Auditory Perception and Cognition

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1. Peripheral interactions in auditory temporal processing

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National Institutes of Health, National Institute on Deafness and other Communication Disorders (NIDCD) – R01 DC 03909

Project Staff
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A. Estimating cochlear status via phase effects in masking
The threshold of a sinusoidal signal embedded in a complex-tone masker can depend dramatically on the phase relationships of the masker components. In an earlier study we showed that peripheral compression in a model was necessary to produce the large effects of masker phase found empirically [Oxenham, 2001 #5010]. We have now followed this up by measuring masker-phase effects in hearing-impaired listeners. To test the hypothesis that the size of the masker-phase effects were related to the amount of cochlear compression, we also measured auditory filters shapes in the same subjects. Auditory filter bandwidths have been shown to be highly correlated with other behavioral measures of cochlear compression. Our results showed a strong correlation between auditory filter bandwidth and maximum masker phase effect, in line with predictions based on the effects of cochlear compression.

B. On- and off-frequency forward masking in normal and impaired hearing
In recent years, some studies have shown that temporal processing can be greatly affected by certain types of hearing disorders. The most dramatic example is perhaps that of auditory neuropathy, where patients who have ostensibly normal cochlear function show dramatic deficits in tasks such as amplitude modulation detection. One hypothesis of the current project is that the temporal deficits shown by the majority of hearing-impaired listeners can be accounted for by cochlear nonlinearity. This is clearly not the case for auditory neuropathy patients, and suggests that there may be other subsets of patients whose temporal processing deficits may not be purely due to cochlear pathology. A recent method of estimating cochlear nonlinearity uses the difference in decay of forward masking for on- and off-frequency maskers with a fixed low-level signal. The assumption is that on-frequency masking reflects both cochlear compression and the decay of forward masking, whereas the off-frequency masking reflects only the forward masking. This is because the response to the off-frequency masker is thought to be linear. In other words, using an off-frequency forward masker and a fixed signal level can essentially bypass the effects of cochlear compression, thereby revealing the “true” decay of forward masking. We are measuring on- and off-frequency forward masking with the aim of distinguishing the temporal deficits due to cochlear compression and those due to other (presumably retrocochlear) causes.

C. Using a nonlinear model of effective cochlear processing to predict psychophysical performance
Work has continued in collaboration with Dr. Chris Plack (University of Essex, U.K.) in refining a model of auditory processing, which involves nonlinear filtering and subsequent linear processing.

Using a recent nonlinear peripheral model we were able to successfully simulate a number of psychoacoustic results in normal-hearing listeners, including the growth of on- and off-frequency forward masking, and the differences between psychophysical tuning curves in forward and simultaneous masking.

D. Significance

The fact that masker phase effects can provide an indirect estimate of cochlear compression has potentially important implications. As only two data points are required in principle to measure the maximum masker phase effect, it may provide a very efficient method for estimating cochlear compression, to the extent that it could feasibly be a clinical tool. The second study, using on- and off-frequency forward masking may enable us to separate, for the first time, effects of cochlear nonlinearity from other mechanisms underlying temporal processing deficits in hearing impairment. While there have been reports of correlations between speech reception and, for instance, auditory gap detection, there has been no attempt so far to define the underlying mechanisms. The modeling work should result in a general model of psychoacoustic performance, based in part on known physiological processes. The ability to change the amount of nonlinearity in the model will allow researchers to explore the predicted implications of a loss of cochlear nonlinearity and to test the predictions against empirical data.

2. Complex pitch perception in complex environments

Sponsors

National Institutes of Health, National Institute on Deafness and other Communication Disorders (NIDCD) – R01 DC 05216

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A. Harmonic resolvability and pitch perception

We have studied how fundamental frequency difference limens (F0DLs) for complex tones are affected by spectral region and harmonic resolvability. We were able to dissociate harmonic number from harmonic resolution by presenting alternate components to opposite ears. First, we confirmed that the ability to hear out individual harmonics is limited peripherally and not after the binaural information has been combined. This was confirmed through listeners' ability to hear out twice as many components when alternate harmonics were presented to opposite ears as when all components were presented to both ears. That first experiment also showed that, if presented in a manner designed to draw attention to the target component, listeners could hear out the first 10 harmonics of complexes with 100- and 200-Hz fundamental frequencies. This number is higher than has been found in previous studies, but resolves an apparent discrepancy between "direct" and "indirect" measures of harmonic resolution. The next part of the study showed that the point at which there is a transition from good to poor F0DLs depends on the lowest harmonic number present, and not on peripheral harmonic resolution. In other words, even though presenting the harmonics to opposite ears enabled listeners to hear out more harmonics, they were not able to utilize this information to process F0 information.

