Journal of Child Language Acquisition and Development – JCLAD
Vol: 11 Issue: 1 747-758, 2023
ISSN: 2148-1997

Speech exposure at 3-months-old and communicative development in later infancy

Received : 21.07.2022
Accepted : 18.12.2022
Published : 30.03.2023
DOI: https://doi.org/10.5281/zenodo.7958374

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Abstract

Exposure to language in infancy is a crucial part of infant communicative development. Infant-directed speech (IDS) refers to the way in which adults speak to babies, with a higher and more variable pitch and exaggerated vowels. It is part of most infants' environment. Infants have been shown to prefer IDS over adult-directed speech (ADS). IDS helps older infants learn words and exposure to IDS predicts later language comprehension. Previous studies have investigated IDS experience and outcomes in older infants. IN this study, exposure to speech characteristic of IDS at the earlier age of 3 months was investigated as a predictor of later word comprehension. Audiovisual data was collected from the infants' perspectives at 3 months and processed in linguistic software to quantify IDS exposure by measuring three variables: pitch range, glissando, and speech rate. Comprehension was measured using the MacArthur-Bates Communicative Development Inventory (MCDI) at 12 months. Pitch range and glissando had the greatest predictive value regarding the amount of words understood at 12 months, whereas speech rate was negatively predictive. These findings imply that speech containing higher pitch variability and a greater number of large pitch changes may help facilitate infant word comprehension.

Keywords: early childhood development, infant development, language development, MacArthur-Bates Communicative Development Inventory (MCDI), Infant-Directed Speech (IDS), prosody, pitch

1. Introduction

When adults talk to babies, it is clear to anyone within earshot, even if they are not watching the interaction, that the speaker is addressing an infant or very young child. The way in which adults speak to babies is quite different from how they talk to their colleagues, partners, and friends – it would be strange and unexpected to talk to other adults in the same way that they talk to babies. Infant-directed speech (IDS), also known as "babytalk", "mother-ese", and "parent-ese", sounds more like a sing-song version of speaking compared to the more monotonous way that adults speak to each other. Because of the notable difference in adult communication with infants, the communicative environment that infants experience is much different from that of adults. Even adults who have no experience with infants automatically switch to producing IDS when they interact with an infant (Fernald, 1989). But why is it that adults automatically switch speaking style, depending on the age of their audience? Researchers have suggested that the way in which adults talk to babies facilitates language development. Naturally, since language input is present in most typically-developing infants' experiences before they begin producing words, it is important to look at the relationship between early language exposure and infants' later linguistic abilities.

IDS is characterized by unique intonational properties, the most salient of which are higher overall pitch (Kitamura & Burnham, 2003; Zangl et al., 2005), more pitch variability (Kitamura & Burnham, 2003; Zangl et al., 2005), slower speaking rate (Yung et al., 2010), and 'hyper-articulation' (an exaggerated lengthening) of vowels (Yung et al., 2010). The modifications that adults make when speaking to babies are nearly universal (Smith & Strader, 2014). These characteristics have been found across multiple languages, including those as diverse as Hebrew, Italian, Japanese, and even tonal languages such as Mandarin (Smith & Strader, 2014; Kuhl et al., 1997). Kuhl et al. (1997) found that in spoken Swedish, English, and Russian, vowels presented in IDS were hyperarticulated to a similar degree across the three languages.

