REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
6/15/95

3. REPORT TYPE AND DATES COVERED
Final, 11/1/91 - 3/31/95

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

5. FUNDING NUMBERS
AFOSR Grant (G)
F496 20-92-J-0062
61102F
2313/AS

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

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

8. PERFORMING ORGANIZATION REPORT NUMBER
AFOSR-TR-95-0433

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
Approved for public release;
distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

During the last granting period, we continued to make substantial progress consistent with the objectives outlined in our last proposal. Our efforts resulted in 17 published papers and book chapters. In addition to our empirical investigations, we updated the hardware and software necessary to conduct experiments employing complex, digitally-generated stimuli. Our experiments concerned 1) listeners' use of "off-frequency" and "on-frequency" information in the detection of tones in noise; 2) how spectrally remote information can affect the processing of interaural temporal disparities (ITDs) within a "target" spectral region as measured in detection and true lateralization paradigms; 3) listeners' sensitivities to short-lived ITDs presented within longer duration bands of noise; 4) the degree to which listeners can ignore information in one ear while processing information in the other.

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

Final Technical Report

Re: AFOSR F496 20-92-J-0062

Monaural and Binaural Processing of Complex Waveforms

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

Keywords: centrality, CMR, cross-correlation, generation of complex digital stimuli, interference, masking, MLD, off-frequency cuing, straightness

In order to facilitate use of information provided in this document, we have combined categories included in amendment No. 2 to "Administration of U.S. Air Force Grants and cooperative Agreements for Basic Research" brochure and will include essentially two reports: 1) a "short form" that contains extremely concise statements that are elaborated upon in 2) a "long form" that provides more detail regarding each facet of our progress.

SHORT-FORM PROGRESS REPORT

I.) Progress concerning hardware and software

The only major equipment-related "progress" was a series of modifications to install and to incorporate the Tucker-Davis array processor and accompanying D/A converter. The array processor has enabled us to generate very complex stimuli "on-line" and in a manner that saves a great deal of time both in terms of writing the necessary code and in terms of the time required to set up and bring to fruition a given set of experimental conditions.

A second general area of progress was the creation and implementation of a host of software-based waveform-analysis procedures.

II.) Progress concerning our program of research

Progress concerning our program of research can be efficiently described as being composed of three major categories: a) experiments explicitly proposed in the last competitive renewal; b) new experiments stemming from the collection of data in experiments *not* explicitly proposed for support by AFOSR, but clearly relevant to the attainment of the scientific goals described in the last competitive renewal; c) chapter-length reviews and summaries.

a) Experiments explicitly proposed in the last competitive renewal

We performed a series of experiments concerning: 1) advantages to the listener provided by reproducible noise; 2) conditions under which listeners base their decisions on "energy" and 3) how changes in the statistics of the envelope produced by adding tonal signals to bands of noise affect performance. The most important aspect of these experiments was the determination that *off-frequency* 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, but not during, the temporal interval containing the signal. On the other hand, we found that providing *on-frequency*, envelope-based information both before and after the "signal" interval could enhance detection greatly.

A second series of studies concerned spectral interference in a binaural detection task. The data showed the effects of temporal fringes and the bandwidth of the masker. The two major results are that much more interference is observed with narrowband than with wideband 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 (1992) and Stellmack and Dye (1993).

We have completed a comprehensive set of experiments concerning how varying the forward fringe of a masker affects the magnitude of the binaural masking-level difference. Currently, the data are being collated and graphed and preparation of a manuscript reporting the findings will begin shortly.

