LANGUAGE LEARNING
A Journal of Research in Language Studies

Language Learning ISSN 0023-8333

Dynamic Adaptation in Child–Adult Language Interaction

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When speaking to young children, adults adapt their language to that of the child. In this article, we suggest that this child-directed speech (CDS) is the result of a transactional process of dynamic adaptation between the child and the adult. The study compares developmental trajectories of three children to those of the CDS of their caregivers. Furthermore, a mathematical-conceptual model is built that captures the essential dynamics of adaptation in a series of coupled equations. This model is sensitive to changes in the language development of the child. The results show evidence for a dynamic form of adaptation, although there are also clear individual differences.

Keywords child-directed speech; CDS; child language; adaptation; scaffolding; dynamic systems; MLU; vocabulary

Introduction

When speaking to young children, adults have the tendency to adapt their language to the child's linguistic abilities: They speak in shorter sentences and make syntactic simplifications. This child-directed speech (CDS) becomes more complex as the child grows into a more competent speaker. In this article, we argue that CDS can be described as the result of a dynamic adaptation between child and adult. In a general sense, developing a language implies that a child is continuously adapting his or her speech to the speech of the adult—the CDS forms the target language—while the adult in turn continuously adapts

This research was supported by a grant from the French National Agency for Research (ANR-06-BLAN-0011).

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DOI: 10.1111/lang.12002

his or her language to the level of the child. Although the specific adaptive processes in the child and the adult are fundamentally different, we contend that in spite of these differences both can be subsumed under the encompassing term of *adaptation*. This article takes a dynamic systems perspective on global quantitative adaptation between child language and CDS. The first goal is to compare the trajectories in mean length of utterance (MLU) and vocabulary of three children with the trajectories of the CDS of their caregivers. Second, we aim at validating a dynamic model of mutual adaptation of child and adult by comparing it with the data of the children and their input.[1]

Background to the Study

CDS, Adaptation, and Scaffolding

There is a large amount of (cross-sectional and longitudinal) research supporting the claim that CDS is an adaptive phenomenon. Already in the earliest publications, Snow (1972) argued that CDS becomes more complex with the age of the child. Caregivers are likely to tailor the complexity of their utterances to the linguistic abilities of their children, in the sense that they use slightly more complex language than the child uses (Harris, 1992, pp. 200–201). The mother's speech is probably maximally simplified around the child's first birthday. Philips (1973), for instance, reported significant differences between the CDS of (North American) mothers of 18- and 28-month-old infants, but not between that of mothers of 8- and 18-month-olds (the average mean length of utterance measurements [MLUs] at 8, 18, and 28 months were 3.56, 3.47, and 4.01, respectively). According to the author this implies that "the trend of complexity of mother's speech on age of child seems to have a point of origin, or a floor, at some time around the first birthday" (p. 185). This floor effect is also supported by the finding that maternal MLU is higher in samples of CDS to an infant of 4 months than in those to a 1-year-old child (Stern, Spieker, Barnett, & MacKain, 1983). Mothers decrease their MLU when infant word comprehension increases, around the age of 8 to 9 months (Sherrod, Friedman, Crawley, Drake, & Devieux, 1977), and infants start producing canonical babble, suggesting that they tailor their input to the receptive and expressive abilities of the child.

There are several studies that have addressed the process of language adaptation in time-serial data. For instance, the study by Huttenlocher, Waterfall, Vasilyeva, Vevea, and Hedges (2007) is based on five repeated observations of CDS to children between the ages of 14 and 30 months in a sample of 50 children. The analyses revealed that, on average, complexity measures (such as number of word types, number of noun phrases, and number of words per sentence) changed with the child's age. The authors concluded that these results indicate parents react sensitively to the language levels of their children, and that the parents' reactions are not just due to, for instance, motivation or interest in talking to older children. Dale and Spivey (2006) addressed the question of whether CDS and child language show characteristics of the more specific linguistic phenomenon known as syntactic coordination using recurrence analysis on three corpora. The study is in line with the one of Sokolov (1993), which supported the existence of such a process of morphosyntactic fine tuning in CDS. The results showed that children and caregivers were inclined to produce syntactic constructions that are used in the context of the conversation and that they hear the other speech partner use. The authors stressed that the term fine-tuning is often used with a unidirectional connotation in the literature, whereas the data suggested that the child is actively involved in shaping the syntactical conversational context.

There are indications that there might also exist crosslinguistic differences with regard to which aspects of a language are adapted and which not. Savickienė and Dressler (2007) found explicit adaptation in individual data of the use of diminutives in some—but not all—languages (roughly between the ages of 1;6 [years; months] and 2;6). For Italian, Finnish, and Greek, the frequency of diminutives in the CDS appeared to decrease with the child's age, whereas for German, Hungarian, and Russian, the use of diminutives remained high and interindividual differences were large.

The most intensive time-serial approach was taken in the single case study of Roy, Frank, and Roy (2009) by collecting the majority of all speech of a single child and the majority of the language spoken to him from ages 9 to 24 months. Results showed that the use of a new word by the child was predicted by a higher frequency of that specific word in the speech of the caregivers. Most support was found for what the authors call 'coarse tuning,' adaptation to the *general* linguistic competence of the child, by using shorter utterances and a more limited vocabulary. However, the authors concluded that caregivers also fine tune utterance length on a word-by-word basis, in the sense that they adjust their utterance length depending on whether the utterance consists of unfamiliar words or not.

In summary, though most time-serial studies of CDS describe changes in global linguistic measures (such as MLU and vocabulary), others show that comparable changes can also be found for several more specific variables (such as the use of diminutives and syntactic phrases). The focus of studies varies. Whereas some of the earlier studies are directed at showing unidirectional influences—either by showing how CDS changes depending on the language of the child or by describing how child language adapts to the input of their caregivers—other studies stress bidirectional influences.

A Dynamic Model of Mutual Adaptation

It has been suggested that caregivers adapt their language to the level just above that of the children they speak to and in doing so they bridge the gap between their toddlers' current level and the level that will emerge in the next stage of development (Cross, 1977; Harris, 1992). This observation fits well with Bruner's (e.g., 1978) concept of scaffolding and Vygotsky's notion of the Zone of Proximal Development (e.g., Murray, Johnson, & Peters, 1983). Several authors consider scaffolding and mutual adaptation in everyday situations as an important motor behind the process of language acquisition (Del Rio, Galván, & Gràcia, 2001; Lock, 1980; Ninio, 1992; Snow, 1982; Tomasello & Brooks, 1999; Vilaseca & Del Rio, 2004). According to van Geert and Steenbeek (2006) scaffolding must be understood as a transactional and recursive process, a view that is in line with a dynamic systems theoretical framework.