There are many suggested explanations as to why exaggerated prosodic and structural properties are used when speaking to infants. Numerous studies have shown that infants prefer IDS over ADS in lab settings (Pegg et al., 1992; Fernald & Kuhl 1987; Cooper & Aslin, 1990; Cooper et al., 1997). Fernald and Kuhl (1987) examined infant responses to IDS and ADS, and found a much stronger attentional preference for IDS over ADS. Moreover, these researchers controlled for the influence of lexical content on preference, and found prosodic properties of IDS alone were sufficient to capture infants' attention. Such findings support the notion that the prosodic properties, namely fundamental frequency and larger pitch range (Fernald & Kuhl, 1987), are the driving forces behind infant IDS preference. Pegg, Werker, and McLeod (1992) looked at 7-week-old infants' ability to discriminate IDS and ADS and their preference for IDS relative to ADS. Infants were able to discriminate between these two types of speech. They also displayed preferential attention to IDS over ADS. This study was one of the first to look at whether infants younger than 4 months of age are responsive to the differences between IDS and ADS, providing further evidence that even very young infants attend more to IDS than to ADS. Although the infants in this study showed preferential attention to the female speaker than the male speaker, they showed preference for the male's IDS over his ADS. This finding supports the notion that IDS has specialized prosodic and acoustic properties (e.g. higher pitch and pitch range), which map onto the perceptual abilities of infants to process language (Pegg, Werker, & Mcleod, 1992). Another hypothesis of why IDS is spontaneously used by adults and preferred by infants is the mechanistic perspective; perhaps IDS attracts and modulates social learning, by which the infant eventually associates IDS to their needs being met. In this view, the infants also learn to use IDS to differentiate caregiver intentions, which contingently rewards communication between infant and caregiver (Monnot, 1999). ERP evidence also indicates that infants are quite adept at processing pitch from sound input; Stefanics et al. (2009) found that 2-3 day old infants were able to discriminate between tones of different pitch intervals nearly as well as adults can. This indicates that very early in life, infants are equipped with the ability to process the important auditory cues needed to understand speech prosody. Thiessen, Hill, and Saffran (2005) presented 6.5 and 7.5-month-old infants with audio clips of sentences spoken in either IDS and ADS, with only the prosody, not the content, differing in each respective speech type. They found that infants were better able to segment words spoken in IDS.

Another component of IDS is greater variety in pitch, specifically that this speech contains more "peaks" in pitch. To study the role of pitch in infants' perception of IDS, Trainor and Desjardins (2002) They found that although high pitch seemed to actually hinder vowel discrimination, the pitch contours of ID speech did promote vowel discrimination in 6-7 months old infants. Graf Estes and Hurley (2013) presented 17-month-old infants with objects that were labeled in either IDS or ADS. Infants failed to learn the object labels that had been spoken in ADS, but were able to learn those same object labels when they were spoken in IDS. Furthermore, Graf Estes and Hurley (2013) also looked at whether manipulating the variation in pitch in spoken ID labels would affect learning, and found that infants failed to learn the labels when presented in IDS without prosodic variation. These findings support the notion that the prosody of IDS helps infants map the words to objects and that IDS prosody facilitates language acquisition.

Studies focusing on the "natural" infant environment have shown support for the role of IDS in language acquisition. Hurtado et al. (2008) looked at primary caregivers' speech towards 18-month-old infants in their homes, and used the MacArthur-Bates Communicative Development Inventory (MCDI), a standardized measure of infants' language development, to measure the infants' language production at 18 months and then again at 24 months. Infants of mothers who spoke more to them when they were 18 months old had a larger vocabulary at 24 months, relative to infants who experienced less talk from their primary caregiver. Thus, more language exposure is related to better language outcomes. But is IDS *in particular* critical for language development? Ramírez-Esparza, García-Sierra, and Kuhl (2014) found that infants who experienced more IDS, not ADS, in one-on-one contexts had greater word production at 24 months. Such results demonstrate a specific link between IDS exposure in particular (not just overall language exposure) and infants' language development.

Although previous literature has demonstrated that IDS exposure is related to later language development, no studies have yet examined whether exposure to IDS earlier than 11 months influences subsequent language development. The current study investigates whether IDS experience as young as 3 months is predictive of communicative development at 12 months of age. In other words, is the quantity of the infant-directed speech that infants hear at 3 months predictive of the number of words they understand at 12 months?

2. Methodology

2.1. Participants

Infants who participated in a previous longitudinal study were re-recruited for the current study when they reached 12 months old. These infants were previously recruited through the Ryerson Infant and Child Database (RICD) when they were 3 months of age (±2 weeks of their 3-month birthday, *M*=86.9 days). At 3 months old, infants collected audiovisual data from their own perspective by wearing small, head-mounted cameras for approximately 1 week. Seventeen infants who had recorded video at 3 months were re-recruited before their 12-month birthday and participated in the current study between the ages of 12 and 14 months (*M*=431.1 days).