We are currently measuring listeners' abilities to detect an interaural time delay (ITD) within a 5-ms segment of a 50 ms-long burst of (otherwise diotic) broadband noise. The ITD is presented at one of several times after the onset of the entire burst of noise. The main purpose of our experiment was to measure listeners' abilities to discriminate ITDs when they were restricted to a narrow spectral region of the broadband noise. Our experiment, in essence, combines the study of binaural interference and precedence-like phenomena. Our experiment, in essence, combines the study of binaural interference and precedence-like phenomena. It is important to note that all of the experiments conducted to date are of the "minimal uncertainty" type because both the spectral region containing the ITD as well as the temporal segment during which the ITD occurs are held constant throughout a block of trials. The same listeners will be tested in conditions where the spectral region containing the ITD and/or the temporal segment during which the ITD occurs are varied from trial-to-trial in a manner that produces "uncertainty." Recently, Buell and Trahiotis (1994) demonstrated that the *combination* of uncertainty and binaural interference can produce devastating deficits in the detectability of ITDs at high frequencies.

This experiment contains a large set of conditions that requires many months for the collection of the behavioral data. We have collected sufficient data to state with confidence that ITDs conveyed by a 5-ms segment of a 50-ms-long burst of noise are virtually impossible to detect when those ITDs are conveyed only by the high-frequency portions of the noise. This inability to process ITDs occurs *regardless of the time between the onset of the burst of broadband noise and the onset of the segment containing the ITD*. We were surprised by this outcome and have collected data in a large series of follow-up conditions designed to pinpoint the factor or factors responsible for the incredibly poor resolution of ITDs that we found. To date, we have studied the effects of 1) varying the bandwidth of the spectral region containing the ITD, 2) lengthening the duration of the temporal segment containing the ITD and 3) narrowing the bandwidth of the "flanking" diotic broadband noise.

b) New experiments *not* explicitly proposed to AFOSR, but clearly relevant to the attainment of the scientific goals described in the last competitive renewal.

Two experiments concerning binaural interference have been completed and have resulted in manuscripts submitted to JASA. The first concerns the mechanism by which interference in the detection of ITDs in a SAM tone centered at a high frequency is produced by a second, spectrally-remote SAM tone. A major finding, consistent with our conclusions from earlier studies of the binaural interference effect was that interference is not produced peripherally (monaurally). Instead, it appears that the interference effects occur more "centrally" at or subsequent to the site(s) of binaural interaction.

The second concerns how *extents of laterality* produced by ITDs can be affected under conditions of binaural interference. The major finding was that extents of laterality produced by ITDs conveyed by high-frequency signals were, indeed, diminished by the presence of low-frequency interferers. These are the first measures showing that spectrally-remote information affects the intracranial position of high-frequency targets. We believe that these data also have great import for many practical situations in which listeners are asked to locate target sounds in the presence of competing acoustic inputs.

A third, independent, experiment focused on the discrimination of samples of noise in monotic, diotic and dichotic conditions. The study demonstrates the conditions under which information presented simultaneously to the two ears is combined. A major finding was that combination of information across the ears can occur across disparate frequency regions that *do not* produce "fused" binaural images.

In addition, Trahiotis and Stern (1994) studied the nature of the mechanisms by which the binaural auditory system combines, across frequency, interaural timing information. New observations are presented which indicate that the integration of information across frequency is *not* due to a simple averaging. Instead, the observations are consistent with a mechanism which relies on temporally-coincident activity across frequency channels that monitor the same interaural delays. This outcome strongly reinforces the recent modeling of Stern and Trahiotis.

On a completely different topic, we reported an analysis of the recent electrophysiological findings of Dolphin and Mountain (1993), who measured the scalp-recorded amplitude-modulation frequency-following response in the presence of a pure tone. The analysis documents how the main effect reported by Dolphin and Mountain is an artifactual manifestation of the consequences of the rectification and low-pass filtering (envelope extraction) in the peripheral auditory system. It was shown that Dolphin and Mountain's findings reflect more a change in the stimulus than any subsequent biological effect.

c) Chapter-length reviews and summaries

As detailed in the "Long-form Progress Report," five invited chapters were completed, two of which were prepared for the proceedings of the AFOSR-sponsored meeting on Binaural Spatial Hearing.

