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ScienceDirect
International Journal of Psychophysiology 65 (2007) 69–84
INTERNATIONAL JOURNAL OF PSYCHOPHYSIOLOGY
www.elsevier.com/locate/ijpsycho

Metabolic and electric brain patterns during pleasant and unpleasant emotions induced by music masterpieces

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Received 7 July 2006; received in revised form 27 February 2007; accepted 5 March 2007
Available online 14 March 2007

Abstract

Brain correlates comparing pleasant and unpleasant states induced by three dissimilar masterpiece excerpts were obtained. Related emotional reactions to the music were studied using Principal Component Analysis of validated reports, fMRI, and EEG coherent activity. A piano selection by Bach and a symphonic passage from Mahler widely differing in musical features were used as pleasing pieces. A segment by Prodromidès was used as an unpleasing stimulus. Ten consecutive 30 s segments of each piece alternating with random static noise were played to 19 non-musician volunteers for a total of 30 min of auditory stimulation. Both brain approaches identified a left cortical network involved with pleasant feelings (Bach and Mahler *vs.* Prodromidès) including the left primary auditory area, posterior temporal, inferior parietal and prefrontal regions. While the primary auditory zone may provide an early affective quality, left cognitive areas may contribute to pleasant feelings when melodic sequences follow expected rules. In contrast, unpleasant emotions (Prodromidès *vs.* Bach and Mahler) involved the activation of the right frontopolar and paralimbic areas. Left activation with pleasant and right with unpleasant musical feelings is consistent with right supremacy in novel situations and left in predictable processes. When all musical excerpts were jointly compared to noise, in addition to bilateral auditory activation, the left temporal pole, inferior frontal gyrus, and frontopolar area were activated suggesting that cognitive and language processes were recruited in general responses to music. Sensory and cognitive integration seems required for musical emotion.

Keywords: Brain; Emotion; Music; fMRI; EEG coherence; Auditory processing; Music cognition

1. Introduction

Music is a humanly-produced complex auditory stimulus that is created, desired, and enjoyed mainly because of its powerful effects on emotions, feelings, and mood states (Thayer et al., 1994; Balkwill and Thompson, 1999; Huron, 2001; Baumgartner et al., 2006). Brain responses to experimentally-produced core musical features such as melodic stimuli (Zatorre et al., 1994; Patterson et al., 2002; Gagnon and Peretz, 2000), tonal information (Zatorre, 2001; Janata et al., 2002), musical timbre (Halpern et al., 2004), or rhythmic structure (Sakai et al., 1999; Samson et al., 2001) have been extensively studied. Since the intricate arrangement of musical features is what evokes an overall affective response (Hevner, 1936; Altenmüller et al., 2002) there has been an increasing interest to use real music as experimental stimulus (Krumhansl, 2003). Indeed, the use of actual music seems not only pertinent but required to study musical emotion. Specifically, music masterpieces are characterized by a skilful handling of various sound resources and musical elements to obtain the expression of an idea that usually evokes defined affective states, and consequently are ideally suited to analyze the neural correlates of the emotional response to music (Ogata, 1995; Blood and Zatorre, 2001; Altenmüller et al., 2002).

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0167-8760/$ - see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.ijpsycho.2007.03.004

Neural correlates of the emotional reactions to music were not studied until recently. A relatively few brain image studies have shown that some intense musical emotions require limbic and paralimbic networks involving the integration of sensory and cognitive information. Thus, stirring and thrilling feelings produced by favourite musical stimuli increase the blood flow in orbitofrontal cortex, medial subcallosal cingulate, and right frontopolar regions (Blood and Zatorre, 2001). Conversely, unpleasant feelings elicited by dissonant stimuli increase the flow in the right parahippocampal gyrus (Blood et al., 1999). An integration of limbic structures with perceptual and cognitive regions has been reported in non-musicians experiencing pleasant feelings elicited by the passive listening of unfamiliar instrumental music (Brown et al., 2004; Koelsch et al., 2006).

