3aPP2. Evaluating the role of efferent inhibition on cochlear responses: Simultaneous psychophysical and otoacoustic emission measurements

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The auditory system continuously adapts to changes in the acoustic environment. Behavioral experiments in humans have demonstrated that changes in the acoustic environment produce dynamic changes in perception, for example increases in thresholds in the presence of background noise. This dynamic change in the auditory system is hypothesized to be mediated by efferent feedback from the olivocochlear system. The effect of efferent inhibition on cochlear mechanics was investigated using a simultaneous psychoacoustics and otoacoustic emissions (OAEs) task using identical stimulus conditions. Cochlear responses to short tone-burst stimuli were analyzed under various masking conditions. Robust modification of cochlear responses to the short tone-burst stimuli was observed during contralateral acoustic stimulation and during long-duration ipsilateral masking. Concomitant changes in perceptual thresholds and OAEs are consistent with the hypothesis that both stem from efferent activation. This novel paradigm provides simultaneous perceptual and physiological estimates of cochlear-based efferent activation in the same human subjects.
INTRODUCTION

One of the remarkable features of the mammalian auditory system is its ability to discriminate sounds in a complex acoustic environment. The ability of the auditory system to separate (segregate) out meaningful aural information from a noisy background necessitates sophisticated processing strategies throughout the auditory system. To this end, auditory masking, or the ability of a sound to mask another, has been the subject of a considerable amount of research. However, this research has tended to focus mainly on the spectral content and/or intensity levels involved in masking. Given that our complex, everyday acoustic environment contains signals whose spectrum content and intensity varies rapidly over-time, an understanding of temporal characteristics of auditory processing is critical.

A classic example of this temporal processing is demonstrated by the increased perceptual salience of pure tones as they are delayed from the onset of a simultaneous noise masker. This indicates that the dynamics of the auditory system continually ‘adapt’ to changes in the acoustic environment. First described by Elliott (1964), and elaborated by Zwicker (1965), the mechanisms underlying this temporal ‘overshoot’ have been the subject of considerable debate.

The most compelling hypothesis suggests that temporal overshoot is the result of a more peripheral ‘gain adaptation’ mechanism at the level of the basilar membrane (von Klitzing and Kohlrausch, 1994; Strickland, 2001; Jennings et al., 2011). The nonlinear amplification mechanism (or ‘active process’) in the cochlea has been widely studied (reviewed in Cooper et al., 2007). It provides a substantial dynamic range increase by mapping the wide range of acoustic input levels onto the relatively smaller dynamic range of neurons at later stages of auditory processing (cf. Sachs and Abbas, 1974; Dean et al., 2005). This hypothesis proposes that the efferent projections of the medial olivocochlear (MOC) system, which synapse on the outer hair cells (OHCs) of the cochlea, provide an inhibitory feedback mechanism, selectively reducing the gain provided to the basilar membrane. This reduction in cochlear amplification thus provides an increase in signal-to-noise to which the afferent auditory nerve may respond.

Otoacoustic emissions (OAEs) provide a unique, non-invasive assay of basilar membrane mechanics. As a byproduct of the active mechanical amplification process in the cochlea, low-level sounds can be emitted by the ear and recorded with a sensitive microphone placed in the ear canal. First reported by Kemp (1978), OAEs are thought to result from at least two separate mechanisms; a linear coherent reflection-source in which mechanical perturbations along the BM produce a backward traveling wave and a nonlinear-source in which the backward traveling wave results from the nonlinear processing on the basilar membrane (cf. Shera and Guinan, 1999; Shera, 2004). In humans, OAEs may be used to assess mechanical properties at the level of the basilar membrane, and additionally, to assess modification of these properties under temporal conditions.

To test the hypothesis that temporal processing is mediated by MOC inhibition of cochlear amplification in the auditory periphery, an assay of MOC inhibition in temporal masking was used. Combining measurements of otoacoustic emissions with a psychophysical masking task, a measure of cochlear processing will be obtained in conjunction with behavioral threshold estimates in an ‘overshoot’ experiment.

