International Journal of Psychophysiology 71 (2009) 37–42

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Modulation of the startle reflex by pleasant and unpleasant music

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ARTICLE INFO

Available online 23 July 2008

Keywords:
Music
Emotion
Startle reflex
Zygomatic
Corrugator
Skin conductance
Heart rate

ABSTRACT

The issue of emotional feelings to music is the object of a classic debate in music psychology. Emotivists argue that emotions are really felt in response to music, whereas cognitivists believe that music is only representative of emotions. Psychophysiological recordings of emotional feelings to music might help to resolve the debate, but past studies have failed to show clear and consistent differences between musical excerpts of different emotional valence. Here, we compared the effects of pleasant and unpleasant musical excerpts on the startle eye blink reflex and associated body markers (such as the corrugator and zygomatic activity, skin conductance level and heart rate). The startle eye blink amplitude was larger and its latency was shorter during unpleasant compared with pleasant music, suggesting that the defensive emotional system was indeed modulated by music. Corrugator activity was also enhanced during unpleasant music, whereas skin conductance level was higher for pleasant excerpts. The startle reflex was the response that contributed the most in distinguishing pleasant and unpleasant music. Taken together, these results provide strong evidence that emotions were felt in response to music, supporting the emotivist stance.

1. Introduction

The emotional power of music remains a mystery. Unlike most emotional inducers, music is not a sentient being nor does it seem to have any obvious adaptive value (Pinker, 1997). Yet, most people affirm that they feel strong emotions when they listen to music (Sloboda and O'Neill, 2001). This paradox led many music scholars to believe that music is only iconic or representative of emotion, a position coined as 'cognitivist' by Kivy (1990). Opponents to this view, known as 'emotivists', feel that the cognitivist position does not render justice to the direct and unmediated fashion in which emotions are experienced by listeners (Davies, 2001). Although the debate is at a theoretical level, its resolution has practical implications for interpreting music effects. Indeed, if music is only representative of emotion, its therapeutic value could be seriously questioned. Studies measuring physiological, endocrine and brain responses to music as indices of emotional reactivity have supported the emotivist view, but the nature of these emotional responses and their resemblance with emotions induced by other stimuli is unclear.

1.1. Autonomic nervous system responses

In order to show that people not only recognize but feel emotions in response to music, emotional reactions should be measured by techniques that are independent of voluntary subject control, such as psychophysiological measures. Following this line of research, Krumhansl (1997) compared the autonomic responses elicited by different musical emotions and found that sad, happy, and fearful music could be differentiated by their autonomic activation patterns: Sad music was most strongly associated with changes in heart rate, blood pressure, skin conductance and skin temperature, fearful music was mostly associated with changes in the rate and amplitude of blood flow, and happy music principally produced changes in respiratory activity and showed the highest skin conductance level (SCL). However, subsequent studies have failed to replicate many of these findings. Khalfa et al. (2002) found that skin conductance responses (SCR) were highest during the listening of fearful music, Baumgartner et al. (2006) observed increased SCL during sad and fearful music compared to happy music, and Nater et al. (2006) found higher SCL during the listening of unpleasant compared to pleasant music. Moreover, Nater et al. (2006) found higher heart rates during unpleasant compared to pleasant music, whereas Sammler et al. (2007), Witvliet and Vrana (2007), and Krumhansl (1997) found the opposite. Therefore, there are inconsistent findings of the intensity and direction of these autonomic responses between studies.

