3aPP4. The effect of the medial olivocochlear reflex on click-evoked otoacoustic emissions during psychoacoustic forward-masking tasks

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Measurements of otoacoustic emissions in animals have shown that the effects of efferent activation are greater in attentive than in anesthetized animals suggesting that the MOCR effects can be modulated by attention. In this study, the effect of efferent activation was measured in humans using click-evoked otoacoustic emissions while listeners were performing a psychoacoustic forward-masking task. Each trial within a block started with a sequence of 40-dB pSPL clicks presented at a rate of 40 Hz that were followed by a 200-ms harmonic-complex masker. The masker was immediately followed by a 10-ms tonal probe and another click train. The listeners' task was to detect the probe. A constant stimuli method was used to measure performance in the forward-masking task, with the probe presented at seven randomized levels around the predetermined masked threshold. Catch trials were dispersed randomly throughout the block. Click trains before and after the masker-signal segments were recorded from the ear canal and analyzed to extract effects of efferent activation at different levels of difficulty of the psychoacoustic task. The results will be discussed with respect to the role of attention and the role of the MOCR in forward masking.

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INTRODUCTION

A number of recent psychophysical studies have speculated that using relatively long forward maskers or precursors of short maskers in experiments designed to estimate the basilar-membrane (BM) input-output function may lead to the activation of medial olivocochlear (MOC) efferents, and thereby affect the estimated cochlear gain and compression (e.g., Krull and Strickland, 2008; Jennings et al., 2009; Wojtczak and Oxenham, 2009b). These speculations were based on well-documented physiological evidence that activation of MOC efferents results in a decrease in cochlear gain via an efferent feedback mechanism (Guinan, 2006). Since efferent activation can affect cochlear gain at characteristic frequencies (CFs) a half-octave to an octave above the frequency of the elicitor (Lilaonitkul and Guinan, 2009), Wojtczak and Oxenham (2009a) hypothesized that MOC efferents may have affected forward masking by Schroeder-phase complexes with components centered around a frequency an octave below the signal in their study. Although many aspects of their data were consistent with this hypothesis, more direct physiological measurements are needed to verify the hypothesized efferent effects.

In this study, the role of efferent activation in forward masking by Schroeder-phase complexes was investigated using a noninvasive physiological method based on the measurement of click-evoked otoacoustic emissions (CEOAEs). The CEOAEs were recorded for clicks presented before and after Schroeder-phase complexes (maskers) with different phase curvatures while listeners performed a psychophysical forward-masking task, in order to ascertain that listeners paid attention to the stimuli. Recent evidence from animal studies suggests that effects of MOC efferent activation are significantly greater in attentive listening (Delano et al., 2007; Chambers et al., 2012). In addition, the difficulty of the forward-masking task was manipulated to examine if attention demands of the task were correlated with changes of the cochlear response following the elicitor (i.e., masker). Finally, the recorded CEOAEs were filtered into different frequency bands to examine tuning of the elicited MOC efferent effects.

EXPERIMENT: SIMULTANEOUS MEASUREMENT OF FORWARD MASKING AND CEOAEs

A forward-masking task was conducted to encourage the listeners to attend to the stimuli during the measurements of CEOAEs, as they were required to do while performing the forward-masking experiments in the study of Wojtczak and Oxenham (2009a). A schematic illustration of the time course of the stimuli within a trial is shown in Fig. 1. Each trial started with a click train (ct1) that varied in duration across trials. This was done to prevent listeners from anticipating the masker after a specific duration of a click train. The clicks were followed by a harmonic complex (masker), which in turn was followed by a tonal signal and a fixed-duration click train (ct2). The masker was the elicitor of MOC efferent activation that was expected to affect the cochlear responses to the later portion of the masker, the signal, and the second click train.

![Figure 1](image1.png)