METHODS

Subjects participated in a psychophysical masking experiment measuring temporal overshoot. To measure concomitant changes in MOC-inhibited cochlear responses, the level of a 10-ms probe stimulus was fixed at 30dB SPL, and the level of the a broadband, frozen masker was varied. The frequency of the probe stimulus was set the largest emission measured near 1000Hz (±200Hz), and determined during a screening experiment. In order to make
simultaneous psychophysical & OAE measurements, all signals were presented using a
ER-10B+ probe assembly (Etymotic Research, Elk Grove Village, IL), with integrated ER-2
speakers. A single interval up/down (SIUD, Lecluyse and Meddis, 2009) procedure was used to
estimate thresholds of the probe under two conditions: 1) Early-onset, in which the probe
stimulus was placed 10-ms from the onset of the masker, 2) Late-onset, in which the probe
stimulus was delayed by 210-ms from the onset of the stimulus.

Once an estimate of masked threshold converged, this masker level at threshold was
maintained for an additional 64 runs in which OAE measurement commenced. Ear canal
recordings were digitized at a sampling rate of 44kHz and stored to disk for offline analysis.

An additional control condition consisted of contralateral acoustic stimulation (broadband)
presented to the subject’s contralateral ear while OAEs were measured with the same
ipsilateral probe stimulus as described above. The purpose of this control condition was to
establish the presence of efferent-activity in each subject.

**Data Analysis**

Ear canal recordings were averaged, and the waveforms time-aligned to restrict the analysis
to the 200-ms portion containing the tone-burst (e.g. t=0, 200ms for early-onset and late-onset,
respectively). An estimate of the OAE level and phase was obtained using a least-squares fit
estimation method, essentially performing a single-point Discrete Fourier Transform (DFT)
analysis (custom MATLAB software). Overlapping hann-windowed segments of data were
analyzed with a step-size of approximately 0.5ms, and a filter bandwidth of 80Hz (step-size = 64
samples, filter = 256 points).

**RESULTS**

The amplitude of the probe and subsequent OAE was analyzed as described above. The level
of the probe itself was included in the analysis to assess if any differences existed in the probe
itself under the two conditions, as well as to show the delay between the measured emission.
Figure 1 shows the results for one subject in the modified ‘temporal overshoot’ experiment, in
which the masker-probe delay was varied. In this figure a clear reduction in OAE amplitude
occurs around 25-ms (indicated with an arrow marked ‘OAE’ in the figure), when the probe
stimulus was delayed by 210-ms from the onset of the masker (red line).

Figure 2 shows analysis of OAE responses using contralateral acoustic stimulation (CAS), a
known elicitor of the MOC system. In this figure, a clear reduction in amplitude of the OAE (e.g.
beginning around 25-ms) is exhibited, confirming the ability of the technique to detect
MOC-related cochlear inhibition.

**FIGURE 1:** Example of mean OAE response analysis for two signal-masker delays. The black curve shows the re-
sponse to the tone at a delay of 10-ms. The red curve represents the response to the tone with a delay of 210-ms.
Errors bars represent standard error.
FIGURE 2: Example OAE response analysis using contralateral acoustic stimulation (CAS) using a 55 dB SPL CAS. The black curve shows the response without CAS and the red curve with CAS. Error bars represent the mean and standard deviation of three consecutive trials. Errors bars represent standard error.

DISCUSSION

This paper presents a novel method for measuring simultaneous psychophysical and otoacoustic measures of temporal overshot. Robust changes in measured OAEs (e.g. reduction in OAE amplitude in the late-onset condition relative to early-onset condition), provide supporting evidence for the role of the MOC system in temporal thresholds improvements, such as is seen in the temporal effect.

REFERENCES