Such inconsistencies across psychophysiological emotion studies are relatively common (Cacioppo et al., 2000), and the outcomes may be related to some context-bound patterns of actions that allow the same emotion to be associated with a wide range of behavior and varying patterns of somatovisceral activation (Lang et al., 1990). However, it should be noted that some psychophysiological measures appear more reliable than others. For example, respiration rate appears to be consistently higher during happy and fearful music than during

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doi:10.1016/j.ijpsycho.2008.07.010

sad music (Baumgartner et al., 2006; Etzel et al., 2006; Krumhansl, 1997; Nyklicek et al., 1997), although this effect may reflect differences in arousal that differentiate happiness and fear from sadness, and not musical emotions *per se* (Nyklicek et al., 1997). Indeed, cognitive theories of emotion have criticised the use of autonomic measures as indexes of felt emotions due to the non-specific nature of arousal (Schacter and Singer, 1962). For example, high arousal characterizes both fear and happiness. Moreover, in music, arousal is known to be mainly driven by its tempo (Gomez and Danuser, 2007). The fact that respiration rate has been linked to tempo through what appears to be a general entrainment mechanism further contributes to discredit respiration rate as a clear index of musical emotions (Etzel et al., 2006). Although tempo is one of the main determinants of musical emotions, musical emotions depend on many other factors than simple tempo perception (Peretz et al., 1998). Thus, until the context-bound patterns of action that affect the autonomic responses to musical emotions understood and controlled, more specific measures of emotional reactions to music are needed to convince the sceptical cognitivist that music effectively induces emotions in the listener.

1.2. Hormonal responses

Neuroendocrine and hormonal responses constitute yet another type of involuntary response that can be linked to emotional feelings. Contrary to physiological responses, some hormones can be more readily associated with positive or negative emotion (Barak, 2006), such as cortisol with stress and negative emotions, or immunoglobin A (S-IgA) with relaxation and positive emotions (Watanuki and Kim, 2005). A few studies have found that listening to relaxing and pleasant music was associated with lower levels of cortisol (Khalfa et al., 2003; Miluk-Kolasa et al., 1994), lower plasmatic levels of β-endorphins (McKinney et al., 1997) and higher mu-opiate receptor expression (Stefano et al., 2004). However, those studies only compared music with a silent control condition. Therefore, the observed effect may be attributed to non-emotional aspects of the musical condition, such as distraction. Indeed, when two musical conditions are compared, no differences were found between music inducing positive or negative moods on levels of cortisol (Clark et al., 2001), nor between up- or down-lifting musical excerpts on levels of S-Iga, dopamine, norepinephrenine, epinephrine or number of lymphocites (Hirokawa and Ohira, 2003), suggesting that the differences previously observed were mainly related to non-specific aspects of the task. One exception is the study by Gerra et al. (1998), who observed higher levels of β-endorphins, adrenocorticotropic hormone (ACTH), cortisol, norepinephrine and growth hormone in youngsters listening to techno-music compared to classical music. However, these changes in neuroendocrine responses appeared to be mainly linked to the high arousal induced by the techno-music, combined with the novelty-seeking temperament of the participants. Neuroendocrine responses, although promising, appear to have the same limitations as autonomic responses.

1.3. Brain imaging

Brain imaging techniques provide yet another way to measure emotional reactions objectively. Studies using such techniques have shown that pleasant emotional reactions to music activate regions previously known to be involved in approach-related behaviors, such as the prefrontal cortex (Blood and Zatorre, 2001; Blood et al., 1999; Koelsch et al., 2006; Menon and Levitin, 2005), periacqueductal gray matter (Blood and Zatorre, 2001), and the nucleus accumbens (Blood and Zatorre, 2001; Menon and Levitin, 2005). Negative emotions in contrast activate regions involved in withdrawal-related behavior, such as the parahippocampal gyrus (Blood et al., 1999) and amygdala (Koelsch et al., 2006). Although these observations are fairly consistent with activations observed with other emotional inducers, brain activations alone do not allow for the distinction between processes involved in emotional perception and emotional feeling. Physiological changes that affect the body and its responses are necessary to demonstrate the induction of emotional feelings.

1.4. Present study

Although these studies demonstrate that some emotions are felt in response to music, the results do not definitely refute the cognitivist viewpoint, as many psychophysiological responses are inconsistent, and the responses that appear to induce the most stable responses (e.g., respiration rate or hormonal responses) may be influenced by other confounding factors, such as arousal or distraction. Finally, brain imaging techniques cannot solely discriminate emotional feelings from other aspects of emotional processing.

