;1.10 ($M = 3.52$ syllables/s), $p < 0.001$, and those at age 3;10.10 ($M = 3.63$ syllables/s), $p < 0.001$. However, the differences between the speaking rates at ages 2;1.10 and 3;10.10 were not significant (Fig. 6). This result resonates with the findings made earlier in this paper that the CDS speaking rate rapidly accelerated in the beginning of a child's early speech production period, but that there is a turning point after which it shifts to a different phase.

Table 5
Summary of the number of utterances available, number of utterances analyzed, average number of syllables, average speaking rate based on acoustic signal, and the speaking rate based on transcripts in five-word sentences selected from 10 sessions of the Naima data. Speaking rates gradually increase toward the breakpoint (nai49, nai50) and then decrease in both measures based on speech and transcripts.

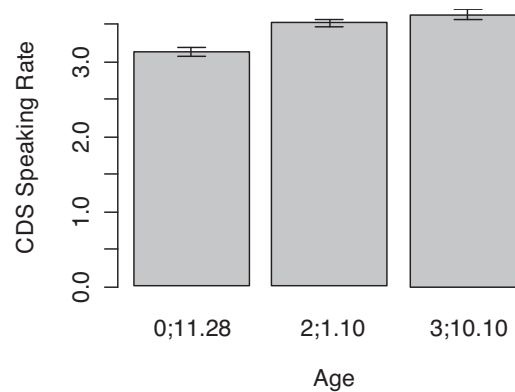| Session id	Number of utterances available	Number of utterances analyzed	Mean number of syllables	Mean speaking rate based on acoustic signal (syllable/s)	Mean speaking rate based on transcripts (word/s)
nai01	61	49	6.02	3.77	1.10
nai03	76	45	5.64	3.40	1.28
nai21	62	56	6.39	4.63	1.81
nai22	83	51	6.10	4.44	1.87
nai49	35	31	5.94	4.90	2.16
nai50	23	21	6.48	4.90	2.16
nai65	58	41	5.98	4.62	1.77
nai66	39	37	6.32	4.46	1.58
nai82	50	37	5.78	4.46	1.79
nai83	65	57	5.91	4.69	2.05

Fig. 6. CDS speaking rates in syllables/s at three temporal points in Naima's language development.

The two supplementary analyses of speaking rates presented in this section corroborate findings made in earlier sections based on the transcripts. There is, however, one important limitation of the transcript-based analysis that is worth mentioning. Given the lack of guideline on the exact points of segmenting the utterances in CHILDES, the time stamps found in the transcripts include varying amount of pauses before and after the actual utterance. Because the error is random, the developmental shape is not likely to be affected by the presence of these pauses. Nevertheless, we cannot completely rule out the possibility that different practices across transcribers in marking the boundaries could have affected the results in some way, and, in particular, the exact rate of words in a given time unit calculated this way is likely to be smaller than the actual rate due to the temporal margins included. Thus, comparison of rates across corpora or studies should be conducted with caution (see also fn. 3).

4. Discussion

We set out to detect any quantal changes in the developmental pattern of CDS speaking rate, a hypothesis compatible with the so-called ''tutorial function'' hypothesis of CDS. The results indicate that the CDS speaking rate changes over the course of child language development in a nonlinear pattern. When the child is pre-verbal, there is no uniform linear trend among mothers' speaking rates. There is some indication that the CDS speaking rate is reset around the onset of child speech production, which rapidly accelerates until a certain point around the age 2. After this transitional stage, the CDS speaking rate demonstrates a greater variation with no clear pattern in the direction of the development. Overall, then, it seems that the results of the current study support the notion that CDS is adapted to the changing linguistic needs of the child interlocutor at a given stage of language development.[3]

Nonlinearity was also found in the child's own speaking rate, as well as in the MLU of both mother and child. The similarity shown between the developments of CDS and the child's speech does not in itself elucidate cause and effect in their relation. However, the finding of abrupt shifts in both the development of CDS and the development of speech in the child provides an important methodological clue. If CDS serves as a model for the language-learning child, one would expect the shift in development to occur slightly earlier in the CDS than in the child speech, due to the processing time needed for the child. The summary of child age at the breakpoint of CDS speaking rate, child speaking rate, mother MLU, and child MLU, presented in Table 4, does not provide a definite answer to this hypothesis as the precedence relationship appears to be mixed. Whether this is because of the lack of such effects or the limitation of the current data (e.g. small number (*n* = 6) of observations regarding this effect) is not clear. However, the finding of breakpoints in the current study suggests future avenues of research that could provide important evidence for the much-debated role of input in language acquisition.