B. Effects of simulated cochlear-implant processing on speech in complex backgrounds

By dividing the spectrum into contiguous frequency bands, and replacing the temporal fine structure with noise, it has been shown that speech can be understood in quiet with severely reduced spectral information and no temporal fine-structure information. The hypothesis of this study was that good frequency selectivity and fine-structure information are required to segregate the target speech from competing backgrounds. This was tested by measuring speech reception thresholds for sentences in the presence of steady-state speech-shaped noise, modulated speech-shaped noise, and single male or female interfering talkers. The results were very clear: whereas maskers with temporal and spectral modulations improved performance relative to steady-state noise in the unprocessed condition, they either produced no improvement or in many cases led to *poorer* performance than steady-state noise in the processed conditions. This was true even with 24 frequency bands, where the spectral resolution approached that of normal hearing. The results may be interpreted as follows: if speech is perceived primarily via temporal envelope fluctuations, then the auditory system must have a way of distinguishing the fluctuations of the target speech from the fluctuations of other competing sources. Eliminating the fine structure and reducing spectral information severely reduces these cues.

C. Pitch of transposed stimuli

One of the earliest (and still unresolved) questions in auditory research is whether place or timing cues are used by the auditory system to determine the frequency of a sinusoid. Most researchers believe that timing cues are important, at least at low frequencies, and many time-interval-based models of pitch are essentially "place blind," in that the timing information is pooled across all frequency channels before a pitch calculation is made. Transposed stimuli (van de Par and Kohlrausch, 1997; J. Acoust. Soc. Am. 101:1671-1680) represent an attempt to transpose low-frequency fine-structure information into the envelope of a high-frequency carrier. In principle the technique allows one to dissociate place and time information by presenting low-frequency time information at a high-frequency place. The technique has been used with binaural stimuli to show that the auditory system can use low-frequency timing information at high carrier frequencies in a way similar to that used with unaltered low-frequency stimuli. Our results show that this is not the case for frequency discrimination and pitch perception. Instead, performance with transposed stimuli is much worse than for the comparable low-frequency stimuli. The success of transposed stimuli in transmitting binaural information, together with their failure in transmitting frequency information, suggests a role for place coding of frequency.

D. Significance

The results from the first study have important implications for models of pitch perception. They show that the auditory system cannot efficiently use spectral information from harmonics higher than the 10^{th}, even when they are peripherally resolved. One interpretation of this is in terms of "harmonic template" models of pitch perception. The reasoning would be that if harmonics higher than the 10^{th} are not normally resolved then neural templates involving those harmonics would not develop. The second study has implications for both our understanding of normal hearing and for cochlear-implant processing. It shows that temporal fine-structure information (or lower, resolved harmonics), while not necessary for speech reception in quiet, may be vital for source segregation in complex acoustic environments. The same is true for good frequency selectivity. This provides insight into how cues such as F0 differences are used in everyday environments. The data also provide strong support for efforts towards introducing temporal fine-structure information into cochlear implants, and towards providing a greater number of independent frequency channels to implant patients. The third study is of a fundamental nature and addresses the age-old question of whether place or timing information is most important in conveying frequency information. It may also have implications for cochlear-implant processing, as it suggests that timing information alone may not be sufficient to accurately code frequency.

Publications

Journal Articles, Published

C.A. Shera, J.J. Guinan, and A.J. Oxenham, "Revised estimates of human cochlear tuning from otoacoustic and behavioral measurements," *Proc. Nat. Acad. Sci.* 99: 3318-23 (2002).

Z.M. Smith, B. Delgutte, and A.J. Oxenham, "Chimaeric sounds reveal dichotomies in auditory perception," *Nature* 416: 87-90 (2002).

C.J. Plack, A.J. Oxenham, and V. Drga, "Linear and nonlinear processes in temporal masking," *Acustica/Acta-Acustica* 88: 348-58 (2002).

Journal Articles, Accepted for Publication
A.J. Oxenham and C.A. Shera, "Estimates of human cochlear tuning at low levels using forward and simultaneous masking," *J. Assoc. Res. Otolaryngol.*, forthcoming.

Journal Articles, Submitted for Publication
J.G. Bernstein and A.J. Oxenham, "Pitch discrimination of diotic and dichotic complexes: Harmonic number or harmonic resolvability?" submitted to *J. Acoust. Soc. Am.*

C. Micheyl and A.J. Oxenham, "Pitch discrimination learning with resolved and unresolved harmonics: Further evidence for two pitch mechanisms," submitted to *J. Acoust. Soc. Am.*

A.J. Oxenham and S.P. Bacon, "Cochlear compression: Perceptual measures and implications for normal and impaired hearing," submitted to *Ear and Hearing*.

A.J. Oxenham, B. Fligor, C.R. Mason, and G. Kidd, Jr., "Informational masking and musical training," submitted to *J. Acoust. Soc. Am.*

M.K. Qin and A.J. Oxenham, "Effects of simulated cochlear-implant processing on speech reception in fluctuating maskers," submitted to *J. Acoust. Soc. Am.*

Book/Chapters in Books
A.J. Oxenham and S.P. Bacon, "Psychophysical manifestations of cochlear compression: Normal-hearing listeners," in *Auditory Compression*, eds. S.P. Bacon, A.N. Popper, and R. Fay (Springer Verlag, New York).

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