This sample (N=17) had recorded a total of 69 hours, 28 minutes, and 26 seconds of video at 3 months of age.

2.2. Data collection and processing

Audiovisual data was collected from infants at 3 months using small, head-mounted cameras. To record data, parents would place the camera on a headband on the baby's head while the baby was awake and alert. This infant-perspective video data is audiovisual.

At 12 months old, infants' ability to understand words was assessed using a standardized communicative development inventory, called the MCDI Words and Gestures, completed by the parents. The MCDI Words and Gestures is a reliable, standardized measure of communicative development and has been normed for infants 9-18 months of age (Fenson et al., 1994); thus, it is the most appropriate measure for the 12-month-old infants in the current study. Families completed the communicative inventory in the Brain and Early Experiences (BEE) Lab at Ryerson University or online through an electronic version created in Qualtrics.

2.3. Data analysis

The audio content from the infant-perspective videos was analyzed using Praat (Boersma & Weenink, 2005), a free software program that measures phonetics from speech data. Within Praat, a script called Prosogram (Mertens, 1995) was used to process audio data. Prosogram provides measures of prosodic information contained in waveform files. The infant-perspective videos were first converted from VLC video files into waveform files using Audacity, free audio editing software. The videos were then segmented into 9-minute parts if they were longer than 9 minutes, to be successfully processed in the Praat software. Once audio data had been processed by running the Prosogram script in Praat, a profile of the prosodic contents of each file was automatically extracted. The important components of this profile are total speech time, speech rate (mean number of syllables spoken per second), pitch range used by the speaker(s), and the percent of glissando used by the speaker(s). Each of these components is important in characterizing the prosodic properties of the speech that infants experienced, IDS generally has slower speech rate, greater pitch range, and a greater percentage of glissando. These variables, and how they were extracted using Prosogram, are described in Figure 1:

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total speech time =88.23 s (= internucleus time + intranucleus time + pause time)*0.05 ss
estimated phonation time =39.44 (44.70% of speech time) (= internucleus time + intranucleus time)
estimated pause time =48.79 (55.30% of speech time) (= when internucleus time >= 0.3)
estimated speech rate    = 5.53 (nrof_nuclei/phonation_time), StdevOfST
ANON: 23.4ST, 101Hz, (79.9ST), 223Hz (93.6ST), 217Hz (93.1ST), 390Hz (103.3ST), 92.5ST, 6.4ST
Pitch and duration profile of speaker(s):
Speaker label: NuclDur, InterNuclDur, TrajIntra, TrajInter, TrajPhon, TrajIntraZ, TrajInterZ, TrajPhonZ, Gliss, Rises, Falls,
ANON: 19.71 s, 19.73 s, 14.2 ST/s, 28.1 ST/s, 21.1 ST/s, 2.2 sd/s, 4.4 sd/s, 3.3 sd/s, 5.0%, 0.9%,
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Figure 1. Example of a Prosogram prosodic profile, highlighting the variables considered for analyzing the predictive value of speech exposure within the infant-perspective data

To calculate total speech time, Praat uses the Prosogram script to detect speech from the waveform file in intervals of 0.05 steps per second. Prosogram provides the total duration of speech in the prosodic profile, which in the above example is 88.23s. For each video, the total duration of speech was divided by the total duration of the video in order to calculate the proportion of time infants were exposed to speech. The total time of speech was then used to analyze what the three variables of speech rate, pitch range, and glissando represent in the infant environment. Speech rate was calculated by the number of syllables spoken per minute, which describes the average speed of each stream of speech. Speech rate is selected for analysis because slowed speech rate has been shown in previous literature to be a critical component of IDS that helps infants segment words from speech.

Pitch range refers to the difference between the lowest pitch and the highest pitch that Prosogram detected in each video. Speech rate was selected for analysis because slowed speech rate is associated with typical IDS, and is largely supported as a critical component of IDS that aids infant word comprehension. Glissando refers to a change in pitch in a spoken/sung syllable that has a slope greater than 60Hz at 0.16 semitones (which is 1/12th of an octave) per second. Prosogram provides glissando, or "Gliss" as a percentage, which refers to the percentage of pitch changes in the syllables detected by Praat with a slope above 200Hz. In Figure 1 above, the glissando is 5.0%, indicating that 5% of the pitch glides were above 200Hz. Glissando is considered for analysis of IDS due to it being a common component of IDS that also supports infant discrimination and perception of speech.

