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Event-related skin conductance responses to musical emotions in humans

Stéphanie Khalfa*, Peretz Isabelle, Blondin Jean-Pierre, Robert Manon

Department of Psychology, University of Montreal, CP 6128 Succursale Centre-Ville, Montréal, Québec H3C 3J7, Canada

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Abstract

While the reasons underlying musical emotions are unclear, music is nevertheless a powerful elicitor of emotion, and as such, may induce autonomic nervous system responses. One typical measure of this neural pathway is the skin conductance response (SCR). This response generally depends upon stimulus arousal, one of the two motivational determinants of emotion. The objective of the present study was to verify whether emotional reactions to music elicit such event-related autonomic responses. To this aim, four musical emotions varying in arousal were employed: fear, happiness, sadness and peacefulness. SCRs were found to be greater with the two more stimulating emotions, fear and happiness, as compared to the two more relaxing emotions, sadness and peacefulness ($P < 0.05$). In addition, subjects' ratings of the emotional clarity for each excerpt did not parallel the corresponding SCRs magnitudes. The results show that SCRs can be evoked and modulated by musical emotional arousal, but are not sensitive to emotional clarity. While several studies have been performed with visual scenes and environmental sounds, the present study brings similar evidence from the musical domain.

Keywords: Emotion; Music; Electrodermal activity; Arousal; Sympathetic nervous system

The primary motivation for listening to music is the resulting emotional response that is experienced [12,15]. Music is indeed able to elicit particularly strong and immediate emotional reactions such as thrills and tears [6]. In this way, music is a unique route evoking emotions in the auditory domain. Research on emotion has shown that autonomic responses, among other measures, can offer reliable indices about emotional reactions. For instance, autonomic responses have been shown to vary according to reports of affective valence (i.e. pleasant or unpleasant) and arousal (i.e. calming or stimulating), which are two motivational determinants of emotions [8], including musical emotions [11]. Thus, music that induces intense emotions [6] should also activate the neural autonomic pathway.

Measuring electrodermal activity is one technique that provides readily accessible autonomic indices, such as the skin conductance response (SCR). SCR is due to rapid fluctuations in eccrine sweat gland activity, which result from the liberation of acetylcholin by the sympathetic nervous system [2]. This measure has the advantage over other measures of the autonomic nervous system such as heart rate, since SCR is under strict control of the sympathetic branch of the nervous system. Moreover, SCRs have been shown to be reliable measures of autonomic expressions of emotions, in domains other than music. For instance, in both visual (affective picture such as a beautiful landscape) and auditory (naturally occurring sounds such as crying baby) modalities, SCRs proved to be modulated by valence and to increase with rated arousal [3,8]. Accordingly, we expected to observe a proportionally more important effect of arousal than valence for musical stimuli.

The study of emotions induced by music has already benefited from the use of electrodermal indices. However, studies have typically monitored tonic levels of electrodermal activity over long-duration periods of music listening (30-s–6-min) [1,7], rather than the phasic, more transient changes occurring in response to brief stimulations (i.e. a few seconds). Tonic changes in skin conductance level, such as those recorded over a few minutes during long-duration stimuli, and phasic changes in the form of SCRs occurring 1–4 s after discrete stimuli, may not reflect the same underlying physiological and psychological processes [10]. Indeed, emotions are brief and event-related, generally

* Corresponding author. Tel.: +1-514-343-6111/4322; fax: +1-514-343-5787.

E-mail address: skhalfa@skhalfa.com (S. Khalfa).

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occurring when adaptation is required, whereas mood is of a longer duration and corresponds to diffuse affective states [16]. Studying the phasic SCR provides an opportunity to study emotions rather than mood.

The primary goal of the present experiment was to determine whether emotions that are expressed in musical excerpts could induce event-related responses of the sympathetic nervous system. To this aim, SCR measurements were used. Musical excerpts of a few seconds in duration should be appropriate to evoke such event-related responses, since even 0.25 s musical excerpts are sufficient for accurate distinction between happiness and sadness [13]. Therefore, in the present study, SCRs were expected to distinguish between musical excerpts according to their emotional determinants. To this aim, four distinct musical emotions (fear, happiness, sadness, and peacefulness) varying in valence and arousal were evaluated. Judgments of emotional intensity/clarity were obtained after each musical excerpt presentation, so as to ensure listeners recognized the intended emotion.

