Is the auditory continuity illusion based on a change-detection mechanism? A MEG study

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Introduction

Auditory scene analysis involves making sense of complex mixtures of sounds, with many physical sources overlapping both in time and in frequency. Imagine listening to a piece of music. It is quite common to hear someone singing at the same time as a rhythm is performed on a percussive instrument. In this case, it is likely that the percussion will repeatedly mask the singer for briefs periods of time. We are nevertheless able to maintain the perceptual continuity of the singing voice. Without such an ability, communication in noisy environments would be very much compromised.

This perceptual mechanism has been studied psycho-physically through the 'auditory continuity illusion' [1], also termed 'auditory induction' [2]. The continuity illusion occurs when a signal is briefly interrupted and when the interruptions are filled with a sound that could have masked the interrupted signal. In this case, listeners report hearing the (physically) interrupted signal as continuous. The illusion is remarkably robust with respect to the type of sounds it can accomodate: speech [3], pure and complex tones [1,2], frequency-modulated tones [4]. It is also not peculiar to humans as it has been observed in behavioral animal studies [5].

The neural mechanisms underlying the illusion are still largely unkown. Micheyl et al. [4] provided the first electro-physiological correlate of the phenomenon by using EEG and the mismatch-negativity technique (MMN). They concluded that the illusion did not require attention and probably occurred at or below the auditory cortex level. While this places important constraints on the mechanims involved, the underlying neural activity remains unspecified.

Imaging an illusory amplitude-modulation

We chose to produce a continuity illusion with a purely temporal feature: amplitude modulation (AM) of a noise. The stimulus with a 100% AM at a 62.5 Hz rate is illustrated in Fig. 1A. In a second condition, an easily detectable gap of 128 ms was imposed on the AM (Fig. 2A). When the gap is filled with a noise with the same spectral composition as the AM-noise, but louder, listeners hear an illusory modulation continuing throughout the stimulus (Fig. 3A).

A whole-head MEG system with axial gradiometers (CTF Omega 151) was used to record brain activity when subjects listened passively to the 4 conditions illustrated in Figs 1-4A. Fifteen normal hearing listeners took part in the experiment. Five hundred repeats of each condition were presented in sequences of about 10 s. The beginning and end of each sequence were excluded from the analysis to remove the onset/offset responses associated with the signal arising from silence. In this report, we will focus on the grand average of surface signals for all listeners.

Results

Averaged surface signal for the 4 conditions are presented in Figs 1-4B. The responses show the superposition of an auditory steady state response to the amplitude modulation (aSSR, [6]), and middle-latency and late evoked potentials related to various discontinuities in the stimuli.

In order to examine the time course of the aSSR, the data were filtered in a narrow frequency band around the physical

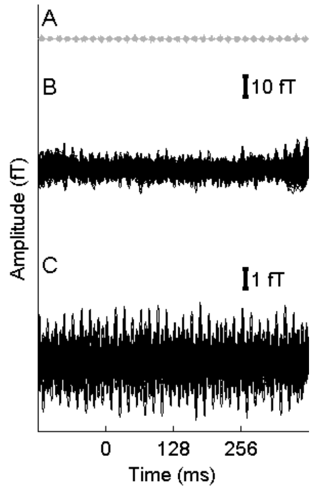

Figure 1: 'Continuous' condition. A. Stimulus waveform. B. Overlay of the 151 sensors, grand average across the 500 repeats and 15 listeners, filtered between 2 and 200 Hz. C. As in B., filtered between 57.5 and 67.5 Hz.

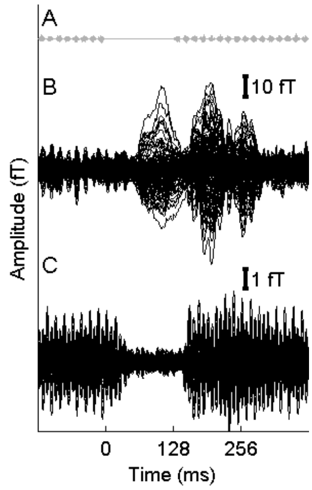

Figure 2: 'Interrupted' condition. Layout as in Fig. 1.