Another point of note is the less variation in CDS speaking rate across the sessions and the speakers in the early speech production stage as observed in Fig. 2. This contrasts with the great inter-individual variation during the child's pre-verbal period, and the great intra-individual variation in speaking rate during the multi-word stage. In other words, CDS is produced with a consistently slow speaking rate in the very early speech production period. In phonological and phonetic literature, CDS produced in the child's early speech production period is characterized as being less variable and more

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[3] Mothers' adaptation of their speaking rate is likely to be a behavior taking place below the level of conscious attention. The assumption is that speaking is only a means to the end of conveying messages, thus attention to phonetic medium is usually superseded by attention to message content (Kingston and Diehl, 1994).

articulate, compared to ADS; for example, less overlap between the voice onset time (VOT) of voiced and voiceless stops (Malsheen, 1980); less application of phonological rules such as deletion (Bernstein Ratner, 1984a); and consistent vowel space expansion in content and function words (Bernstein Ratner, 1984b). Could there be any relationship among the effects of articulatory precision in CDS demonstrated by these phonological variables and the slow CDS speaking rate demonstrated during the child's early speech production period? Kessinger and Blumstein (1997) reports that voice onset time (VOT) increases in almost equal proportions as speaking rate slows. Given that the greater separation between voiced and voiceless stops found in CDS to children of the early speech stage (Malsheen, 1980) was because of the longer VOT of voiceless stops in CDS, it is likely that the lesser overlap in the VOT is a by-product of slow CDS speaking rates in the early speech stage. It is also reasonable to assume that slower speech incurs less deletion and promotes hyperarticulation. Thus, it is likely that the articulatory precision of CDS reported in various studies is, at least in part, a by-product of the slower speaking rate in CDS during the early speech stage rather than being the articulatory goal.

The suggested interpretation of the articulatory precision in CDS provides a particularly insightful explanation for the findings in Malsheen (1980). Several studies have proposed that hyperarticulation helps acquisition of phonological categories by delivering information about the sound system of the native language in an exaggerated form (Kuhl et al., 1997; Werker et al., 2007). However, as noted in Soderstrom (2007), there is difficulty in applying this hypothesis to the exaggerated VOT in Malsheen (1980) because, by 15 months, children have already developed elaborate phonological representation of voice and voiceless features (White and Morgan, 2008; Ko et al., 2009). The exaggerated VOT in Malsheen (1980) is, thus, not likely to be driven by an effort to facilitate the phonological learning of children at the early speech stage. In the absence of other possible explanations, a mismatch of the phonological adaptation of the mother and the language-learning needs of the child has been suggested (Soderstrom, 2007). However, if the longer VOT in CDS is a by-product of the slow speaking rate, then it is not a matter of the mother misjudging the needs of the child. Rather, the mother is sensitive to the needs of the child, but in another domain.

Do the changes in CDS speaking rates represent random changes in speaking pattern? If not, what could be the driving force behind such changes? Firstly, the change is not likely to be a random effect because of the nonlinearity in the developmental pattern commonly observed in additional linguistic variables, as in Fig. 4, Table 4, and other studies (e.g. Brown, 1973; Scarborough et al., 1986), is best interpreted as a systematic reflection of change at a higher level. Given the similar developmental patterns observed in the CDS speaking rate and the CDS MLU, however, we should consider the possibility that the changes in CDS speaking rate may be a by-product of the mother's MLU development. Shorter utterances tend to contain fewer function words, which are shorter in duration than content words. Thus, with the increase of MLU in their speech, mothers may be able to use more words within a given unit of time. In addition, speakers might speak with a slower speaking rate for shorter sentence to maintain a consistent overall sentence duration. Such speculations are supported by the finding that the speaking rate rises rapidly for short turn length, remains level or falls gradually for medium turn length, and rises slowly for longer turn length in adult–adult conversation (Yuan et al., 2006). Application of this finding to the change of the CDS speaking rate is appealing because the rapid rise of CDS speaking rate is accompanied, overall, by a rapid rise in mother's MLU. However, one problem is that the timing of the turning points in the development of CDS speaking rate and MLU do not necessarily coincide (Fig. 4 and Table 4). Further, the tendency in CDS for function words to be deleted (Phillips, 1973) or contracted (Newport, 1976) requires more careful examination of this explanation.

