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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0168

AD-A277 414

REPORT DATE

3. REPORT TYPE AND DATES COVERED: ANNUAL 1 Jan 93 TO 31 Dec 93

5. FUNDING NUMBERS: F49620-93-1-0070, 61102F, 2313, AS

AUDITORY PERCEPTION

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8. PERFORMING ORGANIZATION REPORT NUMBER

AFOSR-TR- 94 0105

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BOLLING AFB DC 20332-0001

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94-09361

11. SUPPLEMENTARY NOTES

DTIC ELECTE MAR 2 8 1994 S F D

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The experiments described in this report were designed to study the effects of certain acoustic cues on detectability of a delayed signal. The purpose was to gain insight into how the ear suppress multiple hearings in a reverberant setting. Results of the experiments indicate that a signal, intended to simulate an echo, ismore difficult to detect when it is following an identical masker, intended to simulate a primary sound,than when it is leading that masker. If, however, the signal is not acoustically similar to the masker, this asymmetry disappears, even if the masker is equally effective in the simutaneous condition. Further, if the signal and masker are not identical, but share an important acoustic attribute such as harmonicity, the asymmetry is observed. In summary, detectability of the delayed signal seems to be dependent on the strength of acoustic connection between the signal and masker, whereas detectability of the leading signal does not demonstrate that dependence.

94 3 25 033

14. SUBJECT TERMS			15. NUMBER OF PAGES
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT (U)	18. SECURITY CLASSIFICATION OF THIS PAGE (U)	19. SECURITY CLASSIFICATION OF ABSTRACT (U)	20. LIMITATION OF ABSTRACT (U)

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AEOSR-TR- 94 0105

Annual Technical Report

AFOSR Grant No. F49620-93-1-0070

AUDITORY PERCEPTION

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ABSTRACT

The experiments described in this report were designed to study the effects of certain acoustic cues on detectability of a delayed signal. The purpose was to gain insight into how the ear suppress multiple hearings in a reverberant setting. Results of the experiments indicate that a signal, intended to simulate an echo, is more difficult to detect when it is following an identical masker, intended to simulate a primary sound, than when it is leading that masker. If, however, the signal is not acoustically similar to the masker, this asymmetry disappears, even if the masker is equally effective in the simultaneous condition. Further, if the signal and masker are not identical, but share an important acoustic attribute such as harmonicity, the asymmetry is observed. In summary, detectability of the delayed signal seems to be dependent on the strength of acoustic connection between the signal and masker, whereas detectability of the leading signal does not demonstrate that dependence.

This report is intended to provide information regarding the grant-related activities which have taken place in our lab during the first year of this grant period.

Our research is currently directed towards determining the specific acoustic cues used by the auditory system to fuse an echo with a previously received primary sound. This suppression of multiple hearings is similar to sound source segregation, in that, presumably, the auditory system must first recognize acoustic similarities between the echo and the primary sound, before it can be suppressed. It seems reasonable to assume that for a stimulus to be analyzed as an echo, it must first be delayed relative to a previously received stimulus, and second, it must be acoustically similar to that stimulus The experiments are based on the assumption that when a signal is perceived as an echo, echo fusion can be measured by reduced detectability of that signal.

Experimental series I: Our first series of experiments was performed to demonstrate that a delayed signal, intended to simulate an echo, is more difficult to detect when it is acoustically identical to the masker, intended to simulate an echo. Two acoustic cues, frequency similarity and harmonicity, are examined.

Experiment 1: For this experiment, the masker was a 500 Hz sinusoid presented at 70 dB SPL. The signal, also a sinusoid, was either 500 or 750 Hz. Both had a duration of 125 ms. The onset of the signal either preceded or followed the onset of the masker within a range of ± 60 ms. The step sizes were chosen to allow the signal to be added in phase for each temporal shift, and also to represent delays that might occur in the environment. A two-interval forced-choice adaptive procedure was used to measure signal detectability.

