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Research Paper

Effect of efferent activation on binaural frequency selectivity

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ABSTRACT

Binaural notched-noise experiments indicate a reduced frequency selectivity of the binaural system compared to monaural processing. The present study investigates how auditory efferent activation (via the medial olivocochlear system) affects binaural frequency selectivity in normal-hearing listeners. Thresholds were measured for a 1-kHz signal embedded in a diotic notched-noise masker for various notch widths. The signal was either presented in phase (diotic) or in antiphase (dichotic), gated with the noise. Stimulus duration was 25 ms, in order to avoid efferent activation due to the masker or the signal. A bandpass-filtered noise precursor was presented prior to the masker and signal stimuli to activate the efferent system. The silent interval between the precursor and the masker-signal complex was 50 ms. For comparison, thresholds for detectability of the masked signal were also measured in a baseline condition without the precursor and, in addition, without the masker. On average, the results of the baseline condition indicate an effectively wider binaural filter, as expected. For both signal phases, the addition of the precursor results in effectively wider filters, which is in agreement with the hypothesis that cochlear gain is reduced due to the presence of the precursor.

1. Introduction

Several psychoacoustic experiments have been designed to measure characteristics of auditory frequency selectivity. One of the earliest experiments is the bandwidening experiment where a sinusoidal signal is masked by a bandpass-noise masker spectrally centered at the signal frequency (Fletcher, 1940). Another common type of experiment is the notched-noise experiment (de Boer and Bos, 1962; Patterson, 1976; Patterson and Nimmo-Smith, 1980). For both experimental paradigms (bandwidening and the notched-noise experiment) the estimate of the bandwidth of the auditory filter centered at the signal frequency (with diotic N_0 noise) depends on binaural signal phase. For diotic stimuli (N_0S_0) the same critical bandwidth estimate is obtained as for monaural experiments, but for the dichotic binaural stimuli N_0S_π (i.e., a diotic noise and a signal with an interaural phase of π) the estimated filter bandwidth is found to be considerably larger than for the monaural or N_0S_0 case (Hall et al., 1983; Zurek and Durlach, 1987; Nitschmann et al., 2009; Nitschmann and Verhey, 2013). This increase in filter bandwidth for the N_0S_π compared to the N_0S_0 condition varies between studies. For a 500-Hz signal, it ranges from 20% (Kollmeier and Holube, 1992) to six times as large (Hall et al., 1983). In previous studies (e.g., Nitschmann et al., 2010; Nitschmann and Verhey, 2013), the filters derived from the dichotic data were referred to as (effective) binaural filters since the dichotic thresholds involve binaural processing. In contrast, the filters derived from the diotic data were referred to as monaural filters. These terms will be used interchangeably with the longer terms for the filters derived from the diotic/dichotic data whenever necessary. Different mechanisms have been proposed to account for the difference in the widths of the monaural and binaural filter (see, e.g., Hall et al., 1983; van de Par and Kohlrausch, 1999; Nitschmann and Verhey, 2013). All approaches have in common that the effective wider binaural filter results from retrocochlear processes.

Hearing-impaired individuals often show reduced frequency selectivity compared to normal-hearing individuals (Peters and Moore, 1992; Leek and Summers, 1993), so it could be assumed that a reduction in frequency selectivity may impair binaural processing. However, although hearing-impaired individuals show reduced frequency selectivity (as measured by the equivalent rectangular bandwidth; ERB), for both N_0S_0 and N_0S_π conditions, the ratio of binaural to monaural ERB is the same as for normal-hearing listeners (Nitschmann et al., 2010). This indicates that a

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Abbreviations: ERB, equivalent rectangular bandwidth; MOC, medial olivocochlear

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hearing impairment has no explicit retrocochlear component which affects binaural processing, but affects a stage of the auditory pathway prior to binaural processing, i.e., leads to reduced cochlear gain (Plack et al., 2004) and nonlinearity (compression) (Oxenham and Bacon, 2003).

In normal-hearing listeners, activation of the auditory efferent system can result in a reduction of auditory gain and frequency selectivity. The mammalian auditory system includes a brainstem-mediated efferent pathway from the superior olivary complex, by way of the medial olivocochlear (MOC) reflex, which reduces the cochlear response to sound (Warr and Guinan, 1979; Liberman et al., 1996). The human medial olivocochlear response has an onset delay of between 25 and 40 ms and rise and decay constants in the region of 280 and 160 ms, respectively (Backus and Guinan, 2006). Physiological studies with nonhuman mammals indicate that onset and decay characteristics of efferent activation are dependent on the temporal and level characteristics of the auditory stimulus (Bacon and Smith, 1991; Guinan and Stankovic, 1996). In humans, this MOC feedback is suggested to be involved in improving speech perception in noisy environments (Clark et al., 2012) by reducing the effect of noise masking (Kawase et al., 1993). In addition, binaural hearing is known to greatly benefit speech intelligibility (Hawley et al., 2004). How this efferent feedback operates to influence the binaural hearing system is still largely unknown (Yasin and Henning, 2012). This study will investigate the influence of efferent activation on binaural filter estimates by using a psychophysical experiment that incorporates aspects of psychophysical methodology often used to study the human efferent response (signal detectability in the presence of a forward masker with or without presentation of a prior precursor sound to activate the efferent system) and binaural frequency selectivity (signal detectability in the presence of a notched noise simultaneous masker).