A related possibility is that the slow speaking rate in CDS may be due to the greater number of boundaries, and thus, more frequent pre-boundary lengthening effects present in CDS due to the short MLU. Although plausible, this explanation also faces the same problem; the breakpoints in MLU and speaking rate do not coincide (Fig. 4 and Table 4). Alternatively, it could be that CDS simply has a greater magnitude of pre-boundary lengthening than adult-directed speech, which translates into slower speaking rate when the duration of all syllables are averaged (Church et al., 2005). If this is the case, the nonlinearity in speaking rate may be a reflection of a change in the magnitude of pre-boundary lengthening, at least to a certain extent. Recent findings in Ko and Soderstrom (2011), however, suggest that the elongation in CDS is a global effect affecting all words in sentences, at least in the relatively short five-word sentences elicited in a controlled setting. Then the slower speaking rate in CDS could not be attributed to the localized lengthening effect at utterance boundaries.

An additional possible source for the change in CDS may be the adjustment in the sensitivity of the mother to wide differences in the sophistication of the child listener. As previous research has proposed, mothers may continually monitor the degree of cognitive and communicative maturity of their child and adjust various features of their CDS, although such adjustments may not take place simultaneously (Snow, 1972; Phillips, 1973; Cross, 1977, 1978). One crucial prediction made in this view is that such an adaptation will not be made until the child is able to process the linguistic input and respond differentially to adult speech at around 1;0–1;4, depending on the linguistic variable (Snow, 1977b). A comparison of the analysis in pre-verbal vs. post-verbal data in the current study indirectly supports this prediction. During the pre-verbal period, mothers showed great individual variations in their pattern of speaking rate but all the mothers in the early speech period uniformly demonstrated a steady increase in their speaking rates. In addition, the significantly higher mean CDS speaking in the preverbal data than in the early speech period point to the possibility of shift in mothers' speaking rate. As mentioned

earlier, a robust shift from continuous decrease to continuous increase in the development of MLU in three caregivers of a child from Roy et al. (2009) also takes place around the onset of speech production, which accords with this hypothesis.

The driving force behind the second breakpoint around the time child begins to produce multiword utterances needs to be further clarified. One possibility is that by the time a child is able to put together multiple words and form a phrase or a sentence, the mother might judge that her child has achieved a certain level of grammatical knowledge. As mentioned earlier, proponents of the Prosodic Bootstrapping Hypothesis suggest that the lengthening at phrasal boundaries serves as an important cue for children's learning of syntactic structures, which is exaggerated in CDS due to its slow speaking rate. A mother, therefore, might provide gradually smaller amounts of enhancement in the boundary cues, i.e. gradually speak faster, as she senses the progress in the development of syntactic knowledge in the child listener. If the prime mover of such a change is the sensitivity of a mother to the linguistic needs of her child, future research will be able to confirm this hypothesis by a careful study of precedence relationship between the breakpoints of CDS and child speech.

5. Conclusion

This study set out to test the hypothesis that CDS directly facilitates language learning as might be indicated by mothers' continuous adaptation of their speech address to the child in response to the changing needs of the language learner at a given stage of language development. The investigation of the developmental trajectories in CDS speaking rate indicates that there is an abrupt shift in mothers' speaking rate when the child begins to put together words in an utterance, and points to an additional shift earlier around the time the child begins to speak. Such a quantal change in the development pattern was also observed with the child's speaking rate, as well as the MLU of CDS and child speech. The results thus seem to suggest that mothers continuously monitor the linguistic advances in their children, and make appropriate adaptations in their speech presumably to help facilitate their language learning.