3. Findings

Infants had recorded a total of 69 hours, 28 minutes, and 26 seconds, of which a total of 5 hours, 26 minutes, and 17 seconds failed to be successfully processed in Praat. These videos were reviewed and most contained speech; however, the speech was not detected by Praat, potentially because of the pitch of speech in the videos being below Praat's threshold for speech detection (i.e., 60hz), or because the speaker was too quiet (e.g. if speaker was in another room). Thus, a total of 64 hours, 2 minutes, and 9 seconds of video were successfully processed in Praat, meaning that Prosogram provided a prosodic profile for these data.

The infant auditory environment of 3-month-olds consisted of 24.8% speech (SD = 14.05). In regards to speech rate, the average speech rate was 21 syllables per minute (SD = 17.87). The range in pitch across infant perspectives had a lowest-pitch average of 5057.09Hz (SD=8140.80) for total lowest pitch, and a highest total pitch average of 9856.20Hz (SD = 11204.88), with an average total pitch range of 4799.10Hz (SD = 7291.90) across infants. The average percentage of glissando in total speech data is 6.08% (SD = 6.33). Infants understood an average of 99.70 words (SD = 72.61).

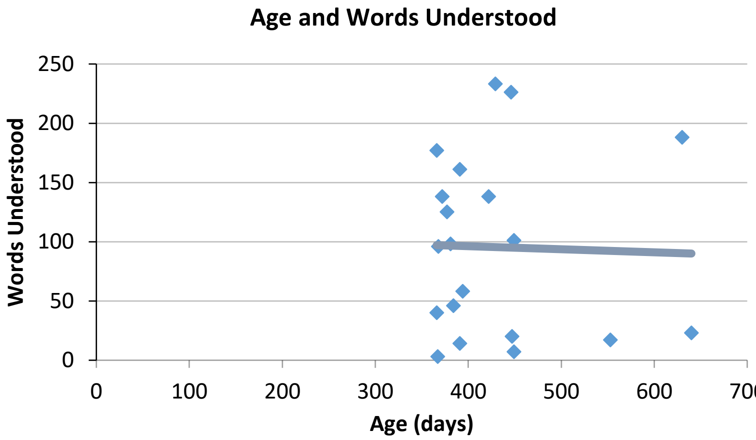

Figure 2. Overview of the moderator of age in relation to the number of words understood at 12 months

To analyze the relation between speech exposure at 3 months of age and word understanding at 12 months, a multiple linear regression was conducted with control for age. Total speech exposure, when controlling for age at 12-month assessment, had a very slight predictive relationship with words (r = 0.097, b = -0.019, t(3) = -0.07, p = 0.945). Total speech explains -13% of variance in words understood, when controlling for age at assessment (adjusted r^2 = - 0.13). Age (in days) at the time of MCDI assessment had the lowest effect size (adjusted r^2 = 0.03), indicating that age accounted for very little of the variance in words understood. The same analyses was then performed with the IDS-related variables, again controlling for age in each regression model. It was hypothesized that slower speech rate, greater pitch range, and greater percentage of glissandi in pitch would predict a greater number of words understood.

Consistent with the hypothesis, speech rate (Figure 2) was inversely predictive of the number of words understood. Controlling for age at the time of MCDI use, the association was moderate (r = -0.56) in support of an association between higher speech rate at 3 months of age and fewer words understood at 12 months. Conversely, slower speech rate predicted higher scores in the number of words understood at 12 months (b = -0.16, t(3) = -0.66, p = 0.759). The effect size of speech rate on words understood is modest, (*adjusted* r^2 = 0.18), indicating that the speed of speaking accounted for almost 1/5th of the variance in words understood.