Only subjects who showed detectable electrodermal responses (a minimum of 0.1 microSiemens (μS)) to any stimuli were included in the study. In addition, subjects demonstrating a habituation to their SCRs before the 14th excerpt (i.e. half the number of stimuli), using a three-trials criterion [9], were excluded. Three out of the 37 non-musicians participants were excluded for these reasons. The remaining 34 subjects (12 males and 22 females) had a mean age of 23.8 years (SD = 4.21).

The experiment was approved by the institutional ethics committee of the Geriatric University Institute of Montreal and was conducted with the understanding and consent of each subject.

Stimuli consisted of 28 musical clips of 7 s duration, for which the emotional content has been previously assessed and validated [14]. These clips were composed in a film music genre for research means, and so were completely novel for the subjects. The clips were equally distributed across four emotions, and equated in terms of arousal and valence. However, due to a strong habituation effect across the entire set of musical clips, SCRs were analyzed for the first half of excerpts presented. In this smaller set, four excerpts were to evoke a sense of fear ('peur'), another four happiness ('gaieté'), three others sadness ('tristesse') and three clips peacefulness ('apaisement') (see musical scores in Appendix A). As in the literature, happy excerpts were characterized by a fast tempo and were played in a major mode whereas sad excerpts had a slow tempo and were played in a minor mode [13]. The structural determinants of the peaceful and fearful excerpts are less well established and were empirically verified in our previous study [14].

In the validation of our material, arousal and valence of each stimulus was evaluated on a 10-point scale, from 1 to 10 (with 1 meaning 'very calming' and 10 'very stimulating' on the arousal scale; and with 1 meaning 'very unpleasant' and 10 'very pleasant' on the valence scale). In Fig. 1, average values of valence and arousal of the 14 first excerpts for which the SCRs did not show habituation, are given as a function of each musical emotion. A significant effect of the emotion category was observed on the ratings of arousal ($F(3,36) = 139.6$, $P < 0.001$) and valence ($F(3,36) = 58.4$, $P < 0.0001$). Both Fearful and happy melodies were rated more stimulating than those peaceful or sad melodies (Tuckey test, $P < 0.05$). In contrast, melodies associated with peacefulness and happiness were judged as more pleasant than melodies associated with sadness and fear (Tuckey test, $P < 0.05$).

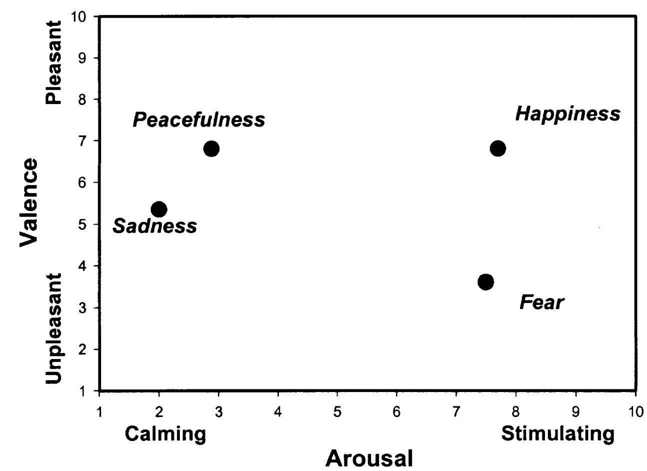

Fig. 1. Average values of valence and arousal of the ten musical excerpts used in the study.

The melodies were computer-generated via a synthesizer (Rolland Sound Canevas SC50) using an approximation of a piano timbre. The loudness of all musical excerpts was equalized.

Skin conductance was recorded from the right hand, with a pair of Ag-AgCl electrodes (0.8 cm diameter) attached to the palmar surface of the medial phalange of the index and middle fingers, and filled with a 0.050 molar NaCl paste. All recording procedures followed the recommendations set forth by Fowles et al. [5]. Data acquisition and quantification was performed using a Coulbourn S71-23 Coupler, and a customized program created with InstEP Systems v3.3.