In order to demonstrate the induction of emotional feelings, involuntary changes that affect the body and emotional processing have to be observed in response to musical excerpts conveying different emotions. In this context, the startle reflex is a good candidate measure, as it has been extensively and successfully used to probe emotional reactions. It is an automatic defensive reaction to surprising stimuli and can be measured by the magnitude of the eye blink triggered by a loud white noise. As a response of the defensive emotional system, it is frequently used to test the efficacy of anxiolytic drugs (Winslow et al., 2007) or to explore emotional reactivity in affective disorders (Grillon and Baas, 2003). In normal individuals, it is typically enhanced by negative emotions and diminished by positive ones, using pictures (Lang et al., 1998), films (Kaviani et al., 2004), or sounds (Bradley and Lang, 2000) to induce emotions. The present study applied an affective startle modulation paradigm to musical stimuli and compared the effects of pleasant and unpleasant musical excerpts on the acoustic startle blink reflex. If emotions are induced during music listening, then the startle reflex should be larger and of shorter latency during unpleasant music compared to pleasant music.

Moreover, in order to measure music effects on emotional reactions, heart rate and skin conductance responses were also obtained along with facial expressions by assessing electromyographic (EMG) activity of the *zygomaticus major* (smiling) and the *corrugator supercilii* (frowning). Previous studies have shown that the activity of these muscles discriminated well between pleasant and unpleasant emotions elicited by pictures (Lang et al., 1998). Thus, it was expected that zygomatic activity would be higher during pleasant music, and corrugator activity to be more noticeable during unpleasant music (Witvliet and Vrana, 2007).

2. Methods

2.1. Participants

Sixteen participants (9F, 7M), aged between 20 and 40 years (M=25.1±9.3 years) took part in this study. None were musicians, all reported fewer than five years of musical training, and none claimed any regular practice of a musical instrument.

2.2. Musical excerpts

The musical excerpts used in this study were adapted from a prior study on pain modulation (Roy et al., 2008). Three 100 s excerpts of pleasant music and three 100 s excerpts of unpleasant music were selected from a pool of 30 musical excerpts. Each of the 30 excerpts had been previously evaluated by 20 independent participants on the dimensions of valence (on a 0=‘pleasant’ and 9=‘unpleasant’) and arousal (with 0=‘relaxing’ and 9=‘stimulating’). Three highly pleasant and three highly unpleasant excerpts were selected. Since unpleasant excerpts were always judged to be arousing, all excerpts were selected in the high range of arousal. Pleasant excerpts were judged to be more pleasant than unpleasant excerpts (mean valence for pleasant excerpts = 2.40, mean valence for unpleasant excerpts = 6.68; $t(19) = 5.58$, $p < 0.05$) and did not differ in arousal (mean arousal for pleasant excerpts = 5.00, mean arousal for unpleasant excerpts = 5.18; t (19) = 1.535, n.s.). The selected pleasant excerpts were taken from the classical or jazz/pop repertoire and could be described as uplifting, with a rather fast tempo, such as the "Opening of William Tell" by Rossini. Unpleasant excerpts were mainly taken from the contemporary music repertoire. Examples of excerpts for each emotion category can be heard on our web site at www.brams.umontreal.ca/peretz. All selections were normalized to equate loudness across musical excerpts by setting the peaks of the excerpts at 8% of the maximum volume allowed, using the normalisation option of the *Cool Edit 2* sound editing software.

The primary emotions (sadness, happiness, fear, anger, peacefulness and surprise) and moods (anger, depression, fatigue, anxiety, vigor and confusion, as measured with the "profile of mood states", POMS; McNair et al., 1992), induced by those excerpts were also previously assessed (Roy et al., 2008). Results showed that the primary emotions conveyed by the excerpts were consistent with their emotional valence. Pleasant excerpts were associated with happiness whereas unpleasant ones were associated with fear and anger. Results on the mood questionnaire confirmed these observations: The subscales for highly arousing negative moods, such as anger and anxiety, were higher after listening to the unpleasant excerpts, whereas the subscales for less arousing moods, such as depression, remained unaffected. Thus, the selected excerpts convey primary emotions and induce moods consistent with their positive or negative valence and their high level of arousal.

