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Cortical representation of release from auditory masking

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ABSTRACT

The aim of the present study was to find a functional MRI correlate in human auditory cortex of the psychoacoustical effect of release from masking, using amplitude-modulated noise stimuli. A sinusoidal target signal was embedded in a bandlimited white noise, which was either unmodulated or (co)modulated. Psychoacoustical thresholds were measured for the target signals in both types of masking noise, using an adaptive procedure. The mean threshold difference between the unmodulated and the comodulated condition, i.e., the release from masking, was 15 dB. The same listeners then participated in an fMRI experiment, recording activation of auditory cortex in response to tones in the presence of modulated and unmodulated noise maskers at five different signal-to-noise ratios. In general, a spatial dissociation of changes of overall level and signal-to-noise ratio in auditory cortex was found, replicating a previous fMRI study on pure-tone masking. The comparison of the fMRI activation maps for a signal presented in modulated and in unmodulated noise reveals that those regions in the antero-lateral part of Heschl's gyrus previously shown to represent the audibility of a tonal target (rather than overall level) exhibit a stronger activation for the modulated than for the unmodulated conditions. This result is interpreted as a physiological correlate of the psychoacoustical effect of comodulation masking release at the level of the auditory cortex.

Introduction

The ability to separate important acoustical information from the interfering background noise is a key qualification for every life form living and communicating in a noisy world (Klump, 1996). A common property of many natural sounds is that energy in different frequency bands is coherently modulated, i.e. the envelope is comodulated (Nelken et al., 1999). A psychoacoustical phenomenon thought to be related to our sensitivity to coherent modulation is the effect of release from masking. This effect can be observed as a decrease of the detection threshold for a sinusoidal test signal in presence of a noise masker, when the masker is modulated, compared to a reference condition in which the masker is unmodulated. The masking release is especially large when the masker is broadband, i.e. when several auditory channels (or critical bands) are excited simultaneously. Based on this finding, it was suggested that the observer may compare the envelope fluctuations between different auditory channels and hence the effect was referred to as "comodulation masking release" (CMR, Hall et al., 1984; see Verhey et al., 2003, for an overview). A way to quantify the CMR is to calculate the difference between the thresholds for an unmodulated and a comodulated masker (Hall et al., 1984; Verhey et al., 1999). Comodulation masking release was originally studied in human listeners but it can also be observed in many other vertebrates (e.g. birds: Langemann and Klump, 2001; dolphins: Branstetter and Finneran 2008).

Nelken et al. (1999) reported a neural correlate of CMR at the level of the auditory cortex of the cat. They showed that a signal added to amplitude-modulated noise can markedly reduce the neuronal response to the fluctuations of the masker level in primary auditory cortex (PAC). This phenomenon was referred to as envelope locking suppression. Las et al. (2005) showed more envelope locking suppression in PAC of the cat than at lower stages of the auditory system (inferior colliculus, IC, and medial geniculate body, MGB), suggesting a gradual increase in segregation of signal from modulated noise along the auditory pathway. Recent studies using electroencephalography (Androulidakis and Jones, 2006) and magnetoencephalography (Rupp et al., 2007) indicate that a physiological correlate of CMR can also be observed at a cortical level in humans. However, the relative contribution of primary and non-primary auditory regions in human auditory cortex to the reported components in their studies is not clear yet, due to the limited spatial resolution of these electrophysiological methods.

The aim of the present study is to identify a correlate of the effect of masking release in human auditory cortex by means of functional magnetic resonance imaging (fMRI). The study continues a previous fMRI study by the same authors on the neural correlate of masked auditory detection thresholds (Ernst et al., 2008). The results of the previous study indicated a spatial dissociation of the representation of

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overall level and of changes in signal-to-noise ratio (S/N) in different areas of the auditory cortex. Regions sensitive to changes in S/N were mainly found in the antero-lateral part of Heschl's gyrus, whereas regions sensitive to changes in the overall level of a signal were located over large sections of the auditory cortex, including PAC and Planum temporale. Ernst et al. (2008) hypothesized that those regions sensitive to low S/N are regions representing the audibility of a sinusoidal signal whereas regions sensitive to the overall level may be related to the sensation of overall loudness of the signal and masker. According to this hypothesis, the prediction for the results of the present study involving the comparison of modulated and unmodulated masker signals would be, (1) that there are regions in the auditory cortex that will show an increase of activation as the overall level increases, independent of the masker type, and (2) that there are regions in the auditory cortex that will show an increase of activation as audibility increases. These regions should be more sensitive to the signal embedded in modulated noise than in unmodulated noise. In the light of these predictions, the present study also allows to further test the validity of the previous interpretation that certain regions encode the audibility of a signal in noise while others, in partly separate regions are involved in encoding the overall loudness of the combined stimulus.