LONG-FORM PROGRESS REPORT

I.) Progress concerning hardware and software

Because most of the necessary equipment was in place at the beginning of this granting period, the only major equipment-related "progress" was a series of modifications to install and to incorporate the Tucker-Davis array processor and accompanying D/A converter. The array processor has enabled us to generate very complex stimuli "on-line" and in a manner that saves a great deal of time both in terms of writing the necessary code and in terms of the time required to set up and bring to fruition a given set of experimental conditions.

One noteworthy example is a seemingly straightforward, but deceptively intricate, experiment in which we measure listeners' abilities to detect an interaural time delay (ITD) within a 5-ms segment of a 50-ms burst of (otherwise diotic) broadband noise. The ITD was presented at one of several times after the onset of the entire burst of noise and, simultaneously, was restricted to one of several relatively narrow spectral regions within the broadband noise. The trick was to construct such stimuli in a manner that did not result in the listeners' use of spectrally-related artifactual cues that result from producing linear phase-shifts that are discrete in both the time and frequency domains. With the array processor, we were able to construct stimuli of interest in a manner that such artifacts could not be used as cues. This required the generation and combination of sets of independent bands of Gaussian noise that, without the array processor, would have required a near prohibitive amount of "off-line" computing, storage and cataloging of tokens of the required noises. Happily, the array processor permitted us to write an admittedly complex and large regimen, that, once in place allowed the necessary stimuli to be generated "on-line" between trials of the behavioral task! An added benefit was that this freed our laboratory assistant so that he could conduct other experiments in parallel, collate data, etc. Without belaboring the point, suffice it to say that the array processor has increased our efficiency greatly. In passing, it is worth mentioning that the transition to the array processor was accomplished without *any* "down-time" whatsoever.

A second general area of progress was the creation and implementation of a host of software-based waveform-analysis procedures. These procedures were initially required for extensive analyses of the stimulus conditions used in the series of experiments concerning listeners' abilities to use non-simultaneous on-frequency and off-frequency cues while detecting a tonal signal masked by narrow-band noise (Bernstein and Trahiotis, 1994a). Since then, these procedures have been extended and have formed the basis of other necessary analytical routines. For reasons of brevity, other noteworthy achievements concerning software will be discussed in the context of the experiments themselves.

II.) Progress concerning our program of research

Progress concerning our program of research can be efficiently described as being composed of three major categories: 1) experiments explicitly proposed in the last competitive renewal; 2) new experiments stemming from the collection of data in experiments *not* explicitly proposed for support by AFOSR, but clearly relevant to the attainment of the scientific goals described in the last competitive renewal; 3) chapter-length reviews and summaries.

a) Experiments explicitly proposed in the last competitive renewal

One major effort (Bernstein and Trahiotis, 1994a) was *initially* conceived to measure the amount of "comodulation masking release" (CMR) that could be obtained when the coherent envelope information was presented *successively* rather than *simultaneously*. That is, the experiments were designed to assess whether a release from masking could occur when the coherent envelope information was presented across temporally discrete intervals. As experimentation progressed, it became clear that the releases from masking that we observed were quite *unlike* those observed with standard CMR paradigms. A large number of conditions were designed and run 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 a large investigation concerning: 1) advantages to the listener provided by reproducible noise; 2) conditions under which listeners base their decisions on "energy" and 3) how changes in the statistics of the envelope produced by adding tonal signals to bands of noise affect performance. The most important aspect of these experiments was the determination that *off-frequency* 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, but not during, the temporal interval containing the signal.

On the other hand, we found that providing *on-frequency*, envelope-based information both before and after the "signal" interval could enhance detection greatly. We found 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 *7 dB* when an identical, *on-frequency*, 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.

Notably, when all four intervals contained identical envelope information presented such that the cueing information was centered at 900 Hz, thresholds increased. When the cueing 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.

