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Implicit Brain Responses During Fulfillment of Melodic Expectations

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ABSTRACT

Background

Listening to music entails forming expectations about how the music unfolds in time, and the confirmation and violation of these expectations contribute to the experience of emotion and aesthetic effects of music (Huron, 2006). Pearce and Wiggins (2006) developed a computational model to quantify melodic expectation. This model takes sequential melodic context, as well as various other properties of notes, into account and estimates, for every note in a melody, a conditional probability distribution governing the probability of the pitch of the next note in a melody given the preceding notes. Notes with a low conditional probability are assumed to be unexpected at that position in a melody, while notes with a high conditional probability are assumed to be expected. This model allows for the use of natural musical stimuli as the model will identify expected and unexpected notes, without the need to manipulate single notes or melodies to obtain distinct groups of expected and unexpected notes.

Our previous study on melodic expectations using probe notes selected using this model found that unexpected melodic notes elicited a frontal ERP negativity, compared to expected notes (Pearce et al, 2010). This effect occurred in the same time window in which the Early Right Anterior Negativity (ERAN) is commonly found, a component that is thought to reflect a deviance from music syntax that is kept in long-term memory. Although most of the studies reporting an ERAN have used chord sequence, reflecting implicit knowledge of typical chord progressions, the ERAN has also been shown to be elicited by deviant notes in melodies (Koelsch & Jentschke, 2010). Koelsch and Jentschke (2010) found that both harmonic and melodic irregularities resulted in an ERAN with a latency of 125ms, which for the chord progressions only was followed by an additional negativity with a maximum around 180ms.

Aims

Previous studies have investigated the role of attention on the ERAN induced by violations of harmonic sequences and found that the early anterior negativity between 150-300 ms was reduced when participants did not attend primarily to the music (Loui et al, 2005). Studying the effect of anesthesia on cognitive function, it was shown that the ERAN amplitude decreased with increasing sedation but only was completely abolished during unconsciousness (Heinke & Koelsch, 2005).

However, the role of attention has not explicitly been manipulated in previous studies of expectation in melodic processing. The current experiment was designed to dissociate the attentional processes from the effects related to musical expectation. In addition to investigating the effects of expectation and attention on the ERPs, the effects on the induced oscillatory brain activity was studied as well.

Method

We performed three separate 64-channel EEG experiments in which three groups of participants were listening, with different degrees of attention, to ecologically valid monophonic melodies played isochronously with a 500ms ITI. In the Full-Attention condition participants (n=17) just listened to the melodies without any further requirements. In the Within-Modality-Attention condition participants (n=15) had to additionally detect an oddball timbre, a manipulation that requires participants to attend to the music, but not necessarily to the melodic content. In the Across-Modality-Condition participants (n=15) memorized a nine-digit sequence while listening, a relatively demanding secondary task aimed at taking attention away from listening to the melodies. Participants listened with their eyes closed and were only required to make a response after the melody had finished.

We used our statistical learning model that acquires knowledge about sequential structure in music to estimate the conditional probability of the notes in these melodies, and from each melody a high and low probability note was selected for the EEG analyses. The subjective expectedness and unexpectedness of the high and low probability probe notes, respectively, have been validated previously (Pearce et al, 2010).

Results

Our results showed a robust early (~120-160 ms) frontal ERP negativity following the onset of unexpected notes, as compared to expected notes. This early ERP effect was unaffected by our attention manipulations, as no statistically significant differences were found between the three attention manipulation conditions.

In contrast, time-frequency analysis indicated an interaction of expectedness and attentional load in the theta band (5-7 Hz) power during a later time-window (~300 ms).

Conclusions

The expectedness of a melodic event seems to be extracted relatively quickly, within 160 ms after note onset, replicating previous results (Koelsch & Jentschke, 2010; Pearce et al, 2010). Importantly, this extraction is not modulated by the attentional load and seems to occur automatically. This suggests that early melodic processing is largely pre-attentive or implicit.

Previous studies that found modulations of the ERAN as a function of attentional load (Heinke & Koelsch, 2005; Loui et al,

2005) used violations in harmonic sequences, and found these modulations during later time windows (150-300ms, Loui et al, 2005), a time window into which the early negativity evoked by melodic violation does not extend. The results presented here seem to indicate different sensitivities to attentional manipulations for the extraction of harmonic and melodic expectedness.

Theta band activity is often associated with working memory load, and the current finding might reflect the interaction between attention required by the secondary task and the need to update the internal model of the melody. Taken together, these findings suggest that early stages of melodic processes are largely implicit, while later stages of processing might require attentional resources.

Keywords

Melodic Expectation, EEG, ERP, Time-Frequency Representation, Statistical Learning

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