In a typical cross-sectional study, important subtleties present in the individual developmental patterns are likely to be masked because cross-sectional methods would average out individual trajectories, thereby omitting the intermediary changes within the development of an individual child speaker (Ruhland, 1998). Therefore, findings of abrupt shifts in this study highlight the meaningfulness of intra-individual variability in the study of language development.

The notion of nonlinearity presented in the current study is not new. For example, Halliday (1975) conceptualizes this notion in three developmental stages of semantic acquisition. Similarly, based on a review of the literature, Bernstein Ratner (1987) suggests that phonetic modifications in CDS do not occur before the child has begun to speak, and that they do not persist after the child demonstrates the capacity to produce 3- to 4-word utterances. What sets the current study apart from previous studies is the establishment of breakpoints based on a quantificational analysis of longitudinal data that could serve as a methodological breakthrough in understanding the influence of CDS on child language development. A future study based on a larger sample size could analyze the precedence relationships and time lags between the breakpoints in the development of CDS and child speech. If we find that the breakpoints in the development of linguistic features are systematically slightly earlier in CDS than in child speech, it will lend support to the claim that CDS functions as a model for the language-learning child, while changes in CDS that appear slightly later than in child speech would indicate a responsiveness on the part of the speaker to the child's new developmental stage.

CDS is often discussed as if there are certain static features that characterize it as a special register. The results of this study, however, suggest that the hallmark of CDS speaking rate is not in its slow tempo, as much as in its dynamic changes with shifts occurring soon after children put together words roughly between 24 and 29 months, and possibly also around their onset of speech. These findings thus suggest that any studies of language acquisition should pay more attention to the dynamic nature of CDS and of child-produced speech, since the nature of the data can be very different depending on whether it is from the pre-verbal, early speech production, or multi-word stage of the child.

Acknowledgements

References

Adolph, K., Robinson, S., Young, J., Gill-Alvarez, F., 2008. What is the shape of developmental change? Psychological Review 115, 527–543.
Baayen, R.H., 2008. Analyzing Linguistic Data: A Practical Introduction to Statistics Using R. Cambridge University Press, Cambridge.

Bates, D., Maechler, M., Bolker, B., 2011. lme4: Linear Mixed-Effects Models Using S4 Classes. R Package Version 0. 999375-39. , http://CRAN. R-project.org/package=lme4.

Bernstein Ratner, N., 1984a. Phonological rule usage in mother–child speech. Journal of Phonetics 12, 245–254.

Bernstein Ratner, N., 1984b. Patterns of vowel modification in mother–child speech. Journal of Child Language 11, 557–578.

Bernstein Ratner, N., 1987. The phonology of parent–child speech. In: Nelson, E., van Kleeck, A. (Eds.), Children's Language, vol. 6. Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 159–174.

Brent, M.R., Siskind, J.M., 2001. The role of exposure to isolated words in early vocabulary development. Cognition 81, 31–44.

Brown, R., 1973. A First Language: The Early Stages. Harvard University Press, Cambridge, MA.

Chomsky, N., 1965. Aspects of the theory of syntax. The MIT Press, Cambridge, MA.

Church, R., Bernhardt, B., Pichora-Fuller, K., Shi, R., 2005. Infant-directed speech: final syllable lengthening and rate of speech. Canadian Acoustics 33 (4), 13–20.

Cross, T., 1977. Mothers' speech adjustments: the contribution of selected child listener variables. In: Snow, C., Ferguson, C. (Eds.), Talking to Children. Cambridge University Press, New York, pp. 151–188.

Cross, T., 1978. Motherese: its association with the rate of syntactic acquisition in young children. In: Waterson, N., Snow, C. (Eds.), The Development of Communication. Wiley, New York.

De Jong, N.H., Wempe, T., 2009. Praat script to detect syllable nuclei and measure speech rate automatically. Behavior Research Methods 41 (2), 385–390.