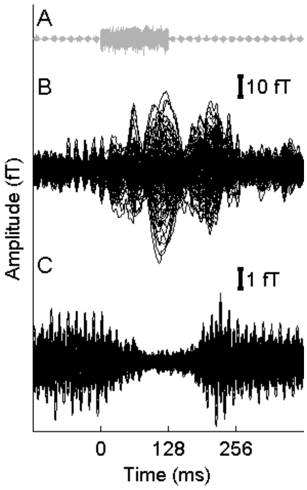

Figure 3: 'Illusion' condition. Layout as in Fig. 1.

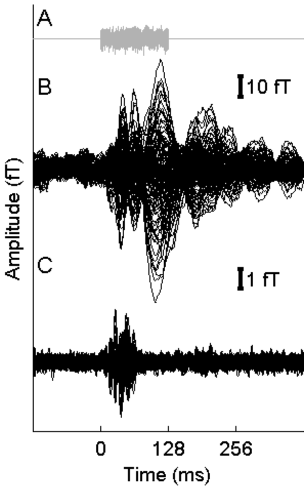

Figure 4: 'Noise' condition. Layout as in Fig. 1.

modulation frequency. In the 'Continuous' case, a clear aSSR is observed (1C). In the 'Interrupted' case, the aSSR stops during the silent gap (2C). In the 'Illusion' case, the aSSR also stops during the gap filled with noise. Even though listeners report hearing an illusory modulation in this case, there is no completion of the modulated aSSR in the recorded MEG signals.

The illusion, however, has an effect on middle-latency and late evoked potentials. Figure 2B shows the responses to the silent gap in the AM in the 'Interrupted' condition. Successively, the response consists of a N100 response to the AM offset, a positive wave that could be either a P200 to the AM offset or a P50 to the second AM onset, and a N100 to the AM onset. These responses are largely reduced in the 'Illusion' case, where all evoked potentials can be linked to the presence of the noise (compare with Fig. 4B).

To illustrate this point further, difference waves were computed between the 'Illusion' and 'Interrupted' plus 'Noise' conditions. If neural signals were simply following the physical stimulus, we would expect the difference wave to be negligible. This is clearly not the case: the offset/onset responses to the gap are still visible in the difference waves at around 200 and 250 ms, which indicates that they are not present in the 'Illusion' neural responses. A subtraction of the 'Continuous' plus 'Noise' conditions results in much smaller difference waves: this might correspond to the subjective percept of listeners of a continous AM.

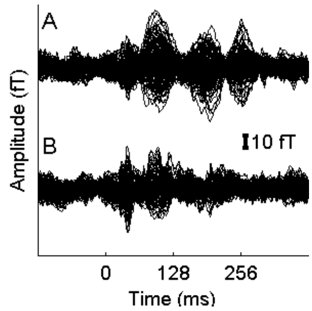

Figure 5: Difference waves. A. 'Illusion' minus 'Interrupted' and 'Noise responses. B. 'Illusion' minus 'Continous' and 'Noise' responses.

Finally, a similar onset-related effect was observed in time-frequency analyses of individual sensors data (not shown). On the sensors that diplayed a sizeable aSSR, an evoked transient gamma-band response was visible after the onset of the AM in the 'Interrupted' case but not in the 'Illusion' case. The transient gamma-band response had been associated with the onset of AM signals [6].

Continuity without continuous features

Amplitude-modulation usually gives rise to modulated neural signals, in the form of the aSSR. We found no completion of the aSSR during the perception of an illusory AM. This could be interpreted in different ways. It is possible that the aSSR is not related to AM perception, or it is possible that the neural basis of the illusion are located at a latter processing stage, where the AM is encoded in a different form. However, we would like to propose that the illusion may not require a completion of the missing feature (here, AM). Middle-latency and late evoked potentials, as well as transient gamma-band responses, suggest that the temporal boundaries of the sound have been altered by the illusion. For these response components, it is as if the AM did not stop or start before or after the introduction of the noise. The auditory system might thus treat the noisy periods as missing information and rely on the lack of onset/offset signals to form a perceptually continuous auditory object. This points to a potentially useful role for 'change detection' mechanisms in the analyses of complex auditory scenes.

References

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