The experiment was performed in a quiet room. A 5-min rest period preceded the onset of the experiment. Subjects were seated comfortably, asked to remain as still as possible, and to listen attentively to the melodies. The stimuli were presented binaurally in a pseudo-randomized order through MDR-v200 Sony headphones. Following each melody, the subjects' task was to select, in a forced-choice format, one emotional category (either sadness, happiness, fear, or peacefulness) that best corresponded to the emotion conveyed by the stimulus, and to rate the intensity/clarity of the chosen emotion on a scale from 1 (unclear) to 10 (very clear). SCRs were recorded throughout the task.

Each stimulus presentation was followed by an interval of

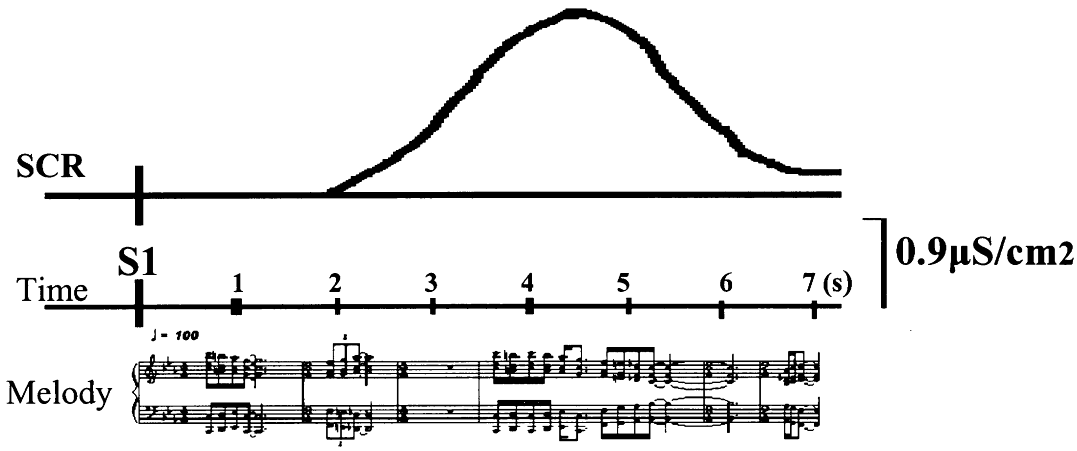

Fig. 2. Example of one SCR to a fearful musical clip.

at least 20 s to allow for skin conductance recovery to baseline before the next stimulus was presented. This inter-trial interval lasted as long as necessary for skin conductance to regain stability, so as to avoid spontaneous electrodermal fluctuations.

Experimental results for a particular stimulus were taken into account if more than 60% of the participants chose the intended emotion, with an emotional intensity (clarity) superior to 4 on a 10-point scale (from 1 (unclear) to 10 (very clear)). Moreover, the first two stimuli presented to any participant were excluded from the analyzes due to the strong orienting component in the SCR to these stimuli. According to these criterion only results for one sad excerpt, three fearful excerpts, two peaceful and four happy melodies out of the 14 initial melodies were retained in the analyzes.

Responses were considered in the analyzes when they occurred within a latency window of 1–3 s following stimulus onset [17]. The measure of electrodermal activity corresponded to the maximal amplitude of the SCR elicited by each stimulus in relation to the onset level (representing the baseline). Fig. 2 shows an example of a typical SCR to a fearful melody. SCR amplitudes corresponding to melodies of each emotional category (i.e. fearful, peaceful, etc.) were averaged. Thus, four different SCR average magnitudes (for the four basic emotions) were calculated for each listener.

Psychophysiological results are characterized by extreme values spread out over a wide range (the coefficient variation is superior to 12%) and are positively skewed. Consequently, the Kolmogorov–Smirnov normality test failed to reach significance. Statistical analyzes were performed using non-parametric tests.

The average SCR magnitudes for excerpts of each emotional category are presented in the lower part of Fig. 3. Friedman repeated measures analysis of variance (RM-ANOVA) revealed an effect of emotional category ($\chi^2 = 17.64$, d.f. = 3, $P < 0.001$). Pairwise multiple comparison procedures (Dunn test) indicated that SCRs were greater for melodies representing both fear and happiness than sadness and peacefulness ($P < 0.05$). No significant difference of SCR was found between happiness and fear nor between sadness and peacefulness.