Results show that, similar to traditional temporal masking data, signal detectability improves with increasing temporal shift, regardless of the direction of that shift. When the signal and masker are identical, detectability of the leading signal improves quickly as a function of increasing temporal shift, but improvement in detectability of the delayed signal is considerably slower, resulting in marked asymmetry in detection thresholds of the leading and delayed signal. It is noteworthy that for signal delays up to 30 ms, the average signal detectability remains nearly constant, despite the fact that as much as 30 ms of the signal is presented with no masker. This would not be predicted by existing temporal masking data. For the 750 Hz masker, the data are nearly symmetrical. That is, detectability of the leading and delayed signals are almost identical. Thus, the data indicate that an acoustically identical signal and masker results in considerably more masking for a delayed signal than the leading signal, but when the signal and masker are different in frequency, we do not observe that asymmetry. Detectability of the leading and delayed signal are similar.

Experiment 2: It is possible, in examining the above data, that the greater effectiveness of the same frequency masker is responsible for the observed asymmetry. The following control experiment was performed to determine if that is the case. The masker was a noise band (100-1000 Hz) with an overall level of 70 dB SPL, selected to be as effective as the 500 Hz masker in the simultaneous condition, but without being acoustically similar to the 500 Hz signal. The signal was a 500 Hz sinusoid. Everything else was as described above.

The data show that for the noise band masker, the asymmetry observed for the 500 Hz sinusoidal masker is nearly eliminated for two of the three subjects and is significantly reduced for the third subject When the signal and masker are simultaneous, the signal is around 8 dB less detectable with the noise masker than the 500 Hz tone, despite the fact that the noise masker contains considerably less energy in the critical band surrounding the signal. Interestingly, the poorer signal detectability with the noise masker does not persist when the signal is delayed. Rather, the delayed signal becomes more detectable with the noise masker than with the tonal masker. For the leading signal, detectability is not very different for the two maskers, resulting in a more symmetric curve for the noise band masker. These data indicate the asymmetry observed in Experiment 1 cannot be attributed to masker effectiveness.

Experiment 3: This experiment was performed to examine the effect of a harmonic relationship between the delayed signal and the masker on signal detectability. The masker consisted of 3 equal-level sinusoids, 400, 600, and 800 Hz, with an overall level of 70 dB SPL. The signal always had two components which were either 1) included in the masker (400 & 800 Hz), 2) not included in the masker but harmonically related (500 & 700 Hz) or 3) not included and also nonharmonic with the masker (474 & 711 Hz). Everything else was as described above. Results indicate that the inclusive signal is considerably more difficult to detect when it is delayed than when it is leading, followed by the harmonic signal and the nonharmonic signal in that order. These data indicate that a signal that has a harmonic relationship with the masker is more difficult to detect than a nonharmonic signal. The data are in agreement with the prior experiments in that acoustic similarity between a delayed signal and a masker adversely affects detectability. The manuscript describing these experiments (Chen and Cohen) was submitted to J. Acoust. Soc. Am. in October

Experimental series II: These experiments were designed to determine the usefulness of harmonicity in providing an acoustic connection between a masker and a simultaneous signal. The information gained from these experiments will be necessary to design future experiments using a non-simultaneous masking paradigm. We used the same paradigm previously developed to measure auditory fusion based on coherent AM [Cohen & Schubert (1987), JASA, 81, 721]. The basic assumption was that when fusion occurs among stimulus components, detection of one of those components will be decreased. The first experiment was designed to test that assumption by comparing detectability of a harmonic and nonharmonic signal in the presence of a harmonic masker. Further, considering the possibility that harmonicity not only fuses the components having the same fundamental, but also separates them from components having other fundamental frequencies, the second experiment was designed to quantify harmonic fusion and segregation respectively.

