

# **Do Infants Discriminate Hyper-from Non-Hyperarticulated Speech?**

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## **ABSTRACT**

Several studies have found that adult caretakers usually hyperarticulate to infants by modifying their voice in ways that promote and sustain infants' attention. This articulation when engaging in infant directed speech (IDS) can result in "clear speech" by the expansion of the vowel space area. The degree of speech clarity produced by caregivers appears to provide advantages for young language learners to promote lexical perception and learning. However few studies have ever examined whether infants are able to perceive the difference between hyperarticulation and normal speech. In this study, 7-to 12-month-olds' ( $n=17$ ) speech discrimination when hearing hyperarticulated and non-hyperarticulated words in mothers' natural speech production was examined. The degree of speech clarity was determined by the relations of the first ( $F_1$ ) and second formant frequencies ( $F_2$ ) of the vowel. The result showed that there was no discrimination between listening to hyperarticulated and non-hyperarticulated words, indicating that the benefit accrued by exposure to clear speech may require no selective attention on the part of the infant. Thus the advantages of hyperarticulation might be related to other characteristics.

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## 1.0 - Introduction

Infants' ability to acquire language depends on the quality of linguistic input from the environment. Current studies of speech perception have suggested that listening to ambient language teaches infants about the phonetic, phonotactic, and prosodic regularities of their native language (Gervain, Berent, & Werker, 2009; Saffran, Werker, & Werner, 2006). For example, 15 minutes of exposure to target speech sounds in a laboratory setting is sufficient to influence vocalizations and even vocal imitations in infants under 20 weeks of age (Kuhl & Meltzoff, 1996). In this study, when infants were subjected to the vowel sound of /a/ spoken by an adult, they produced more /a/-like utterances than either /i/ or /u/. This indicates that infants' perception of specific speech sounds is influenced by what they hear in the voices of adults around them. This not only influences infants' imitation, but also possibly plays a critical role in the process of native language acquisition.

When talking to infants, parents typically use a unique speech style, in which many characteristics are modified, such as higher and greater variability in pitch (Fernald, Taeschner, Dunn, Papousek, de Boysson-Bardies, & Fukui, 1989; Trainor & Desjardins, 2002); exaggerated pitch contours (Fernald & Kuhl, 1987); slower speaking rate (Lindblom, 1963); lengthened vowel and pauses (Englund & Behne, 2006; Albin & Echols, 1996); and exaggerated vowel space area (Fernald & Simon, 1984; Kuhl, Andruski, Chistovich, Chistovich, Kozhevnikova, Ryskina, Stolyarova, Sundberg, & Lacerda, 1997; Burnham, Kitamura, & Vollmer-Conna, 2002; Kitamura & Burnham, 2003; Liu, Kuhl, & Tsao, 2003; Stern, Spieker, Barnett, & MacKain, 1983; Werker, Pons, Dietrich, Kajikawa, Fais, & Amano, 2007). These acoustic modifications in talking are generally called motherese, baby talk, or infant-directed speech (IDS), as compared to adult-directed speech (ADS). Such manner of talking is widely found across various languages. For example, the French, Italian, German, Japanese, American English and British English languages have more acoustic modifications by parents when interacting with their 10-to 14-month-olds than with adults (Fernald et al., 1989). Vowel exaggerations were found to occur in speaking to infants in English, Russian, Swedish, and Japanese, but not when speaking to other adults (Kuhl et al., 1997). Chinese-speaking mothers were also found to use IDS when speaking to their 2-month-old infants (Grieser & Kuhl, 1988). Moreover this modified way of speaking to infants is not restricted to mothers, but also is found in speech by fathers (Fernald, 1989). It is showed that fathers also exaggerate their prosodic features when addressing infants (Fernald et

al., 1989; Papoušek, Papoušek, & Haekel, 1987). These findings suggest that the modifications in acoustic characteristics in IDS may be a universal phenomenon, and it is commonly available to infants to foster language acquisition from their caregivers.

Although the manner of speaking in IDS is determined by a variety of characteristics, one important factor is vowel hyperarticulation. Vowel hyperarticulation is evidenced by the expansion of the first ( $F_1$ ) and second formant ( $F_2$ ) to highlight articulating the acoustic target (e.g., a vowel) in  $F_1/F_2$  space area. Formants are a concentration of acoustic energy around a particular frequency in the speech wave. Formants are mathematically measured and observed as dark bands in a wideband spectrogram. The difference between human vowels is distinguished by the frequency content of  $F_1$  and  $F_2$ . The formant with the lowest frequency is called  $F_0$  (pitch), then  $F_1$ ,  $F_2$ ,  $F_3$ ,  $F_4$  and even more.  $F_1$  and  $F_2$  are the most important formants in defining individual vowels in terms of the position of the tongue (open/close and front/back dimensions). Vowel openness/closeness describes whether the jaw is open or closed during the articulation of a vowel. Vowel backness is named for the position of the tongue that is toward the back of the mouth when articulating a vowel; whereas front vowels are pronounced when the tongue is positioned forward in the mouth. The  $F_1$  is usually found to have higher frequency in an open vowel (e.g. /a/), and lower frequency in a close vowel (e.g. /i/ and /u/). Likewise the  $F_2$  is always found to have higher frequency in a front vowel (e.g. /i/) and lower frequency in a back vowel (e.g. /u/) (Ladefoged, 2006). When mothers are uttering IDS to their infants, the vowel space areas on the formant plot have been observed to be expanded compared to speaking in ADS. In other words, the phonetic units are extremely articulated because of vowel hyperarticulation, which makes the phonemes perceptually distinct from one another (Kuhl et al., 1997). Because of this, vowel hyperarticulation is also characterized as “clear speech” or hyperarticulated speech (Andruski & Kuhl, 1996).