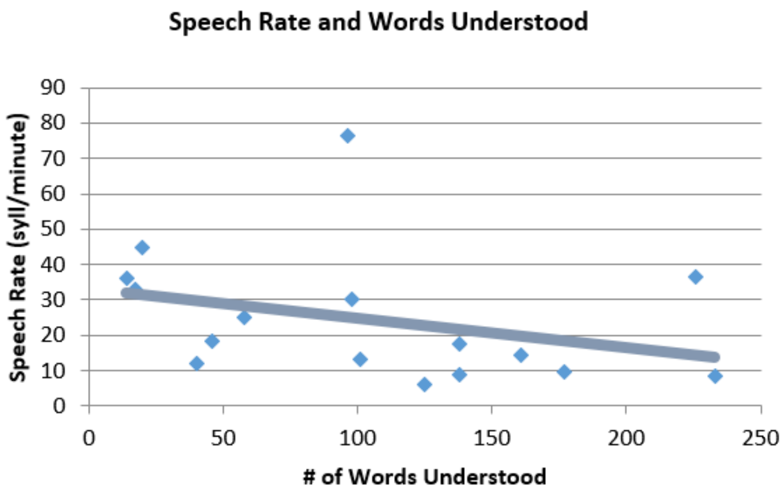

Figure 2. Relation between speech rate (syllables per minute) at 3 months and words understood at 12 months

Pitch range (*Figure 3*) was a moderate predictor of word understanding at 12 months when age is controlled for (r = 0.50). Greater range in pitch (maximum pitch - minimum pitch) in speech exposure at 3 months was mildly predictive of greater number of words understood at 12 months (b = 0.44, t(3) = 1.69, p = 0.78). Pitch range accounted for a modest amount of variance in words understood (adjusted r^2= 0.14).

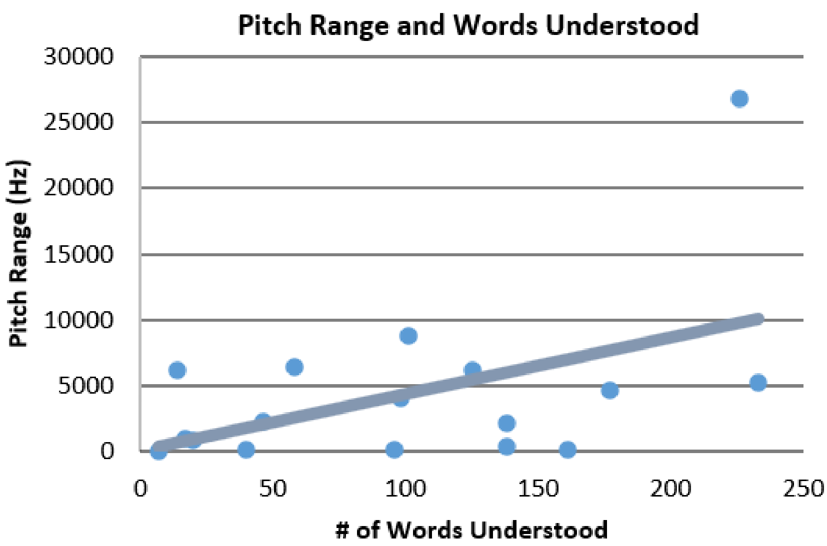

Figure 3. Relation between pitch range at 3 months and number of words understood at 12 months

The percentage of glissando (*Figure 4*) within overall speech is moderately predictive of number of words understood at 12 months (r = 0.36). Glissando showed a modest linear relationship with word understanding outcome (r = 0.19). The effect size of glissando was small, in that glissando accounted for only a very small proportion of variance in words understood (adjusted $r^2 = 0.07$).