**FIGURE 1.** Schematic illustration of the stimuli within one trial.

Methods for the Measurement of Psychophysical Forward Masking

Forward masking was measured using a method of constant stimuli. The masker was a 65-dB SPL harmonic complex with a fundamental frequency of 100 Hz and equal-amplitude components ranging from 1.6 to 4 kHz. Three shapes of the phase spectrum were used for the masker, with all components starting in a 0-degree phase in one condition (0), and with Schroeder-positive (Schr+) and Schroeder-negative (Schr-) phase curvature in the other
two conditions. The maskers had a duration of 200 ms including 5-ms raised-cosine onset/offset ramps. A 10-ms 6-kHz probe followed the masker immediately (i.e., there was a 0-ms delay between zero-voltage offset-onset amplitudes). The signal was gated on and off with a 5-ms raised cosine ramps with no steady state. In each block of trials, six levels of the probe yielding from about 20% (difficult) to 90% (easy) correct signal detections were presented ten times in a random order with ten catch trials (containing no signal) randomly interspersed throughout the block. The levels were chosen based on three pilot runs using the same stimuli but with the signal varied adaptively according to a 2-down, 1-up tracking rule estimating the 70.7% correct point on the psychometric function (Levitt, 1971). In the main experiment, each trial consisted of one masker-signal presentation. Listeners had two response options (‘Yes’ – the signal was present, and ‘No’ – the signal was not present). Visual feedback was provided immediately after each trial. Listeners’ responses and the corresponding signal levels were stored on a PC for subsequent analyses. The percentages of correct responses were converted to $d'$ values for the “Yes-No” task (Macmillan and Creelman, 2005). These values were used to determine if there was a correlation between the performance in the forward-masking task and the effect of efferent activation on the CEOAEs.

The stimuli were generated on a PC with a sampling rate of 100 kHz via a 24-bit LynxStudio Lynx2 sound card and were routed to one earpiece of the ER10C (Etymotic Research) assembly.

Three listeners with normal hearing participated in the study. They had normal hearing as evidenced by their audiometric thresholds measured with a clinically certified audiometer (Madsen Cornera) that were at or below 15 dB HL at the octave frequencies between 0.25 and 8 kHz.

Methods for the Measurement of CEOAEs

The method for measuring MOC efferent effects on CEOAEs was similar to the methods used by Francis and Guinan (2010) and Francis (2012). Two click trains were used in each trial, one preceding and the other following the masker-signal combination (see Fig. 1). The clicks were 80-μs long and were presented at a rate of 40 Hz and a level of 50 dB pSPL. The duration of the first click train (ct1) was randomly selected from the range between 400 through 1600 ms in 400-ms steps. The last click of ct1 appeared 25 ms before the onset of the masker. The second click train (ct2) had a fixed length of 375 ms, with the first click presented 25 ms after the offset of the masker. The waveforms in each trial were recorded during the playback for subsequent analysis. The ct1 was presumed to be unaffected by MOC efferent activation. The average CEOAE elicited by the clicks in ct1 was calculated by averaging recorded waveforms from 24-ms windows following each click in the train. This allowed for separation of the emissions from the evoking clicks. The windows had 2-ms raised-cosine ramps. The averaged CEOAE from ct1 served as a reference with which to compare the CEOAEs after the presumed MOC efferent activation by the complex-harmonic masker. The CEOAEs elicited by ct2 were also obtained by applying 24-ms windows to exclude the eliciting clicks but the windowed waveforms were averaged over consecutive triplets of CEOAEs to capture the effects of recovery from MOC efferent activation. The averaged CEOAE waveforms were filtered into contiguous bands of one equivalent rectangular bandwidth (ERB; Moore and Glasberg, 1981) using 8th-order bandpass Butterworth filters. The magnitudes of the CEOAEs were estimated separately for each band to examine tuning of the MOC efferent effect.

Preliminary Results

The forward-masking task was a background task used mainly to force the listeners to attend to the stimuli. However, performance in this task was evaluated by comparing signal levels corresponding to the value of $d' = 1$ across the three masker phase curvatures used (0, Schr+, and Schr-). The $d'$ values for each signal level were computed from z-transformed hit and false-alarm rates. The false-alarm rates were estimated from catch trials. Straight-line fits to the data ($d'$ versus signal level) were used to estimate the signal level yielding $d' = 1$. The masked thresholds defined this way are shown for the three masker phase curvatures in Table 1.

<table>
<thead>
<tr>
<th>Listener</th>
<th>Schr-</th>
<th>0</th>
<th>Schr+</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>16.9</td>
<td>18.3</td>
<td>17.9</td>
</tr>
<tr>
<td>S2</td>
<td>19.1</td>
<td>24.5</td>
<td>19.8</td>
</tr>
<tr>
<td>S3</td>
<td>18.5</td>
<td>21.5</td>
<td>19.6</td>
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TABLE 1. Signal levels corresponding to $d'=1$ in one-interval forward masking task, for masker phase curvatures of 0, Schr-, and Schr+. Data from three listeners.
A repeated-measures ANOVA showed no significant effect of the masker phase curvature on forward-masked threshold \([F(2,4) = 5.166, p = 0.078]\). This result contrasts with the data of Wojtczak and Oxenham (2009a) showing the least amount of masking for the masker with all components starting at a 0-degree phase. The reason for this discrepancy between the masker phase effects are not clear but differences in methods (an adaptive three-alternative forced choice versus the method of constant-stimuli and a “yes-no” task) and the stimuli (i.e., the presence of the click trains) may have contributed to the different results.