Kuhl et al. (1997) examined the natural language input to infants in English, Russian, and Swedish. Ten native women speakers were asked to speak with their 2-to 5-month-old infants and an adult native speaker. The words included vowels /i/, /a/ and /u/, which are the most common ones in human languages (Ladefoged & Maddieson, 1996). The vowel hyperarticulation was analyzed by plotting  $F_1$  and  $F_2$  values, and the size of the acoustic vowel space was measured by a triangular area because /i/, /a/ and /u/ were usually defined as the traditional “corner” vowels in the past. When these vowels were plotted by  $F_1$  and  $F_2$ , they

naturally formed a triangular shape (Bradlow, Toretta, & Pisoni, 1996). The result showed that the range of formant values was greater in IDS in all languages, which was manifested by stretched and increased size of vowel triangles. In other words, the “distance” among every single vowel in IDS on the formant plot was extended and thereby formed a larger vowel space area. This indicated that across all three languages mothers produced more extreme vowels when addressing infants rather than addressing adults. The same has been observed for Australian English (Burnham et al., 2002), and Japanese (Burnham, Sekiyama & Tsukada, 2006).

Other studies have compared the vowel triangle between speaking to humans and pets. Burnham et al. (2002) compared a variety of acoustic and emotion characteristics by testing 12 mothers’ speaking to their infant (IDS), their pets (PDS) and an unfamiliar adult (ADS). Vowel hyperarticulation was analyzed by examining  $F_1$  and  $F_2$  values of the vowels /i/, /a/ and /u/, and comparing the vowel triangles. The result showed that even though both IDS and PDS were higher and more variable in their pitch, only IDS contained hyperarticulated vowels. That is, mothers only hyperarticulated vowels when speaking to infants. However, this result was not replicated in a recent study examining hyperarticulation to infants and puppies. Panneton, Moon, Diehl and Kim (2006) tested 10 mothers’ speaking to their own 6-month-old infants, to a puppy (age range 8-12 weeks), and an adult. They found mothers significantly increased pitch levels and variability and expanded their vowel space when speaking to infants and puppies, but not to adults. Importantly, Panneton et al. (2006) also found that the positive emotion of mothers’ voices when speaking to infants and puppies was significantly higher than their ADS, and not significantly different from each other (i.e., IDS = PDS). This fact alone may account for hyperarticulation to a non-human infant given that more positive emotion is often equated with speaking more clearly. Although this finding is not consistent with the literature, vowel hyperarticulation is still widely regarded as one of the most important features in IDS.

A large amount of evidence about the occurrence of vowel hyperarticulation has always been found in addressing infants. Speaking with an infant is more likely to automatically activate individuals’ interest to express their language more clearly. However Uther, Knoll and Burnham (2007) reported that vowel hyperarticulation could also occur when addressing adults. They recorded ten British English mothers’ speech sound when these mothers were interacting with native British English speaking adults, a foreign adult (Chinese female with accents) and their own infant. The acoustic analysis showed that vowels in mothers’ spoken language were

equivalently hyperarticulated in both IDS and foreigner-directed speech (FDS), although IDS had higher pitch than FDS. Thus these authors suggested that speakers were actually able to modify and adapt their speech style to address the needs of the audience.

Why vowel hyperarticulation is usually defined as “clear speech” is due to the fact that hyperarticulated speech can increase speech intelligibility and is perceived as having better vowel exemplars by listeners. This clear effect has been shown to be robust in normal populations and even individuals with learning disabilities. Bradlow et al. (1996) examined the talker-related correlates of speech intelligibility from 20 adult speakers who produced 2000 sentences each. The size of vowel spaces enclosed in /i/, /a/, and /u/ and the association between a speaker’s vowel space and the intelligibility of this speaker’s sentences when produced were examined. There was a positive correlation between the spacing of vowels in the  $F_1 \times F_2$  plane and the speech intelligibility, with the higher the degree of expansion of vowel space and the overall increased intelligibility of these speakers perceived by others. Ferguson and Kewley-Port (2002) reported that vowels produced in a clear articulated manner were longer in duration than vowels produced in the conversational speech, and clear vowels displayed a larger  $F_1 \times F_2$  plane in the formant plot than the shrunk vowel space in the conversational speech style. Hazan and Markham (2004) found that  $F_1$  and  $F_2$  differences between /i/ and /u/ had significant link to word intelligibility in British English. Bradlow and Bent (2002) investigated the extent to which naturally clear speech input enhanced the speech intelligibility for native English and non-native English listeners. Listeners were exposed to naturally produced English sentences that varied in speech styles (conversational versus clear speech), signal-to-noise ratios, and genders. Results showed that native listeners obtained substantial benefit from the clear speech, and non-native listeners exhibited a small clear speech effect as well. It is also found that native and non-native speakers both had difficulties to understand the talker’s speech when it had reduced vowel space area (Bond & Moore, 1994). Bradlow, Kraus, and Hayes (2003) reported that normal children and children with learning disabilities both substantially benefited from the naturally produced clear speech, and this benefit required no listener training. Additionally the production of clarity was the most important characteristics to promote the intelligibility for children with learning disabilities.

