2pPPb21. Selective auditory or visual attention reduces physiological noise in the ear canals of human subjects

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A nonlinear version of the stimulus-frequency OAE (SFOAE), called the nSFOAE, was used to measure cochlear responses from human subjects while they simultaneously performed behavioral tasks requiring selective auditory attention (dichotic or diotic listening), selective visual attention, or relatively little attention. The auditory- and visual-attention tasks both were digit-recall tasks, where the nSFOAE-stimuli were interleaved with seven spoken (or displayed) digits. Unlike many previous studies, the required motor behavior always was the same across all tasks, including the inattention tasks. A 30-ms recording in the quiet followed every nSFOAE-eliciting stimulus to provide an estimate of the magnitude of each subject's physiological noise in each experimental condition. For every subject, physiological-noise magnitudes were higher (noisier) in the inattention tasks, and lower (quieter) in the selective auditory- and visual-attention tasks. The differences in noise levels were about 3 - 6 dB, on average, and the effect sizes for those differences all were greater than 2.5. Our interpretation is that the efferent innervation of the cochlea is activated maximally during selective attention (be it auditory or visual), potentially to the benefit of the observer. [Supported by NIDCD grant DC00153.]

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INTRODUCTION

Otoacoustic emissions (OAEs) provide a noninvasive measure of responses from the cochlea (Kemp, 1978), and have been used to examine how activation of the efferent auditory system, specifically the medial olivocochlear bundle (MOCB), changes cochlear responses (e.g., Guinan et al., 2003). The MOCB can be activated reflexively by acoustic stimuli such as moderate-level tones or noise (Guinan et al., 2003), and the amount of efferent activation has been shown to be dependent upon the attentional demands of different behavioral tasks, even when the sounds presented to the ears were the same in the attention and inattention tasks alike (e.g., Puel et al., 1988; Giard et al., 1994; Maison et al., 2001; de Boer and Thornton, 2007; Harkrider and Bowers, 2009; Francis, 2011).

In this study, as in other previous studies (e.g., Froehlich et al., 1993; Ferber-Viart et al., 1995; de Boer and Thornton, 2007; Harkrider and Bowers, 2009) we used OAEs to measure the levels of background noise in the ear canals of our subjects during behavioral tasks requiring selective attention or relative inattention. Unlike the majority of previous studies, however, we observed large systematic differences in the noise across the various tasks, indicating that the amount of efferent activation was dependent on the attentional demands of the different tasks, and that the noise measured in the ear canal was of cochlear origin.

METHODS

Physiological and behavioral measures were obtained simultaneously from eight normal-hearing human subjects, who were tested individually. Our physiological measure was a nonlinear version of the stimulus-frequency otoacoustic emission (SFOAE), called the nSFOAE (Walsh et al., 2010). This measure is derived from the "double-evoked" procedure (Keefe, 1998). The nSFOAE response is calculated as the difference in ear-canal pressure between the sum of two identical stimuli presented in succession (single-amplitude presentations), and the same two stimuli presented simultaneously (double-amplitude presentation). We refer to this sequence of three stimulus presentations as a "triplet." Two such sequences are shown in Figure 1 as Triplet 1 and Triplet 2. In this study, our probe stimulus was a 300-ms, 4.0-kHz tone, and our MOCB-elicting stimulus was a 250-ms frozen sample of wideband noise that was presented with the tone. Appended to each stimulus presentation, and included in the calculation of each nSFOAE response, was a 30-ms silent interval that was used to estimate the level of physiological noise in the ear canals of our subjects during each behavioral condition. For analysis, these noise measures were made at the frequency of our probe tone, and are the focus of this report.

The physiological-noise measures were recorded from our subjects while they simultaneously performed tasks that required selective attention to speech, which was presented either dichotically or diotically. In these attention conditions, two independent series of 7 digits were presented simultaneously to the two ears. One series was spoken by a female talker, the other series was spoken by a male talker, and the task of the subject was to remember the series of numbers spoken by the female talker (and to ignore the other, irrelevant series spoken by the male). At the end of each trial in the attention conditions, the subject chose which of two 5-digit strings displayed visually was a subset of the string spoken by the female talker. Subjects also completed an inattention condition that required the same motor response as the attention conditions (a key press), but did not require selective attention to the sounds at the ears.