Demuth, K., Culbertson, J., Alter, J., 2006. Word-minimality, epenthesis, and coda licensing in the acquisition of English. Language, Speech 49, 137–174.

Englund, K., Behne, D., 2006. Changes in infant directed speech in the first six months. Journal of Infant and Child Development 15, 139–160.

Fernald, A., 2000. Speech to infants as hyperspeech: knowledge-driven processes in early word recognition. Phonetica 57, 242–254.

Foulke, E., 1968. Listening comprehension as a function of word rate. Journal of Communication 18, 198–206.

Gelman, A., Hill, J., 2007. Data Analysis Using Regression and Multilevel/Hierarchical Model. Cambridge University Press, New York.

Halliday, M., 1975. Learning How to Mean: Explorations in the Development of Language. Elsevier, New York.

Hirsh-Pasek, K., Kemler Nelson, D.G., Jusczyk, P.W., Wright Cassidy, K., Druss, B., Kennedy, L., 1987. Clauses are perceptual units for young infants. Cognition 26, 269–286.

Kessinger, R.H., Blumstein, S.E., 1997. Effects of speaking rate on voice-onset time in Thai, French, and English. Journal of Phonetics 25, 143–168.

Kingston, J., Diehl, R.L., 1994. Phonetic knowledge. Language 70, 419–454.

Kitamura, C., Burnham, D., 2003. Pitch and communicative intent in mothers speech: adjustments for age and sex in the first year. Infancy 4, 85–110.

Klatt, D.H., 1976. Linguistic uses of segment duration in English: acoustic and perceptual evidence. Journal of the Acoustical Society of America 59, 1208–1221.

Ko, E.-S., Soderstrom, M., 2011. Patterns of temporal modifications in child-directed speech. Journal of the Acoustical Society of America 130, 2523.

Ko, E.-S., Soderstrom, M., Morgan, J.L., 2009. Infants' perceptual sensitivity to extrinsic vowel duration in American English. Journal of the Acoustical Society of America 126 (5), EL134–EL139.

Kuhl, P., Andruski, J., Chistovich, I., Chistovich, L., Kozhevnikova, E., Ryskina, V., Stolyarova, E., Sundberg, U., Lacerda, F., 1997. Cross-language analysis of phonetic units in language addressed to infants. Science 277, 684–686.

Lieven, E., Salomo, D., Tomasello, M., 2009. Two-year-old children's production of multiword utterances: a usage-based analysis. Cognitive Linguistics 20, 481–508.

Liu, H., Tsao, F., Kuhl, P., 2007. Acoustic analysis of lexical tone in Mandarin infant-directed speech. Developmental Psychology 43, 912–917.

Liu, H.-M., Tsao, F.-M., Kuhl, P., 2009. Age-related changes in acoustic modifications of Mandarin maternal speech to preverbal infants and five-year-old children: a longitudinal study. Journal of Child Language 36, 909–922.

MacWhinney, B., 2000. The CHILDES Project: Tools for Analyzing Talk, third ed. Lawrence Erlbaum Associates, Mahwah, NJ.

Malsheen, B.J., 1980. Two hypotheses for phonetic clarification in the speech of mothers to children. Child Phonology Perception, vol. 2. Academic Press, pp. 173–184.

McCroskey, R.L, Thopson, N.W., 1973. Comprehension of rate-controlled speech by children with specific learning disabilities. Journal of Learning Disabilities 6, 621–627.

Morgan, J.L., 1986. From Simple Input to Complex Grammar. MIT Press, Cambridge, MA.

Morgan, J.L., Meier, R.P., Newport, E.L., 1987. Structural packaging in the input to language learning: contributions of prosodic and morphological marking of phrases to the acquisition of language. Cognitive Psychology 19, 498–550.

Newport, E.L., 1976. Motherese: the speech of mothers to young children. In: Castelan, N.J., Pisoni, D.B., Potts, G.R. (Eds.), Cognitive Theory, vol. 2. Lawrence Erlbaum, Hillsdale, NJ.