A number of other studies corroborate the correlation between the vowel space area and the speech intelligibility from the aspect of examining special populations, such as individuals

with speech disorders. It is predicted that the speech intelligibility of individuals with speech disorders will be impaired because of the reduction of articulatory working space of vowels. This assumption has been supported by many studies. The investigations have documented that the reduced vowel space areas are found in individuals with speech disorders in dysarthria (a motor speech disorder characterized by poor articulation) in adults (Bunton, 2006) and children (Liu, Tsao, & Kuhl, 2005), and hearing-impaired individuals (Palethorpe & Watson, 2003). More importantly, the benefit of listening to clear speech is not only qualitatively examined by studies, but also quantitatively assessed by some experiments. It has been reported that vowel space areas account for 9%–12% of variance in identification scores for individuals with normal hearing abilities (Neel, 2008), 6%–8% of variance in intelligibility for females with Parkinson disease (Tjaden & Wilding, 2004), 45% of variance in intelligibility scores for speakers with dysarthria (Weismer, Yi-Jeng, Laures, Kent, & Kent, 2001). Higgins and Hodge (2002) even demonstrated that the vowel space area predicted 64% of variance in intelligibility of sentences for children with a dysarthria. All these suggest that vowel hyperarticulation may affect perceived speech intelligibility and contribute a significant amount of variance to clear speech.

Given that infants are often times exposed to the clear speech environment because caretakers automatically articulate clearly to infants, it would be interesting to know how experience with these surroundings influences infants' language development. To date, there have been few empirical investigations about the direct effect of "clear speech" on infants' speech perception and language acquisition. Also, there have been no studies to date assessing whether the availability of clear speech differentially elicits and maintains infants' attention to speakers. One important question for this literature is whether infants are more likely to listen to caretakers' speech when it is hyperarticulated.

It has been proposed that listening to "clear speech" would be helpful to infants in forming vowel categories. Kuhl et al. (1997) suggested that expanded vowel spaces make phonetic units more different from one another and thereby more distinguishable from one another. Good articulation of phonetics by parents might provide infants with a prototype, with which infants gradually possess the ability to compare a particular category of vowel to another category. For example, infants produced more /a/-like utterances after listening to their mother's production of the /a/ sound (Kuhl & Meltzoff, 1996). This reveals that a good vowel could be an exemplar to help infants imitate in the right way, thereby acquire a better vowel category. A

study by Liu et al. (2003) provides some evidence for the potential long-term advantage of listening to “clear speech” for phonetic discrimination in infants. Liu and colleagues examined the association between mothers’ speech clarity and infants’ (6-8 and 10-12-month-olds) speech discrimination. Mandarin-speaking mothers were audio-taped while saying words with the vowels /i/, /a/ and /u/ to their infants, and also to another native Mandarin-speaking adult. All of the vowel segments were measured using  $F_1$  and  $F_2$ . The acoustic analysis showed that mothers’ vowel space significantly expanded when speaking to infants, but not to adults. In addition a positive correlation between the size of mothers’ vowel space area and their own infants’ phoneme discrimination performance was observed in some subsequent perception tasks. This study provides the first evidence of a relationship between the quality of maternal speech input and infants’ speech discrimination at the phonetic unit level.

By 6 months, infants’ perception of vowels is strongly affected by the phonetic distribution in their native language. For vowels which were prototypical in infants’ language, they were perceived much stronger by infants than those with less prototypical features (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992). By 9 months, infants were able to discriminate between the speech sounds that appeared frequently in their native language and those that occurred with lower probability (Jusczyk, Luce, & Charles-Luce, 1994). The timings of infants’ sensitivity to distributional patterns rely on the exposure of the speech input. In caretakers’ speech productions, they contain distributional cues of infants’ native language, in which infants can acquire the learning mechanism and establish their native language phonetic categories. In a study by Werker et al. (2007), they recorded Japanese and English mothers teaching words in their own language to their 12-month-old infants. They found that the vowel pair /E-ee/ and /I-ii/ differed more in length in the production of Japanese mothers, while the difference between  $F_1$  and  $F_2$  in vowels was more pronounced in the production of English mothers. It is suggested that the speech input produced by caretakers carries the critical language-specific acoustic variables, which help infants reshape the acoustic categories in their native language repertoire. Other studies also found that the listening skill of language-delayed children was improved when the phonetic differences increased between every single vowel category (Tallal, Miller, Bedi, Byma, Wang, Nagarajan., ... & Merzenich, 1996).

Other findings also suggest that listening to clear speech can facilitate word recognition development (Song, Demuth & Morgan, 2010). In this study, familiar word recognition in 19-

month-olds was examined to see if their performance would be facilitated by the presentation of hyperarticulated vowels. Nineteen-month-olds recognized the target words faster when they were presented with hyperarticulated vowels as compared to hypoarticulated vowels. In addition, the clarity of words also facilitated comprehension by modifying phonetic properties in individual words. All these studies indicate that the well articulated vowels in IDS make the phonetic units more distinguished from one another, which may aid infants to acquire their native language by providing more useful acoustic cues to form vowel categories. Additionally the exaggerated acoustic properties in clear speech may be also important for infants to segment and identify individual words, which would be helpful to provide contextual information thereby facilitating better comprehension.