Figure 2 shows the effects of the masker with 0-phase curvature on CEOAEs, for listener S1, plotted along the abscissa for contiguous 1-ERB bands spanning an octave range around the signal frequency (6 kHz). Each bar was obtained by calculating the magnitude of the CEOAE averaged across triplets evoked by three consecutive clicks in ct2 and dividing it by the magnitude of CEOAE averaged across the CEOAEs evoked by all the clicks in ct1. The ratios were converted to decibels, and thus each bar represents the decibel difference between the CEOAE after and before the elicitor.

**FIGURE 2.** Effects of MOC efferent activation on CEOAEs in 1-ERB bands around 6 kHz. Different rows show the effects averaged across consecutive CEOAE triplets following the masker/elicitor. The data are from listener S1.

As shown in Fig. 2, the magnitude of the CEOAEs in the 6-kHz band was larger after than before the elicitor and it decreased with increasing delay from the elicitor (the bar height decreased in the 6-kHz band in successive rows). However, the effects were not as systematic in other frequency bands. The other two listeners also showed noisy patterns of results both across frequency band and the delay from the elicitor. To examine the effects of the masker/elicitor phase curvature on the MOC efferent effects, a repeated-measures ANOVA was performed on the effect size in the 6-kHz band, for the first CEOAE triplets following the elicitor. The ANOVA showed no significant effects of the phase curvature for all three listeners [S1: \(F(2,18) = 0.184, p = 0.834\); S2: \(F(2,6) = 0.208, p = 0.818\); S3: \(F(2,14) = 1.113, p = 0.356\)]. The effects of the MOC efferent activation in the 6-kHz band for the first CEOAE triplet after the elicitor calculated for each signal level were correlated with each listener’s performance represented by \(d’\) values for the respective signal levels. No significant correlation was found between the two quantities (S1: \(r = 0.27, p = 0.61\); S2: \(r = -0.34, p = 0.515\); S3: \(r = -0.05, p = 0.92\)).

**DISCUSSION AND SUMMARY**

The aim of this study was to obtain physiological support for the hypothesis put forth in the study by Wojtczak and Oxenham (2009a) that MOC efferent activation plays a role in forward masking and that an off-frequency harmonic masker, centered around 3 kHz, with all components starting at a 0-degree phase is more effective at turning down cochlear gain at the CF of 6 kHz via MOC efferent circuit than off-frequency harmonic maskers with the Schr- and Schr+ phase curvatures. The limited data from three listeners provided no support for the hypothesis. The effect of efferent activation is known to turn down cochlear gain (Guinan, 2006). The recorded CEOAEs often
had a larger magnitude in the 6-kHz band following off-frequency maskers compared with the average magnitudes of the reference CEOAEs evoked by clicks preceding the maskers. Moreover, the effects did not systematically decay with increasing delay from the masker/elicitor. An additional analysis of changes in CEOAE magnitudes in a band centered on 3 kHz (the center frequency of the elicitor) also did not show systematic decreases following the elicitors or systematic decays of the elicited effects with increasing delay from the offset of the elicitor. One reason for the failure to show the effects of MOC efferent activation could have been insufficient time for recovery from the effect between trials. A recent study by Walsh et al. (2013) showed that recovery from efferent effects on the stimulus frequency otoacoustic emissions are substantially longer at higher frequencies than those reported by Backus and Guinan (2006). It is possible that the effect of efferent activation in one trial could have affected the magnitudes of the CEOAEs evoked by clicks preceding the masker in a subsequent trial, thereby affecting the estimate of the reference CEOAE. However, it is also possible that at high frequencies, the effects of efferent activation are very small as suggested by the recent data of Lilaonitkul and Guinan (2012) and thus they played a negligible role in the forward-masking experiment using a 6-kHz signal.

The task difficulty, as depicted by the value of $d'$ for signal detection was not significantly correlated with the changes in CEOAEs magnitude. Because the data did not provide sufficient evidence for a robust effect of efferent activation, the lack of correlation between the listeners’ performance and changes in the magnitude of CEOAEs cannot be interpreted as indicating that attention does not affect peripheral responses via MOC efferent circuit.

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REFERENCES


