DISCRIMINATION OF STATIC AND DYNAMIC FREQUENCY CHANGES BY CHILDREN AND YOUNG ADULTS

Jane F. MacNeil and Elzbieta B. Slawinski, The University of Calgary, Calgary, Alberta.

Introduction

Although there is much research documenting discrimination of pure tone frequencies, there is less work assessing dynamic frequency glides. Investigation of this nature is relevant, not only to real listening environments where signal frequencies, or spectral components, rapidly change, but also to speech perception where the correct identification of phonemes is dependent upon the sensitivity of the auditory system to respond to rapid changes of short duration frequency sweeps (formant transitions) that are critical for distinguishing consonants.

Audiological studies have shown that consonant discrimination tends to deteriorate with age before vowel recognition does (Working Group on Speech Understanding and Aging, 1988). Since consonants are characterized by formant transitions, the ability to differentiate rapidly changing components is implicated in this decline. The fact that vowel discrimination remains largely intact further suggests that the mechanisms employed to discriminate steady state signals (which characterize vowel segments) are not the same as those which differentiate dynamic signals. Evidence that the thresholds for steady state signals are lower than thresholds for gliding stimuli (Horst, 1989) additionally supports the hypothesis of the involvement of two different mechanisms.

Developmental aspects are an important focus in the study of auditory sensitivity. Elliott et al (1989) reported that young children required significantly larger differences than did young adults to differentiate signals which simulated the second formant of speech. In contrast, little improvement in masked thresholds beyond 10 years of age has been noted (Schneider et al, 1989). With respect to rapidly changing signals, some research has centered on factors such as discriminating glides from steady states, and upward glides from downward glides (Dooley & Moore, 1989, Schouten & Pols, 1989), but discrimination of dynamic signals as a function of age has received little focus.

The purpose of the present study is to evaluate the ability of children and young adults to distinguish steady state and unilaterally gliding frequency signals corresponding to the second formant of speech. Due to the difficulty of separating language from perceptual skills when actual speech signals are used, this study used signals which were dynamic and had frequency characteristics analogous to some aspects of speech but that occurred in isolation. Information derived from these fundamental auditory abilities constitutes the basis for understanding more complex auditory performance.

Method

Stimuli

Stimuli were 50 ms in duration and synthesized on a Micro Vax II computer. Digital outputs were sampled at 20 KHz , 16 bit resolution, and lowpass filtered at 3 KHz. A continuum of 17 signals increasing in 10 Hz steps was generated for both sets of signals. Gliding tones had a constant onset frequency of 900 Hz and diverged to varying offset frequencies of 950 Hz to 1110 Hz in 10 Hz steps. The frequencies of the steady state stimuli corresponded to the offset frequencies of the gliding set.

Subjects

Twenty three subjects : 13 adults (mean age 25.8 years, range 19-38 years), and 10 children (mean age 9.4 years, range 8-10 years) participated in this study. Data from 2 adults were eliminated from the final analysis due to their inability to discriminate any of the signals; as well, data from 2 of the children were also eliminated: one due to an attentional disorder, and the other because of failure to complete the experimental session. All subjects had normal hearing (better than +10 dB HL) for a range of frequencies from 500 Hz to 8 KHz determined with a Bruel and Kjaer audiometer (Model 1800).

Procedure

A two cue, two alternative forced-choice same-different paradigm designed to determine the smallest differences that subjects could discriminate between frequency changes was used. On each trial, subjects were presented with two stimuli separated by 500 ms and asked to determine if they were the 'same' or 'different'. Stimuli were presented monaurally via Kross Pro/4x headphones at the most comfortable listening level for each subject in a double walled sound attenuating anechoic chamber . For all of the children, the experimenter was also present in the chamber. Calibration of sound pressure levels was accomplished with a Bruel and Kjaer impulse precision sound level meter and a Bruel and Kjaer artificial ear positioned over the headphones;linear scale readings were taken with a 0.5 in microphone. Average sound pressure variation was 76 dB SPL with a deviation of +/- 4 dB across subjects.

Each condition consisted of 200 trials; 160 trials of 'different' stimuli, and 40 catch trials to avoid subjects developing a proclivity towards responding 'different' and to provide a metric of bias. The first stimulus in a continuum served as the constant stimulus and was presented on every test trial although its position as either first or second member of the pair was randomly varied.

Just noticeable differences (JNDs) were measured relative to the constant stimulus; therefore, for the gliding stimuli this meant that the JNDs were relative to the stimulus that had the smallest frequency change. A short practice session to familiarize subjects with the stimuli and procedure preceded the beginning of each experimental session. Individual psychometric functions were plotted with percentage correct as a function of stimulus separation in Hz, and these functions were used to specify thresholds for each age group for each stimulus type. Criterion for threshold was defined as the stimulus separation corresponding to the 70% correct position and was determined by fitting a nonlinear function to the data.

