REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE 1/5/93

3. REPORT TYPE AND DATES COVERED Annual Technical, 11/1/91 - 10/31/92

4. TITLE AND SUBTITLE
Monaural and Binaural Processing of Complex Waveforms

5. FUNDING NUMBERS
AFOSR Grant (G)
[redacted] F49620-92-J-0062
2313
A6
61102F

6. AUTHOR(S)
Constantine Trahiotis and Leslie R. Bernstein

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Connecticut Health Center
263 Farmington Ave. L-4071
Farmington, CT 06030-3405

8. PERFORMING ORGANIZATION REPORT NUMBER
AFOSR-TR- 93 0091

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Dr. John Tangney, Program Manager
Life Sciences Directorate
AFOSR/NL Building 410
Bolling AFB, DC 20332-6448

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

13. ABSTRACT (Maximum 200 words)

Data were collected concerning the amount of "comodulation masking release" (CMR) obtained when coherent envelope information is presented successively rather than simultaneously. It was determined that "off-frequency" information, which produces a CMR, can provide only a small release from masking when presented prior and subsequent to the temporal interval containing the signal. Three papers were published and a fourth is undergoing revision. One assessed sensitivity to interaural correlation of the envelope of high-frequency waveforms and whether such sensitivity might account for detectability in an MLD paradigm. Another showed sensitivity to antiphasic sinusoids added only to the envelopes of high-frequency bands of noise as a function of the frequency of the sinusoid and the bandwidth of the masker. A third, with Dr. R. M. Stern, depicts how "straightness" weighting can be accomplished by a second, physiologically demonstrated, stage of neural processing. The complex, cross-correlation-based model was extended to account for how interaural intensitive disparities in combination with interaural temporal disparities affects lateralization. Software was written for experiments concerning effects of forward masking fringes on the high-frequency MLD and to perform the theoretical analyses of stimuli used in the "successive" CMR paradigm.

14. SUBJECT TERMS
CMR, cross-correlation, generation of complex digital stimuli, interference, masking, M.L.D., off-frequency cuing, straightness

15. NUMBER OF PAGES 12 (including SF-298)

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

ANNUAL TECHNICAL REPORT

RE: AFOSR-89-0030

Monaural and Binaural Processing of Complex Waveforms

Constantine Trahiotis and Leslie R. Bernstein
University of Connecticut Health Center
Farmington, CT 06030

ABSTRACT OF TECHNICAL PROGRESS (November 1, 1991 - October 31, 1992)

During the past year of the granting period, we have continued to make substantial progress consistent with the objectives outlined in our latest proposal.

1) We have collected a very comprehensive set of data concerning the amount of "comodulation masking release" (CMR) that can be obtained when the coherent envelope information is presented <u>successively</u> rather than <u>simultaneously</u>. It was determined that "<u>off-frequency</u>" information, such as that which usually produces a CMR, can provide only a very small release from masking when it is presented prior and subsequent to the temporal interval containing the signal. The most striking finding was that the threshold for detecting a 1-kHz tone masked by an 50-Hz-wide band of noise centered on 1 kHz, was reduced by <u>7 dB</u> when an identical, "<u>on-frequency</u>", masking noise was presented in all four intervals of our two-cue, two-interval, forced-choice procedure.

2) We have published three papers, and a fourth is undergoing revision. We included all four manuscripts in our six-month report. The Bernstein and Trahiotis (1992) paper published in the Journal of the Acoustical Society of America assessed listeners' sensitivity to interaural correlation of the envelope of high-frequency waveforms and whether such sensitivity might account for detectability in a masking-level difference paradigm. Another Bernstein and Trahiotis (1992) paper published in Hearing Research measured listeners' sensitivity to antiphasic sinusoids added <u>only to the envelopes</u> of high-frequency bands of noise as a function of the frequency of the sinusoid and the bandwidth of the masker. The third paper concerns, principally, our theoretical efforts (Stern and Trahiotis, 1992) and depicts how "straightness" weighting can be accomplished by a stage of neural processing which records coincidences of activity from outputs of primary coincidence counting units with the same characteristic internal delay but with different characteristic frequencies.

