German Stop Contrasts Are Hypoarticulated in Infant-Directed Speech

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1. Introduction

The present article presents data from a larger study in which we investigated infant-directed speech in German. The two overarching questions are (1) how the register of infant-directed speech is best characterized and (2) which underlying mechanisms cause the differences in register between infant-directed speech and adult-directed speech. Many investigations have shown that, in infant-directed speech, suprasegmental features are exaggerated. For instance, infant-directed speech is characterized by a higher fundamental frequency, a wider range of fundamental frequency (e.g. Papoušek et al., 1987; Fernald et al., 1989), and a slower speech rate (Raneri et al., 2020, but see also Martin et al., 2016). The present study focuses on segmental features, particularly on the contrast between word-initial fortis and lenis stops. We analyzed data from a picture description task completed by five mothers and five fathers of first-born children. We recorded adult- and infant-directed speech data at two points in time; once when the child was 8 months old and once when the child was 13 months old.

The first section (1.1) summarizes articulatory and acoustic characteristics of the particular phonemic contrast under investigation, namely the contrast between fortis and lenis stops in German. A second section (1.2) addresses the acquisition of phonemic contrasts in general and how the characteristics specific to the infant-directed speech can help during acquisition. The third and last section of the introduction (1.3) summarizes cross-linguistic investigations of infant-directed speech on the particular phonemic contrast under investigation. Section 2 provides details about the present study's data collection, and in section 3 we present our analyses of acoustic differences between the contrast in infant-directed speech and the contrast in adult-directed speech. In section 4, we discuss the present findings in light of investigations in other languages. Further, we review how the present findings contribute to answering the larger question of the underlying purpose of a differentiated register for infant-directed speech. We summarize our findings in the concluding section 5.

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1.1. German stops

German is an aspirating language with six phonemic stops at three places of articulation, labial /p, b/, coronal /t, d/ and dorsal /k, g/. In word-initial position, the voiceless stop, with aspiration after the burst until the initiation of vocal fold vibration, is differentiated from the so-called voiced stop, which is realized as a plain voiceless stop (Beckman et al., 2013). This means that voiceless and voiced stops in German are best described as fortis and lenis stops, the terminology we use in the present paper. As a consequence, German word-initial fortis and lenis stops are differentiated by their voice onset time (henceforth VOT). VOT is defined as the time between the burst and the onset of voicing – the onset of vocal fold vibration. VOT is negative if the voicing starts well before the burst. Zero VOT means that voicing starts immediately after the burst (or ranges within 20 ms before and after the burst). VOT is positive if the voicing starts well after the burst (Lisker and Abramson, 1964; Beckman et al., 2011).

While the acoustic cue of VOT varies along a continuum, the phonemic categories of fortis and lenis stops are defined categorically. Cross-linguistically, languages vary in the duration of VOT that is used for certain phonemic categories. In this way, it may happen that the acoustics of one language's lenis stop are similar to another language's fortis stop (Zsiga, 2013). Some languages, like German, have only two-way contrasts, but others such as Thai or Hindi display more contrasts (Lisker and Abramson, 1964; Abramson and Lisker, 1970). Each language-specific category is defined by a certain VOT range on the continuum. The English /b/, for instance, can have a long negative VOT up to a short positive VOT, where then the English /p/ category starts. The Thai /b/ category only allows for long negative VOTs and the Thai /p/ already starts with a short negative VOT.

The question examined in the present investigation is what the German child encounters and needs to learn: Word-initially, Germans differentiate fortis and lenis stops by its VOT (Féry, 2001). Generally speaking, while lenis stops have a short positive VOT, fortis stops in German are best characterized with a long positive VOT (Havy et al., 2016). While lenis stops of all places of articulation are reported to have a VOT of around +16 ms, fortis stops of all places of articulation are reported to have a VOT of over +50 ms (Braunschweiler, 1997; Pouplier et al., 2014).

