Fundamental Frequency Influences Vowel Discrimination in 6-Month-Old Infants

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Introduction

The ability to discriminate different vowel tokens found in one's native language is a fundamental skill necessary for the acquisition of language. Previous research suggests that young infants are able to discriminate readily between vowel categories (e.g., Polka & Werker, 1994; Swoboda, Morse & Leavitt, 1976; Swoboda, Kass, Morse & Leavitt, 1978) as young as 8-weeks of age.

However, previous research has relied primarily on the use of tokens from a male speaker, possibly because these are easier to analyze using commercial speech analysis programs and to produce synthetically. Moreover, vowel discrimination studies have typically employed tokens in which the fundamental frequency (F0) remains constant over the token. One exception, is an experiment by Kuhl and Miller (1982) in which they used both monotone and falling pitch contours with a male speaker. Infants were able to ignore variations in pitch while attending to changes in the vowel category.

Unlike in the vowel perception experiments, speech to infants varies significantly in F0 (e.g., Fernald & Simon, 1984; Papousek, Papousek & Haekel, 1987) These variations in F0 as well as an overall increase in F0 are notable characteristics of infant-directed speech. Infants show a strong preference, both attentional and affective, for infant-directed speech over adult-directed speech even when the passages are in a non-native language (e.g., Werker, Pegg & McLeod, 1994).

This experiment was designed to study the effects of a female F0 on the discrimination of two vowel tokens, /i/ and /I/, both found in the English language and both known to be discriminable to very young infants (e.g., Swoboda et al, 1976; 1978). We chose to examine three different fundamental frequencies: the low steady F0 of a typical female voice in adult-directed speech, 250 Hz; the F0 more typical of speech directed to infants, 350 Hz; and a falling F0 reminiscent of infant-directed pitch contours, 350 Hz to 250 Hz.

Method

Subjects. Seventy-two infants (36 male and 36 female) between 6 months 0 days and 6 months 30 days were tested. All infants had no reported hearing problems, were healthy at the time of testing and heard English spoken at least 90% of the time. Twenty-four infants were tested at each of three fundamental frequencies; 12 infants in each condition had /i/ as the background token and /I/ as the change token and 12 infants had /I/ as the background and /i/ as the change token.

Stimuli. Synthetic tokens of two English vowels /i/ (as in "heed") and /I/ (as in "hid") were produced using SenSyn (Sensimetrics Corporation) for the Macintosh on a Macintosh IIci computer. Values for the first 3 formants (F1, F2 & F3) were taken from the average values for women's voices as measured by Peterson and Barney (1952). Values for F4 were determined using Syrdal's (1985) formula. Bandwidths were taken from Dunn (1961).

Both vowel tokens were synthesized at three different fundamental frequencies. In the falling condition the F0 began at 350 Hz and fell linearly to 250 Hz over the duration of the vowel (500 ms). In the high steady condition, the F0 remained at 350 Hz for the duration of the vowel and in the low steady condition, the F0 remained at 250 Hz for the duration of the vowel.

Tokens were equalized for loudness by 3 adult listeners and presented at an average of 62 dB (A) in a quiet environment.

Apparatus. Infants were tested in a sound-attenuating chamber (Industrial Acoustics Co.). A Macintosh IIci computer with an audiomedia card presented the stimuli. A Strawberry Tree I/O card connected to a custom interface box was used to operate a button box, lights, and mechanical toys located in the soundbooth. Stimuli were presented via a Dennon amplifier (PMA 480) to a single GSI loudspeaker located 90° to the infant's left. A box with a smoked Plexiglass front was located underneath the speaker. During reinforcement (see below) lights and a toy in one of the four compartments in the box became visible; otherwise the contents were hidden.

Procedure. Infants were tested individually in a go/no-go conditioned head turn procedure. The infant sat on his/her parent's lap across from an experimenter who sat behind a small table. Both the parent and the experimenter listened to masking music through headphones for the duration of the experiment. When the infant was attentive and facing forward (towards the experimenter), the experimenter pressed at button to indicate that a trial was to begin. During both training and testing phases the background vowel was presented continuously repeating every 2 s.

During the training phase, the experimenter familiarized the infant to the contingency between a head turn towards the speaker when a change in the vowel occurred and the animated toy reinforcer. Only change trials occurred during training and the vowel was presented 5 dB(A) louder than the background. Thus, both the vowel token and loudness were cues that indicated that a change had occurred. Infants were required to make four consecutive correct responses within 20 trials in order to proceed to the testing phase. A head turn was considered correct if it occurred within 2 s of the onset of the change and if the infant turned at least 45° to the left to face the speaker.

During the testing phase, a total of 24 trials were presented (12 change and 12 no change control trials, in random order). Only correct head turns were reinforced; the experimenter, who was unaware of what the infant was hearing, recorded by a button press whenever a head turn occurred.

Results

For each infant an A' score was computed. (A' is a nonparametric equivalent of d' and may be better suited for infant studies in which only a small number of trials is used (Grier, 1971).) A' scores were submitted to an Analysis of Variance with 2 between-groups factors: F0 (falling, high steady, low steady) and Direction of vowel change (/I/ to /i/, and /i/ to /I/).

A significant main effect for F0 was obtained, $F(2, 12) = 3.76$, $p < .03$. Protected *t*-tests were performed in order to determine which conditions differed. Infants in the low steady and falling F0 conditions obtained higher A' scores on average than did infants in the high steady conditions, $p < .02$, $p < .03$, respectively. These results are summarized in Figure 1.

The main effect of Direction of change was not significant. The interaction between F0 and Direction of Change was also not significant.

