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3aPP25. Can cochlear mechanics contribute to amplitude modulation perception?
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Amplitude modulation (AM) detection has been successfully used as a psychophysical measure of auditory temporal processing. Our understanding of the role of the auditory periphery in processing AM signals is emerging through physiological and psychophysical studies. Unfortunately, direct physiological estimates of the cochlea's mechanical response to AM signals are not obtainable in humans. This study tries to fill this critical gap in knowledge by exploring the relationship between perception (through psychophysical AM detection) and mechanics (through otoacoustic emissions). Psychometric function for AM perception was measured for a 2-kHz carrier frequency and 10-Hz modulation frequency (fm). Distortion product otoacoustic emissions (DPOAEs) were recorded with amplitude-modulated f1 with fm = 10 Hz and steady-state f2. The frequencies of f1 and f2 were chosen to yield a 2f1-f2 DPOAE around 2 kHz near a peak in the fine structure. The ratio between the DPOAE pressure at 2f1-f2 and that of the sidebands separated by fm (AMOAE depth) was calculated as a function of different modulation depths. Results indicate that there might be a correlation between AM perception performance and AMOAE magnitude, suggesting that cochlear mechanics might play a role for AM perception [supported by the Knowles Hearing Center and Northwestern University]

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INTRODUCTION

Many individuals with cochlear hearing loss experience excessive difficulty perceiving speech in background noise or competing speech. The cause of this difficulty has not been clearly identified. Speech is a complex acoustic signal, which varies in amplitude over time and frequency. There is convincing evidence that speech understanding in individuals is closely related to their ability to detect slow changes in temporal patterns (i.e., envelope) within speech (Hochmair-Desoyer et al., 1980, 1985; Houtgast and Steeneken, 1985; Van Tasell et al., 1987; Rosen, 1992; Shannon et al., 1995). The ability to detect amplitude modulation (AM) is one measure of auditory envelope processing. The impact of hearing loss on envelope information in speech is not conclusive. Moreover, any alterations in the modulation spectrum pattern caused by amplification (i.e., hearing aids) seem to degrade discrimination of consonants with similar modulation spectra (Souza and Gallun, 2010).

When healthy, the auditory system is compressively nonlinear partially due to the cochlea’s mechanical response (Ruggero, 1992). Degradation of this amplification-dependent process in hearing-impaired (HI) individuals leads to a linearization of the cochlear response resulting in an exaggerated loudness percept for a given input as compared to normal-hearing (NH) individuals. This linearization of cochlear response in HI individuals may lead to enhancement in the perception of amplitude fluctuations measured as greater sensitivity to AM (Brown and Lee, 2009; Lee and Yook, 2009; Moore et al., 1996). Further, our preliminary data suggest that the exaggerated AM in the masker seems to produce more interference of AM detection of the target. Our understanding of the role of the auditory periphery in processing AM signals is emerging. For example, auditory nerve synchrony to AM signals and single formant stimuli were stronger for chinchillas with noise-induced hearing loss as compared to those with NH (Kale and Heinz, 2010). This greater auditory nerve synchrony appears to depend on mechanical events in the cochlea (Rhode and Recio, 2001; Khanna, 2002; Cooper, 2006). Unfortunately, direct estimates of the cochlea’s mechanical response to AM signals are not obtainable in humans. However, otoacoustic emissions (OAEs), sounds generated in the inner ear by the cochlear amplifier, provide a non-invasive tool to examine the mechanical response to AM signals in humans (Goodman et al., 2004; Neely et al., 2005; Bian and Chen, 2011). A significant advance in our knowledge about the physiological processing of AM signals can be achieved by establishing the connection between mechanical events in the cochlea and their final perception. However, the relationship between perception (through psychophysical AM detection) and mechanics (through OAEs) has not been explored. The work proposed here is aimed to fill this critical gap in knowledge and to provide evidence of contribution of cochlear nonlinearity to deficit in temporal envelope processing for hearing impaired.

METHODS

Listeners

Nine listeners between the ages 20 and 35 participated in the present study. All listeners demonstrated normal hearing (absolute thresholds no worse than 25 dB HL between 250 and 8000 Hz) and no history of middle ear pathology. Listeners were recruited by advertisement via campus-wide flyers and recruiting letters and were compensated for participating in the experiment. Consent was obtained and all procedures were executed in compliance with the Northwestern University Institutional Review Board guidelines.