1.2. Phonological contrasts in infant-directed speech

For a child, acquiring a language means learning the relevant phonetic distinctions utilized in a given language. Studies such as Werker and Tees (1984) demonstrated knowledge of relevant consonantal contrasts in infants at around 10 months. For German stops, the infant needs to learn how to divide the perceptual space for the two-fold contrast between fortis and lenis stops. As elucidated in the previous section, VOT proves to be a useful cue. One account of how infants acquire knowledge of contrasts is Kuhl et al.'s Native Language Magnet theory. This theory assumes that children are sensitive to distributional properties of the input. When presented with linguistic input, prototypical instances then function as a magnet for specific categories around which target areas exist. As children receive language input, their perceptual space is mapped by generating these prototypes, allowing them to adapt to their native language's peculiarities (Kuhl, 1991; Kuhl and Iverson, 1995; Kuhl et al., 2008). The underlying process is also assumed to be supported by the exaggerated differences of phonetic units found in infant-directed speech (Adriaans and Swingley, 2017). Through hyperarticulation in infant-directed speech, the learning child is presented with "high-quality" tokens (e.g. Kuhl et al., 1997; Liu et al., 2003; Adriaans and Swingley, 2017). This account assumes that the relevant linguistic information is communicated by distributions in the input. The child learns phonemic categories through linguistic experience and it has been shown that these categories are formed during the second half of the child's first year of life (Kuhl et al., 1992, 2006). It seems likely that exaggerations in infant-directed speech (unconsciously) arise for didactic reasons. A finding by Weirich and Simpson (2017) could further be interpreted in this sense: They demonstrated that the vowel space in adult-directed speech is already modulated by the chosen parental role before a child is born. They compared speech by fathers planning to go on parental leave with speech by fathers not planning to go on parental leave and showed that the former have a larger vowel space than the latter. A larger vowel space may underlie the facilitating character of infant-directed speech: The articulation is realized more extremely and, as a consequence, acoustic differences arise. The contrast in infant-directed speech is enlarged, and formant values are more peripheral, with the consequence that vowel categories lay further apart. Thus, the learning child is presented with more easily distinguishable input. In fact, the enlarged vowel space in infant-directed speech is a well-known cross-linguistic finding (Kuhl et al., 1997; Burnham et al., 2002; Xu et al., 2013).

The idea that phonemic contrasts in infant-directed speech are enhanced for didactic reasons has also been raised in connection to findings concerning consonants, though to a lesser extent than for vowels (Liu et al., 2003; Dilley et al., 2014). The motivation behind the hyperarticulation, however, is the same. Dilley et al. (2014), for instance, found more canonical than assimilated, glottalized or deleted word-final coronal consonants before a following consonant of another place of articulation in infant-directed speech as compared to adult-directed speech. They interpret the changes as signs of clarity in infant-directed speech.

1.3. VOT contrast in infant-directed speech

One particular aspect which has been under investigation in studies on consonants in infant-directed speech is VOT. The majority of studies investigated languages with a two-way voicing contrast such as English (Beckman et al., 2013), Swedish (Helgason and Ringen, 2008) and Norwegian (Ringen and van Dommelen, 2013). However, a study on Nepali, a language with a four-way contrast, was recently published (Benders et al., 2019). In what follows, we will briefly summarize the results of studies investigating VOT in stops and point to some problems, such as sparse data and mixed results.

Evidence regarding the fortis/lenis contrast in infant-directed speech is controversial. McMurray et al. (2013) have investigated VOT in English word pairs like *peach* and *beach* and found differences between infant- and adult-directed speech, namely that both fortis and lenis stops have lengthened VOT values in infant-directed speech towards nine to 13-month-old children. The changes found were almost entirely attributed to the slower speech rate in infant-directed speech. Baran et al. (1977) who investigated VOT of three English participants speaking to one-month-old children found a decrease for VOT values in fortis stops in infant-directed speech. Malsheen (1980) who investigated six English participants speaking to their child at seven months, 12 months, and 24+ months, found increased VOT values for fortis stops, but only near the first birthday. Another much larger-scaled study of English (Burnham et al., 2013) reported increased VOT values for fortis stops in infant-directed speech towards three-, nine-, 13- and 20-month-olds. For Swedish, there exist reports on both increased (towards one-year-olds, Sundberg, 2001) and decreased VOT values in infant-directed speech (towards three-month-olds, along with an hypoarticulated contrast; Sundberg and Lacerda, 1999). Hence, Sundberg and colleagues hypothesized that the specification of VOT contrast varies as a function of age. In Norwegian, VOT in infant-directed speech has been reported to be increased overall with the exception of one place of articulation (Englund, 2005). As mentioned above, Benders et al. (2019) systematically investigated the contrast in Nepali, which distinguishes four stop variants. Interestingly, VOT were altered in a way that finally had a hypoarticulation effect on the contrast. Instead of a perceptual space widened to allow for a better discrimination, Benders et al. (2019) found the opposite. The authors proposed that the hypoarticulation happens for the benefit of other contrasts.

