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Effects of musical expertise on oscillatory brain activity in response to emotional sounds

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ABSTRACT

Emotions can be conveyed through a variety of channels in the auditory domain, be it via music, non-linguistic vocalizations, or speech prosody. Moreover, recent studies suggest that expertise in one sound category can impact the processing of emotional sounds in other sound categories as they found that musicians process more efficiently emotional musical and vocal sounds than non-musicians. However, the neural correlates of these modulations, especially their time course, are not very well understood. Consequently, we focused here on how the neural processing of emotional information varies as a function of sound category and expertise of participants. Electroencephalogram (EEG) of 20 non-musicians and 17 musicians was recorded while they listened to vocal (speech and vocalizations) and musical sounds. The amplitude of EEG-oscillatory activity in the theta, alpha, beta, and gamma band was quantified and Independent Component Analysis (ICA) was used to identify underlying components of brain activity in each band. Category differences were found in theta and alpha bands, due to larger responses to music and speech than to vocalizations, and in posterior beta, mainly due to differential processing of speech. In addition, we observed greater activation in frontal theta and alpha for musicians than for non-musicians, as well as an interaction between expertise and emotional content of sounds in frontal alpha. The results reflect musicians' expertise in recognition of emotion-conveying music, which seems to also generalize to emotional expressions conveyed by the human voice, in line with previous accounts of effects of expertise on musical and vocal sounds processing.

1. Introduction

Music, human non-linguistic vocalizations (e.g., laughter, scream, cry), and speech prosody (i.e., tone of the voice) constitute different types of sounds produced by humans that can convey information about their emotional state. While most hearing human adults are arguably experts in voice processing (see Kreiman, 1997; Belin et al., 2004; Campanella and Belin, 2007), there is wide variability in musical expertise across individuals. Numerous studies show that musicians are more accurate than non-musicians to discriminate musical timbre and to detect pitch violations within melodies (Brattico et al., 2006; Chartrand and Belin, 2006; Habibi et al., 2013). Musicianship is associated with altered brain structure, for example altered grey matter architecture in the left planum temporale, as well as with increased brain activity in response to different types of sound compared to non-musicians (e.g., Angulo-Perkins et al., 2014; Bermudez et al., 2009; Herdener et al., 2010; Schlaug et al., 1995; for a review see Pantev and Herholz, 2011). Furthermore, these differences might affect the processing of the emotional content of musical but also vocal sounds in musicians (Lima and Castro, 2011).

Recent research has focused on the neural networks underpinning music and speech processing. It is not yet entirely clear if the neural networks supporting speech and music processing are identical or not. There is evidence for both possibilities, as some works suggest that there is overlap between music and speech processing but other investigations found important differences (Brown et al., 2006; Rogalsky et al., 2011; Tierney et al., 2013). The shared syntactic integration resource hypothesis (SSIRH), for example, stresses the similarities across

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music and speech syntax, and hypothesizes overlapping processing regions on a neural level (Patel, 2003). Empirical support for this position comes from functional magnetic resonance imaging (fMRI) studies such as the one by Abrams et al. (2011) that revealed that – on a coarse scale – activity in similar brain areas is correlated with the processing of the temporal structure of music and language, while showing differences on a fine-grained scale. The brain areas supporting the processing of the temporal structure of music and speech included the inferior frontal cortex, parts of the superior and middle temporal cortex, and the auditory brainstem (Abrams et al., 2011).[1]

On the other hand, evidence for at least partly distinct neural networks comes from studies with patients suffering from bilateral lesions of the auditory cortex. They have shown that some patients may become aphasic but are still able to produce melodies (Hébert et al., 2003; Peretz et al., 2004) and that other patients suffering from amusia do not become aphasic (Peretz et al., 1994). Therefore, a specific functional network for the processing of music has been proposed (Peretz and Coltheart, 2003) and convergent findings have been found using fMRI (Rogalsky et al., 2011; Tierney et al., 2013).

In addition to studies focusing on differences between auditory processing of different sound categories like music and speech, there has been increasing scientific interest in the processing of emotions conveyed by auditory stimuli. Research and theory development pertaining to emotional processing have been largely based on studies using facial expressions (e.g., Ekman, 1993; Vuilleumier et al., 2001). Studies on the processing of auditory emotional expressions constitute an important complement. A positron emission tomography (PET) study comparing brain activity in response to pleasant and unpleasant musical stimuli revealed specific paralimbic, anterior cingulate, and frontal brain areas responding to emotional music (Blood et al., 1999; for brain activity related to chills elicited by music, see Blood and Zatorre, 2001; Salimpoor et al., 2011). In addition, lesion studies suggest an important role of the amygdala in the recognition of emotions conveyed by music (Gosselin et al., 2007). The brain areas suggested to be related to the emotional processing overlap to a certain degree with areas related to the processing of emotions expressed through other modalities, such as faces and voices, particularly in the amygdala (Aubé et al., 2015; Schirmer and Kotz, 2006; Wildgruber et al., 2009).