Materials and methods

Two separate experiments were performed. First, a psychoacoustical detection experiment was conducted to quantify the effect of masking release individually. Then, fMRI scanning with the same sort of stimuli was performed to identify a correlate of the psychoacoustical effect at the level of auditory cortex.

Subjects

Twelve listeners between 23 and 44 years of age (mean 26.2, nine males, three females, all but one were right-handed) participated in the study. None of the volunteers had a history of neurological illness, head injury, or hearing impairment. Written informed consent was obtained from all volunteers. The study was approved by the local ethics committee of the University of Oldenburg and by the ethics committee of the Medical School of the University of Göttingen.

Stimuli

The masker signal was an unmodulated or an irregular rectangular modulated noise with a mean modulation frequency of 40 Hz as used in Verhey and Ernst (2009). It has been shown that square-wave modulators give rise to larger CMR than low-pass noise modulators, the latter being a common modulator type in CMR experiment (e.g., Carlyon et al., 1989; Verhey et al., 1999). The comparatively high modulation rate of 40 Hz was chosen to achieve a masker signal similar to the initial description of the CMR effect by Hall et al. (1984). Due to the relatively short silence intervals it reduces a potential interference with forward-masking effects. The noise had a lower cut-off frequency of 250 Hz and an upper cut-off frequency of 4000 Hz. The modulation was a unipolar square wave (0, 1), i.e. the carrier is switched on and off by the modulator (see Fig. 1). The duty cycle of a regular square wave was 50%, i.e., for each 25-ms period, the signal was switched on for half of the time. In order to generate the irregular square waves, onset and offset times were slightly jittered (see Fig. 1a). Jittering the modulation rate was introduced to avoid a periodicity pitch in the masker signal. In addition, it reduces the potential effect of listening into the dips without across-frequency processes, which is generally believed to be the mechanism responsible for CMR. The magnitude of the jitter was 10% of a period, which introduced random fluctuations of the duty cycle in the range from 30 to 70%. On- and offset times were jittered independently. Fig. 1b shows one example of the time waveform of an irregular modulator. The square-wave modulator is convolved with a 5-ms Hanning window in order to avoid on- and offset clicks. The level of the masking noise was 62 dB SPL. The overall duration of single masker signals was 350 ms, including on- and offset ramps of 50-ms duration.

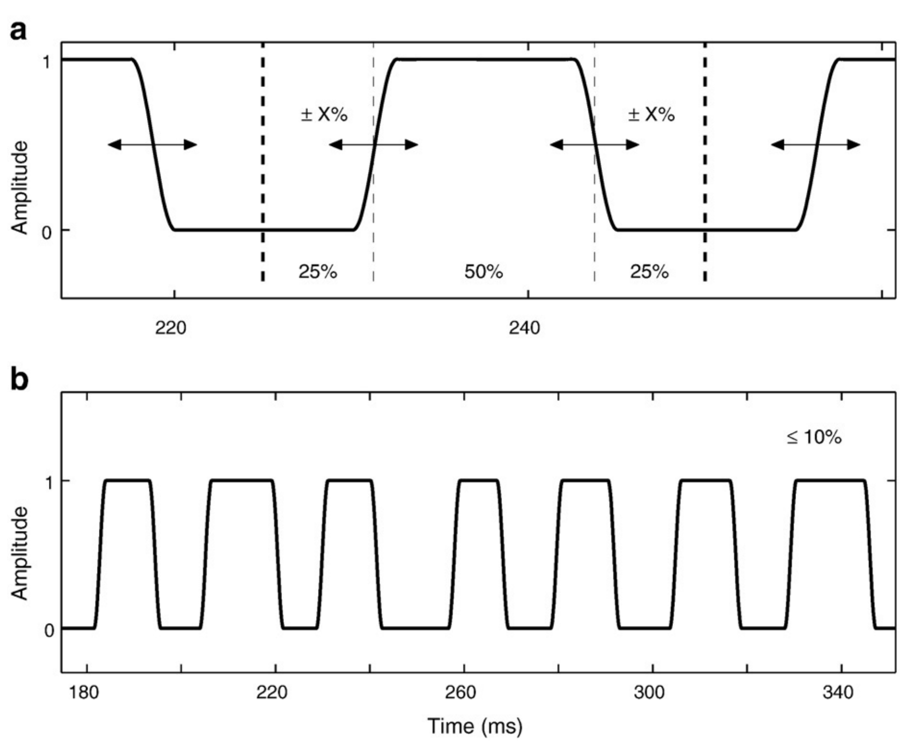

Fig. 1. Time waveforms of the square-wave modulator. (a) Irregular square waves are generated by jittering the onset and offset times within each period. (b) Example of the square-wave modulators with a 10% degree of maximum jitter. The modulator is convolved with a 5-ms Hanning window.