3) We and Dr. R. M. Stern, have extended our complex, cross-correlation-based model to account for new data concerning how interaural intensitive disparities in combination with interaural temporal disparities affect the location of intracranial images.

4) We wrote software for experiments concerning effects of forward masking fringes on the high-frequency MLD and wrote routines to perform the theoretical analyses of stimuli used in the "successive" CMR paradigm.

A) Statement of Work

The purpose of the proposed research continues to be a broader understanding of the manners by which the "monaural" and "binaural" auditory systems process information in complex sounds. Our empirical investigations are intimately related to our theoretical orientation, on the one hand, and to our strain to incorporate and to understand diverse, yet certainly related behavioral phenomena on the other.

One subset of experiments concerns our recent finding that the detectability of an 800-Hz tone (the target) in the N_0S_π configuration is degraded or "interfered with" by the presence of a 400-Hz tone gated with the same temporal characteristics as the target in both intervals of a two-interval, forced-choice task. We proposed a series of experiments in which various temporal and spectral aspects of the target, interferer and accompanying masking noise are varied in order to better characterize the mechanism or mechanisms responsible for interference. We are especially interested in determining whether the interference we have observed reflects mechanisms responsible for the segregation of sources of sound.

A second subset of experiments concerns the effect of temporal/spectral variations on the masking level difference, but in a different context. Here, we investigate how the detectability of tonal targets is enhanced by turning on the relevant masking energy earlier and earlier. We are especially interested in collecting such data for high-frequency targets and narrow-band maskers.

A third, rather large, subset of experiments concerns the detectability of interaural disparities that occur shortly after the beginning of an acoustic event. These experiments are designed to investigate phenomena typically discussed in the context of the "precedence" effect. We are especially interested in determining how the detectability of such interaural information is affected by other binaural information in close (or remote) spectral/temporal proximity. Several of the experiments are designed to assess sensitivity to interaural disparities when the listener is uncertain about the temporal/spectral placement of the cues to be detected.

A fourth subset of experiments represents a continuation of our efforts to elucidate the temporal properties of stimuli required to produce a sizeable comodulation masking-release (CMR). Some of these experiments employ stimuli designed to shed light on the "time-constants" of the mechanisms underlying the CMR. Others will capitalize on our specially-constructed digital signals whereby envelope-variations across two spectrally discrete regions can be presented in manner that will allow us to assess further the applicability of binaural models as explanations for the monaural CMR.

Finally, we have continued our fruitful collaboration with Dr. Richard Stern to extend a complex, comprehensive, pattern-processing model of binaural hearing that utilizes the cross-correlation functions of temporally and spectrally complex stimuli to describe behavior phenomena. A large portion of this effort will include incorporation of interaural intensitive differences across frequency in manner that will produce quantitative predictions for "realistic" stimuli.

B) Specific Progress

During the past year, which represents the first portion of the new granting period, we have made substantial progress consistent with the objectives outlined in our latest proposal. As is our norm, we will discuss our progress in three separate, but related areas. They are 1) collection of behavioral data; 2) publication of empirical data and 3) extension of our comprehensive, complex model of binaural processing to include interaural intensitive differences. In the interest of brevity, we will only mention and not document extensively 1) development of new software necessary to conduct the behavioral experiments especially including the experiments concerning the effects of forward masking fringes on the high-frequency masking-level difference and 2) development of computer routines to assist in the analysis and interpretation of our behavioral experiments concerning the use of "successive" cues in a "comodulation masking release" (CMR) paradigm. Such software development was absolutely crucial to our efforts and both reflects and represents work that is progress.