Given that clear speech appears to advantage some aspects of infants' speech perception (Liu et al., 2003) and possibly word learning (Song et al., 2010), it is important to explore whether this benefit stems from the ability of hyperarticulation to differentially elicit and maintain infants' attention. On the basis of previous work, exaggerated prosodic properties in IDS (e.g., expanded pitch range, slower duration, and higher rhythmicity) serve to facilitate infants' attention to the linguistic characteristic of speech and thus increase the opportunities for language learning (Cooper, Abraham, Berman, & Staska, 1997; Fernald, 1985; 1992; Papoušek & Papoušek, 1991; Werker & McLeod, 1989; Werker, Pegg, & McLeod, 1994; Kitamura & Burnham, 2003). Thus, hyperarticulation may be another feature of IDS that increases and maintains infants' attention.

On the other hand, the ability of infants to benefit from hyperarticulated speech may be a by-product of their attraction to speech that is high in positive affect (Fernald, 1993, Werker et al., 1994; Panneton et al., 2006; Trainor, Austin, & Desjardin, 2000). These studies suggest that the emotional interaction between the caretaker and the infant serves a function of keeping infant's early interest to language learning. The positive emotional affect conveyed by the caretaker could drive infants' interest in IDS, thereby keeps infants more focused on speech sounds obtained from the caretaker, regardless of whether the speech is hyperarticulated or not. Several studies have supported this point of view. As it is known that infants prefer IDS over ADS, one important possibility is IDS conveys more positive emotional affect than ADS (Burnham et al., 2002). Kitamura and Burnham (1998) found that infants preferred the happy infant talk over neutral infant talk. Singh, Morgan, & Best (2002) showed that when the

emotional affect was kept constant, no preference in 6-month-olds was observed for either IDS or ADS. However when ADS was added with more positive affect, infants' preference still followed the positive affect. Another study found that when the affect between ADS and IDS was controlled, the acoustic features between IDS and ADS almost had no difference. The ID love-comfort sample was slower than the sample in ADS and the pitch in IDS overall was higher than ADS (Trainor et al., 2000). With this, it could possibly be assumed that the emotional influence of IDS is the factor which plays an important role in maintaining infants' interest in IDS, with a potential side-benefit accruing if the speech is also hyperarticulated. However, in this scenario, the infant would not attend differentially to speech based on clarity alone; in fact, it may be the case that infants are not able to distinguish hyperarticulated from non-hyperarticulated speech.

The purpose of current study is to fill the gap in this area and shed light on whether infants are able to discriminate between clear speech and less-clear speech. Infants between the ages of 7- to 12-months were tested in a discrimination protocol during which they were exposed to strings of words that were either hyperarticulated (or non-hyperarticulated), and then tested after habituation to a change in word clarity. All words were initially spoken by mothers in physical contact with their infants, in the context of reciting full sentences in an IDS manner. For the purposes of this study, target words were extracted from running speech, analyzed, and classified as either hyperarticulated (e.g., expanded  $F_1/F_2$  relations in vowels; HA) or non-hyperarticulated (e.g., non-expanded  $F_1/F_2$  vowels; NHA), even though all words were from IDS. It was predicted that if the benefit of speech clarity for infant language perception stems from differential attention, infants would significantly discriminate a change from one category (e.g., HA) to the other (e.g., NHA), regardless of their order of presentation.

## 2.0 Method

### 2.1 - Participants

A total of 17 infants (5 boys and 12 girls) aged between 7- and 12-months of age ( $M=9.94$  months;  $SD=1.62$ ) were recruited from Blacksburg, Christiansburg, Radford, and surrounding New River Valley areas to participate in this study. English was the only language to which infants were exposed at home. Parents' education level was ranked by the degree of education they finished at school (13% mothers and 19% fathers were below college; 87% mothers and 81% fathers were and above college). Annual personal income was ranked on a 7-point scale from low income (\$10,000-\$20,000) to high income (>\$95,000). In this study, the medium annual household income was \$72,500-\$87,500, and the mode was \$80,000-\$95,000. All infants were recruited from a participant database maintained in the Developmental Research Suite in the Department of Psychology, with the majority of parents of infants initially obtained from a commercial mailing list. To acquire subjects, invitations were sent to the family's address on this mailing list. One week later, the parent received a call from one research assistant from the Infant Perception Lab to ask whether they were interested in participating in this study. Parents who were interested in this study were finally scheduled by the research assistant and made an appointment with the lab. Other infants were recruited by an advertisement placed in the local newspaper. These parents either called or emailed the lab to notify their interest and eventually scheduled a time to participate. All infants were healthy and had no history of any medical problems (determined by parental report).

When parents arrived at the lab, they were asked to complete a short survey. The survey included one infant temperament questionnaire (e.g. how easy is it for you to calm or soothe your baby when he/she is upset), one demographic questionnaire (see Table 1), and one contact information sheet. Parents additionally received two copies of informed consent to authorize their infants' participation, with one copy returned to them, and the other copy filed in the lab's records. Regardless of whether infants successfully completed the research, they all received a colorful certificate by way of thanking them for their participation in the study.