In a psychophysical study using forward masking to study the effect of efferent activation on stimulus detectability, Yasin et al. (2014) showed that activation of the MOC reflex by presentation of a precursor sound (>= 40 dB sound pressure level, SPL) prior to the signal of interest, resulted in a decrease in both maximum gain and maximum compression, with linearization of the compressive function for input sound levels between 50 and 70 dB SPL. If the gain is reduced due to activation of the MOC reflex then it follows that there should also be a reduction in frequency selectivity, as shown by physiological (e.g., Guinan and Gifford, 1988) and psychophysical (Jennings and Strickland, 2012) studies.

The aim of the present study was to investigate the effect of MOC reflex activation on estimates of auditory filter bandwidths obtained in the N_0S_0 and N_0S_π condition. The notched-noise method was used to infer filter bandwidths in the N_0S_0 and N_0S_π condition for a signal frequency of 1 kHz and a series of notch widths introduced into the masker stimulus. This signal frequency (1 kHz) and a similar notched-noise masking procedure were already used by Nitschmann and Verhey (2013) to measure binaural frequency selectivity but with longer signals and maskers than in this study and no precursor was present. A probe signal frequency of 1 kHz has also been used in a study of the effect of efferent-mediated gain reduction (using a binaural elicitor) on stimulus-frequency otoacoustic emissions (Lilaonitkul and Guinan, 2009); the results showed patterns of gain reduction due to efferent activation at 1 kHz similar to that found with a higher frequency signal of 4 kHz. A precursor sound (presented at a level to activate the MOC reflex) was presented prior to the N_0S_0 or N_0S_π stimulus to estimate the effect of MOC reflex activation on monaural and binaural filter bandwidth estimates. In the absence of MOC reflex activation (no precursor) it is expected that filter bandwidths in the N_0S_π case will be broader than for the N_0S_0 case. With MOC reflex activation (precursor present) it is expected that filter bandwidths would be wider for both N_0S_0 and N_0S_π conditions, but since MOC reflex activation is expected to affect mainly cochlear gain reduction and not retrocochlear processes, the relative difference in bandwidth between the N_0S_0 and N_0S_π case may remain unaffected.

2. Materials and methods

Eleven listeners (8 male, 3 female, aged between 22 and 50 years) participated in the experiment. Four listeners were members of the research team, the seven other listeners were paid volunteers. All listeners had normal hearing within frequency range from 0.125 to 8 kHz, with hearing thresholds <15 dB HL for the entire frequency range. Informed consent was obtained from all participants.

Thresholds of a 1-kHz sinusoidal signal were measured in the two masking conditions shown in Fig. 1: a condition with precursor (right column of panels) and a baseline condition without precursor (left column of panels). The top row of panels show the temporal envelopes of signal (red), masker and precursor (both in grey) and the bottom row of panels show the spectrograms of the two conditions. In both conditions, the masker was a bandpass noise (60–2000 Hz) with a spectral notch that was arithmetically centered at the signal frequency. The notch width was 0 (no notch), 100, 200, 400 or 800 Hz. The spectral parameters of the notch-noise masker were similar to those used by Nitschmann and Verhey (2013). The precursor had the same spectral characteristics as the no-notch masker. The masker noise and precursor noise each had a mean spectrum level of 30 dB [see Hartmann (1998) for a definition of spectrum level]. This results in an overall SPL for the precursor of about 63 dB SPL. They were generated by transforming a Gaussian noise of the desired duration into the frequency domain via a fast Fourier transform, setting all Fourier components outside the desired passband to zero (while Fourier components within the notch were zeroed for the masker only), and performing an inverse fast Fourier transform on the complex spectrum. The resulting noise waveforms were then gated as needed. Both the signal and masker were 25 ms in duration, gated on and off simultaneously with 12.5-ms long raised cosine ramps (0-ms steady state). A total duration of 25 ms is below the onset delay of the MOC reflex (Backus and Guinan, 2006), therefore the signal and masker stimuli will not be affected by self-activation of the efferent system, and the effect of efferent activation can be studied separately by presentation of a precursor sound (with a sufficiently long duration and

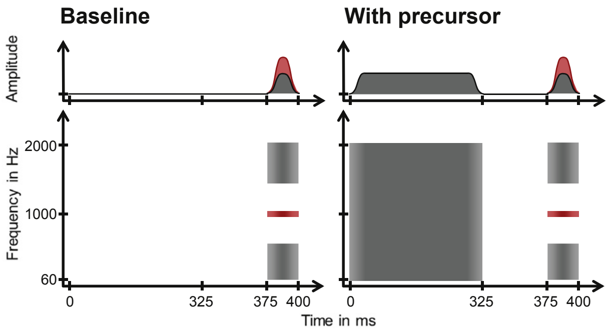

Fig. 1. Schematic plot of the stimuli for the two masking conditions: baseline condition (left column of panels) and precursor condition (right column of panels). The temporal envelopes of signal (red), masker (grey) and, for the precursor condition, the precursor (also grey) are shown in the top row of panels. The bottom row of panels shows the spectrograms of the stimuli. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)