The framework of Dynamic Systems Theory (see Thelen & Smith, 1994; also Lewis, 2000; van Geert, 2003) originates from the natural sciences where it is used to explain complex processes. In this view, *systems* are conceived to consist of interacting components that self-organize in such a way that complex patterns emerge. Applied to the domain of human development the concept of mutual causality implies that components influence each other continuously and mutually, though the strength of the connections can vary and the relations are often nonlinear. Another central concept is *iterativity*, meaning that the state of a certain variable is dependent on the previous state of that variable. From a dynamic systems point of view, adaptation between a child and an adult can be conceived of as an attractor landscape in which the behavior that occurs in both dyadic partners is continuously changing and depending on the behavior that has just occurred. Dynamic systems concepts have been applied to various domains of developmental psychology, such as motor development (e.g., Thelen & Smith, 1994; also Goldfield, 1993), brain development (Fischer, 2008; Lewis & Liu, 2011), cognitive development (Fischer & Bidell, 2006; Granott & Parziale, 2002; van Geert, 1991), and parent–child interactions (e.g., Fogel, Garvey, Hsu, & West-Stroming, 2006; Granic, Hollenstein, Dishion, & Patterson, 2003; Lichtwarck-Aschoff, Kunnen, & van Geert, 2009; van Dijk, Hunnius, & van Geert, 2012).

In the present study, we propose the idea of adaptation in CDS as a fundamentally transactional process between two mutually dependent variables that

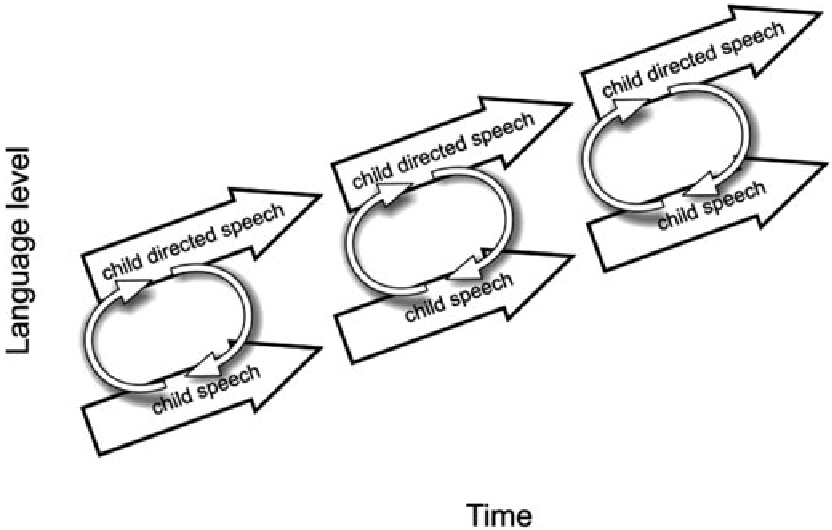

Figure 1 Graphical representation of the proposed recursive nature of the adaptation between child language and child-directed speech.

continuously influence each other. Note that the language input to a child is much broader than the CDS of one specific parent. Moreover, the language level at each point in time is not only a function of the specific CDS at that point in time, but also of the language level of the child itself at the previous point in time, as depicted in Figure 1. In a developmental context, short-term adaptation by a mature person consists of a temporary modification to fit the needs or possibilities of the less mature person. It can also contain elements of imitation and simplification.

The dynamic systems characterization of CDS just described forms the basis for the mathematical model of van Geert and Steenbeek (2006) on scaffolding in educational settings. In this model, the change in the child's level (of any developmental variable of interest) is considered to be a function of the support given, and the change in the support level is conceived of as a function of the child's current level and of the child's learning. However, it has to be stressed that in the informal context of early language learning, adaptation is largely unconscious, and that the unconscious inclination to adapt might be different for different parents or at different points in time. In this study, we pose the question of whether this specific mathematical model of scaffolding adjusted to the domain of early language acquisition is able to predict the developmental shapes of both the change in the language of the child and that in CDS.

Mathematical Model of CDS

The scaffolding model we adjusted from van Geert and Steenbeek (2006) for the present study has two major components. The first is *the adaptation in the parent* expressed as I_t in the model (I stands for input, i.e., the language addressed to the child), which depends on the tendency of the parent to adapt (A_t; and ΔA_t which is the change in the adaptation tendency), and the habitual level of the language of the parent (I_H), for example, the MLU level in the parent's adult-directed speech (ADS). The second component is the *language growth in the child* (ΔL_t), which is a function of the tendency of children to adapt their language to the language of the parent (C_t) in relation to the current level of the already adapted language level. Note again that the concept of adaptation is used in a very broad sense, and covers processes of short-term adaptation to a communication partner such as a child, on the one hand, and the processes of long-term adaptation in the sense of learning and developing one's mother tongue.

Let us start with the first component of the model, the side of the parent. It is important to begin with the parent's *tendency* to adapt to the child. In an informal learning process such as language acquisition, this tendency is spontaneous and less explicitly controlled than in the context of formal learning and teaching that was originally considered by van Geert and Steenbeek (2006). Parents may change their tendency over time, depending on the learning of the child and on whether they perceive the child as having entered a specific language-learning trajectory or not (see, e.g., the studies of Philips, 1973). Some adults will have a stronger tendency to adapt, that is, they adapt more strongly to the child's level than others. Parents may also differ in the ease with which they change their tendency to adapt their language to that of the children. Why would a parent intuitively decide to adapt his or her language to the child? Imagine a parent who employs a particular level of MLU while addressing the child. It is likely that this level is adapted to the level of the child, that is, the child-addressed MLU is likely to be lower than the parent's habitual MLU in language addressed to other adults. If the parent perceives sufficient linguistic progress in the child, there is no need for the parent to change this child-directed MLU level to better stimulate the child's language learning. However, if the parent perceives little or no change in the language of the child, the parent may intuitively decide to change his or her child-directed MLU, either by further reducing it so as to come closer to the child's level and to make it easier for the child to learn, or by moving back to the habitual adult-oriented MLU level, in view of the fact that the adaptation does not seem to be effective. Note again that this does not imply that this process is intentional, in the sense that parents consciously change their CDS to teach the child something. Instead, it might be highly intuitive and resulting from the more general phenomenon of infant-parent intersubjectivity (Trevarthen & Aitken, 2001).