2.3. Data collection and reduction

Startle responses were elicited by a 100 dB SPL, 50 ms burst of white noise, with instantaneous rise time. The acoustic startle probe was presented over Sony MDR-v200 headphones. The eye blink component of the startle reflex was recorded electromyographically from the orbicularis oculi muscle beneath the left eye, using two miniature 4 mm Ag/AgCl shielded electrodes placed 1.5 cm apart and a signal ground electrode placed on the forehead, following the guidelines of Blumenthal et al. (2005). The signal was amplified by 1000 and band-pass filtered at 90 Hz–500 Hz using a Biopac MP150 System (Biopac Systems, Inc., Santa Barbara, CA). The sampling rate was set at 1000 Hz. The amplified signal was then transformed using the root mean square.

The maximum amplitude and latency of each startle response were extracted from the data. Following the guidelines of Balaban et al. (1986), only responses for which the onset occurred between 21 and 120 ms from noise onset were considered as startle responses and included in the analysis. The raw blink measurements were then standardised within each subject to decrease variability due to differences in the absolute size of the startle blink across subjects, and expressed as T scores ($50 + 10z$), which yielded a mean of 50 and a standard deviation of 10 for each subject. The blink amplitudes and latencies T scores were then averaged for the pleasant and unpleasant music condition.

To assess the sound intensity of the musical excerpts prior to each startle probe, the total root mean square amplitude (RMS) power was extracted for 1 s windows preceding each burst of white noise and averaged for each subject and musical condition. Facial EMG was recorded over the left corrugator and zygomatic sites (Fridlund and Cacioppo, 1986), using 8 mm Ag/AgCl shielded electrodes. Signals were bandpass filtered from 90 Hz to 1000 Hz and transformed using the root mean square. Sampling rate was set at 1000 Hz. Area under the curve of the rectified EMG signal were then extracted for the corrugator and zygomatic muscle.

Electrocardiogram (ECG) was recorded using a standard 3 lead montage (Einthoven lead 2 configuration) (Biopac EL503). Instantaneous intervals between each R-wave of the ECG (RRI) were calculated from the ECG using a peak detection algorithm to detect successive R-waves and obtain a continuous R–R tachogram. Careful examination of the ECG and the tachogram ensured that the automatic R-wave detection procedure had been performed correctly.

Skin conductance level (SCL) was recorded on the palmar surface of the left hand, at the thenar and hypothenar eminences (Fowles et al., 1981). The signal was smoothed and the mean SCL was calculated for the whole duration of each musical excerpt and averaged for the pleasant and unpleasant music condition.

2.4. Procedure

The physiological sensors were affixed while the participants sat comfortably in a quiet room. The pleasant and unpleasant excerpts were presented in a counterbalanced order across participants. Fig. 1 illustrates the procedure for one musical excerpt. Each musical excerpt started with an emotional induction period of 21.3 s in which there were no startle probes. The remaining 78.7 s were divided in six 11 s time window in which a startle probe occurred randomly. Each time window was separated by a period of 2.3 s in which no startle probe occurred. After each musical excerpt, the subject rated his/her emotional reaction to the music on the dimensions of valence (0 = unpleasant, 9 = pleasant) and arousal (0 = relaxing, 9 = stimulating).

2.5. Data analysis

The musical excerpts were assessed statistically for the expected emotional effects by comparing the mean ratings of valence and arousal. Sound intensity was assessed before each startle probe in both musical conditions using RMS power preceding each startle probe for the pleasant and unpleasant music conditions. After these control analyses, a multivariate analysis of variance (MANOVA) was conducted to test for the effects of emotional condition (pleasant or unpleasant) on the means of all the physiological measures used (startle blink reflex amplitude and latency, corrugator and zygomatic activity, RRI and SCL). The MANOVA was followed by separate t-tests for each physiological measure. Finally, a discriminant function analysis was conducted to test if some patterns of physiological activation could reliably discriminate between the pleasant and unpleasant musical conditions.

