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Technical Notes

EFFECT OF COCHLEA DAMAGE ON THE DETECTION OF DIFFERENCE TONE IN SIGNAL ENVELOPE

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Recent studies have demonstrated that the detection of complex temporal envelopes relies on the perception of a distortion component generated by cochlear and postcochlear (central) nonlinearity. In the present study, 4-kHz carrier was modulated by tones f_1 and f_2 to produce the difference tone $f_3 = f_2 - f_1$ in the amplitude modulation domain. Detection thresholds for canceling tone f_3 were obtained for subjects with normal-hearing and hearing-impaired subjects. In three experimental conditions, monaural and binaural presentation of tones was used to test possible central origin of the nonlinearity in modulation domain. Modulation depth at threshold was measured as a function of the phase of the canceling component f_3 varied from $0°$ to $270°$ in $45°$ steps. Results showed that level of canceling tone f_3 was phase dependent at all signal frequencies. Thresholds for normal-hearing and hearing-impaired subjects were lower for the in-phase condition than for the antiphase condition. Results demonstrated that cochlear damage had no large effect on the nonlinearity in the AM envelope indicating that the distortion component must be generated by a more central non linear effects.

Key words: perception of amplitude modulation, difference tone, hearing impairment.

1. Introduction

Hearing-impaired people often find it difficult to understand speech in the presence of background noise. It is recognized that part of this difficulty comes from abnormalities in the perception of amplitude modulation (AM). The purpose of the present study was to investigate the effects of cochlear damage on the nonlinearity generated in the AM domain. Cochlear damage is assumed to result in reduction or complete loss of the compressive nonlinearity normally present in the input-output function of the basilar membrane [1-4]. Loss of compressive nonlinearity theoretically leads to the reduction or elimination of distortion component seen in the envelope beat rate. Processing of amplitude modulation by normal-hearing and hearing-impaired subjects presented in this paper was investigated with monaural and binaural signal presentation to test the idea whether nonlinearities in the auditory system can introduce a distortion in perception of the AM signal envelope.

2. Subjects, apparatus, stimuli and procedure

Three subjects aged 20–25 with audiologically normal hearing and three subjects with sensorineural hearing loss aged 40–60 participated in the experiments. Hearing loss of hearing-impaired subjects was classified as mild to moderate as measured for audiometric frequencies in frequency range from 250 Hz to 8 kHz. Three normal hearing listeners reported no hearing impairments, and their audiogram for tested ear was better than 10 dB HL at all audiometric frequencies. Signals used in experiments were generated by means of the Tucker Davis Technology System II at a 50 kHz sampling rate with a 16-bit resolution. Signals were delivered monaurally and binaurally via Sennheiser 580 earphones to subjects seated in double-walled acoustically isolated chamber.

A 4-kHz sinusoidal carrier was amplitude modulated by a complex of three tones f_1, f_2, and f_3. Tones f_1 and f_2 were used to produce difference tone $(f_2 - f_1)$ in modulation domain, test ton f_3 was employed to detect $f_2 - f_1$ intermodulation product by canceling method. The frequencies of tones f_1, f_2, and f_3 in three experimental conditions respectively were: 60, 65, and 5 Hz; 120, 150, and 30 Hz; and 97, 127, and 30 Hz. The initial phase of the modulating signal f_3 was set from $0°$ to $270°$ in $45°$ steps. A three-alternative forced-choice (3AFC) paradigm and 1-up 3-down adaptive procedure were used to determine threshold which was calculated as the geometric mean of last eight reversals in adaptive track. At least six single threshold determinations were made for each measurement condition. In the monaural condition, all signals were presented to the left ear. In the binaural condition A, the AM signal produced by modulating tones f_1 and f_2 was presented to the left ear whereas the AM signal produced by modulating tone f_3 was presented to the right ear. In the binaural condition B, the AM signal produced by modulating tones f_1 and f_2 was presented monotically to the left and right ear. Tone f_3 was presented to the right ear. Level of each f_1 and f_2 tones was 50 dB SPL in measurements with normally hearing subjects. For hearing-impaired subjects, level of tones was adjusted in each individual condition to produce comfortable loudness. Stimulus duration was 1 s, including 20-ms rise/fall signal portions. Listeners received visual feedback as to the correctness of their responses after each trial.

3. Results

Open symbols in Figs. 1 and 2 show the AM detection thresholds of 5-Hz and 30-Hz modulation by tone f_3 respectively for a normal-hearing subject and hearing-impaired subject. The frequencies of f_1 and f_2 producing difference tone f_3 are listed in each panel. For comparison, closed symbols indicate thresholds for the AM by 4- and 32-Hz signal when no tones f_1 and f_2 are presented. Lower thresholds by as much as 10–20 dB in certain cases when no f_1 and f_2 tones are presented (filled symbols vs. open symbols) strongly suggest the presence of the $f_2 - f_1$ difference tone in the amplitude modulation domain.

In monaural condition (Fig. 1, upper panel, circles) for f_1 and f_2 of 60 and 65 Hz, subjects showed a maximum threshold at $90°$ and $135°$, referred to as the antiphase condition. The maximum effect of phase i.e. the threshold difference between the in-phase and the antiphase conditions is 10 dB for normal-hearing subject (Fig. 1) and about 7 dB for hearing impaired subject (Fig. 2). In monaural condition with difference between f_1 and f_2 of 30 Hz ($f_2 - f_1 = 30$ Hz), normal-hearing and hearing-impaired subjects showed a maximum threshold at 135°.