To sum up, the results presented are inconclusive as to whether the phonemic contrast between fortis and lenis stops is enhanced or not. These inconsistencies might originate from the following potential confounding factors: First, some of the above mentioned studies report overall lengthening of the VOT (Sundberg, 2001; McMurray et al., 2013). However, the authors do not consider how consonants of the different categories change relative to the contrastive counterpart. Second, it has been assumed that hypo- and hyperarticulation of the specific contrast varies with age of the child in that the contrast is only enhanced by the time that it becomes relevant for the learning child (Sundberg, 2001; Sundberg and Lacerda, 1999). Some studies, however, contradict this assumption of change with age of the child. Third, the methodology, especially regarding the recordings, is inconsistent. While some included read speech, others solely used free speech. While some studies recorded under laboratory conditions, others preferred the more natural surrounding of the participant's home. Further inconistencies can be seen in the presence or absence of an interlocutor in the adult-directed speech condition. It is unclear whether these factors affected the speech. Fourth, many studies lacked statistical power (Cristià, 2010).

The present data investigates the issue by looking at voice onset time of German word-initial stops as a test case, a language in which VOT differences that come with infant-directed speech have not yet been investigated. The question is whether this contrast is hyperarticulated, hypoarticulated, or whether we find no difference between registers. We chose a "controlled" method to assess relatively natural speech. We tested mothers as well as fathers, as studies of fatherese are also underrepresented. With respect to the infants' age, we decided to test infant-directed speech at two points in time: towards eight-month-olds and 13-month-olds.

2. The present data

2.1. Participants

For the data collection, we recruited five families, each consisting of a mother, a father, and their first-born child. Two of the infants were boys, and three were girls. Mothers and fathers grew up in different parts of Germany, but all spoke Standard German. All families were based in North-Rhine Westphalia except for one family which was located in Hamburg. We recorded the same set of participants at two times. The first time, their child had a mean age of 8 months and 8 days (ranging from 0;7;25 – 0;8;29). The second time, the child was 13 months old and had started producing their first words. At the time of the first recording, the parents had a mean age of 33;7, ranging from 32-39. All participants signed a consent form.

2.2. Materials

We selected 18 target words for our experiment. Each word started with a CV-sequence of interest. Three German target words were chosen for each fortis and lenis stop consonant of all places of articulation ([b, d, ɡ, p, t, k]). Each target began with one of these stops followed by one of the vowels [ɑ, ʊ, i]. This resulted in a target item collection of 18 words (6 consonants x 3 vowels), all of which were appropriate for the experiment with children. Examples for target items are [bi]*ne* (engl. 'bee'), [dʊ]*tt* (engl. 'bun' (hair style)), [ɡɑ]*ns* (engl. 'goose'), [pʊ]*ppe* (engl. 'doll'), [ti]*ger* (engl. 'tiger'), [kɑ]*tze* (engl. 'cat').

To elicit the speech data, we used a picture description task. The method was adapted from Weirich and Simpson (2017). The picture description task allowed us to simultaneously elicit free speech and control for item selection. The 18 targets appeared 3 times on different pictures. Each picture randomly showed several targets in one of the three scenes, resulting in a storybook containing 15 colorful child-friendly pictures. The pictures were created specifically for the purpose of the present study.

2.3. Recordings

Infant-directed speech was collected while the participant spoke to their child and adult-directed speech was collected while the participant spoke to the experimenter (a student assistant). In both cases, the participant and the interlocutor were alone in the room. Recordings were carried out at the families' homes. For the first recording in one family we used a Philips Voice Trace DVT2710. Due to technical problems we were not able to analyze these data. In the second recording session with the family as well as all other recording sessions with the other families, we used a Zoom H4n Pro Handy Recorder with an amplitude resolution of 24 bits and a sampling rate of 48 kHz. These data went into the analysis.

3. Analyses

We collected 1848 target words in total. These were relatively evenly distributed across the variables of recording, register, and gender. During the first recording, we collected 201 words in ADS and 193 words in IDS from the mothers. From fathers, we collected 218 words in ADS and 225 words in IDS. During the second recording, we collected 249 words in ADS and 264 words in IDS from the mothers. From fathers, we collected 249 words in ADS and 249 words in IDS.

