Auditory Perception and Cognition

RLE Groups
Auditory Perception and Cognition Group, Sensory Communication Group

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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

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A. Auditory filter shapes at low frequencies
We recently established two important findings on frequency tuning in the human inner ear. First, tuning was sharper than previously thought, and sharpened considerably with increasing frequency from 1000 to 8000 Hz; second, human tuning was sharper by a factor of two than that found in other mammals that are often used as models of human hearing (Shera, Guinan & Oxenham, 2002; PNAS 99:3318-23). The technique used that in that study was suitable only for frequencies at and above 1000 Hz. Important speech information is carried at lower frequencies, particularly when the speech is mixed with interfering sources. We have therefore developed a behavioral technique that allows us to estimate human filter shapes at lower frequencies. We find that the divergence between our new measures and the earlier estimates of filter tuning are less at low than at high frequencies and we are now in the position to provide a complete estimate of low-level human cochlear filter tuning from 250 Hz to 8000 Hz.

B. Changes in cochlear tuning with level
It has been known since the early days of hearing research that the auditory system has many nonlinearities. One of the most well-known is the deterioration of cochlear tuning at high levels. It remains unknown how much of the deterioration in tuning is because of a broadening of the response area of individual primary auditory neurons (or places along the basilar membrane), and how much is because of nonlinear suppression effects that can strongly affect behavioral tuning estimates when the masker and probe are presented at the same time. We have addressed this issue by using non-simultaneous masking to measure cochlear tuning as a function of the probe frequency. We find that tuning is strongly level dependent at higher signal frequency of 4000 Hz and above, but essentially independent of level for low and medium stimulation levels at 1000 Hz. The results, along with those of Sect. 1A, provide important new data and constraints for computational models of human cochlear filtering, which will be important in a variety of applications, including audio compression and automatic speech recognition systems.

C. Refining measures of cochlear compression in normal and impaired hearing: Additivity and sub-threshold masking effects

Earlier work from our group demonstrated that it is possible to derive a behavioral measure of the input-output function of the cochlea's basilar membrane. This has potential as a clinical tool, because reduced compression in the input-output function is a common feature of hearing loss, and one which may require different medical intervention than a loss related more to sensorineural transduction abnormalities. The disadvantage of our current techniques is that they are too time-consuming to be practical in a clinical setting. We have been working on new techniques that provide similar outcomes in much short time spans. This work has involved devising new methods and validating them against more established, but more time-consuming, methods. We have concentrated on tasks involving the additivity of two independent maskers. As a by-product of this research, we have discovered that a masker, which itself is inaudible, can have significant masking effects that are well-predicted by a theory of linear summation of neural events.

2. Complex pitch perception in complex environments

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Project Staff

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A. Exploring the relationship between complex pitch perception and frequency selectivity in normal and impaired hearing

In pitch perception there is a strong dichotomy between the pitch strength (or salience) produced by low-order harmonics, which are thought to be peripherally *resolved*, and high-order harmonics (with harmonic numbers greater than 10), which are considered to be *unresolved*. The question we address here is how tight the relationship is between pitch salience (assessed indirectly using fundamental frequency difference limens – F0DLs) and the peripheral resolvability of the harmonics. In normal-hearing listeners, F0DLs were measured as a function of F0 for bandpass-filtered harmonic tone complexes, embedded in a background noise that was designed to maintain each component at a fixed sensation level, and to rule out the perception of distortion products. At low and medium sound levels, as found in previous studies, there was a dramatic deterioration in performance as F0 decreased to a point where only harmonics above the 10^{th} were present in the passband. However, at high sound levels, the deterioration occurred at a higher F0 (or lower harmonic number). To see whether this change with level related to changes in peripheral frequency selectivity, we measured auditory filter shapes in the same subjects, using the notched-noise method, also as a function of level. We then used the derived filter shapes to predict performance in the F0DL task in the same subjects. Model predictions provided a good description of the data, provided certain assumptions were made about the nature of the F0 detection processes. We have recently collected similar data from hearing-impaired listeners who have broader auditory filters. The results are in good agreement with the prediction is that broader auditory filters will lead to a lowering in the harmonic number at which F0DL performance begins to deteriorate for a given bandpass region.

B. Reintroducing low-frequency fine structure in simulations of cochlear-implant processing

We have recently shown that cochlear-implant processing results in greatly impaired pitch processing, including the inability to use pitch differences in perceptually segregating competing sources. The question was whether reintroducing some low-frequency fine-structure information might enable subjects to make use of F0 differences to help with segregation. This question is not only of theoretical interest, but has practical implications: many recent cochlear implantees have some residual (usually low-frequency) hearing in the non-operated ear. Also, there has been some interest in short-insertion cochlear implants, where residual hearing in the apical part of the implanted cochlea can be preserved. Results from our study suggest that even a small amount of residual hearing (> 300 Hz) can improve performance, both for sentence recognition and for concurrent-vowel identification. This provides encouragement for strategies that involve combining a cochlear implant with a hearing aid, in order to improve speech reception in noisy backgrounds.

C. Detection and discrimination of harmonic tone complexes in the presence of other competing tone complexes
Decades of research have gone into understanding how the pitch of a single complex tone is processed by the auditory system. In contrast, studies of pitch perception involving more than one complex tone are very rare. This is an important omission, in that it is relatively rare that sounds we encounter in our everyday environment are presented in total isolation. This study marks a first step in systematically studying the conditions in which the pitch of one complex is perceived in the presence of another. One important observation is that many models of pitch perception rely on spectrally resolved harmonics. While such harmonics may be resolved when presented in isolation, considerably fewer harmonics will be resolved when more than one complex tone is presented at a time. Our experiments involve three stages: first, the F0DLs for a complex in isolation is measured; second, the detection threshold of one complex in the presence of another is measured; third the signal-to-interferer threshold is measured for achieving F0 discrimination at level 2 or 4 times higher than that found for a complex in quiet. By using equal-amplitude harmonic complexes in random and sine phase within a fixed spectral bandwidth, we can carefully control for the peripheral resolvability of individual components. Our results provide strong tests for models of pitch, in that spectrally-based models would predict a breakdown in performance once no resolved harmonics are present, whereas temporal models are generally less reliant on spectral resolvability.

D. Functional anatomy of pitch perception and auditory stream segregation
Recent work has shown areas of anterior lateral Heschl's gyrus are sensitive to stimulus regularity, in that more periodic sounds elicit greater activity, as measured using techniques such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). Similar changes can also be observed in the brainstem. The question we posed, in collaboration with Dr. Jennifer Melcher of Mass. Eye and Ear Infirmary (MEEI), was whether this increase in activity reflected increased *physical* stimulus regularity or whether it more closely followed changes in *perceived* pitch salience. We addressed this question by measuring the blood oxygenation level difference (BOLD) responses to harmonic tone complexes that contained either resolved or unresolved harmonics. The reasoning was that all the stimulus were equally regular in their temporal structure, but that the unresolved harmonic complexes had a much weaker pitch salience. Other conditions controlled for the effect of spectral region and F0, independent of resolvability. The fMRI results showed a marked reduction in activation in antero-lateral Heschl's gyrus for the condition containing only unresolved harmonics. However, a similar reduction was not observed in the brainstem. This suggests that the auditory cortical activity reflects pitch salience rather than stimulus regularity per se, and further suggests a hierarchy of processing, whereby the brainstem responses may reflect more the physical stimulus attributes rather than the percept.

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