In short, the *tendency to adapt* one's adult language to that of the child may increase or decrease as a function of the learning or progress made by the child. This is expressed in the following mathematical equation:

$$\Delta A_t = a\, A_t(1 - \Delta L_t/L_t) \qquad \text{[Equation 1]}$$

Equation 1 states that the change (ΔA_t) in the adaptation tendency (A) is a function of the current tendency to adapt (A_t), the inverse of the amount of learning that takes place (here expressed as $1 - \Delta L_t/L_t$), and a constant change parameter, *a* (note that the learning is expressed relative to what is already there, i.e., relative to L_t). Parents with a strong natural inclination to adapt their language levels toward those of their children will have a high initial adaptation tendency A and are also likely to have a high positive value of *a.* Those who are less child directed are likely to have a negative value of *a,* meaning that they will have a greater tendency to go back to habitual speech levels if their CDS does not seem to be immediately effective. Using the inverse of the learning implies that the tendency to change one's level of child directed adaptation is greater at times during which the child learns little to nothing, provided the adult is expecting the child to learn from the CDS. The associated time scale is that of long-term change (i.e., over weeks or months).

Second, the *actual* CDS (I_t), or how close the parent comes to the level of the child, is given by the following mathematical expression:

$$I_t = I_H + A_t\,(L_t - I_H) \qquad \text{[Equation 2]}$$

Equation 2 should be read as: The actual CDS of the parent (I_t) is a function of the parent's habitual, nonadapted ADS level (I_H), the adaptation tendency (A_t), and the difference between the child's (L_t) and the parent's habitual level (I_H). When this difference between I_H and L_t is large, parents show maximal levels of adaptation resulting in maximally simplified CDS (and the limits of the simplification are determined by the adaptation tendency of the parent). However, if the child's level is close to the adult's, the actual adaptation required will be virtually nonexistent. The timescale associated with Equation 2 is that of short-term change: The adult will adapt his or her language to that of the child in real time, that is, adapt when addressing the child, and move back to the habitual ADS level when addressing an adult.[2]

Combined, Equations 1 and 2 imply that when children are functioning at a low level, the CDS is highly adapted (simplified). As soon as the child begins to show an increase in linguistic capacity, the level of adaptation is reduced, as a consequence of the increasing linguistic capacity of the child and of the change in the tendency to adapt.

Let us turn now to the second component of the model, the side of the child. The growth model of the *child language level* will take the following form:

$$\Delta L_t = r L_t^p (1 - L_t/(q I_t)) \qquad \text{[Equation 3]}$$

The basic form of Equation 3 is that of the logistic growth equation, which is one of the most common sigmoid (also called *s-shaped*) curves. In this equation, growth is constrained by limited resources. As a result, the increase is initially exponential but it slows down after saturation sets in and a certain maximal level is attained. Equation 3 implies that, in the end, the language of the child (L) will stabilize at the level of the target use (I) and will show an adaptation rate that is a function of a constant parameter[3] of change (r), the current level of the child (L_t) and the difference between the target level (I) and the current level of the child (L_t). (For a detailed description and justification of this model, see van Geert, 1991, 1994, 2008.) This current level L_t has an exponent p, which in the standard model has a value of 1, and allows in the case of $p > 1$ (in combination with a lower value of r) for a slower initial growth. Finally, qI_t is called the attractor level (in other logistic models often called the *carrying capacity*). The attractor parameter specifies how close the child can come to the level of the parent's language at that point in time and is basically a proportion of the parent's current use. The language development of the child is a form of change captured under various possible terms, namely *learning*, *acquisition*, and *growth*. It is important to stress that in this model the CDS of the parent is conceived of as the target language for the child. The adaptation of the child should thus be seen as a more general form of change toward the target language, in this case represented by the CDS. We admit that in this sense, the model is highly simplified, because in the real world the target language is offered to the child in many additional ways. However, we take the CDS as a representative sample of the target language toward which the child adapts his or her language. This target is thus characterized by a certain level, I_t, which is the CDS at time t, and L_t is the child's current level. The timescale associated with Equation 3 is that of long-term change, that is, change in the child's language level over the course of months to years.

Importantly, the equations we have described above are *coupled* in the sense that they are mutually dependent upon each other: $-L_t$ is dependent on I_t and I_t is dependent on L_t. The model thus describes a form of cyclical causality that is a central characteristic in a dynamic systems framework. Events on the short-term time scale of real linguistic interaction (Equation 2) affect changes on the long-term time scale of language development (Equation 3) or of the adult's general tendency to adapt to the level of the child (Equation 1). These long-term time scale events, in turn, determine the properties of the short-term or real-time communicative interactions between the parent and the child, thus closing the causal cycle.

Above, we have described a model of language adaptation that can be fitted to the empirical data. We can also test it against the simplest alternative, which would be that there is no adaptation at all. In other words, parents might use language that is different from—or even simpler than—their habitual use, but this language does not increase in complexity as the competence of the child increases. There might be an adjustment in topics and content, but quantitatively speaking the data can be fitted with a model that has a constant average and standard deviation.

The Present Study

In this study, we take a quantitative approach to adaptation in the communicative interaction by comparing the developmental trajectories of CDS and child language. We focus only on relatively global measures (MLU and vocabulary) and look at the relatively global time scale (over the course of multiple weeks and months). However, it might be suggested that this type of adaptation is produced by short-term influences, such as immediate imitations during a specific dialogue or the specific context (e.g., a type of activities or a setting). For instance, when parent and child discuss a certain activity, they might both use types of constructions and words that are apparently adapted to each other, but are in fact caused by the highly specific circumstances in which they are produced. This would imply that the local peaks of the CDS correspond with the local peaks of the child, partly explaining a possible long-term correspondence between both trajectories. When we aim at describing the general trajectories, we thus also need to consider these local types of adaptation. We therefore will address the following questions in our analysis of the speech of three children participating in a crosslinguistic study on the acquisition of Dutch, Austrian German, and French:

1. What are the similarities and differences in the developmental trajectories of the language of the child and the speech of the caregiver?
2. To what degree are the results influenced by local adaptation?
3. Can our mathematical scaffolding model be validated with the empirical data of the child language and the CDS?

Method

Participants

The database used in the study consists of samples of longitudinal speech from three monolingual children in conversation with their parents: one girl learning Dutch (Jessica), one boy learning Austrian German (Jan), and one girl learning French (Pauline). The Dutch girl was studied from age 1;6 to 2;6, with an additional session at 2;10, the Austrian boy was studied from roughly age 1;3 to 3;0 and the French girl was studied from roughly age 1;2 to 3;0. The children came from average to higher socioeconomic status backgrounds. The participating adults were in all cases the biological parents of the children. In Pauline's and Jan's cases, the CDS samples always consisted of mother's utterances. For Jessica, they consisted of mother's or father's utterances (which in her case was also more representative, because both parents were equally involved in daily caregiving).