We discussed above that previous investigations of VOT changes due to the register have not always allowed conclusions to be drawn as to whether the phonemic contrast is enhanced or not. The present investigation aims at investigating a possible change of the contrast. We thus focus on the difference between VOTs of fortis and lenis stops. We analyzed both the absolute VOT difference as well as the VOT difference in relation to the whole CV-sequence to examine whether possible differences can be accounted for by variation in speech rate (McMurray et al., 2013).

Measurements were carried out using Praat (Boersma and Weenink, 2018). For the analyses we used R (R Development Core Team, 2020) and RStudio (RStudio Team, 2018). We analyzed the data fitting linear mixed-effects regression models using the lme4 package (Bates et al., 2015). The explanatory variables of interest REGISTER (IDS/ ADS), GENDER (F/ M) and RECORDING (first/ second) were centered following Winter (2019). The model in the first analysis took the absolute VOT difference as a dependent variable, while the model in the second analysis took the relative VOT difference as a dependent variable. Participant and vowel were included as random factors. Each time, the full model was reduced stepwise by exclusion of non-significant factors using the step function of the lmerTest package (Kuznetsova et al., 2017). An explanatory variable was kept if (1) its F-value was below -2 or above 2; (2) the model's AIC criterion that contained the variable was lower that the model's AIC criterion that did not contain the variable and (3) the log-likelihood test comparison of the model with and without the variable reached a p-value lower than 0.05.

3.1. Absolute VOT difference

In the first analysis, we looked at absolute VOT differences in ms between fortis and lenis stops. Of the whole data set, we removed data points that exceeded 1.5 times the interquartile range. N = 9 outliers were removed. To assess VOT difference measures between fortis and lenis stop variants, we aggregated the whole data set with respect to the participant, the recording, gender, register, vowel, and place of articulation of the stop and calculated the difference between the fortis stop's VOT and lenis stop's VOT in ms. After step-wise reduction of the full model we only find a main effect for REGISTER, namely that the difference of VOT between fortis and lenis stops is reduced in infant-directed speech as compared to adult-directed speech (β = -0.006975, SE = 0.002590, p = 0.0075). Participant and following vowel as random intercepts significantly improved the model fit. Data are visualized in figure 1.

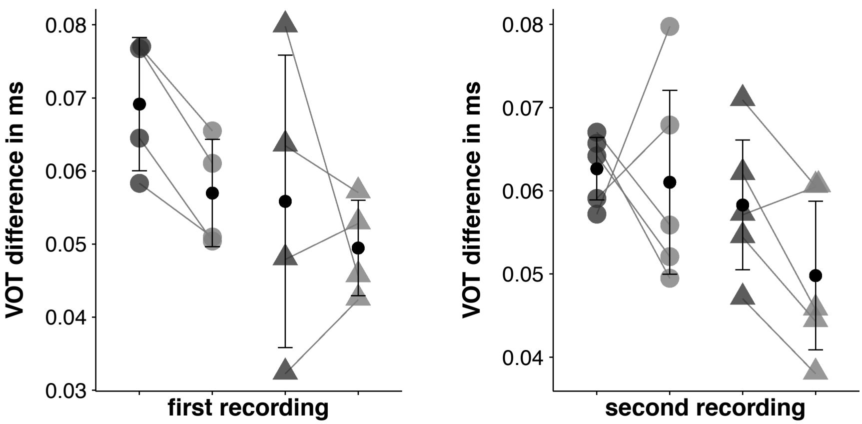

Figure 1: Mean absolute VOT difference for each register, gender and recording are shown as black dots, error bars indicate confidence intervals. In addition, the graph shows means of the individual participants across register conditions (dark shade: adult-directed speech, light shade: infant-directed speech) connected by a solid line. Gender is coded as different shapes (circles: females; triangles: males).