3. Results

3.1. Self-reported emotions

The mean valence and arousal ratings were calculated for the pleasant and unpleasant excerpts. The t-tests performed on these

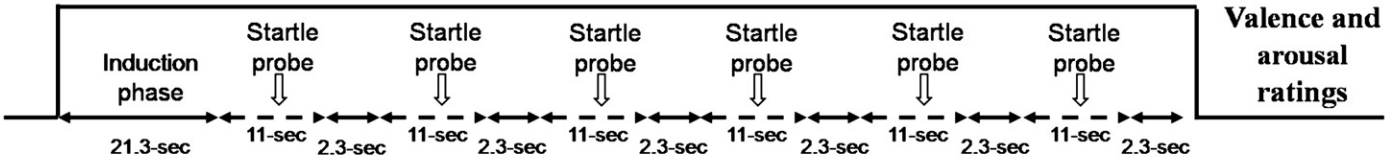

Fig. 1. Distribution of startle probes during one musical excerpt. Participants listened passively to music for 21.3 s. In the last 78.7 s of the excerpts, six startle probes were randomly delivered within 11 tie windows separated by periods of 2.3 s during which no probe could occur.

average ratings confirmed that the intended emotions of the musical excerpts were well recognized. The pleasant and unpleasant excerpts differed significantly on the dimension of valence (with a mean rating of 8.49 and 1.91, respectively; t (15) = 13.04, $p < 0.001$). In contrast, pleasant and unpleasant musical excerpts did not differ on the dimension of arousal (with a mean rating of 6.41 and 7.50, respectively; t (15) = 1.79, n.s.).

3.2. Sound amplitude

The RMS power of the 1 s windows preceding each startle probe was equivalent for the pleasant (23.03 ± 0.68) and unpleasant (23.21 ± 0.49) musical excerpts (t (15) = 0.31, n.s.).

3.3. Physiological measures

Fig. 2 illustrates the mean values of each physiological measure for the pleasant and unpleasant music condition. The results of the MANOVA showed that the physiological responses were significantly affected by the musical condition (F (6, 10) = 6.86, $p < 0.01$, $\eta^2 = 0.81$). The startle blink reflex was larger ($t(15) = 3.35$, $p < 0.01$, $\eta^2 = 0.43$) and faster (t (15) = 2.81, $p < 0.05$, $\eta^2 = 0.35$) during the unpleasant music as compared to the pleasant music. Activity of the corrugator muscle was higher during the unpleasant condition (t (15) = 2.79, $p < 0.05$, $\eta^2 = 0.34$), but no significant difference in the activity of the zygomatic muscle was obtained between the two musical conditions (t (15) = 1.35, n.s., $\eta^2 = 0.11$). RRI was also not affected by the valence of the musical excerpts (t (15) = 0.72, n.s., $\eta^2 = 0.03$). In contrast, the SCL was found to be larger during the pleasant than the unpleasant music condition (t (15) = 2.43, $p < 0.05$, $\eta^2 = 0.28$). The physiological responses were not limited to the 21.3 initial seconds without startle probes but were considered for the whole excerpt instead because only non-significant trends in the same direction were obtained on the initial part of the musical excerpts.