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, computer routines were generated that permitted us to evaluate simulated performance based on three potentially utilizable envelope statistics: 1) The normalized envelope fourth moment (Hartmann and Pumplin, 1988); 2) the envelope sigma-to-mean ratio (similar to a statistic utilized by Viemeister(1979) and 3) the envelope "mean-slope" (as suggested by Richards (1992)).

Each of these three statistics was computed for several samples of noise and for several signal-to-noise ratios. Richards' envelope mean-slope statistic yielded predicted differences in threshold produced by frozen and truly random samples of noise, respectively that were almost identical to the differences in threshold measured behaviorally The envelope mean-slope statistic can be thought of as reflecting 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 for our signals, we were pleased to see that Green and his colleagues (1992) used a similar analysis to predict spectral shape discrimination in narrowband stimuli We were successful in extending the envelope mean-slope statistic to account for data recently published by Kidd et al (1993). Interestingly, our analysis showed that the envelope mean-slope statistic was quite successful in accounting for their data, a conclusion counter to the one in their paper. Their analysis considered only the properties of the masking waveforms, while ours considered the *differences* in the statistic calculated for each signal-plus-masker and masker combination. The other two envelope statistics failed to yield any consistent difference between the two types of masking conditions and, therefore, could not explain our behavioral data.

The Bernstein and Trahiotis (1993) paper appeared in the August issue of the Journal of the Acoustical Society of America. This paper reports the latest in a series of experiments concerning spectral interference in a binaural detection task. The data concerned the effects of temporal fringes and the bandwidth of the masker. The two major results are that much more interference is observed with narrowband than with wideband 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 (1992) and Stellmack and Dye (1993).

We have completed a comprehensive set of experiments concerning how varying the forward fringe of a masker affects the magnitude of the binaural masking-level difference. The experiments were conducted with: 1) low-frequency signals where the interaural cues are conveyed by the *fine-structure* of the waveform and 2) high-frequency signals where the interaural cues are conveyed via the *envelope* of the waveform. The main parameters of interest were: 1) duration (of the signal and, separately, of the masker) and 2) the bandwidth of the masker. The experiments were conducted using a single-interval procedure and stimuli were presented either homophasically (NoSo) or antiphasically (NoSπ). Currently, the data are being collated and graphed and preparation of a manuscript reporting the findings will begin shortly.

We are currently measuring listeners' abilities to detect an interaural time delay (ITD) within a 5-ms segment of a 50 ms-long burst of (otherwise diotic) broadband noise. The ITD is presented at one of several times after the onset of the entire burst of noise. An important aspect of the experiment is that the ITD is restricted to one of several relatively narrow spectral regions within the broadband noise. The set of experiments was stimulated by Zurek's (1980) observation that the discriminability of ITDs was especially poor when the 5-ms segment of the noise containing the ITD began about 5 to 15 ms or so after the onset of the 50-ms-long burst of noise. This degradation in the ability to process ITD is consistent with the well-known "precedence effect." We have been able to replicate Zurek's general findings.

The main purpose of our experiment was to measure listeners' abilities to discriminate ITDs when they were restricted to a narrow spectral region of the broadband noise. In Zurek's experiment, the ITDs were conveyed by the entire broadband noise. Our experiment, in essence, combines the study of binaural interference and precedence-like phenomena. It is important to note that all of the experiments conducted to date are of the "minimal uncertainty" type because both the spectral region containing the ITD as well as the temporal segment during which the ITD occurs are held constant throughout a block of trials. The same listeners will be tested in conditions where the spectral region containing the ITD and/or the temporal segment during which the ITD occurs are varied from trial-to-trial in a manner that produces "uncertainty." Recently, Buell and Trahiotis (1994) demonstrated that the *combination* of uncertainty and binaural interference can produce devastating deficits in the detectability of ITDs at high frequencies.