#### Speech Recordings

The speech productions were provided by mothers of infants who were involved in a large study in the Mechanisms of Audio-Visual Categorization Lab (MACL) at the University of

Iowa. The mothers were seated in a chair with their infant on their lap, reading a simple picture book to their infant. The target words were highlighted as the target of interest in sentences at three positions in the picture book: 1<sup>st</sup> word, 2<sup>nd</sup> word after “The”, and the final word. The target words were extracted from various mothers’ running sentences with Praat freeware (available in the Infant Perception Lab). After isolating target words from the sentences, the vowels in the target words were then subject to analysis. The first two formants  $F_1$  and  $F_2$  were extracted and written to a file to examine  $F_1$  and  $F_2$  distance. Based on the difference between  $F_1/F_2$  averages across a wide selection of words, those with good recording qualities which were above the group average and those at or below the group average were initially segregated as hyperarticulated (HA) and non-hyperarticulated (NHA), respectfully. Next, final groups of hyperarticulated and non-hyperarticulated words were formed such that they did not differ from each other in pitch or duration, and were spoken by 8 different women. As a result, 10 target words in each category with the vowels /ai/ (Time and Dime), /əu/ (Coat and Goat), /i/ (Tear and Deer), /u/ (Tune and Dune) and /ə/ (Curl and Girl) were selected for the presentation to the infants. In each hyperarticulated and non-hyperarticulated word category, there were 3 words for each vowel because one of the words listed in the parentheses above was repeated. Thus in each word category, there were a total of 5 (vowels) x 3 (words).

Differences in speech clarity were verified by extracting and analyzing vowel space for all five vowel categories, for HA and NHA productions (see Figure 1 for the area plots of  $F_1$  and  $F_2$  of the target vowels). Across all five vowels, the  $F_1/F_2$  difference was significantly greater for the words in the HA category compared to those in the NHA category as shown in a series of  $t$ -tests comparing 3 HA and 3 NHA productions for each vowel (/ai/  $t(2)=12.42, p< .007$ ; /i/  $t(2)=9.27, p< .02$ ; /o/  $t(2)= -5.03, p< .04$ ; /u/  $t(2)= -6.81, p< .03$ ; /ə/  $t(2)= -4.36, p< .05$ ). In addition, as is shown in Figure 1, the vowel space area in the hyperarticulated category is larger than in the non-hyperarticulated category. In addition, the difference of the duration and pitch between these two categories was not significant. Acoustic characteristics for the target words are displayed in Table 2 and Table 3.

#### Discrimination Protocol

An auditory and visual digital movie was constructed to test infants’ discrimination of hyperarticulated and non-hyperarticulated words. This movie consisted of a moving geometric figure (three moving objects with different colors) and a voice track. Infants were facing a 32-

inch LCD television monitor situated on a shelf, with the distance between the infants and the TV screen, being approximately 70 cm. Two speakers were on either side of the monitor, both of which were hidden from infants by black cloth, and all speech sound was played at 65-70 dB SPL (measured at the head of the infant). There was a remotely controlled video camera (Panasonic WV-cs574) mounted five inches above the screen. It was used to transmit infants' faces to an adjoining observation room, thereby allowing the observer to make judgments regarding infants' looking time. The observer was trained (prior to the experiment) to record infant attention to the central screen as well as termination of attention to the screen. During an actual session, all observers were 'blind and deaf' to which movie was being presented on each trial. All sessions were digitized on a CD recorder (Sony) for later offline coding.

## **2.2 - Procedure**

Infants and parents were guided into the testing room and the infant was seated on the parent's lap. After infants were assessed by the observer to be calm and alert, a centering movie consisting of a smiling, giggling infant appeared on the monitor to attract infants' attention. Parents were instructed prior to the experiment to not help their infant pay attention or interrupt their infant's activities during the video. Moreover, parents wore noise-cancelling Bose headphones and listened to soft music to prevent them from hearing the speech presented to the infants. Once infants were oriented toward the monitor for three seconds (controlled by the computer program), the observer pushed a button on the computer keyboard and the habituation phase began. The habituation phase consisted of a series of auditory-visual trials (each trial presented the same words but with different orders), with a maximum of 16 habituation trials allowed per infant. An infant-controlled habituation procedure was used in that the duration of each trial was determined by the infant's sustained attention to the monitor (however, a maximum duration of 20 seconds per trial was imposed, as is common in the infant habituation literature). The order in which word category was presented during habituation was counterbalanced across infants (HA first vs. NHA first). When infants looked away from the monitor for at least 1 second, the habituation movie stopped and the attention centering movie returned. When infants looked back to the monitor, the next habituation trial started. This sequence was repeated until the infant met the habituation criterion, which was a decrement in mean looking time on two consecutive trials that fell below 50% of the mean looking time on the first two trials of the habituation session. Given that infants were allowed to view trials for a

maximum of 20 sec, it was possible for a given participant to experience all 16 trials at this maximum duration. However, all infants in current study actually met the habituation criterion (i.e., showed systematic decrements in attention over trials).

Once infants met the habituation criterion, the test phase began. There were 8 trials in the test phase, with the same moving objects from the habituation phase presented. However, novel trials now consisted of words from the novel category (compared to the category presented during habituation). A variation of an odd-ball procedure was used in current study (see Houston et al., 2007) to test infants' speech discrimination, in that infants were presented with a series of test trials consisting primarily of the familiar category, with an occasional trial consisting of the novel category. For all infants, the test sequence was as follows (Novel = N and Familiar = F): NFFFNFFN. This testing sequence is a variant of the Visual Habituation Procedure (VHP), which is commonly used to test infants' speech discrimination. The VHP was initially developed as the methodology for infant visual discrimination and was later modified to test infant auditory discrimination (Polka & Werker, 1994). The logic of the VHP is that a change from a familiar to novel auditory event will affect infants' visual attentive behavior to the display. Significant increases in looking time in response to the novel trials are expected, and regarded as the evidence for discrimination of the two word categories. One advantage of this odd-ball sequencing is that the probability of individual infants showing significant recovery of attention to the novel event is increased by way of maximizing the contrast between novel and familiar trials. This method has been validated as a robust methodology to assess discrimination and has also shown good test-retest reliability (Houston et al., 2007).