Experiment 1: The masker was a harmonic series (480, 600, 720 Hz; 1320, 1440 1560 Hz; or 3480, 3600, 3720 Hz) with an overall level of 70 dB SPL. The signal, varying in frequency, was a tone either harmonically related to the masker or not. The signal and masker were 125 ms in duration and were presented simultaneously. Everything else was as described above. Results indicate that for the low-frequency masker, a harmonic signal is less detectable than the neighboring nonharmonic signal, suggesting that the harmonic relationship between signal and masker caused poorer signal detectability. For the mid-frequency masker, the difference in detectability is even greater, in some instances as high as 30 dB. This persists when the signal is as much as five harmonics away from the masker, which well exceeds the critical bandwidth in that frequency range. For the high-frequency masker, the harmonic signal is less detectable than the nonharmonic signal only when it is one or two harmonics below the masker. Overall, this harmonic fusion seems to be relatively independent of energetic masking. This detection difference between a harmonic and nonharmonic signal could be due to either the harmonic signal fusing with the masker, the nonharmonic signal segregating from the masker, or both. It would be due only to harmonic fusion if the harmonic signal fuses with the masker, causing poorer detectability, while the nonharmonic signal is not fused or segregated and so is detected by a general detection model. Or, it would be due only to harmonic segregation if the nonharmonic signal is segregated from the masker, resulting in improved detectability, while the harmonic signal is not fused and so is detected by a general detection model. The following experiment was designed to answer this question.

Experiment 2: Data were collected to compare signal detectability among three stimulus configurations: 1) all components in the masker and signal are harmonically related (harmonic configuration); 2) the masker is a harmonic complex, but the signal is not harmonically related to the masker (nonharmonic configuration); and 3) none of the masker or signal components were harmonically related (arbitrary configuration). Signal detectability in the arbitrary configuration, in which neither segregation or fusion is likely to occur, serves as a reference to measure the fusion in the harmonic configuration and the segregation in the nonharmonic configuration. The signal was a 660 Hz sinusoid. The masker contained either 1, 2, or 3 tones, which were all either harmonic with the signal, harmonic with each other but not the signal, or not harmonic with each other or the signal. The signal and masker were gated together with a 125 ms duration and overall level of 75 dB SPL. Everything else was as described for Experiment 2. Results indicate that harmonic fusion, measured as a decrease in detectability in the harmonic configuration relative to the arbitrary configuration, is about 10 dB with both the 2 and 3 component maskers. And harmonic segregation, measured as increased detectability in the nonharmonic configuration relative to the arbitrary configuration, is about 4 dB with the 2 component masker and 12 dB with the 3 component masker. These results indicate that harmonicity can be important to both fusion and segregation. The manuscript describing these experiments is in preparation.

Experimental Series III: We have continued are experiments on cross-spectrum coding of coherent frequency change. Briefly, we have measured cross-spectrum fusion for a set of stimulus components that are coherently changing in frequency, and for a set of components with the same carrier frequencies, that are not changing in frequency. Results indicate considerably greater fusion for the frequency glides than for the sinusoids, despite the fact that spectral distance between components is identical for the two conditions. We will report these data at the Spring, 1994 meeting of the Acoustical Society.

Marion F. Cohen AFOSR Grant # F49620-93-1-0070

Students working on grant:

Xiaofen Chen, doctoral student
Julie Westmoreland, master's student
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Meeting Papers:

Chen, X. and Cohen, M.F. (1993). "Monaural echo suppression: Detectability of a delayed signal based on vowel formant structure," J. Acoust. Soc. Am., 93, 2350.

Chen, X. and Cohen, M.F. (1994). "The effect of coherent frequency change on signal detectability," To be presented to the spring meeting of The Acoustical Society of America, May 1994.

Manuscripts:

Chen, Xiaofen and Cohen, Marion F. "Acoustic factors influencing detectability of a delayed monaural signal," J. Acoust. Soc. Am. (submitted).

Cohen, Marion F. and Chen, Xiaofen. "Effect of harmonicity on detectability of a masked signal." (manuscript in progress)