This experiment contains a large set of conditions that requires many months for the collection of the behavioral data. We have collected sufficient data to state with confidence that ITDs conveyed by a 5-ms segment of a 50-ms-long burst of noise are virtually impossible to detect when those ITDs are conveyed only by the high-frequency portions of the noise. This inability to process ITDs occurs *regardless of the time between the onset of the burst of broadband noise and the onset of the segment containing the ITD.* We were surprised by this outcome and have collected data in a large series of follow-up conditions designed to pinpoint the factor or factors responsible for the incredibly poor resolution of ITDs that we found. To date, we have studied the effects of 1) varying the bandwidth of the spectral region containing the ITD, 2) lengthening the duration of the temporal segment containing the ITD and 3) narrowing the bandwidth of the "flanking" diotic broadband noise.

b) New experiments *not* explicitly proposed to AFOSR, but clearly relevant to the attainment of the scientific goals described in the last competitive renewal

Two experiments concerning binaural interference have been completed and have resulted in manuscripts submitted to JASA. The first, Heller and Trahiotis (1995a), concerns the mechanism by which interference in the detection of ITDs in a SAM tone centered at a high frequency is produced by a second, spectrally-remote SAM tone. A major finding, consistent with our conclusions from earlier studies of the binaural interference effect (e.g., Trahiotis and Bernstein, 1990) was that interference is not produced peripherally (monaurally). Instead, it appears that the interference effects occur more "centrally" at or subsequent to the site(s) of binaural interaction. The data clearly indicate that more interference is produced by low-frequency interferers, spectrally within the so-called dominance region (Bilsen and Raatgever, 1973), than by high-frequency interferers which are spectrally more proximal to the target region containing the ITD. An analysis of the data indicated that the greater interference effects that occur with low-frequency interferers could not be accounted for by combining information across frequency channels in a manner proposed by Buell and Hafter (1991).

The second Heller and Trahiotis paper concerning binaural interference (1995b) was submitted to JASA, and has been revised. The main thrust of this effort was to measure *extents of laterality* produced by ITDs under conditions of binaural interference. Measures of extent of laterality were obtained from the same listeners who participated in experiments focusing on the *discriminability* of ITDs under conditions of binaural interference. The major finding of the study was that extents of laterality produced by ITDs conveyed by high-frequency signals were, indeed, diminished by the presence of low-frequency interferers. These are the first measures showing that spectrally-remote information affects the intracranial position of high-frequency targets. We believe that these data also have great import for many practical situations in which listeners are asked to locate target sounds in the presence of competing acoustic inputs.

The third Heller and Trahiotis paper (1995c) focused on the discrimination of samples of noise in monotic, diotic and dichotic conditions. This paper was submitted to JASA and is scheduled for the June, 1995 issue. The study demonstrates the conditions under which information presented simultaneously to the two ears is combined. A major finding was that combination of information across the ears can occur across disparate frequency regions that *do not* produce "fused" binaural images. We found that, in some conditions, performance was severely degraded because the listeners could not behave "optimally" by ignoring the information at one ear. This finding is particularly relevant to the design and evaluation of binaural hearing aids and binaural cochlear implants because the data clearly indicate that a second channel of information can actually be detrimental. The detriment is different from and should not be confused with central masking effects.

The paper by Trahiotis and Stern (1994) concerns the nature of the mechanisms by which the binaural auditory system combines, across frequency, interaural timing information. New observations are presented which indicate that the integration of information across frequency is *not* due to a simple averaging. Instead, the observations are consistent with a mechanism which relies on temporally-coincident activity across frequency channels that monitor the same interaural delays. This outcome strongly reinforces the recent modeling of Stern and Trahiotis (1992) in a chapter written for the proceedings of a conference in Europe. The new model postulates a "second layer" of coincidence in order to account for changes in lateralization produced by varying the bandwidth of the stimuli *while holding ITD constant*. The model specifies the manner in which listeners combine information across frequency channels. Interestingly, physiological evidence confirming such a mechanism has been presented by Takahashi and Konishi (1986). It is important to note that the lateralization phenomena are *not* predictable from the model put forth by Shackleton, Meddis, and Hewitt (1992), who suggested a simple averaging mechanism.