### 3.0 - Results

To determine whether infants discriminated the two speech types (HA words or NHA words), infants' mean looking times were calculated by dividing the total time spent looking during novel and familiar trials during test. The logic behind this analysis was that if the words presented on a given trial were both novel (i.e., from a different category) and infrequent (with respect to trials presenting words from the familiar category), this would be relatively more salient to infants and greater looking time would significantly increase.

Overall, no significant differences in infants' looking times on novel and familiar test trials were found, regardless of which order (HA first vs. NHA first) infants experienced first. Infants' mean looking times in the habituation phase are displayed in Table 4. A  $2 \times 3$  mixed repeated-measures analysis of variance (ANOVA) was conducted with the order (HA first vs. NHA first) as the between subject factor and trial type (Pre-change trial (the mean of last two habituation trials) vs. Novel vs. Familiar) as the within subject factor. The ANOVA revealed no significant main effect for trial type ( $F(2,30) = .07, p = .93, \eta^2 = .01$ ) and no effect for order ( $F(2, 30) = .00, p = .99, \eta^2 = .00$ ). Likewise, the trial  $\times$  order interaction was not significant ( $F(2, 30) = .59, p = .56, \eta^2 = .04$ ).

Even though the average attention on novel and familiar trials during test was not significantly different, it is possible that the initial presentation of the novel category (i.e., the first test trial after habituation) showed evidence of some recovery of attention, but that over repeated test trials, this effect was cancelled by infants' lack of attention to either trial type (novel or familiar). Thus, a second analysis comparing looking time on the pre-change, first novel trial, and the first familiar trial was conducted. The results of this mixed ANOVA (same model as above) indicated that the main effect for trial type was not significant ( $F(2, 30) = 2.13, p = .14, \eta^2 = .13$ ), and there was no effect for the order type ( $F(2,30) = .00, p = .96, \eta^2 = .00$ ). The trial  $\times$  order interaction was not significant as well ( $F(2,30) = .36, p = .70, \eta^2 = .02$ ).

Although the trial  $\times$  order interaction was not statistically significant in either of the above analyses, the ability of infants to recover attention on the first novel trial was examined as a function of order given that there was reason to expect that the category during habituation may differentially affect word processing. That is, hearing clear productions of words first (HA) may have enhanced learning such that hearing less clear productions (NHA) would not be perceived

as a change. However, hearing less clear words first (NHA) may have attenuated learning such that hearing clear productions (NHA) would be perceived as a change because word learning itself was incomplete. This order effect could be reflected in several measures. First, hearing HA words first may have resulted in more attention on initial trials, fewer trials to meet habituation criterion, and/or faster rate of habituation (less time in habituation overall). As can be seen in Table 4, however, none of these measures differentiated the two groups by order of presentation. Second, infants may have looked longer on N1 compared to F1 trials during test if one of the orders promoted discrimination of the two word categories. Separate *t*-tests by order showed that infants hearing the HA category during habituation looked on average 5.92 sec (*SD*=4.56) on F1 and 7.0 sec (*SD*=4.57) on N1 trials ( $t(8)=-.76, p=.47$ ), but infants hearing NHA category first looked on average 4.93 sec (*SD*=2.6) on F1 and 7.84 sec (*SD*=4.47) on N1 trials ( $t(8)=-1.74, p=.13$ ). Although neither is statistically significant, the second order (NHA first) appeared to reduce average looking time and variability in infants' responding on the first familiar trial.

## 4.0 - Discussion

The purpose of the current study was to examine whether infants between the ages of 7- to 12-months could discriminate a change in hyperarticulation as they listened to isolated, female-produced, IDS words. It was predicted that if hyperarticulation was a feature of IDS that elicited and guided infants' attention, discrimination of this feature would be reflected in infants' increased attention to the novel category type (either hyperarticulated or non-hyperarticulated) compared to the familiar category. The results obtained fail to support this prediction in that there was no significant increase in attention to a change in category, regardless of whether infants heard hyperarticulated or non-hyperarticulated words during habituation.

There are several possible reasons for this lack of discrimination between the novel and familiar word categories. First, some habituation protocols may underestimate the sensitivity of the infants to a shift from familiar to novel events. For example, a study by Theaux, McCartney and Panneton (1997) found that if the number of habituation trials was fixed (i.e., trial length was not dependent on infant attention), infants (as a group) did not discriminate a change in gender of speaker. However, in the same study, an infant-controlled procedure using the same events did produce statistically significant increases in attention on novel trials (evidence that infants can discriminate changes in speaker gender). The current study was designed to maximize the probability of showing increases in attention to novel trials by incorporating two powerful methodologies: (1) trials were infant-controlled, and (2) the testing sequence followed an odd-ball format (i.e., more familiar to novel trials 5:3; Houston et al., 2007). The failure to find evidence for infants' discrimination in a change in speech clarity is most likely not due to a weak habituation method.