Table 1
Canonical variate correlation coefficients for the discriminant function

Startle amplitude	0.875
Startle latency	−0.728
Corrugator activity	0.080
Zygomatic activity	−0.074
Skin conductance level	−0.030
R–R interval	−0.009

3.4. Discriminant analysis

The results of the discriminant analysis showed that the pleasant and unpleasant excerpts could easily be differentiated by a single function (Wilk's lambda (6) = 0.51, $p < 0.01$). This function correctly classified pleasant excerpts in 75% of cases and unpleasant excerpts in 87.5% of cases. Table 1 summarizes the canonical variate correlation coefficients of each physiological variable for the discriminant function. These canonical variate correlation coefficients were much more important for startle amplitude and latency compared to the other physiological measures, indicating that the startle reflex was the measure that contributed the most to the separation of the musical conditions. Although there is a lack of consensus regarding how high correlations in a loading matrix should be interpreted, typically only

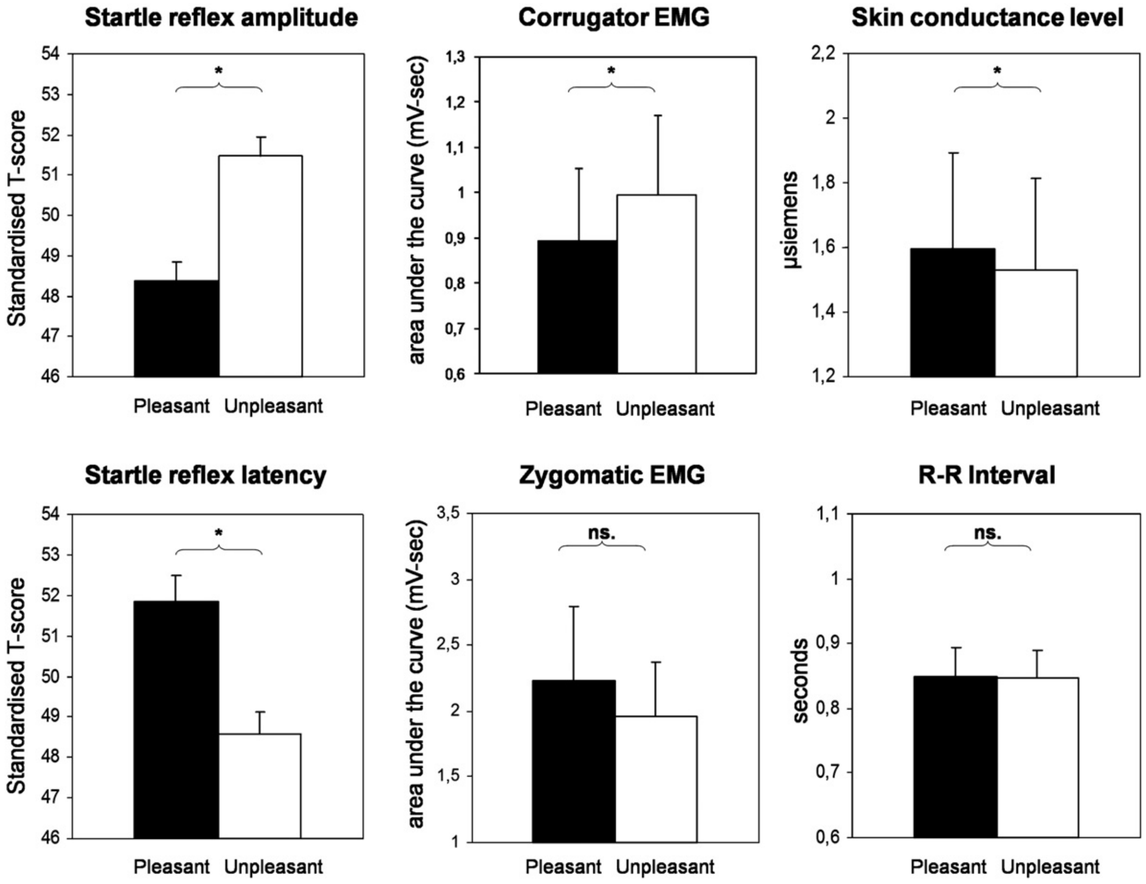

Fig. 2. Mean physiological responses for the pleasant and unpleasant musical conditions. Error bar represents one standard error above the mean. Significant differences ($p < 0.05$) are indicated by asterisks. Note that error bars reflect the between-subjects variance in each condition whereas the results of the statistical tests reflect the within-subject contrast across experimental conditions.

variables with loadings of .32 and above are considered interpretable. Comrey and Lee (1992) suggest that loadings over 0.71 are considered excellent, 0.63, very good, 0.55, good, 0.45, fair and 0.32, poor. In light of those guidelines, the canonical variates coefficients appear excellent for the startle reflex, but difficult to interpret for the other physiological measures.