On a completely different topic, Bernstein (1994a) contains an explanatory analysis of the recent electrophysiological findings of Dolphin and Mountain (1993), who measured the scalp-recorded amplitude-modulation frequency-following response in the presence of a pure tone. The analysis documents how the main effect reported by Dolphin and Mountain is an artifactual manifestation of the consequences of the rectification and low-pass filtering (envelope extraction) in the peripheral auditory system. The article is tutorial and demonstrates how the addition of a pure tone to a SAM signal necessarily reduces the magnitude of the component in the spectrum of the envelope that corresponds to the sinusoidal modulating frequency. It was shown that Dolphin and Mountain's findings reflect more a change in the stimulus than any subsequent biological effect.

c) Chapter-length reviews and summaries

Two chapters were written for the book to be published that reports the proceedings of the AFOSR sponsored meeting on Binaural and Spatial Hearing. The purpose of one of the chapters (Bernstein, 1994b) was to integrate the findings from two seemingly separate topics: 1) "binaural sluggishness" and 2) sensitivity to interaural disparities within the envelopes of high-frequency, complex waveforms. It was argued that the mechanisms responsible for the "time-constants" measured in studies concerning sensitivity to dynamically-changing interaural cues also manifest themselves in studies concerning sensitivity to interaural disparities within the envelopes of high-frequency, complex waveforms.

The second chapter (Buell and Trahiotis, 1994) concerns how interaural disparities within and across spectral regions are combined in discrimination and lateralization tasks. The most interesting findings are the interactive effects that occur with certain combinations of the cues. An example of an interactive effect was the finding that a small IID, say 3 dB, could, depending upon the combination of ITD and bandwidth, cause the intracranial image to "move" almost completely across the head! Another very important finding was the observation that ITDs conveyed solely by the onsets of binaural stimuli are, principally, relatively impotent as compared to ongoing ITDs in experiments concerning the lateralization of acoustic images. However, the chapter also highlights data indicating that onset ITDs can, indeed, play an important role in resolving or "disambiguating" binaural images. This is another example of an interactive effect.

A third chapter (Bernstein and Trahiotis, 1994c), based on an invited talk presented at an international meeting in Germany, will be published as part of *Advances in Hearing Research, Proceedings of the 10th International Symposium on Hearing*. It describes recent findings from our laboratory concerning binaural spectral interference in detection and discrimination paradigms. The chapter is an integration of many of the findings concerning binaural interference in publications discussed above.

Finally, two chapters concerning modeling of binaural processing (Stern and Trahiotis, 1992; Stern and Trahiotis, 1993) were completed. The first describes a presentation at an international meeting concerning a postulated mechanism to account for the interactive effects of bandwidth, interaural phase and interaural time on the laterality of intracranial images. It was in this chapter that the "second-layer" coincidence mechanism was described and shown to be successful in predicting a host of behavioral data without changing the original parameters of a comprehensive cross-correlation-based model. Interestingly, the second layer of coincidence "sharpens" the patterns of cross-correlation *without* resorting to inhibitory interactions in a manner suggested by Lindemann (1986). This chapter served as motivation for the Trahiotis and Stern (1994) report in JASA described above wherein the second layer of coincidence was shown to be consistent with listeners' percepts of the intracranial positions of stimuli designed to differentiate between a second layer of coincidence and a simple averaging of information across frequency (as postulated by others). The second chapter concerning models of binaural hearing is a critical and integrative overview that is also tutorial in nature. It was written for a new volume of a handbook of perception and cognition that, judging from the status of the other authors asked to contribute, should become a staple of graduate education for the many disciplines that compose the area of audition.