A second potential design flaw stems from the use of maternal infant-directed words for both hyper- and non-hyperarticulated categories. Although it was predicted that using natural IDS words would enhance infants' overall attention to the task (given their general preference for IDS over ADS; Fernald, 1985; Cooper & Aslin, 1990), this may have actually masked their discrimination given that infants could listen to IDS words regardless if they were familiar or novel (i.e., at all points in the procedure, the words being presented were IDS). Perhaps a better design would be to use ADS words only, manipulating clarity such that infants would be habituated to one category of ADS words (e.g., hyperarticulated), and then tested with the novel

category (e.g., ADS non-hyperarticulated words). In this case, their attention to the speaking style would be diminished, which could result in better perception of word clarity. Some contrary support for this suggestion stems from a preliminary finding in our lab, in which 10-month-olds preferred IDS speech delivered in their native language (i.e., English) to IDS in a foreign language (e.g., French or Mandarin). However, when the experiment was repeated using ADS speech (e.g., English ADS vs. French or Mandarin ADS), no preference was seen (Ostroff & Panneton, 1999). Thus, changing the words from IDS to ADS in the current study may in fact lessen infants' attention even further.

Third, the relatively small sample size ( $n=8$ ) may have masked discrimination of the change from NHA to HA categories (discussed in Result section above), although the results from the opposite order (HA first;  $n=9$ ) appeared more decidedly non-significant. When comparing attention on the first novel and first familiar trials of the test sequence within each presentation order, it appears that performance was less variable only on the familiar trial (NHA words) following the first novel trial (HA words) in the NHA first condition. Contrary to this pattern, one would expect that if hearing less-clear words during habituation compromised infants' abilities to perceive all of the words, hearing the clear words on N1 would produce more uniform (and less variable) attention.

Last, the way in which target words were chosen for the two categories (HA and NHA) may have minimized their classification as 'clear' and 'non-clear' productions, making discrimination difficult. All target words (regardless of category) selected for this study were of good recording quality, and spoken by a mother in interaction with her infant. The only difference between these word categories was the *relative* relationship between  $F_1$  and  $F_2$ . To exaggerate their differences in clarity even further, words could have been selected from an IDS corpus and an ADS corpus; however, this confounds discrimination of clarity with that of speaking style. Perhaps it would be better to create clear and non-clear words using speech synthesis, although this also greatly reduces the 'naturalness' of lexical items, such that using synthetic speech would compromise the purpose of this study. The goal for this study is to explore whether the natural caretakers' speech differentially recruits infants' attention when it is more clear. Thus using natural maternal speech productions to examine infants' discrimination of this characteristic was more appropriate and aligned with the primary research question.

If infants are not able to discriminate hyper- and non-hyperarticulated speech, then it is reasonable to conclude that hyperarticulated (i.e., clear) speaking benefits infants' language skills (e.g., phoneme discrimination; vocabulary size) surreptitiously. That is, the benefit is a secondary one, derived from infants' increased attention to IDS for other reasons. But what factors might cause infants to voluntarily allocate the attention to ID speech? One possibility is the emotional affect conveyed by the caretaker when they address the infant, and the effect that positive vocal emotion has on  $F_1/F_2$  relations in the voice. Recall that recent studies have found infants prefer happy over neutral/sad speech regardless of the speech being ID or AD (e.g., Singh et al., 2002). In one of the published studies, Burnham et al. (2002) found that mothers hyperarticulated when speaking to their infants, but not to their pets or other adults. However, the emotional affect in their IDS recordings was greater than that in their PDS recordings (IDS > PDS), although both of them were greater than in ADS. In a subsequent study, Panneton et al. (2006) found that mothers' hyperarticulation was equally high to babies and puppies when compared to the adults, and their positive vocal affect was the same in IDS and PDS (but both greater than ADS).

Taken together, when the vocal affect is low, hyperarticulation is less probable, but when the degree of vocal affect increases, hyperarticulation increases (Tartter, 1980; Tartter & Braun, 1994). Thus it is possible that the positive association found between mothers' degree of hyperarticulation and their own infants' speech perception in the study by Liu et al. (2003) resulted because of more positive vocal emotion, and not because mothers were intentionally speaking in a more clear style. Mothers' emotional tone in Liu et al. (2003) was not separately measured from their hyperarticulation, so the relationship between these factors is not clear. Maternal vocal emotion may mediate the association between hyperarticulation and improved speech discrimination and word recognition in infancy.

Based on this interpretation, it would be expected that mothers who show difficulty in expressing positive emotion in their speech to infants would also show lower levels of hyperarticulation, and their infants would show lower levels of emerging language skills. Although few studies addressing these specific relationships exist, two promising approaches are available. In one, Lam and Kitamura (2010) extensively studied one mother with twin infant sons, one of whom was hearing-impaired, and recorded her speech to each from 12- to 22-months of age. Interestingly, the mother expressed more positive vocal emotion and

hyperarticulation to the *normal* hearing twin. However, both sons showed similar expressive vocabularies at the older ages. Their equivalency may have come from the fact that the hearing-impaired twin had early amplification as well as speech therapy.

In another series of studies, Kaplan and colleagues (e.g., Kaplan et al., 1999; 2004) found that infants of clinically-depressed mothers showed lower levels of attention and learning in a task in which they were to associate female voices with smiling faces. Subsequently, toddlers of clinical depressed mothers show significant delays in reaching language milestones and lower performance on some language expression measures. Again, it is not clear if the relation between maternal vocal affect and infants' language learning involves differences in features such as hyperarticulation and/or lower levels of focused attention from the infants themselves. In future studies, it would be interesting to explore the relations between emotion and hyperarticulation in terms of the maternal natural sound. For instance, a series studies can be done by examining the degree of the mother's hyperarticulation across positive emotions with various intensities (e.g. low, medium, and high). If mother's vowel space area is expanding as the vocal emotion enhances, this somehow supports the above mentioned notion that hyperarticulation closely relies on the degree of vocal affect, although hyperarticulation can also be independent of the vocal emotion (i.g. hyperarticulating to foreigners but without emotion).