A few recent electrophysiological and behavioral studies have also aimed to reveal the time course of emotional sound processing. Gating studies have revealed that most emotions conveyed by speech prosody can be distinguished at around 500 ms after stimulus onset (Pell and Kotz, 2011; Rigoulot et al., 2013). Event-related potential (ERPs) studies have shown different electrophysiological responses between emotional and neutral prosody as early as 200 ms (Paulmann and Kotz, 2008; Schirmer et al., 2005) which is similar to the time course of the recognition of emotions conveyed with vocalizations such as screams (Liu et al., 2012; Sauter and Eimer, 2010).

In a related previous exploration, the impact of expertise in the processing of emotional sounds was investigated (music and human voice; Rigoulot et al., 2015, see also Sammler et al., 2007, for emotions conveyed by long musical excerpts). Piano and violin musical excerpts and speech and non-linguistic human vocalizations were presented to musicians and non-musicians, whose task was to listen attentively to the sounds and detect occasional targets (pure tones). All stimuli were expressing either fear, sadness, happiness, or were neutral. Although analyses were not focused on the emotional content of the sounds, the data revealed an early differentiation of sound category, within the first 100 ms after the onset of the sounds. Later effects were also found with higher responses to vocal stimuli. Importantly, in early and late temporal windows, brain responses were influenced by the level of expertise of participants, as musicians were more responsive to musical sounds than non-musicians, in line with the idea that musical training increases sensitivity to musical sounds. A positive transfer between music and speech has also been observed for the recognition of emotions. For example, in a training study, a randomly assigned group of 6-years-old received one year of musical training and outperformed a randomly assigned control group in the recognition of emotions conveyed by prosody (Thompson et al., 2004, see also Lappe et al., 2008).

The goal of the present study was to further investigate the time course of the neural processing of emotional sounds conveyed by different sound categories, as well as examining how the neural processing of these sounds was modulated by expertise. To do this, we reanalyzed our previous EEG experiment (Rigoulot et al., 2015) focusing on the oscillatory activity elicited by the different sound categories and emotions. Hence, the goal of the study was similar as in Rigoulot et al. (2015), namely assessing differences in the neural processing of vocal and musical emotional stimuli between musicians and non-musicians. The difference lies on the type of complementary analyses performed (event-related and frequency based, respectively). Specifically, we quantified the amplitudes of oscillatory brain activity in three frequency bands (theta: 4–8 Hz, alpha: 8–12 Hz, beta: 18–28 Hz, gamma: 30–40 Hz). Time-frequency analyses are a useful supplement to classic ERP analyses because the latter are subject to phase cancellation during signal averaging (Tallon-Baudry and Bertrand, 1999). In addition, dissociative patterns in different frequency bands might elucidate how different, yet related, processes take place at the same time. Brain activity in these frequency bands is invisible to imaging methods that rely on the hemodynamic response. Our results therefore provide important new information that complements that from studies using fMRI or PET.

Studies using fMRI have shown that different sound categories may activate different brain regions to different extents (Angulo-Perkins et al., 2014). Therefore, we used spatial independent component analysis to obtain components that were maximally independent in scalp distributions and time course. A detailed analysis of these components revealed differences between musicians and non-musicians in the processing of emotional sounds. Differences between the processing of music and speech were expected especially in the beta band (Shahin et al., 2009; Weiss and Müller, 2012). In addition, as vocalizations share little syntactic similarities with music and speech, we expected less overlap between the processing of vocalization and either music or speech than between music and speech. We anticipated that musicians would be more sensitive to the emotion content of musical excerpts than non-musicians which would be reflected in stronger electrophysiological responses to emotional sounds (see Lima and Castro, 2011).

2. Method

2.1. Participants

Forty-three fluent English or French-speaking participants were recruited through campus advertisement and participated in the experiment. They all reported normal hearing and normal or corrected-to-normal vision. Before the experiment, participants completed a questionnaire on demographic data and musical experience. They were assigned to one of two groups based on their musical experience. Those who had more than 5 years of musical training and played at least one instrument on a daily basis were classified as musicians (N = 20; 12 female, 17 right-handed, mean age = 25 years, age range = 20–32 years, mean number of years of musical training = 12 years, range of years of training = 7–23 years). The others were classified as non-musicians (N = 23; 12 female, 18 right-handed, mean age = 25 years, age range = 20–31 years, mean number of years of musical training = 1 year, range of years of training = 0–2 years). The study was approved by the Faculty of Medicine Institutional Review Board at McGill University (Montréal, Canada). Informed written consent was obtained

[1] The similarities of speech and music processing are also manifested in transfer effects found between speech and music. For example, music lessons can have a positive effect on reading ability (Lamb and Gregory, 1993) or verbal recall (Ho et al., 2003; Kilgour et al., 2000).