3.2. Relative VOT difference

A second analysis was performed to control for speaking rate. Therefore, we assessed the VOT difference as a ratio relative to the vowel length of the CV-sequence (absolute VOT/ duration of the following vowel). Of the whole data set, we removed data points that exceeded 1.5 times the interquartile range. N = 70 outliers were removed. Similar to the first analysis, we aggregated the whole data set with respect to participant, recording, gender, register, vowel, and place of articulation of the stop. We calculated the difference between the fortis stop's VOT and lenis stop's VOT in ms. Again, after step-wise reduction of the full model, we find a main effect only for REGISTER. VOT between fortis and lenis stops is reduced in infant-directed speech as compared to adult-directed speech (β = -0.19094, SE = 0.04934, p = 0.0001). Participant and following vowel as random intercepts significantly improved the model fit. Data are visualized in figure 2.

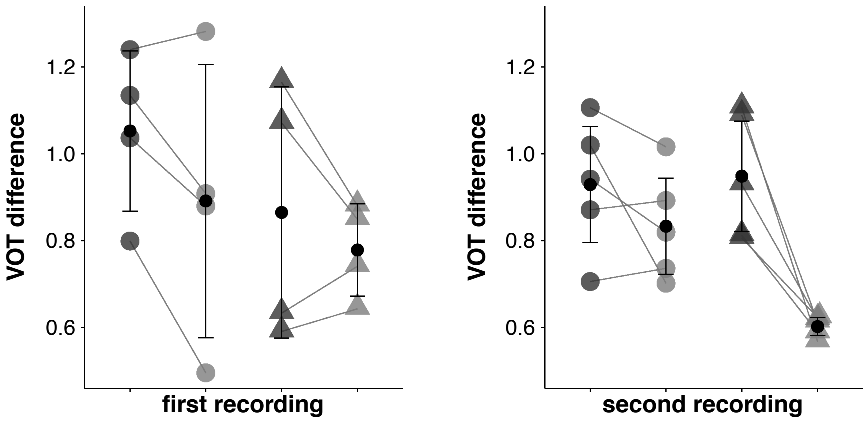

Figure 2: Mean relative VOT difference for each register, gender and recording are shown as black dots, error bars indicate confidence intervals. In addition, the graph shows means of the individual participants across register conditions (dark shade: adult-directed speech, light shade: infant-directed speech) connected by a solid line. Gender is coded as different shapes (circles: females; triangles: males).

4. Discussion

The research question was whether the phonemic contrast between German fortis and lenis stop is hyperarticulated between registers and thus would provide additional evidence that infant-directed speech is adjusted to the needs of the language-learning child. More specifically, the question is whether changes in infant-directed speech occur for pedagogical reasons, and our test case can serve as an example for this. In this section, we first summarize core findings of the present project and evaluate them in light of the hyperarticulation hypothesis (e.g. Kuhl et al., 1997). We then consider the present study in light of previous investigations and reflect on possible explanations for the present findings.

The present data show that the phonemic contrast between German fortis and lenis stops is hypoarticulated in infant-directed speech as compared to adult-directed speech. Hypoarticulation is found even when controlling for speech rate. We found no differences between mothers and fathers. Moreover, the phonemic contrast was consistently hypoarticulated whether the addressed child was eight months old or 13 months old and had started speaking his/her first words. The hyperarticulation hypothesis, which has been proposed predominantly for vowels (Kuhl et al., 1997; Burnham et al., 2002; Liu et al., 2003; Xu et al., 2013; Dilley et al., 2014), and which says that articulation in infant-directed speech changes so that the perceptual space is wider and contrasts are easier for infant listeners to detect is thus not applicable for the present data. In fact, the opposite is true.

As discussed above, the literature on infant-directed speech does not always show robust hyperarticulation effects (Cristià and Seidl, 2014). Notably, when it comes to consonantal contrasts, particularly the contrast between fortis and lenis stops, the literature is inconclusive. In contrast to other studies that looked at variation in absolute VOT values (e.g. McMurray et al., 2013), we have taken a different perspective, which focused on the VOT contrast between German stops rather than VOT values. Using this method we do find a hypo- and not a hyperarticulated contrast. McMurray et al. (2013) found overall lengthened VOT values, which were explained as a side effect of lowered speech rate. Other findings could possibly point to an enhanced phonemic contrast in English stops: Baran et al. (1977) and Malsheen (1980) found only lengthened VOT values for fortis stops infant-directed speech, at least for some age groups, but data is sparse (Cristià, 2010). Only Burnham et al. (2013) reported lengthened VOT in English fortis stops in infant-directed speech consistently for several age groups up to 20 months of age. However, unlike our study, their data consisted of read speech, and their adult-directed speech was recorded without interlocutor.