Newport, E.L., Gleitman, H., Gleitman, L.R., 1977. Mother, I'd rather do it myself: some effects and noneffects of maternal speech style. In: Snow, C.E., Ferguson, C.A. (Eds.), Talking to Children. Cambridge University Press, Cambridge, UK, pp. 109–149.

Panneton, R., Kitamura, C., Mattock, K., Burnham, D., 2006. Slow speech enhances younger but not older infants' perception of vocal emotion Research in Human Development. Special Issue: The Ecology of Emotion in Parenting Relationships 3 (1), 7–19.

Phillips, J.R., 1973. Syntax and vocabulary of mothers' speech to young children: age and sex comparisons. Child Development 44, 182–185.

Pinheiro, J.C., Bates, D.M., 2000. Mixed Effects Models in S and S-Plus (Statistics and Computing). Springer, New York.

Pinker, S., 1984. Language Learnability and Language Development. Harvard University Press, Cambridge, MA.

R Development Core Team, 2010. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN: 3-900051-07-0, http://www.R-project.org.

Roy, B.C., Frank, M.C., Roy, D., 2009. Exploring word learning in a high-density longitudinal corpus. In: Proceedings of the 31st Annual Meeting of the Cognitive Science Society, Amsterdam, Netherlands.

Ruhland, R., 1998. Going the distance; a non-linear approach to change in language development. Unpublished Dissertation. University of Groningen.

Saxton, M., 2010. Child language: Acquisition and development. Sage Publications, London.

Scarborough, H., Wyckoff, J., Davidson, R., 1986. A reconsideration of the relation between age and mean utterance length. Journal of Speech and Hearing Research 29, 394–399.

Singh, L., Morgan, J.L., Best, C.T., 2002. Infants' listening preferences: baby talk or happy talk? Infancy 3, 365–394.

Snow, C.E., 1972. Mothers' speech to children learning language. Child Development 43, 549–565.

Snow, C.E., 1977a. Mother's speech research: from input to interaction. In: Snow, C.E., Ferguson, C.A. (Eds.), Talking to Children: Language Input and Acquisition. Cambridge University Press, Cambridge, pp. 31–49.

Snow, C.E., 1977b. The development of conversation between mothers and babies. Journal of Child Language 4, 1–22.

Soderstrom, M., 2007. Beyond babytalk: re-evaluating the nature and content of speech input to preverbal infants. Developmental Review 27, 501–532.

Soderstrom, M., Kemler Nelson, D.G., Jusczyk, P.W., 2005. Six-month-olds recognize clauses embedded in different passages of fluent speech. Infant Behavior and Development 28, 87–94.

Soderstrom, M., Blossom, M., Foygel, I., Morgan, J.L., 2008. Acoustical cues and grammatical units in speech to two preverbal infants. Journal of Child Language 35, 869–902.

Sokolov, J.L., 1993. A local contingency analysis of the fine-tuning hypothesis. Developmental Psychology 29, 1008–1023.

Stern, D.M., Spieker, S., Barnett, R.K., MacKain, K., 1983. The prosody of maternal speech: infant age and context related changes. Journal of Child Language 10, 1–15.

Swanson, L., Leonard, L., Gandour, J., 1992. Vowel duration in mothers' speech to young children. Journal of Speech and Hearing Research 35, 617–625.

Tomasello, M., Stahl, D., 2004. Sampling children's spontaneous speech: how much is enough? Journal of Child Language 31, 101–121.

Toms, J.D., Lesperance, M.L., 2003. Piecewise regression A tool for identifying ecological thresholds. Ecology 84, 2034–2041.

Werker, J.F., Pons, F., Dietrich, C., Kajikawa, S., Fais, L., Amano, S., 2007. Infant-directed speech supports phonetic category learning in English and Japanese. Cognition 103, 147–162.

White, K.S., Morgan, J.L., 2008. Sub-segmental detail in early lexical representations. Journal of Memory and Language 59, 114–132.

Yuan, J., Liberman, M., Cieri, C., 2006. Towards an integrated understanding of speaking rate in conversation. In: Proceedings of Interspeech 2006, Pittsburgh, PA, pp. 541–544.