We have collected a very comprehensive set of data concerning the amount of "comodulation masking release" (CMR) that can be obtained when the coherent envelope information is presented <u>successively</u> rather than <u>simultaneously</u>. This series of experiments was initially designed to assess whether a release from masking could occur when the coherent envelope information was presented across temporally discrete intervals. A large number of conditions were added to permit an assessment of the actual cues listeners use when detecting a tone masked by a narrow band of noise. We also measured detectability in several of the same conditions with the stimuli randomly "roved" in level. In essence, our original experiment blossomed into an investigation concerning advantages to the listener provided by reproducible noise, conditions under which listeners base their decisions on "energy" and how changes in the statistics of the signal-plus-noise envelope affect performance. The most important aspect of these experiments was the determination that "<u>off-frequency</u>" information, such as that which usually produces a CMR, can provide only a very small release from masking when it is presented prior and subsequent to the temporal interval containing the signal.

Another important finding was that the threshold for detecting a 1-kHz tone masked by a 50-Hz-wide band of noise centered on 1 kHz, was reduced by <u>7 dB</u> when an identical, "<u>on-frequency</u>", masking noise was presented in all four intervals of our two-cue, two-interval, forced-choice procedure. Of course, a new sample of "frozen" noise was chosen for each trial, precluding the listeners' use of cues specific to any one sample of noise. Notably, when all four intervals contained identical envelope information presented such that the cuing information was centered at 900 Hz, thresholds increased. When the cuing information was centered at 700 Hz, thresholds increased by about 5 dB and were essentially equivalent to those obtained in a two-alternative, forced-choice task with identical noise samples used in both intervals. That is, the off-frequency cues centered at 700-Hz provided absolutely no advantage. This outcome is fundamentally different from that obtained in "real" CMR conditions where the (Joe) Hall-mark is a release from masking due to the simultaneous presence of envelope information presented even an octave away from the target band's center frequency.

One aspect of the data that was intriguing was a consistently measured 3-dB advantage when the masking noise in a standard two-interval forced-choice paradigm was frozen during a trial as opposed to being chosen randomly for each of the two intervals within a trial. This outcome, which was similar to one obtained by Murray Spiegel and Dave Green persisted even when the level of the stimuli was roved over a 40-dB range. This manipulation precluded listeners' use of energy-based cues for detecting the signal.

In order to determine the nature of the processing used by the listeners and the specific aspects of the stimuli that were important, we investigated whether performance could be accounted for by one or more decision statistics derived from aspects of the envelopes of the stimuli. To this end, new computer routines were generated that permitted us to evaluate simulated performance based on three apparently relevant and potentially utilizable envelope statistics: 1) The normalized envelope fourth moment (as suggested by Hartmann and his colleagues); 2) the envelope sigma-to-mean ratio (similar to a statistic utilized by Viemeister and his colleagues) and 3) the envelope "mean-slope" (as suggested by Ginny Richards). Each of these three statistics was computed for several samples of noise and for several signal-to-noise ratios. Richards' envelope mean-slope statistic produced differences between frozen and truly random samples of noise as used in our behavioral experiment that were almost identical to the differences found behaviorally. The other two statistics failed to yield any consistent difference and, therefore, do not appear to be relevant to our listeners' processing of envelope information.

The envelope mean-slope statistic is not particularly intuitive but it helps to note that changes in this statistic reflect changes in the spectral content of the envelope of the noise and signal-plus-noise waveforms used in the experiments. After we calculated such spectra, we were pleased to see that Dave Green and his colleagues published a paper using a similar analysis to predict spectral shape discrimination in narrow-band stimuli. We are finally at a point where we feel comfortable writing a paper about these experiments.

We are presently starting collection of behavioral data in the series of experiments discussed in our most proposal concerning the effects of a forward masking fringe on the high-frequency masking-level difference.

We have published three papers, and a fourth is undergoing revision. We have included all four manuscripts in our six-month report. The Bernstein and Trahiotis (1992) paper published in the Journal of the Acoustical Society of America assessed listeners' sensitivity to interaural correlation of the envelope of high-frequency waveforms and whether such sensitivity might account for detectability in a masking-level difference paradigm. A portion of the experiments yielded data that strongly indicate that listeners are able to focus on the lowest frequency components of a critical-band-wide high-frequency band of noise and this enables them effectively to process envelope information that otherwise fluctuates too rapidly for the efficient use of binaural cues. A series of "split-correlation" conditions revealed that listeners cannot focus on only the higher spectral regions of such a noise. The data are similar to the asymmetrical results found in studies of "spectral interference."