Hence, it remains unclear whether methodological confounds could explain the pattern. Generally, it has been found that in laboratory settings overall CV durations have been reported to be lengthened, while the VOT values were relatively stable (Robb et al., 2005). For Swedish (Sundberg, 2001) and Norwegian (Englund, 2005), an overall increased VOT for both categories in infant-directed speech was reported, but the implication of these findings regarding the possible enhancement of the phonemic contrast remains unclear. Like our German data, Sundberg and Lacerda (1999)'s Swedish data from speech to relatively young children suggest a hypoarticulated contrast (together with overall decreased VOT values). According to Sundberg (1998) infant-directed speech is adjusted to the children's needs, and the contrast may be enhanced only later. However, at least for German, we do not find variation with age.

The present German data ties in with data from Nepali (Benders et al., 2019), in which a four-way stop contrast seems to be hypoarticulated in infant-directed speech. Benders et al. (2019) propose that this could happen as the learning child is faced with a more complicated system than that of languages with a two-way contrast. Therefore, the specific contrast may be hypoarticulated to let the learning child concentrate on other aspects of the surrounding language, too. The present data, however, suggest that it is unlikely that complexity of the system is responsible for the hypoarticulation as German has only a two-way contrast. What could be the reasons for a hypoarticulated phonemic contrast in German infant-directed speech? Following studies like Benders et al. (2019), we must take the whole system into account when interpreting these results. This means we must examine neighboring sounds both quantitatively and qualitatively and acquire data that looks at more than one contrast. It is likely that phenomena like hyper- and hypoarticulation of contrasts alter the whole system, and that neighboring sounds are also affected. We are in need of data that looks at more than just one contrast. Exploratory analyses of the Nepali data suggest that in their case, hypoarticulation of the stop contrast comes with a temporal reorganization of the whole surrounding. Benders et al. (2019) suggest that hypoarticulation in infant-directed speech may be less puzzling if it occurred for the benefit of another contrast. Thus, the present analysis of German fortis/lenis contrast could serve as a starting point for a more detailed analysis of German infant-directed speech and will inform our own further research.

Another question for further research should indeed be whether the particular phonemic contrast may change with age if children older than 13 months are included. We have seen in numerous studies, as well as our own, that we observe differences between infant-directed speech and adult-directed speech and that infant-directed speech is a register in its own right. Even so, the pedagogical function of infant-directed speech may be overstated. Hyperarticulating phonemic contrasts to facilitate their acquisition may not be the predominant intention of infant-directed speech. Recent research has shown that changes in register may stem from an intention to express affection and other emotions (Benders, 2013). The main intent for infant-directed speech could be to attract the child's attention by using higher and more variable frequency ranges and possibly by enhancing vowel quality and durations. It has been shown that children prefer to listen to this register (Frank et al., 2020). It is the suprasegmental information as well as formant frequencies that transport emotions in speech (Tartter, 1980). The idea is that changes in infant-directed speech may appear as a consequence of the emotional content of speech (Fernald and Simon, 1984; Singh et al., 2002; Benders, 2013; Kalashnikova et al., 2017). Under such an account, the reduced VOT contrast between fortis and lenis stops may appear for the benefit of other suprasegmental and vowel-related contrasts – namely those that are much better suited to attract the attention of the child.

5. Conclusion

The present investigation looked at whether the German contrast between word-initial fortis and lenis stops is enhanced in the register of infant-directed speech as compared to the register of adult-directed speech. While the hyperarticulation hypothesis assumed that such an enhancement of the contrast may be beneficial for the child learning the contrast, we were not able to confirm this hypothesis. In fact, what we found was the opposite. The contrast between fortis and lenis stops, exemplified by a difference in voice onset time in German, is *hypo*articulated, and therefore less distinct, in infant-directed speech. We hypothesize that this happens because the aim of the infant-directed speech under investigation is to enhance other aspects or contrasts within the speech by hypoarticulating the fortis and lenis stop contrast. Alternatively, the infant-directed speech may differ from adult-directed speech because of emotion or to attract the child's attention rather than for pedagogical purposes. For future studies we argue that it is important to investigate phonemic contrasts in the context of contrasts in neighboring sounds. Future investigations exploring this, vowel quality, and other aspects of the temporal organization of the full CV sequence will shed further light on this issue.

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