Corpus Data, Transcription, and Measures

The three corpora were part of a crosslinguistic project on the grammaticalization of nouns and verbs (Bassano et al., 2011) and stem from larger databases on each target language, respectively, by the Dutch, the Austrian, and the French team. Although the data were collected independently, these specific corpora were chosen because they had been obtained using similar methods and research designs. The specific samples were chosen to obtain maximal similarity of the design (we selected solely the 2-weekly samples and only used the first part of the transcripts). Each child was (audio or video) recorded at home, roughly two times per month in unstructured interactive sessions during everyday activities, and the total recordings were each between 30 minutes and 2 hours long. Appendices S1 through S3 in the Supporting Information online show the descriptive statistics for each child, including the ages at each collection point.

Transcriptions were made according to the CHAT format (MacWhinney, 2000). All child speech and CDS was transcribed orthographically. The reliability of the transcription was resolved within each team by double-checking transcriptions by a second transcriber. For the purpose of the present study, all further analyses of the transcripts are based on 60 child utterances and 50 utterances of the caregiver (which means the first 20–30 minutes of each recording). The child speech and CDS (i.e., the samples of 60 and 50 utterances, respectively) were submitted to various steps of coding. Methodological questions raised with respect to one of the corpora were discussed among the teams to ensure consistency in data coding. Each team had the help of extensively trained master students.

Adaptation between child and caregiver was examined in two general language variables, comparable to measures used in Roy et al. (2009). The first is mean length of utterance in words or MLU-w, which in the remainder of this article will be referred to as MLU for simplicity. It was calculated as the average number of words in one utterance. We used a net version that excluded vocalizations, babbling, false starts, completely incomprehensible productions, and singing/rhymes (see Bassano & van Geert, 2007). Imitations, repetitions, citations (i.e., when someone was quoting someone else's speech), and yes/no utterances were included, because we considered these aspects as a natural part of the everyday discourse between child and adult. The second variable is vocabulary types (i.e., total number of lemmas), which was calculated as the number of unique words in each transcript. Here, variations of inflections (regular and irregular) in the same verb were calculated as one type, and the same was true for singular/plural nouns. In the remainder of this article we will refer to this measure as just vocabulary for simplicity.

Analyses

The analyses started with individual curve analysis that addressed our first research question. First, the raw data were plotted in combination with a Loess smoothing in order to capture the general tendencies and get a sense of the local variability at the same time. In order to get a general impression of the correspondence between the trend of the child and the trend of the CDS, we computed correlations between the smoothed data of the CDS and that of the child. We continued with a visual exploration of the curves. Note that for Jessica, there was a relatively large gap between the final observation at the age of 2;10 and the one before that at age 2;6, from which follows that the end tail of these smoothed trajectories contained less data points and was therefore somewhat less robust. As a second step, the smoothed data were also normalized using the formula: (x-min)/(max-min) to fit the same scale (between 0 and 1). This way, we were able to compare more easily the relative changes and qualitative similarities between parent and child.

Second, in order to address our second research question and analyze the correspondence between the local patterns of variability in child speech and CDS, we first calculated the residuals (by subtracting the original data from the smoothed data). These values represent the local fluctuations in the original data. We then computed a correlation coefficient between the residuals of the child speech and those of the CDS in order to see how local fluctuations in the parent go together with local fluctuations in the child.

Third, in order to test our main hypothesis related to our third research question as to how adaptation would be captured in our mathematical model, we used a parameter estimation procedure to calculate the optimal model parameters for each individual child–adult pair, for both the scaffolding and the linear models. The resulting fitted model was consequently plotted in a line graph, in combination with the empirical smoothed curves. The r^2 was used as a measure of the fit between the model and the empirically found data. We fitted the scaffolding model to the smoothed empirical data of MLU and vocabulary, simply because the fit between the scaffolding model and the smoothed data is easier to visually inspect than that between the model and the raw data. Moreover, mathematically speaking, fitting the model to the smoothed data is equivalent to fitting it to the raw data, and the differences in the respective estimated parameter sets are only minute.

Finally, and also as part of our third research question, in order to test whether the CDS changes in relation to the child's language, a Monte Carlo analysis was carried out to test the simplest alternative, which is that no adaptation takes place. The analysis was based on the repeated (5,000 times) random reshuffling of the original data, calculating a criterion and comparing this with the empirically found values (in this case, we used the raw data for practical reasons). Consequently, the r^2 was taken as our testing criterion and we computed in how many cases (of the 5,000 permutations) the resampled data replicates the empirical values (see Good, 2000, and Simon, 1997, for an introduction to resampling methods). This frequency was consequently transformed into a p value.

Results

Curve Analysis

We start by comparing the developmental trends of the CDS with the development in the child. The main results are shown in Figure 2 and are presented below. The data (original and smoothed) which these graphs are based on can be found in Appendices S1 through S3 in the online Supporting Information.

Mean Length of Utterance

As a very crude measure of the correspondence between the child language and the CDS, we calculated the correlations between the smoothed trajectories of child and parent MLU (see Figure 2; the number of data points is 25 for Jessica, 39 for Jan, and 38 for Pauline). The resulting correlation coefficients were $r = .95$ ($p < .001$) for Jessica, $r = .81$ ($p < .001$) for Jan, and $r = .98$