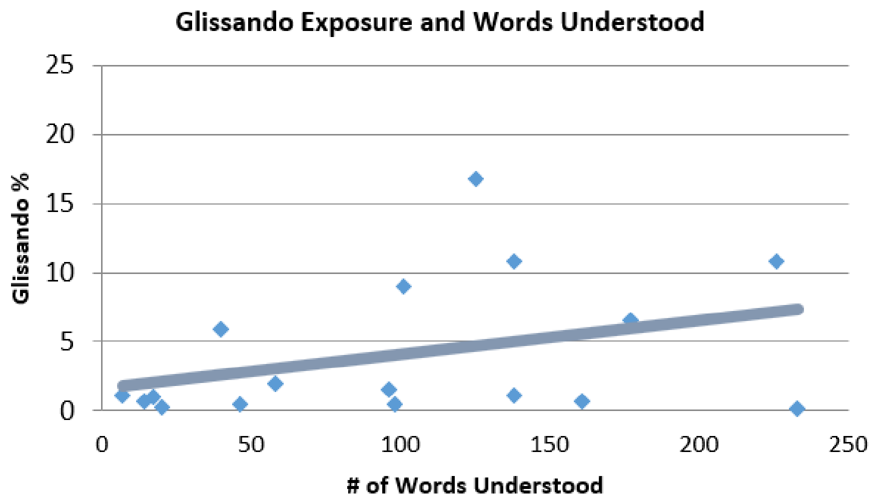

Figure 4. Relation between percentage of glissando at 3 months and number of words understood at 12 months

4. Discussion

Rather than focusing on only target words and small snippets of scripted speech produced in a lab setting, this study provides an important preliminary look into the infant's natural auditory environment at 3 months old. The results of this study indicate that speech rate, pitch range and glissando exposure at 3 months are modestly predictive of the number of words understood by infants at 12 months, which is consistent with previous IDS literature.

The inverse relationship fond between speech rate and words understood is consistent with the findings of both Zangl et al. (2005) and Yung et al. (2010), in that slowed IDS was critical for infant word recognition, which is necessary to facilitate comprehension. Slow speaking rate, as a characteristic of typical IDS, may provide an appropriate accommodation for the perceptual abilities of young infants who do not have the experience to process typical ADS.

Pitch range was a modestly positive predictor of words understood, which is consistent with the findings of Graf Estes and Hurley (2013), who found that 17-month-old infants learned new object-label associations when they had been presented in IDS and not in ADS due to differences between IDS and ADS pitch range. A larger range in pitch may help infants segment words from streams of speech by providing cues to word boundaries, which may explain why IDS predicts word understanding. This finding is also synchronous with the results of Yung et al.'s (2010) study, which indicated that wide pitch range likely enhances word recognition for young infants (e.g. under 9 months). The properties of pitch range and slowed speaking rate may provide a concrete perceptual advantage by allowing words and sounds to be more easily segmented by infants (Thiessen, Hill, & Saffran, 2005; Seidl

& Johnson, 2008). Trainor and Desjardins (2002) similarly found that moderate pitch contours of IDS promoted vowel discrimination.

Since higher percentage of glissando predicts greater number of words understood, this suggests that speech containing more dramatic glides between pitch overall is somehow beneficial to infants' perception of speech. Papousek et al. (1990) similarly found that expanded contours in the melody of IDS helped to both obtain and maintain infant attention. However, not only are the findings consistent with the notion of providing attentional cues to infants, as the predictive value pitch glissandi in the outcome of infant learning is also concurrent with the more recent findings of Graf Estes and Hurley (2013).

In the current study, IDS exposure at 3 months is modestly predictive of later vocabulary; this suggests that IDS has an impact on language development earlier than previous literature has shown. Although the relations between speech characteristics and word understanding were in the anticipated direction, none of the relations were significant. This is possibly because of the small sample size in the current study (n = 17). Further testing of more 12-month-olds will clarify whether speech characteristics at 3 months significantly impact word understanding at 12 months. That being said, although the findings were not significant, the three variables of speech modestly explained variance in words understood at 12 months when age at 12-month assessment was controlled for, each with a modest effect size. A potential limitation to this study is the small sample size, which limit the statistical power of this research. Additionally, the processing of infant-perspective videos was occasionally limited by the unpredictable quality of these videos, in that sometimes speech data could be compromised by insufficient loudness in speech. The results suggest variance in the characteristics of speech that is present in the infant environment, with a small effect size on the acquisition of language in later evaluation. The results of this study are important because they suggest that these three characteristics of IDS help scaffold the acquisition of language for 3-month-olds, who cannot yet understand words. This suggests that IDS might have an impact when used around infants as young as 3 months of age to promote language development; at the very least, it does not seem to be detrimental to speak with a greater range in pitch in an infant's environment. A further application that future research could explore is whether exposure IDS earlier may serve as an intervention to enhance early communicative development for infants at risk for poor language development (such as infants of low socio-economic status; Hurtado, Marchman & Fernald, 2008; Hart & Risley, 1992).