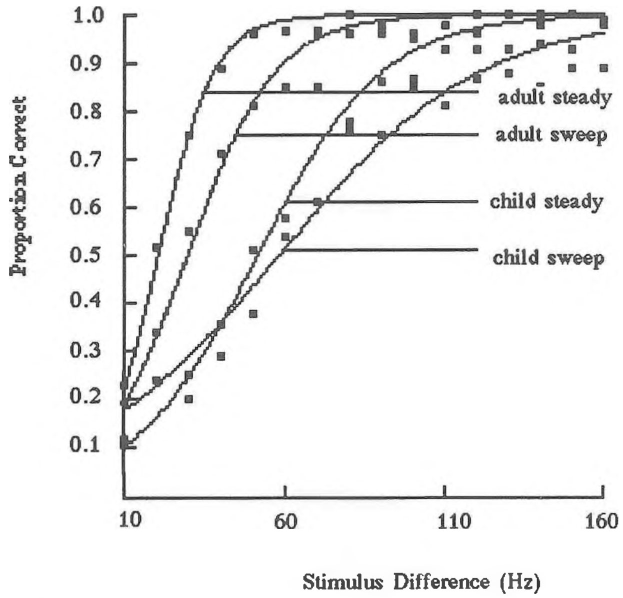
Results

Discrimination of frequency differences was evaluated in terms of JNDs and the results for each subject were based on an average of 400 trials (2 conditions X 200 trials). Each point on the psychometric function (Figure 1) is based upon 110 responses for the adults (10 trials of each stimulus difference X 11 listeners) and 80 responses for the children (10 X 8 listeners). For all subjects a nonlinear function was fit to the data and the 70% correct.position was determined. A multivariate analysis of variance (MANOVA) was conducted on the interpolated threshold data. There was a significant effect for group, $F(1,17) = 32.901$, $p< .001$, and signal type, $F(1,17) = 13.286$, $p<.001$. The interaction of group and signal type was not significant ($F=2.035$).

Adults had significantly lower thresholds than did children, and for both groups the thresholds for steady state stimuli were lower than those for sweeping stimuli. For steady tones, the adults needed smaller acoustic differences (M = 22.6 Hz, SD = 10.4 Hz) than did the children (M = 59 Hz, SD = 9.8

Hz). For sweeping tones, the thresholds are higher for both groups, but are still lower for the adults (M = 35 Hz, SD= 13 Hz) than for the children (M = 64 , SD = 19 Hz). A shift to the left in the psychometric functions of the adult data suggests an increased sensitivity relative to children. As well, the functions for the steady tones are to the left of the sweep tones demonstrating a greater sensitivity for discrimination of steady frequency changes compared to discrimination of dynamic frequency changes.

Figure 1. Psychometric Functions for Group and Signal Type



An analysis of the catch trial performance did not reveal any significant differences across groups (p>.05) or signal type (p>.05). This tentatively suggests that subjects did not adopt a more stringent criterion for any condition, nor did confidence in their decisions change across conditions. The important indication is that the relatively poorer auditory discrimination of children compared to that of adults is a function of general auditory processing and not specific features of the task or response bias.

Conclusions

(1) Thresholds for just noticeable differences have an age-related component to them. Even by 10 years of age, children require significantly larger acoustic differences than do young adults in order to be able to distinguish either steady state or gliding signals. The implication of this pattern of age differences is the presence of an unidentified, but crucial, developmental component. These findings support the results of Elliott et al (1989) who also documented age-related aspects involved in the discrimination of complex sounds.

(2) The increase in threshold which some listeners demonstrate has been attributed to a broadening of the auditory filter (Moore, 1982), but Irwin et al (1986) reported that the auditory filters of 10 year old children were not significantly wider than those of young adults. It appears that these changes are cognitive in nature and reflect more central aspects of auditory processing. The results of this study show that even at 10 years of age, some auditory abilities have not yet attained adult-like sensitivity.

(3) The pattern of children's results resembles that of the adults. For both groups, thresholds for steady state signals were lower than that for frequency glide signals. This supports the hypothesis that two different mechanisms encode steady state and gliding signals respectively and that these mechanisms are not as developed in children as they are in adults. This also concurs with the data from some hearing impaired studies where listeners with sensorineural hearing loss may perform well on one dimension, but poorly on another, again suggesting the involvement of two different processes.

(4) The poorer discrimination of gliding stimuli versus steady stimuli is consistent with research on speech perception which demonstrates poorer consonant discrimination as opposed to vowel discrimination. These results may help to explain why consonant perception deteriorates before vowel perception does. Frequency discrimination, however, is only one of many factors involved in the perception of speech, but knowledge of fundamental processing mechanisms assists in the comprehension of more complex auditory behavior. These findings may further enhance understanding of why certain listeners (particularly children and elderly people) despite having good pure tone sensitivity as measured by conventional audiological methods, experience difficulty in understanding speech or processing other complex auditory signals. It is apparent that significantly more acoustic information is needed by children, for example, in order to differentiate dynamic signals.

(5) The lack of differences among the catch trial data for both the adults and the children suggests that the poorer auditory discrimination of children is a reflection of general auditory processing , and not attributable to task difficulty or response bias.

References

Dooley, G. J. & Moore, B.C.J. (1988). Detection of linear frequency glides as a function of frequency and duration, Journal of the Acoustical Society of America, 84(6), 2045-2057.

Elliott, L.L., Hammer, M.A., Scholl, M.E. & Wasowicz, J.M. (1989). Age differences in discrimination of simulated single-formant frequency transitions, Perception & Psychophysics , 46(2), 181-186.

Horst, J.W. (1989). Detection and discrimination of frequency modulation of complex signals, Journal of the Acoustical Society of America , 85(5), 2022-2030.

Irwin, R.J., Stillman, J.A., & Schade, A. 1981. The width of the auditory filter in children, Journal of Experimental Child Psychology , 41, 429-442.

Moore, B.C.J. (1982). An Introduction to the Psychology of Hearing, (2nd ed). New York: Academic Press.

Schneider,B.A., Trehub, S. E. & Morrongiello, B.A. & Thorpe, L.A. (1989). Developmental changes in masked thresholds, Journal of the Acoustical Society of America, 86(5), 1733-1742.

Schouten, M.E.H. & Pols, L.C.W. (1989). Identification and discrimination of sweep formants, Perception & Psychophysics , 46(3), 235-244.

Working group on speech understanding and aging. (1988). Speech understanding and aging, Journal of the Acoustical Society of America , 83(3), 859-895.