As shown in the upper part of Fig. 3, the intensity (clarity) assessment of the emotion conveyed by melodies varied according to the emotional category. Fear was judged as less clearly represented than the other three emotions. The one-way RM-ANOVA confirmed this observation ($F(3,91) = 14.2$, $P < 0.001$). As well, post-hoc comparisons indicated that intensity scores for the fearful excerpts were lower for fear than for the other emotional excerpts (Tukey test, $P < 0.001$), although fear is the emotion that provided the greatest SCR.

The present study convincingly demonstrates that event-related SCRs are sensitive measures of music-induced emotions. Moreover, results revealed that musical excerpts could induce SCRs that differ according to underlying dimensions of emotion. Both fear and happiness were associated with higher SCR magnitudes than sadness and peace-

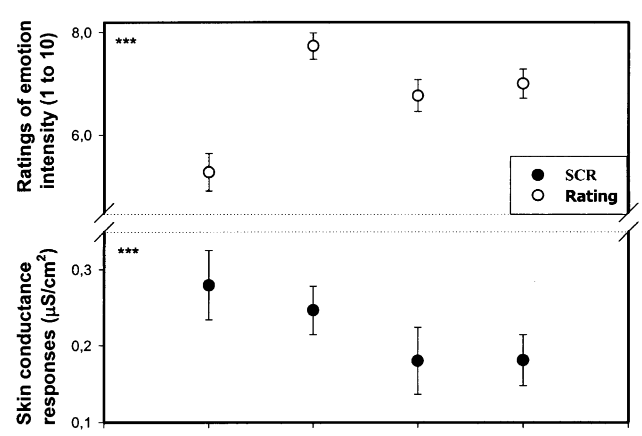

Fig. 3. Means and standard errors for SCR magnitudes (lower part) and emotional ratings (upper part) for the musical clips evoking four different emotions. *** ($P < 0.001$) represents level of significance for the effect of emotional category

fulness. The fact that fear and happiness are strongly arousing emotions, as compared to sadness and peacefulness, suggests that arousal is the relevant emotional dimension as related to SCRs. This is in accordance with the literature showing that electrodermal activity is more sensitive to variations in emotional arousal rather than to valence [3,18]. The arousal effect obtained using musical excerpts parallels the one obtained when slides of affective pictures or environmental sounds were employed [3,8]. In these previous experiments, larger SCR changes were significantly related to increased arousal ratings, but not to valence rating. In the present experiment, the pleasant emotion of happiness was not statistically differentiated from the unpleasant emotion of fear.

Another point raised by this study is that SCR magnitudes do not parallel the corresponding clarity judgment of the emotion represented. Fearful excerpts eliciting the greatest SCRs were not rated as the most intense. Therefore, SCR was not a measure of the emotional category and clarity but was dependant upon arousal.

The major finding of the present study is that musical emotions induce SCRs varying according to arousal. The activation of the sympathetic nervous system by musical excerpts is itself under control of many subcortical structures such as the amygdala, the hypothalamus, and cortical structures, especially the orbito-frontal cortex and the temporal lobes [2,4]. Thus, SCR measurement may offer a window to the brain structures involved in emotional responses to music. Indeed, it possible that SCRs sensitivity to arousal in musical emotions is subject to top-down regulations. In further studies, the recording of SCRs, in addition to the use of neuroimaging techniques, would allow the assessment and the localization of neural networks associated with event-related autonomic responses to music arousal.

Processing of emotions in the auditory domain is less well documented than in the visual domain. In order to fill that gap, music seems a choice means to convey emotions and to study auditory emotions. Contrary to affective pictures that possess a spatial structure, music has a temporal structure and is special in that it has unknown evolutionary forces. Despite these differences, our research has shown that event-related measures of musical emotions can be obtained, suggesting similarities in the processing of both musical and visual emotions. The processing of musical emotions may not be domain-specific, that is, it may not be different in nature from the emotions elicited by other events such as words and pictures.

Further studies are necessary to verify this hypothesis and to identify the structures and physiological mechanisms involved in the treatment of musical emotions. Moreover, understanding the physiology of musical emotions processing may provide insight into the biological foundations of music.

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Appendix A. Musical score for each of the first 14 stimuli