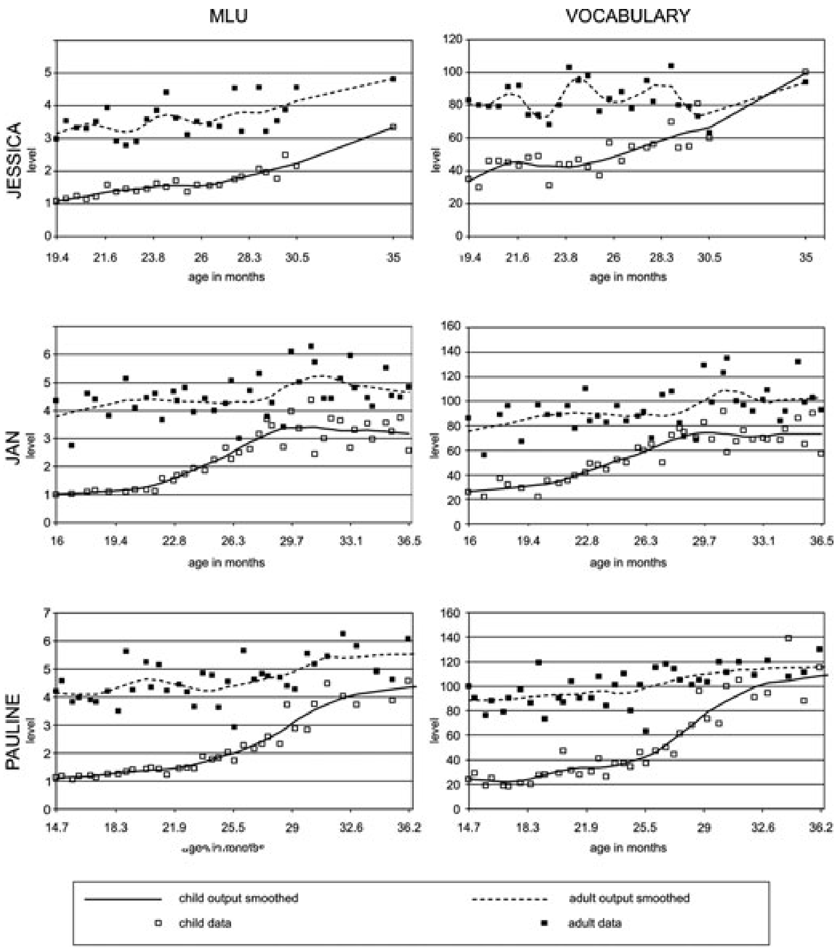

Figure 2 MLU and vocabulary (unique lemmas in sample) of Jessica, Jan, and Pauline (child language and CDS).

($p < .001$) for Pauline, which indicates a fairly strong association between both.

Visual inspection of the developmental trajectories in Figure 2 suggests that in (virtually) all cases, the MLU of CDS is higher than the MLU of the child and that both clearly increase with age. Based on eyeball statistics, the difference in MLU level between the child and the CDS grows smaller over time, because the child's acquisition rate is higher than the growth of the CDS. There are clear differences between the children. Jessica and her CDS seem to

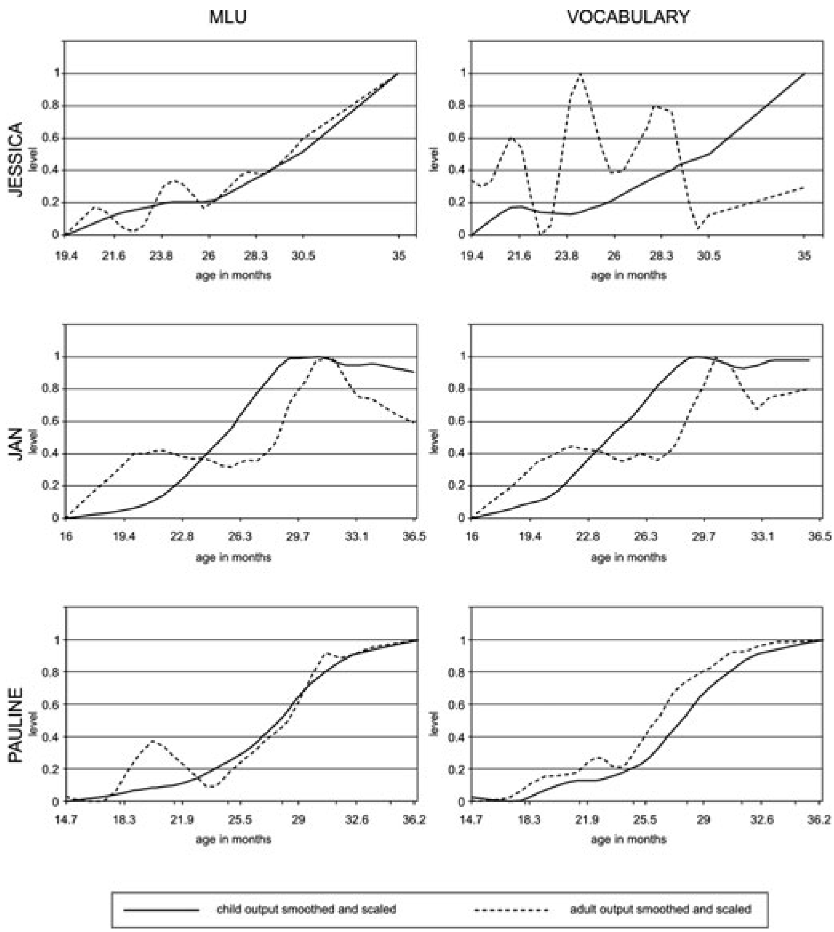

Figure 3 Smoothed and scaled data of the MLU and vocabulary of Jessica, Jan, and Pauline (child language and CDS).

have a relatively gradual (almost linear) trend. Her language is also somewhat behind compared to the other children. For Jan, there is a notable bump in the CDS followed by a short decrease shortly after the child's level stabilizes. For Pauline, there are also some slow oscillations in the caregiver's CDS, when the child's MLU is still steadily increasing. However, as soon as the slope of the child flattens, the slope of the CDS seems to flatten as well.

Figure 3 shows the smoothed and scaled data of the MLU and vocabulary in both the child language and the CDS. With regard to MLU, we observe some initial slow oscillations in the CDS of Jessica and Pauline, followed by a strikingly corresponding (relative) slope in both child speech and CDS. Jan's MLU, on the other hand, increases much earlier than the MLU in his CDS, and the shape of change is also very different. There are also similarities between Jan and Pauline in the sense that both seem to show two accelerations in CDS (although the final decrease is specific to Jan).

Vocabulary

With regard to the data on vocabulary, it will be remembered that we focused on the number of unique words in each sample (lemmas). Because the size of these samples are 60 utterances for the child and 50 utterances for the adult, absolute frequencies of vocabulary should be interpreted with care.[4] The correlation coefficients between the smoothed data of the child and those of the CDS are $r = -.14$ ($p = .475$) for Jessica, $r = .82$ ($p < .001$) for Jan, and $r = .95$ ($p < .001$) for Pauline (see Appendices S1 through S3 in the Supporting Information online for the smoothed frequencies), suggesting clear individual differences. Based on the visual inspection of Figure 2, the vocabulary values in the CDS of Pauline and Jan show a definite increase, while that of Jessica do not. Although in her case there are several slower oscillations (at least three), there seems to be no clear general increase (or decrease) over time. For Jan, we again observe a decrease in the CDS vocabulary when the child language reaches a local plateau. Finally, eyeball statistics suggest that in Pauline's data the CDS vocabulary flattens when the child level stabilizes at the end of the measurement period. Figure 3 shows that only in the case of Pauline is the general (relative) trend of the CDS very similar to that of the child. There are some similarities between Jan and Pauline, in that both seem to show two increases. This means that the child vocabulary growth might imply a model with two acceleration phases. For Jessica, the scaling leads to an overestimation of the local changes in this normalized representation.