Another Bernstein and Trahiotis (1992) paper published in Hearing Research measured listeners' sensitivity to antiphasic sinusoids added only to the envelopes of high-frequency bands of noise as a function of the frequency of the sinusoid and the bandwidth of the masker. The stimuli were constructed such that the added sinusoid produced IIDs that fluctuated at a rate that was equal to the frequency of the sinusoid and was independent of the bandwidth of the masking noise. Performance was relatively unaffected for rates of modulation between 5 Hz and 160 Hz! The data corroborate Grantham's (1984) proposal that the binaural system may possess two independent averaging mechanisms, one for the processing of ITDs and another for the processing of IIDs. The 160 Hz "rate limitation" found with these stimuli was consistent with a similar limitation found and discussed in the Bernstein and Trahiotis (1992) JASA paper discussed above.

The Bernstein and Trahiotis (1992) JASA manuscript currently under revision reports the latest in a series of experiments concerning spectral interference in a binaural detection task. Here we report data concerning the effects of temporal fringes and the bandwidth of the masker. The two major results are that much more interference is observed with narrow-band than with wide-band maskers and that an asynchronous forward fringe of the interferer of up to 320 ms does not restore performance to that obtained with continuous interferers, which are relatively ineffective. These data mesh well with those recently reported by Woods and Colburn (JASA,1992).

The final paper concerns, principally, our theoretical efforts (Stern and Trahiotis, 1992) and depicts how "straightness" weighting can be accomplished by a stage of neural processing which records coincidences of activity from outputs of primary coincidence counting units with the same characteristic internal delay but with different characteristic frequencies. Beyond specifying how straightness could be manifested, the paper shows how processing already found in the barn-owl and in the rabbit can be quantified in a manner that accounts for psychophysical data obtained from humans.

Our current theoretical efforts concerning IIDs are very exciting because they indicate that IIDs must affect where images are heard by weighting the centroid of the cross-correlation pattern (frequency vs. ITD). That is, IIDs do not appear to influence the processing of ITDs per se, only the result of such processing. This outcome indicates a completely separate and possibly later processor for IIDs. In this light, it is interesting to note the great differences in integration times for ITDs and IIDs discussed above in the context of other experiments. Dr. Richard Stern and Dr. Constantine Trahiotis are now writing a theoretical paper concerning how interaural intensitive differences are independent of, but still influence acoustic images formed on the basis of interaural temporal differences.

C) Publications

Bernstein, L. R. and Trahiotis, C. (1992). "Discrimination of interaural envelope correlation and its relation to binaural unmasking at high frequencies," Journal of the Acoustical Society of America 91, 306-316.

Bernstein, L. R. and Trahiotis, C. (1992). "Detection of antiphasic sinusoids added to the envelopes of high-frequency bands of noise," Hearing Research 62, 157-165.

Bernstein, L. R. and Trahiotis, C. (1992). "Spectral interference in a binaural detection task: Effects of temporal fringe and masking bandwidth," J. Acoust. Soc Am., under revision.

Stern, R. M. and Trahiotis, C. (1992) "The Role of Consistency of Interaural Timing Over Frequency in Binaural Lateralization," in *Auditory, Physiology and Perception*, edited by Y. Cazals, L. Demany, K. Horner (Pergamon Press, New York), pp. 547-554.

D) Interactions

A presentation was made at the Fall, 1992 meeting of the Acoustical Society of America:

Bernstein, L. R. and Trahiotis, C. (1992). "The effect of nonsimultaneous off-frequency cues on the detection of a signal masked by narrow-band noise." J. Acoust. Soc Am., 92, 2363.