T-tests were also computed in order to determine whether infants' performance in each of the three F0 conditions differed significantly from chance (A' of .50) in their A' scores.

In the falling fundamental condition, infants who had /I/ as the background token performed significantly above chance, $t(11) = 2.949$, $p < .007$. However, infants who had /i/ as the background token performed at chance, $t(11) = 1.072$, $p > .15$. A' scores for these two groups are plotted in Figure 2.

In the low steady F0 condition, infants obtained A' scores significantly above chance in both background vowel conditions: /I/ background, $t(11) = 3.197$, $p < .005$, and /i/ background, $t(11) = 2.874$, $p < .008$. A' scores for the low steady groups are plotted in Figure 3.

In the high steady F0 condition, performance did not exceed chance for either of the background vowel conditions: /I/

background, both *ps* > .15. The A' scores for the high steady groups are plotted in Figure 4.

Discussion

Taken together the results of this experiment suggest that discrimination of /i/ and /I/ vowel tokens for 6-month-old infants is possible when the F0 is low but steady (250 Hz), and when the F0 is falling (from 350 Hz to 250 Hz)—but only when /I/ is the background token. However, with a high steady F0 (350 Hz), infants perform at chance suggesting that they are unable to discriminate the two vowel tokens.

These findings are surprising given that the /i/-/I/ distinction is one that infants as young as 8 weeks of age can discriminate (e.g. Swoboda et al, 1976; 1978). However, these studies employed only steady F0 tokens in the range of a typical male speaker (i.e., approximately 120 Hz). The infants in the lowest F0 condition in our experiment —250 Hz—were also able to easily discriminate the two tokens. The 250 Hz fundamental is within the range of a woman's F0 in normal adult conversation.

The falling fundamental and high steady F0 conditions correspond more closely to the pitch of a female speaker's voice when directed to an infant. Maternal speech to infants can range in pitch up to at least 600 Hz at times (Fernald & Simon, 1984; Papousek, et al, 1987), yet our results suggest that a high steady F0 makes it difficult for infants to discriminate two vowel tokens.

The wide pitch excursions found in infant-directed speech correspond most closely to the falling F0 condition in this experiment. Infants were able to discriminate the falling fundamental tokens of /I/ and /i/, but when /I/ was the background token. Perhaps, then, the wide pitch excursions of infant-directed speech compensate for the difficulty of discrimination of vowels posed by the use of high fundamental frequencies.

In sum, these findings highlight the necessity for examining more closely the effects of F0 on vowel discrimination in infants.

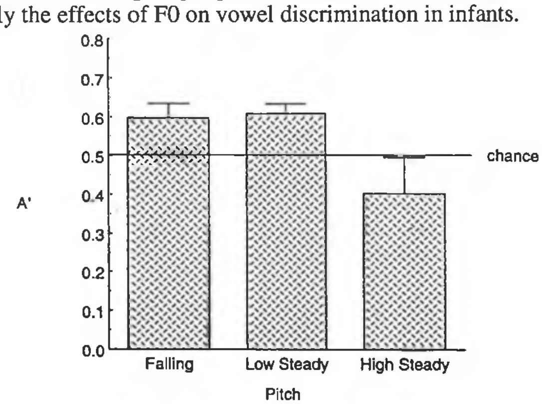

Figure 1. A' scores by pitch condition

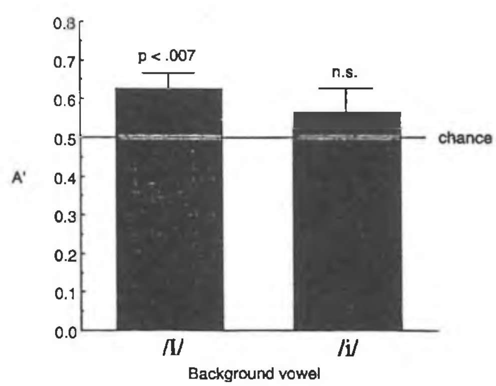

Figure 2. A' scores in the falling pitch condition

The results suggest that high F0 has a negative effect on 6-month-old infants' ability to discriminate two vowel tokens, /I/ and /i/. Further research is necessary in order to determine whether features such as jitter (frequency variation from cycle to cycle of the wave form) normally occurring in natural tokens, would make discrimination of high steady tokens less difficult.

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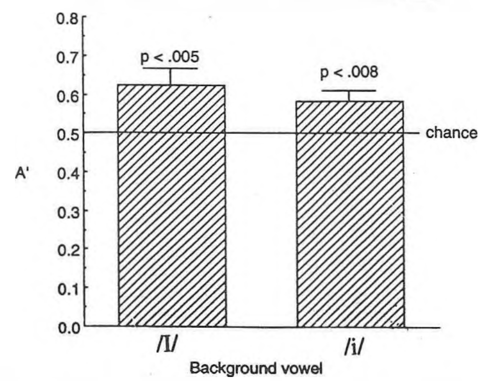

Figure 3. A' scores in the low steady pitch condition.

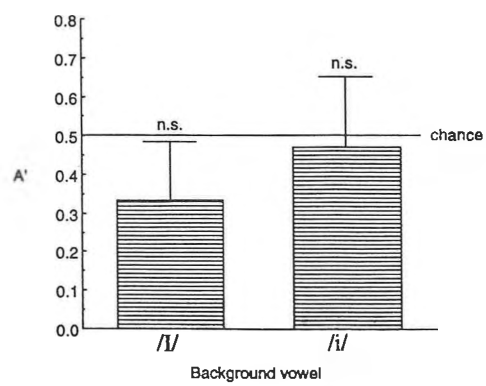

Figure 4. A' scores in the high steady pitch condition