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Earlier timbre processing of instrumental tones compared to equally complex spectrally rotated sounds as revealed by the mismatch negativity

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HIGHLIGHTS

- We tested whether harmonically rich sounds have sensory processing benefits.
- Equally complex natural sounds and spectrally rotated sounds were applied.
- The mismatch negativity was measured in a passive oddball paradigm.
- MMN peak latency was shorter in natural compared to the spectrally rotated sounds.
- Our results suggest that processing benefits are not an effect of sound complexity.

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ABSTRACT

Harmonically rich sounds have been shown to be processed more efficiently by the human brain compared to single sinusoidal tones. To control for stimulus complexity as a potentially confounding factor, tones and equally complex spectrally rotated sounds, have been used in the present study to investigate the role of the overtone series in sensory auditory processing in non-musicians. Timbre differences in instrumental tones with equal pitch elicited a MMN which was earlier compared to that elicited by the spectrally rotated sounds, indicating that harmonically rich tones are processed faster compared to non-musical sounds without an overtone series, even when pitch is not the relevant information.

1. Introduction

Prior research demonstrated that harmonically rich sounds like vowels and tones are processed more efficiently (e.g. faster discrimination of sound) on the sensory level by the human brain compared to single sinusoidal tones [1–3]. These findings were explained in terms of pitch facilitation [4], meaning that the harmonic overtone series supports pitch perception. Moreover, improved discrimination has also been reported in a study manipulating the duration of the stimuli, for which pitch information is not relevant [1].

Single sinusoidal tones are composed of a single frequency and thus do not contain harmonics of the fundamental frequency and are therefore physically less complex compared to harmonically rich sounds. Therefore, it is hard to decide whether enhanced processing of complex sounds is a result of the harmonic structure, or solely of higher stimulus complexity. For instance, Berti [5] demonstrated that complex sounds may trigger different routes of sensory processing compared to sinusoidal tones. This might be due to the broader activation of neurons in the auditory sensory cortices by complex stimuli compared to sinusoidal stimuli. In addition, it has been shown that instrumental tones are processed by a different cortical area compared to chords [6] (see [7] for a recent review), indicating that stimulus complexity might influence the

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processing of musical sounds. To address this question more directly, the present study tested whether musical sounds (tones) possess processing advantages compared to non-musical sounds without harmonic overtone series, when stimulus complexity is controlled.

One objective and reliable correlate of automatic sensory processing is the so-called mismatch negativity (MMN) of the human event related potential (ERP) [8,9]. Within a classical oddball paradigm, the ERP of a frequently presented standard stimulus is subtracted from the ERP of an infrequently presented deviant stimulus. The resulting difference curve shows a negative peak between 150 and 250 ms, known as the MMN. In early studies applying the MMN, pure sinusoidal tones were applied [8,10,11] but it has been shown that the MMN can also be elicited with stimuli of higher complexity like noise bursts, harmonic tones, chords, and speech stimuli like vowels, syllables and words [12]. Moreover, the MMN is also sensitive for differences in timbre [13–15] and, therefore, is very suitable for the investigation of the sensory processing of musical stimuli.

To test for processing differences, we applied an auditory oddball paradigm with two types of complex stimuli serving either as standard and deviant stimuli. As mentioned above, if the proposed effective processing of musical sounds is due to pitch facilitation, the MMN elicited by harmonically rich sounds should differ from equally complex sounds lacking the harmonic structure. In order to create non-musical sounds with the same complexity as the tones, we chose a procedure that was originally introduced for speech research: spectral rotation [16–18]. If the middle frequency is chosen carefully, this means that the middle frequency must not be a harmonic of the original tone; the overtone series of the tone will be eliminated completely by this procedure. Therefore, the resulting spectrally rotated sound is perceived as noise-like. To the best of our knowledge, this is the first time that spectral rotation was applied to musical stimuli in auditory research.

2. Material and methods

Fourteen right-handed students of the Johannes Gutenberg-University Mainz, Germany, participated in the study. All participants were native speakers of German and reported normal hearing. Moreover, in accordance with the Declaration of Helsinki all participants gave written consent after the nature of the experiment was explained to them. The data sets of three participants were excluded for the reason of a bad signal to noise ratio in the EEG data due to a high number of artifacts. The remaining eleven participants had an age range of 18–30 years (5 male). Four of them never learned to play an instrument; the others never played an instrument at a professional level.

Two different natural tones were used, one generated by a saxophone, the other one by a clarinet. The pitch was at 185 Hz (F#) for both, so the two tones differed only with respect to timbre; both sounds had a duration of 145 ms. To create non-harmonic stimuli with the same complexity as the natural tones, we produced one spectrally rotated counterpart for each tone, using a MATLAB (Version: R2011a, Mathworks, Ismaning, Germany) script for stimulus processing provided by Scott and colleagues [19]. Comparable to prior research, 2000 Hz was chosen as center frequency for the rotation, this means that all frequencies are mirrored at this frequency. In order to maintain the perceived naturalness of the tones, which could be affected by the usage of the low pass filter (for more details see [16,17,20]), we modified the procedure to create spectrally rotated stimuli with a complete spectrum. This was achieved by adding all frequencies above 4000 Hz of the tone to the spectrally rotated stimulus with Audition (Version: CS5.5, Adobe, Munich,

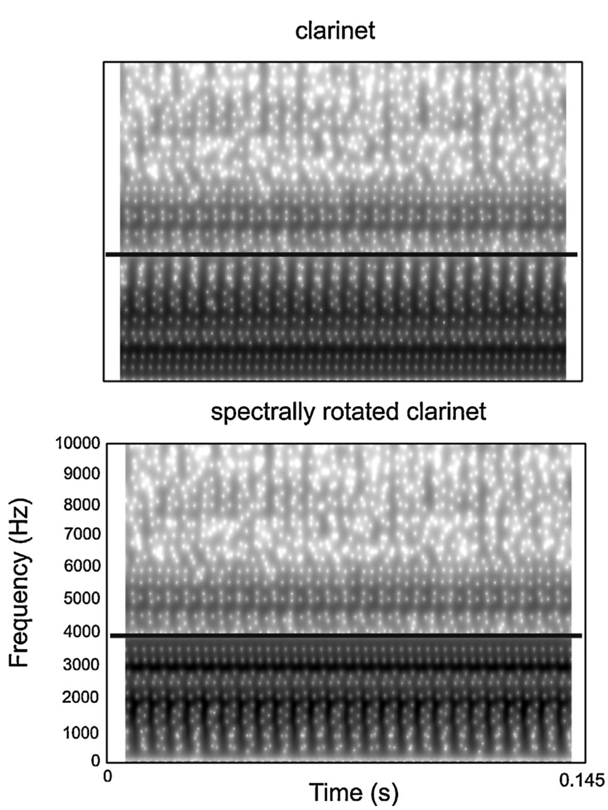

Fig. 1. Spectrograms of the two tones (above) and the two spectrally rotated tones (below). The sounds based on the clarinet are on the left side, those based on the saxophone on the right side. Frequencies above 4000 Hz were not affected by the spectral rotation. Below 4000 Hz, all frequencies were mirrored around 2000 Hz. (The black line is only included for display purposes and marks 4000 Hz.)