Local Adaptation

In order to answer our second research question and analyze whether there is adaptation at the short time scale (i.e., from session to session), local fluctuations expressed as residuals, computed as the original data minus the smoothed data, of the child and the adult were correlated for both variables. The results are shown in Table 1. They show that there is no evidence for a relation between local fluctuations across variables and children. This suggests that the adaptation we found in the previous analyses is more general and is less likely to be the result of immediate imitation or context (e.g., according to type of activities or setting).

Table 1 Correlations between residual values of MLU and vocabulary use for Jessica, Jan, and Pauline

	MLU		Vocabulary	
	r	*p*	*r*	*p*
Jessica	.34	.10	.28	.18
Jan	.18	.44	.15	.36
Pauline	.09	.61	.05	.78

Validating the Scaffolding Model With Empirical Data

Our third research question asked whether our mathematical scaffolding model could be validated with the empirical data of the child language and the CDS. The results are reported in this section as follows. First we started by fitting the scaffolding model to the empirical data of MLU and vocabulary for all children and their respective CDS. The results are depicted visually in Figure 4. The r^2 values are reported in Table 2 for the relation between the model and the smoothed data. Second, we tested this against the null-hypothesis model of no adaptation, and the results for MLU and vocabulary are also shown in Table 2. Finally, we consider the parameters of the scaffolding model in Table 3, and evaluate whether they fit the assumptions or not.

Mean Length of Utterance

The results show that the estimated trajectory of the scaffolding model is able to closely replicate the empirical development of MLU in all children, and two out of three adults: the CDS of Jessica and Pauline. It should be noted that the sharp drop in the CDS MLU values from the first to the second data point is fictitious and represents the *estimated* adaptation from the habitual level of the parent to the level of the actual CDS in the data. The fit is high for most variables (most r^2s are between .91 and .99; see Table 2 for the values). As an exception, for the CDS of Jan, the fit between the model and the smoothed data is only moderate ($r^2 = .79$).

In order to test whether the observed CDS MLUs adapts to the child's current MLU-level, *p* values were calculated for the CDS model, based on the alternative model that no adaptation takes place. The resulting *p* values are all less than .001 (also see Table 2), implying that we can reject the null hypothesis of stationary CDS MLUs for all three children. The scaffolding model provides a set of parameter values that can give qualitative support for the model; Table 3 then provides the results of the parameter estimation of the model to the MLU and vocabulary of Jessica, Jan, and Pauline.

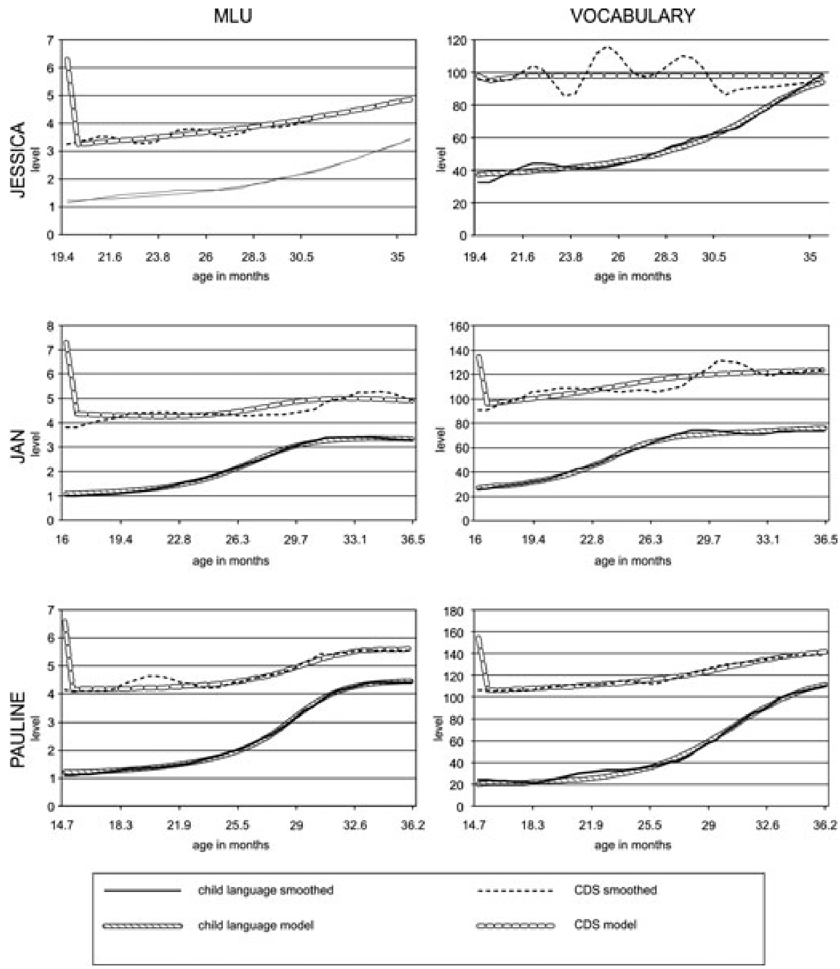

Figure 4 Fitted data for Jessica, Jan, and Pauline and their respective CDS (MLU and vocabulary).

First, with regard to the change of MLU in the child, and looking at Table 3, the C rate parameter (C for child) specifies the logistic growth rate of the children's MLU (*r* in the model) and must be interpreted in combination with the C power parameter (*p* in the model; see Equation 3). The latter parameter determines the effect of the growth level of MLU in the child on the growth of MLU. In the classical growth model, its value is 1. Values greater than 1 correspond with slow growth in the beginning followed by rapid growth in

Table 2 Fit (r^2) between the model and the data of MLU and vocabulary of Jessica, Jan, and Pauline, for the scaffolding model, including the *p* values resulting from the Monte Carlo analyses

	Jessica	Jan	Pauline
MLU			
Scaffolding CDS r^2	.97	.79	.98
Scaffolding child language r^2	.97	>.99	>.99
p value non adaptive model	<.001	<.001	<.001
Vocabulary			
Scaffolding CDS r^2	.07	.86	.99
Scaffolding child language r^2	.99	>.99	>.99
p value non adaptive model	.013	<.001	<.001

Table 3 Parameter estimation of the model to the MLU and vocabulary of Jessica, Jan, and Pauline

	MLU		
	Jessica	Jan	Pauline
C ini	1.16	1.11	1.21
C rate	0.14	0.34	0.20
C power	1.16	1.44	1.84
C attractor	1.00	0.59	0.75
A ini	6.17	7.25	6.58
A rate adapt	−0.008	0.008	0.000
A ini adapt	0.60	0.47	0.45
	Vocabulary		
	Jessica	Jan	Pauline
C ini	38.53	28.25	21.01
C rate	0.005	0.05	0.14
C power	2.00	1.54	1.13
C attractor	1.00	0.42	0.70
A ini	98.86	136.03	154.59
A rate adapt	−0.524	−0.015	−0.007
A ini adapt	0.10	0.37	0.36

Note. C = child, A = adult, ini = initial, adapt = adaptation.

the end. The results summarized in Table 3 show that Jan had the highest growth rate and a power parameter around 1.5. Pauline had a lower growth rate and a power parameter close to two (1.84), explaining the slow increase in the beginning. Jessica had the lowest growth rate and lowest power parameter (1.16), implying that she will need more time than the others to reach her first MLU-equilibrium level.