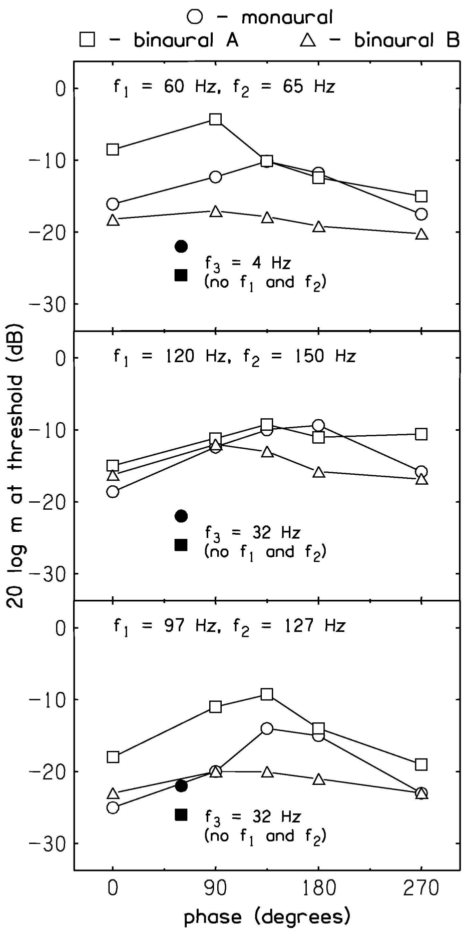

Fig. 1. Depth of amplitude modulation by cancellation tone f_3. Solid symbols refer to modulation depth with absence of tones f_1 and f_2 generating difference tone $f_2 - f_1$. Normally hearing subject.

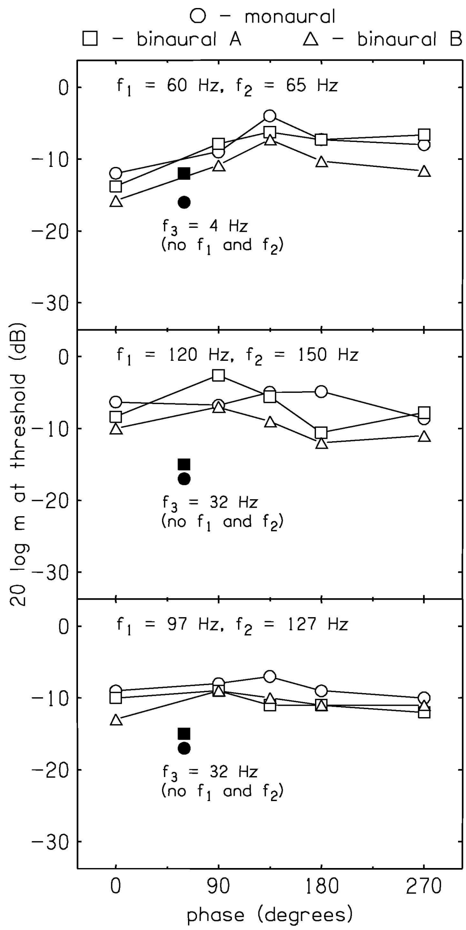

Fig. 2. Depth of amplitude modulation by cancellation tone f_3. Details as in Fig. 1. Hearing impaired subject.

In binaural condition A at $f_1 = 60$ and $f_2 = 65$ Hz, the maximum threshold value is at 90° (Fig. 1, upper panel, squares). The overall change in threshold value is similar to that in the monaural condition. In binaural condition B for $f_1 = 60$ and $f_2 = 65$ Hz (Fig. 1, upper panel, triangles), the thresholds for modulation tone f_3 is almost independent of the phase, and lower than for monaural condition and binaural condition A.

Similar differences between monaural condition, and binaural conditions A and B are seen for $f_1 = 97$ Hz and $f_2 = 127$ Hz (Fig. 1, lower panel). However, the threshold values are by about 5 dB lower than for $f_1 = 60$ and $f_2 = 65$ Hz discussed previously. Surprisingly, there no large difference among the three experimental conditions for $f_1 = 120$ Hz and $f_2 = 150$ Hz (Fig. 1, middle panel). There is still dependence of threshold of the phase of tone f_3 seen in the data.

Differences observed in three experimental conditions for normally hearing person suggest that (1) a nonlinearity leading to generation of difference tone $f_3 = f_2 - f_1$ may be of central origin and (2) variation between binaural conditions A and B may be influenced by the binaural masking release.

There are three major characteristic features seen in the data for hearing impaired subject (Fig. 2). Firstly, the thresholds values are generally higher. Secondly, there is much smaller difference between the three experimental conditions for all f_2 and f_1 frequencies used in the measurements. Thirdly, the change in thresholds with phase of f_3 tone is less pronounced, especially for frequency difference $f_2 - f_3 = 30$ Hz (Fig. 2, middle and lower panels). This is accompanied by generally lower sensitivity to the AM, as can be seen from higher by about 10 dB thresholds for the detection of the AM by the tone f_3 when tones f_2 and f_1 are not present in the stimulus (compare solid points in Fig. 1 and 2).

4. Conclusions

Data obtained in the present study showed that: (1) magnitude of phase effect was nearly the same for signal frequencies 5 and 30 Hz both for normal hearing and hearing impaired subjects; (2) detection thresholds for AM modulation can be affected by the presence of an intermodulation product beating at the same rate; (3) thresholds are consistently lower in the in-phase condition, in which maxima in the signal modulation coincide with the phase (4) observed phase effect still exists for modulation components which are only 6 dB above their threshold; and (5) results support the hypothesis that a nonlinear mechanism in the auditory system introduces a distortion component in the internal representation of envelope modulation.

Acknowledgments

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