III. General statement concerning progress to date

Overall, we feel gratified with our progress and continue to believe that our efforts reflect a pragmatic mix of accomplishment of proposed research and the pursuit of new and interesting phenomena. All of the accomplished and proposed research is part and parcel of our efforts to understand the temporal and spectral aspects of auditory processing that occur between and among discrete spectral regions.

IV. 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.

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.

Bernstein, L. R. and Trahiotis, C. (1993). "Spectral interference in a binaural detection task: Effects of temporal fringe and masking bandwidth," J. Acoust. Soc. Am., **94**, 735-742

Stern, R.M., Jr. and Trahiotis, C. (1993). "Models of binaural interaction," to appear in Handbook of Perception and Cognition, Volume 6: Hearing, edited by B.C.J. Moore (Academic Press, New York).

Bernstein, L. R. and Trahiotis, C. (1994a). "The effects of non-simultaneous on-frequency and off-frequency cues on the detection of a tonal signal masked by narrow-band noise," J. Acoust. Soc. Am., **95**, 920-930.

Bernstein, L. R. and Trahiotis, C. (1994b). "Detection of interaural delay in high-frequency SAM tones, two-tone complexes, and bands of noise,"J. Acoust. Soc Am., **95**, 1482-1489.

Bernstein, L. R. and Trahiotis, C. (1994c). Binaural spectral interference in detection and discrimination paradigms," to appear in *Advances in Hearing Research: Proceedings of the 10th International Symposium on Hearing,* World Scientific Publishers.

Bernstein, L. R. (1994a). "Comments on 'The envelope following response (EFR) in the Mongolian gerbil to sinusoidally amplitude-modulated signals in the presence of simultaneously gated pure tones,' [W. F. Dolphin and D.C. Mountain, J. Acoust. Soc. Am. **94**, 3215-3226 (1993)]," J. Acoust. Soc Am., **96**, 1189-1190.

Bernstein, L. R. (1994b). "Detection and discrimination of interaural disparities: Modern earphone-based studies," to appear in *Binaural and Spatial Hearing,* edited by R. H. Gilkey and T. Anderson, Erlbaum, New Jersey.

Bernstein, L. R. and Trahiotis, C. (1994). "Binaural spectral interference in detection and discrimination paradigms," to appear in report of *10th International Symposium on Hearing,* World Scientific Publishers.

Bernstein, L. R. and Trahiotis, C. (1994). Binaural interference effects measured with masking-level difference and with ITD- and IID-discrimination paradigms, J. Acoust. Soc Am., under review.

Buell, T. N. and Trahiotis, C. (1994). "Recent experiments concerning the relative potency and interaction of interaural disparities," to appear in *Binaural and Spatial Hearing,* edited by R. H. Gilkey and T. Anderson, Erlbaum, New Jersey.

Heller, L. M. and Trahiotis, C. (1995a). "Interference in detection of interaural delay in a SAM tone produced by a second, spectrally remote SAM tone," J. Acoust. Soc. Am, **97**, 1808-1816.

Heller, L. M. and Trahiotis, C. (1995b). "Extents of laterality and binaural interference effects," J. Acoust. Soc. Am, under review.

Heller, L. M. and Trahiotis, C. (1995c). "The discrimination of samples of noise in monotic, diotic, and dichotic conditions," J. Acoust. Soc. Am, schedules for June, 1995 issue.

Trahiotis, C. and Stern, R. M. (1994). Across-frequency interaction in lateralization of complex binaural stimuli." J. Acoust. Soc. Am, **96**, 3804-3806.

Presentations at scientific meetings

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.

Bernstein, L. R. (1993). "Lateralization and the detection/discrimination of interaural disparities: Modern earphone-based studies."

Buell, T.N. and Trahiotis, C. (1993). "Combination of interaural cues: How interaural disparities interact within and across spectral regions."