Second, the parameter called C attractor (q in the model; also Equation 3) specifies the optimal stable level the child can reach at that specific (developmental) point in time. This parameter is expressed as the proportion of the current CDS level. The attractor level of Jessica was estimated at 1, implying that she is able to reach an MLU level equal to that of the parent. This is consistent with the observation that both the child's and the parents' child-directed MLU are slowly growing, and that the more rapid the child's variable is growing, the sooner it will hit an age dependent limit which is below the child directed language level of the parent (see graphs of the other children in Figure 4). Pauline and Jan arrived at values that are 25% and 41% lower than the CDS level of their parents. This difference between Jessica on the one hand and Pauline and Jan on the other suggests that the parental CDS in Pauline and Jan are more linguistically complex or at a higher linguistic level than that of Jessica's parental CDS (at least as measured by MLU-w). This eventual difference in CDS complexity is to a limited extent reflected in the model estimates of the parent's habitual MLU levels (see "A ini" or initial adaptations tendency in Table 3), which for Pauline, Jessica, and Jan are 6.6, 6.17, and 7.25, respectively.

Third, the adult's tendency to adapt, the initial value of which is represented by the A ini adapt parameter shown in Table 3, should have a positive value if our hypothesis that parents lower their MLU level to accommodate that of their children is correct. The greater the initial value of the tendency-to-adapt variable, the more the parents adapt their habitual level of MLU to the current MLU of the child. As shown in Table 3, this parameter is the greatest in Jessica's case, corresponding with the fact that Jessica's parents moved back to an initial MLU level slightly above 3, whereas Jan's and Pauline's parents moved back to initial values around 4.

The A rate-adapt parameter in Table 3 specifies the extent to which the parent's tendency to adapt changes over time. In Pauline this parameter is virtually zero, showing that there is no change in the tendency of Pauline's parent to adapt her MLU to that of Pauline (the value remains about .45). In Jan's parent the value is low and positive, implying that there is a gradual increase in the parent's tendency to adapt over time, from the initial value of .47 to a final value of .64 (the latter is not represented in Table 3). This increasing tendency to adapt might be psychologically explained by the fact that Jan's MLU tends to remain relatively stable at the level well below that of the parent's CDS. In Jessica, the parameter is negative, corresponding with a slow decrease in the parent's tendency to adapt MLU (from initial value of .6 of value of .48 in the end). This gradual but limited decline is consistent with the fact that Jessica's MLU is steadily increasing, corresponding with a steady increase in the MLU of the CDS.

Finally, the C ini values in Table 3 represent the initial levels of MLU of the children are all slightly above 1, as expected (because, for MLU, 1 is the lowest possible value).

Vocabulary

The parameter estimation results on the development of vocabulary show greater interindividual differences (see Table 3). When we apply the scaffolding model to the data, we observe there is no adaptation in Jessica's CDS: The model estimates a perfect flat line, as shown in Figure 4. The parent's initial tendency to adapt is considerably lower than that in the other two children (.1) and the parameter governing the change in adaptation tendency has a strong negative effect (−.52) leading to a rapid disappearance of adaptation tendency. Jessica's growth rate is low (.005), but this is compensated by a high growth power (2.00).

Table 2 shows that the scaffolding model fits very well with the vocabulary data of Jan and Pauline (.86 and .99 for the CDS and .99 for the child language). In this case, the values were calculated on the basis of a two-step model that starts from a certain plateau (and not 1), which is more consistent with the data as shown in Figure 2. Also, the final model had a correction for the 60/50 utterance difference between the child and adults samples.[5] First of all, the parameters show that Pauline had the highest growth rate (C rate) and lowest power parameter (C power; see also Appendix S3 in the Supporting Information online). Jan and Jessica had much lower growth rates and power parameters of 1.54 and 2, respectively, explaining the slow increase in the beginning. However, the important difference between Jessica's CDS and that of the others is that her CDS level was well within Jessica's developmental range (the attractor level is 1). This contrasts with Pauline and Jan, where the parental CDS level is still beyond the child's current developmental capacities (attractors are .7 and .42, respectively).

Also, the A rate-adapt parameter (governing the change in the parent's tendency to adapt) was negative in all children, indicating that the parent's tendency to adapt to the child becomes lower as time passes (from .36 to .28 in Pauline and from .37 to.21 in Jan). The A ini-adapt parameter, which specifies to what extent the parent changes her habitual vocabulary level to the level of the child, was about the same in Jan and Pauline. The values were smaller than in the case of MLU, suggesting that the adaptation is greater in MLU than in vocabulary. Also, the habitual level of Jessica's CDS is considerably lower than that of Pauline's and Jan's (see the A ini parameter in Table 3). Finally, the C ini values—representing the estimated initial levels of vocabulary in the children—were 38.5 (Jessica), 28.3 (Jan), and 21 (Pauline), indicating that Jessica's vocabulary was already more advanced at the start of the measurement period. This more advanced initial level corresponds with the relatively slow growth of vocabulary in Jessica as compared to Jan's and Pauline's.

In summary, the results show clear differences between individuals and variables. More specifically, the null hypothesis that there is no adaptation in the CDS can be rejected in all cases but one (the vocabulary results in Jessica). Furthermore, all estimated parameters in the scaffolding model were consistent with the theoretical and empirical expectations specified in our mathematical model. Most parameters were in the expected direction and showed values that corresponded with the curve analyses presented earlier.

Discussion

In this study, we have suggested that adaptation between child language and CDS is transactional and that it should be studied as a process of change. For this reason, we have taken an individual based, time-serial approach and analyzed the data of three parent–child dyads as they go through the child's first crucial years of the acquisition of language. The results show the following. With regard to MLU, we found evidence for the existence of mutual adaptation between CDS and child language for all three children. In all cases, the MLU of the caregivers increased with the growing MLU of the child and showed striking similarities with regard to the shape of change. The results on the development of vocabulary are similar, with one exception. Although all child language and CDS showed an increasing vocabulary, one case (Jessica's data) basically showed oscillations around a flat line.