Given that we did not find infants discriminate the hyperarticulated speech from non-hyperarticulated speech, the benefits accrued by exposure to clear speech may not require the selective attention on the part of the infant. Infants' process of the clear speech may be a passive language processing approach. The finding of this study implies that infants do not differentially allocate their attention between clear speech and non-clear speech. Although infants seem to benefit from the hyperarticulated speech, their attention span is unaffected. The advantages of hyperarticulation might be related to other speech characteristics, such as emotion. More studies need to be conducted to explore this issue in the future.

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Table 1. *Demographic information for the infant sample (n=17)*

Demographic	n	%
Boys	5	29
Girls	12	71
Caucasian	16	94
Other Ethnicity	1	6
Infants < 9 Months	4	24
9 months ≤ Infants < 11 months	6	35
Infants ≥ 11 Months	7	41

Table 2. *First two formant frequencies for words in hyperarticulated and non-hyperarticulated categories*

	Vowels	Mean of F1	Mean of F2
HA	/ai/	621	2162.7
	/i/	441	2304
	/u/	410.67	1223.7
	/ə/	763.67	1395.7
	/o/	623.33	886.67
NHA	/ai/	832	1373.7
	/i/	472.7	1863.7
	/u/	486	1090.7
	/ə/	544	1652.7
	/o/	521.33	984

Table 3. *Duration and pitch for words in hyperarticulated and non-hyperarticulated categories*

Type		n	Mean	SD
Duration	HA	15	.61	.11
	NHA	15	.63	.24
Pitch	HA	15	220.85	35.22
	NH	15	237.55	49.58

Table 4. *A comparison of habituation metrics between hyperarticulated (HA) and non-hyperarticulated (NHA) word categories; means and standard deviations (in parentheses) are presented for each measure*

Condition	Mean First 2 Trials	Mean Trials to Criterion	Mean Total Habituation Time
HA First	16.39 (2.75)	8.00 (3.32)	95.80 (46.38)
NHA First	16.60 (3.58)	8.50 (4.38)	93.76 (46.73)

Figure 1. Mean of the first two formant frequencies ( $F_1/F_2$ ) of the five target vowels depicted as vowel space

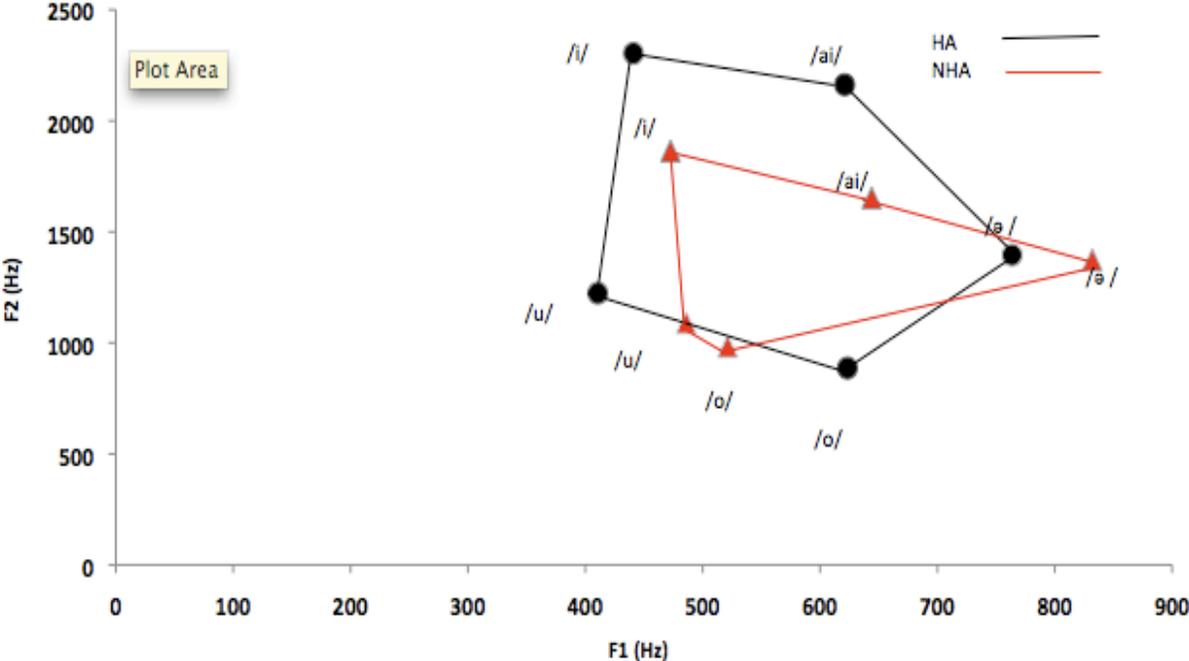


Figure 1. Mean of the first two formant frequencies ( $F_1/F_2$ ) of the five target vowels depicted as vowel space. Means are presented separately for the two word categories (hyperarticulated=HA and non hyperarticulated=NHA)