Figure 1 illustrates how the nSFOAE stimuli were interleaved with the speech stimuli used for the dichotic-listening condition. The female speech stream was presented to one ear—selected randomly on each trial—and the male speech stream was presented to the opposite ear. In both ears, each speech waveform was about 10 dB weaker than the nSFOAE stimuli, so subjects essentially were listening to the digits in the gaps between stronger tone-plus-noise bursts. Response and feedback intervals followed the last stimuli in the two series. The diotic condition differed from the dichotic condition only in that the two speech streams were summed before presentation, each ear receiving both female and male speech streams. The nSFOAE stimuli were identical in the two conditions.
FIGURE 1. An example of the acoustic waveforms presented on a single trial of the dichotic-listening condition. In both ears, the spoken digits used for the behavioral task were interleaved with the nSFOAE stimuli. Each speech waveform was about 500 ms, and each tone-plus-noise stimulus was 300 ms. The 30-ms silent intervals used for our noise measure are seen as gaps following each nSFOAE stimulus. A 2000-ms response interval and a 200-ms feedback interval ended each trial.

RESULTS

For every subject, physiological-noise magnitudes always were highest (noisiest) in the inattentive-listening condition, and lower (quieter) in the two selective-listening conditions. Furthermore, noise magnitudes in the diotic-listening condition always were lower than in the dichotic-listening condition. Within each condition, physiological-noise magnitudes were similar across Triplet 1 and 2, so the data were pooled for presentation. Table 1 shows the average physiological-noise magnitudes calculated across repeated measures of our three behavioral conditions. The individual-subject data (L01 – L08) are shown in successive rows, and the means and standard errors calculated across subjects are shown in the last two rows, respectively. Larger negative values indicate a lower physiological-noise level—a quieter recording, on average, in the brief intervals following the nSFOAE-eliciting stimuli, as measured using the nSFOAE cancellation procedure.

TABLE 1. Physiological-noise levels (dB SPL) in the inattentive-, dichotic-, and diotic-listening conditions averaged across Triplet 1 and Triplet 2 of every trial.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Inattentive</th>
<th>Dichotic</th>
<th>Diotic</th>
</tr>
</thead>
<tbody>
<tr>
<td>L01</td>
<td>-9.5</td>
<td>-12.6</td>
<td>-15.1</td>
</tr>
<tr>
<td>L02</td>
<td>-11.0</td>
<td>-12.3</td>
<td>-14.8</td>
</tr>
<tr>
<td>L03</td>
<td>-9.0</td>
<td>-13.5</td>
<td>-16.5</td>
</tr>
<tr>
<td>L04</td>
<td>-11.7</td>
<td>-13.3</td>
<td>-15.6</td>
</tr>
<tr>
<td>L05</td>
<td>-11.2</td>
<td>-13.4</td>
<td>-16.6</td>
</tr>
<tr>
<td>L06</td>
<td>-11.2</td>
<td>-13.2</td>
<td>-16.5</td>
</tr>
<tr>
<td>L07</td>
<td>-8.7</td>
<td>-11.3</td>
<td>-14.1</td>
</tr>
<tr>
<td>L08</td>
<td>-10.3</td>
<td>-13.2</td>
<td>-16.4</td>
</tr>
<tr>
<td>Mean</td>
<td>-10.3</td>
<td>-12.9</td>
<td>-15.7</td>
</tr>
<tr>
<td>Std. Error</td>
<td>0.4</td>
<td>0.3</td>
<td>0.3</td>
</tr>
</tbody>
</table>
An effect size \((d)\) calculation (Cohen, 1992) was used to compare the physiological-noise magnitudes across conditions. The effect size for the inattentive- and dichotic-listening comparison was \(d = 2.7\), and the effect size for the inattentive- and diotic-listening comparison was \(d = 4.9\). The effect size for the dichotic- and diotic-listening comparison was \(d = 2.6\). By convention, these effects all are considered to be large.

As a test of our procedures, the acoustic stimuli were played to and recorded from a syringe (a non-human, passive cavity), using exactly the same equipment and software as was used with the human subjects. Responses were collected for three blocks of trials for each condition. These physical-noise recordings were averaged and analyzed in the same way as the physiological-noise recordings. Importantly, across the three conditions, average physical-noise magnitudes were similar to one another (about \(-15.5\) dB). The strong implication is that the differences in the human data observed across the three behavioral conditions were not attributable to the software and procedures used.

We also measured physiological-noise magnitudes during behavioral tasks requiring visual attention rather than auditory attention. Those data will be presented elsewhere, but the central outcome was the same: noise magnitudes were higher in the inattention conditions than in the attention conditions, and this was true for every subject.

**DISCUSSION**

We attribute the observed differences in physiological-noise magnitudes between the inattention and attention conditions to different levels of efferent activation associated with the differing attentional demands across the behavioral tasks. Because our noise measures were calculated using the nSFOAE procedure, they can be thought of as the result of adding and subtracting three uncorrelated samples of noise, i.e., spontaneous cochlear activity. One hypothesis is that when the attentional demand is relatively great, and efferent activation is relatively high, an increased stiffening of the basilar membrane leads to lower-amplitude cochlear activity, and thus a smaller measure of noise from the ear.

**ACKNOWLEDGMENTS**

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**REFERENCES**