The Nature of the Adaptation

The evidence shows that there are clear individual and variable-specific differences. For instance, the general shapes of both MLU and vocabulary are different: more s-shaped for Jan and Pauline, and more linear for Jessica. Also, what is striking in the data of Pauline is that the relative increases in the CDS (in both MLU and vocabulary) were almost identical with those of the child language. Another important finding is that Jan's CDS showed a clear deceleration right at the moment the child language seems to stabilize. These phenomena point toward a form of adaptation that is sensitive to the local changes of the language growth of the child.

In the Background section we addressed the question whether the adaptation in CDS is the result of global communicative adaptation, or whether it also reflects the acquisition of specific linguistic aspects. In general, our results support the existence of this type of adaptation to the general linguistic (or conceptual) competence of the child, such as by using simpler utterances and using a more limited vocabulary. These results are in line with earlier work of Roy et al. (2009), who showed the existence of what they call coarse tuning in caregiver speech, specifically in utterance length and word use. Thus, the findings converge to the existence of global communicative adaptation that changes across time as the language of the child increases in complexity. We should note that in this study, we only chose two global linguistic variables. However, in Bassano et al. (2011), we also found support for adaptation in the use of determiner and correct bare noun constructions. We did not find any support for corresponding patterns of local outliers of MLU and vocabulary use. However, there might be other more subtle types of local adaptation that might also co-occur with the global (longer-term) type we have reported here.

It is important to note that in this study our aim was to describe individual differences, but not to explain where they stem from. At present, we have no indication whether the differences reflect general developmental differences between the children or whether more language-specific differences play a role. Further research with longitudinal data of more child parent dyads is needed to address this question.

Validating the Scaffolding Model

Another important aim of this study was to build and validate a dynamic model that captures the process of adaptation between the language of the parent and the child in a series of coupled equations. We have presented a model (based on the scaffolding model of van Geert & Steenbeek, 2006) that describes the adaptation as dependent on the parent's tendency to adapt, the parent's habitual (nonadapted) level of functioning, and the change in the child level. This model was primarily aimed as an existence proof of mutual adaptation in child–adult language interaction. The results of the fitting procedure showed that all estimated parameters in the model are consistent with the expectations we specified in our theoretical background. However, the development of the vocabulary in all children is probably more characteristic of a model with two acceleration phases, whereas the present model allows for only one increase (for other evidence of a two-step lexical growth model, see Dromi, 1986; and van Geert, 1991). Although these repeated accelerations are conceptually consistent with the model (low growth–high adaptation and vice versa), they could not be captured by the simplest form of the model. However, there might be other alternatives to adjust the model to also accommodate stepwise growth.

In summary, although much in our reported results complies with the adaptation hypothesis, the vocabulary in Jessica's CDS showed no adaptation in the sense of CDS change dependent on the child's growing output level. However, it may be the case that Jessica's developmental curve only covers the first part of the developmental curves of Pauline and Jan (with regard to the total number of lemmas in each sample), in the sense that the latter had reached a temporary plateau of vocabulary during the course of the observation period, whereas Jessica was still in the midst of a rapid developmental change. Hence, it is possible that the data set is too limited to observe any form of dynamic, changing adaptation in Jessica's case. The parameter values of the scaffolding model (cf. Table 3) suggest that Jessica's parental CDS is strongly adapted from the beginning, which leads the model to estimate a habitual vocabulary level in the parent which is about similar to the CDS levels in Jan and Pauline. Consequently, the adaptation as such does not change as Jessica begins to increase her vocabulary. What is also worthwhile to note in this context is the fact that Jessica's CDS data come from the two parents (mother and father), while the CDS data of the other children come from only the mother. Though visual inspection of the individual data of Jessica's father and mother separately did not reveal clear differences, it might be speculated that if one of them is much less synchronized with Jessica's changes, this would smooth out changes of the CDS in general. Thus, these data may not be as homogeneous as for Jan and Pauline, which might also have contributed to the lack of adaptation in the sample.

Conclusion

The dynamic model we have proposed incorporates and combines several of the theoretical positions discussed in the CDS literature. For instance, the tendency to adapt equation in our model (i.e., Equation 1) is consistent with the finding of Phillips (1973) and others that adaptation of the CDS starts at a particular age (probably around the child's first birthday). Also, the model's estimates of the parent's habitual MLU level (cf. Table 3) are reconcilable with those found in the literature. For instance the A ini parameters are around 6 while Phillips (1973) reports an MLU of 8.4 in colloquial adult directed speech (ADS).

The fundamental question has been raised whether CDS contributes to language development in the child or not (e.g., Cross, 1977; Furrow, Nelson, & Benedict, 1979; Furrow & Nelson, 1986; Gleitman, Newport, & Gleitman, 1984; Goldberg, 1995; Jackendoff, 2002; Lock, 1980; Matychuck, 2005; Snow, 1982; Tomasello, 2003). In this study, we have defined this causal relation in terms of a mutual dependency. Thus, instead of conceiving of CDS as an independent variable which influences the language development of the child as a dependent variable (or vice versa), we conceive of both child speech and CDS as being dynamically coupled with each other through time. Although our data and model do not prove the proposed causal relation between the change in the child and the adaptation in the CDS, the results of this study can be reconciled with the concept of a mutual dependency between the two. Future research is needed to investigate whether this type of adaptation also occurs during the development of other important linguistic variables and to elaborate on the origin of the attested individual differences.

Final revised version accepted 30 July 2012

Notes

1 In line with most of the literature we will use the term *the linguistic input* of the child in order to refer to the language addressed to the child or the language a child is actively exposed to or is actively responding to.
2 The equation assumes that the habitual language of the parent is more complex than the speech of the child. In the hypothetical case that (L_t-I_H) would have a positive value (the language of the child is more complex than that of the adult) this would lead to (even) more complex language of the adult. However, it goes without saying that this scenario is highly implausible.
3 This is the simplest version of the model sufficient to explain jumps and spurts.
4 Because MLU is a proportional measure, the sample size difference can be interpreted in a straightforward fashion.
5 Note that this correction also changes the frequencies of the CDS in Figure 4. For the real frequencies of vocabulary, see Figure 2.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Appendix S1. Descriptive Statistics for Jessica.
Appendix S2. Descriptive Statistics for Jan.
Appendix S3. Descriptive Statistics for Pauline.