Even though the affective reaction to music engages regions that may explain distinct emotional responses, metabolic brain imaging by itself does not convey information on functional interactions among areas. While functional magnetic resonance imaging (fMRI) provides information on the brain areas involved in the processing of a particular stimulus, some electroencephalographic (EEG) analyses, especially coherent activity, reveal regional and global interactions. Functional coupling or coherent activation among brain sectors has become relevant in the explanation of several attentive, cognitive, and emotional operations. Coherent EEG activity (Singer, 1999; Nunez et al., 2001) related to information processing in specific frequencies (Basar et al., 2001; Patel and Balaban, 2000) may serve as a "binding" mechanism to integrate distant brain processes into unified emotional experiences and an increased coherent activity among cortical areas during musical processing has been reported (Petsche and Etlinger, 1998; Bhattacharya et al., 2001).

Since musical stimuli consist of a temporal flow of organized auditory events, music understanding and concurrent emotions can only be achieved over long time windows, in the order of seconds to minutes. The EEG is not only a suitable method to follow the moment to moment changes induced during prolonged periods of music listening, but also provides a temporal average of brain activity induced by the continuous flow of tones when an epoch of several seconds is analyzed (Bhattacharya et al., 2001; Patel and Balaban, 2000). For example, ongoing electrical activity recorded within the hippocampus changes with dissonant and unsettling musical intervals (Wieser and Mazzola, 1986). Furthermore, Ramos and Corsi-Cabrera (1989) found increased theta and decreased alpha activity using pleasant musical pieces.

In the present study brain correlates of some emotional reactions to music were analyzed in non-musicians during the listening of unfamiliar instrumental masterpieces without the request to perform any cognitive task, except paying attention to the music. In this way, brain resources become more available for spontaneous recollections, impressions, and feelings (Mullholland, 1995). Among the many musical masterpieces that have been carefully tested (Ramos et al., 1996; Flores-Gutiérrez, 2001), three were selected in view of their confirmed affective effects. A piano excerpt by J.S. Bach and a passage from G. Mahler's 5th Symphony were chosen because consistently elicit pleasant emotions, and a segment by J. Prodromidès because it was reliably reported to engender unpleasant emotions. Since there is no emotionally neutral music (Flores-Gutiérrez, 2001) to be used as control, brain correlates of emotional experience were singled out by comparing the pleasant and unpleasant emotional states reported by the subjects after listening to these music excerpts.

The specific emotions induced by each piece were identified using previously validated scales in 335 subjects (Ramos et al., 1996; Flores-Gutiérrez, 2001). Multiple specific feeling-denoting and formally-confirmed terms were recorded for each musical piece using visual-analogue scales and the respective affective profile was derived from a Principal Component Analysis of the data. The control of music characteristics such as structural features, expressive sequences, and cultural or idiosyncratic norms was accomplished by adding and comparing musical samples sharing an emotional effect but differing in musical features. Thus, the pleasant feelings elicited by the first two very different pieces were compared to each other and to the unpleasant feelings elicited by the third dissonant piece. The strategy of using music pieces widely different in melody, rhythm, harmony, intensity, spectrum, or instruments used, but evoking similar emotional effects constitutes a rigorous control of these fundamental musical variables. Moreover, since none of these pieces is commonly played in popular media and our subjects stated that they did not know them, such strategy provides a further control of the cultural and learned effects.

The pleasant or unpleasant responses to these carefully selected music excerpts were expected to correlate with distinctive images of localized brain metabolic activation and patterns of coherent interactions among brain regions. Music emotion possibly emerges from the initial activation of brain regions directly involved in cortical music perception, and the subsequent activation of independent emotional systems of the sensory modality, aside from coherent cortical activations involved in the extraction of musical meaning. Since there are no combined brain fMRI and coherent EEG studies of emotions during musical masterpiece listening, an open approach was adopted and a complete exploration of all possible brain regions and inter-electrode combinations was undertaken. Even though the general metabolic and coherent EEG responses was explored without *a-priori* defining regions of interest, we expected to find predominant left hemisphere activation with pleasant music emotions and right hemisphere activation with negative musical emotions coupled with distinct limbic and paralimbic involvement. A dissociation of the left and right hemisphere participation during pleasant and unpleasant musical emotions can be expected because positive and negative affects involve predominant activation of the left and right hemisphere respectively (Davidson, 1992; Blood et al., 1999; Herrington et al., 2005; Koelsch et al., 2006). Moreover, using music stimuli, Gagnon and Peretz (2000) found left hemisphere advantage for pleasantness ratings of tonal and atonal melodies, and activations of left fronto-temporal regions with musically elicited positive feelings and of right anterior