Future research should investigate how IDS exposure changes over time. It would be valuable to investigate the predictive value of IDS at 3 months and words produced in later infancy, such as at 19 months. Previous literature indicates that slow speech rate has the greatest influence on language processing ability for older infants, therefore future study may aim to investigate these 3-month-old participants in later infancy to determine if there holds predictive value specifically for later comprehension and production.

5. Conclusion

Speech rate, pitch range, and glissando are all important aspects of the linguistic input that infants receive in their first year of life. The results of this research have supported the notion that infants can benefit from exposure to these three components of IDS at as early as 3 months old. The main implication of these results that should be taken away from this paper is that IDS likely helps infants comprehend words and aids their language development, therefore it is something that should be encouraged in those who interact with infants.

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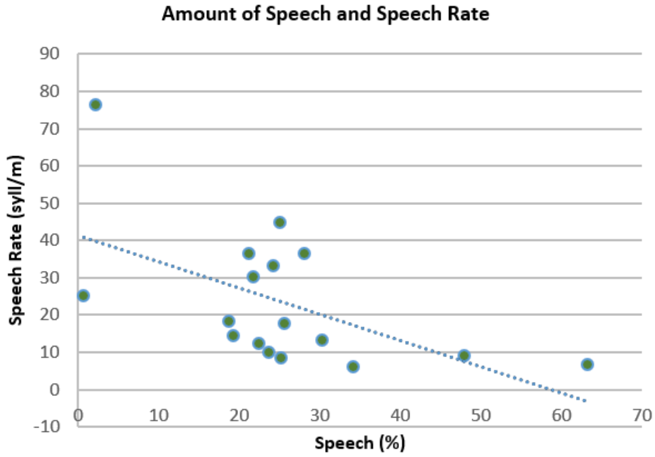
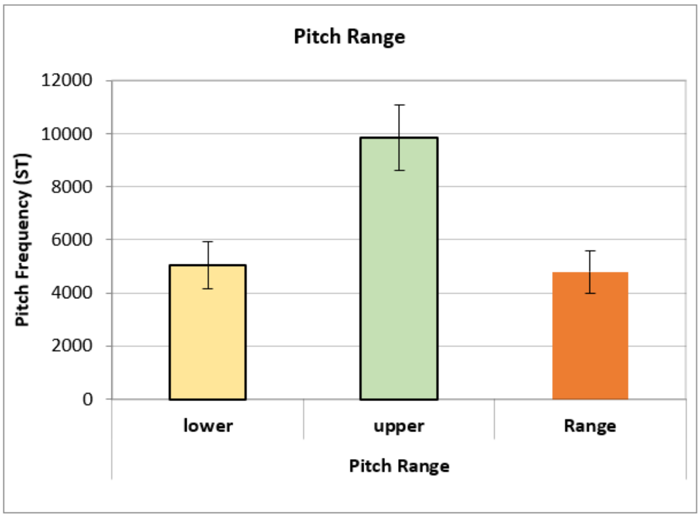
Appendices
Supplementary Analyses



Supplemental Figure 1. Overview of the amount of total speech relative to the rate of speaking



Supplemental Figure 2. Overview of the pitch profile for speech exposure at 3 months. Error bars represent standard deviations

Supplemental Table 1

Regression table of multiple regression analyses for each variable plus age in days, and words understood

	Age + MCDI + Speech	Speech rate + Age + MCDI	Pitch range + Age + MCDI	Glissando + Age + MCDI
B	-0.095	-2.035	0.005	5.2
SE	77.26	65.77	67.16	70.0
Beta	0.019	-0.51	0.44	0.36
R	0.097	-0.56	0.50	0.36
Adjusted r2	-0.13	-0.32	0.14	0.07