Procedures

Distortion Products Otoacoustic Emissions (DPOAEs)

First, two primary tones, \( f_1 \) and \( f_2 \) (\( f_2 > f_1 \)), were swept to record DPOAEs at \( f_2 \) frequencies between 800 and 6500 Hz. Six sets of DPOAE recordings were obtained with \( f_2/f_1 \approx 1.22 \) and level combinations (\( L_1/L_2 \)) of 65/55 dB SPL. The test frequency near DPOAE (2\( f_1-f_2 \)) level maxima near 2 kHz was chosen for further evaluation. DPOAE recordings were obtained at the test frequency using an amplitude-modulated \( f_1 \) and steady state \( f_2 \). The modulation rate was 10 Hz and modulation depths (\( m \), where \( 0 \leq m \leq 1 \)) were 0.05, 0.1, 0.25, 0.5, or 1. In addition to these five modulation depths, modulation depths corresponding to 70% correct response in behavioral AM detection task was also used. The modulation depth was manipulated by changing the relative levels of the two sidebands (e.g., for 100% modulation depth \( [m=1] \), the levels of sidebands were attenuated by 6 dB).
Estimates of level and phase of the total ear canal pressure at the DPOAE probe frequency were obtained using a least-squares-fit algorithm (Long, Talmadge, & Lee, 2008). The median values for DPOAE level and the noise floor were computed over every three successive data points. Data points where the signal-to-noise ratio (SNR) between OAE-level and noise-floor median values is found to be less than 6 dB were eliminated from further analyses. The modulation depth of DPOAE (2f1-f2) was defined as the relative level of the ear canal pressures between the carrier frequency (2f1-f2) and the sidebands. To examine how the modulation depth (m) of 2f1-f2 is encoded in the cochlea, the magnitudes of 2f1-f2 and its two sidebands (upper sideband and lower sideband) were used (Bian and Chen, 2011) as follows:

$$m_{2f1-f2} = \frac{M_{USB} + M_{LSB}}{M_{2f1-f2}}$$  \hspace{1cm} (1)

where $m_{2f1-f2}$ is the modulation depth of 2f1-f2, and $M_{USB}$, $M_{LSB}$, and $M_{2f1-f2}$ are the magnitude of upper sideband, lower sideband, and 2f1-f2 respectively. The growth rate of the modulation depth of 2f1-f2 (from equation 1) as a function of modulation depth of f1 will be computed.

Amplitude Modulation (AM) Detection

Sinusoidally amplitude-modulated (SAM) stimuli with carrier frequencies at 2 kHz and with a modulation rate (MR) of 10 Hz were used to measure AM detection thresholds. The level of signals was 65 dB SPL. The phase of the modulator will be varied randomly. The duration of all stimuli was 500 ms (with cosine-squared 20 ms rise/fall ramps) and all stimuli were presented monaurally. Psychometric functions for AM detection were constructed based on subject response using 2AFC paradigm with two-down one-up procedure (for details, see Dai, 1995). Unmodulated and modulated sounds were presented with a 500 ms inter-stimulus duration in random order and listeners were asked to choose the interval with the modulated sound. Practice runs were provided prior to real measurement, and feedback was given immediately after subjects’ response.

Each psychometric function will be fitted with a cumulative Gaussian probability function as follows (for details, see Dai, 1995):

$$d' = \left( \frac{X}{\alpha} \right)^\beta$$  \hspace{1cm} (2)

where $\alpha$ is the signal strength at threshold, $X$ is defined as $\Delta m$, and $\beta$ is the slope for the psychometric function. The parameters $\alpha$ and $\beta$ will be estimated by using the Simplex procedure ($fminsearch$ function in MATLAB). Using these obtained parameters, percent correct response at a given modulation depth and modulation depth at a given percent correct response will be calculated from equation (2).

RESULTS AND DISCUSSION

FIGURE 1 is an example of a spectrum of DPOAEs recorded with amplitude-modulated f1 (MR = 10 Hz and m = 1) and steady-state f2. Multiple sidebands around DPOAE (2f1-f2) were observed and the sidebands are separated...
from \(2f_1-f_2\) by MR (10Hz), in agreement with Bian and Chen (2011). The modulation depth of \(2f_1-f_2\) (AMOAE depth) was defined as the relative amplitude of the \(2f_1-f_2\) and the sidebands [see equation (1) in METHODS section], and this estimate of AMOAE depth was used as an indicator of how the AM sounds were encoded in the cochlea.

FIGURE 2(a) shows all psychometric functions from 9 NH listeners. Two different groups with different AM detection performance were identified: good (cool-shade lines) vs. poor (hot-shade lines). For example (see two arrows), to obtain a 70% correct response in AM detection, a good performer needed only 2.8% modulation (-31 in 20 log m), and a poor performer needed 7% modulation (-23 in 20 log m). If cochlear mechanics influences behavioral AM detection, then one can predict that AMOAE depth would need to be similar in order to generate the same AM detection performance in both the good and the poor group. To test this, AMOAE depths generated by primaries with the AM depths needed for 70% correct perceptual performance were compared across all subjects (FIGURE 2(b)). AMOAE depths seem very similar across subjects (except one listener, light blue symbol), suggesting that matched AM sound encoding in cochlea might generate the same perceptual performance. This data provide preliminary evidence that cochlear mechanics and behavioral AM perception are related.

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REFERENCES