4. Discussion

4.1. Induction of emotional feelings by music

The startle reflex was of higher amplitude and shorter latency during the listening of unpleasant in comparison with pleasant excerpts, suggesting that different emotional states were effectively induced by music. As the musical excerpts were manipulated to vary on the dimension of valence independently of arousal or loudness, the observed effects are likely to reflect the induction of positive and negative emotional states in response to music, thereby supporting the emotivist's stance in contrast to critiques of cognitivists. First, the startle reflex is an involuntary response that does not depend on the doubtful capacity of the subjects to adequately describe their own experience. Second, the affective startle modulation effect is a reliable measure that avoids the important variability characterizing autonomic nervous system measures. Moreover, startle modulation can be ascribed to the emotional valence rather than arousal or attention, thereby contrasting with prior studies. Third, because the modulation of the startle reflex indicates facilitation or inhibition of a motivational propensity to withdraw, it convincingly distinguishes the induction of emotional states from the cold perception of emotional features. Thus, music appears to be as powerful as pictures (Lang et al., 1998), films (Kaviani et al., 2004) or natural sounds (Bradley and Lang, 2000) to induce positive and negative emotions.

The absence of a neutral control condition complicates the comparisons with studies using different inducers of emotion, since it is difficult to tell if the startle modulation was due to an increase of the reflex during unpleasant music, a decrease of the reflex during pleasant music, or a combination of both. The absence of a neutral control condition, however, was not incidental as it is difficult to find “neutral” music as judged by a majority of listeners. In addition, the use of a silent control condition would not have been informative as sound level by itself has been shown to influence the acoustic startle (Franklin et al., 2007). Similarly, white noise matched with the musical excerpts for sound amplitude could not have been a better control condition because white noise is generally experienced as unpleasant. Nonetheless, a study using a similar design in which three startle probes were delivered within 2-min long video clips, showed that pleasant videos reduced the magnitude of the startle reflex compared to neutral videos, whereas unpleasant ones increased it (Kaviani et al., 2004). Hence, it is reasonable to assume that the present results depend on the effect of a combination of both facilitation and inhibition of the defensive system. Nevertheless, the fact that the startle reflex was modulated by the emotional valence of the excerpts is sufficient to attest that emotional states were induced by music.

4.2. Startle reflex and physiological recordings as indices of felt emotion

In support to the idea that the startle reflex is one of the most reliable indices of emotional valence (Lang et al., 1998), the startle reflex was the best response to discriminate between pleasant and unpleasant musical excerpts. Corrugator activity was the second most discriminative measure but was far behind the startle reflex. Although its contribution to the discriminant function was minimal, the analysis of variance showed that corrugator activity was significantly higher during the unpleasant excerpts compared to the pleasant excerpts, confirming that positive and negative emotions were felt during the listening of those excerpts. Zygomatic activity, however, was not shown to be significantly modulated by the valence of the excerpt. This lack of sensitivity for zygomatic compared to corrugator activity is a common finding (Larsen et al., 2003), perhaps because the zygomatic is implicated in some negative emotions such as disgust or that it is involved with display rules and other fine voluntary motor behaviors.

Skin conductance, while having little contribution to the discriminant function, proved to be higher during the pleasant compared to the unpleasant excerpts. This finding adds to the controversy surrounding the interpretation of skin conductance changes in response to musical emotion. The present findings are consistent with those of Krumhansl (1997) but inconsistent with Baumgartner et al. (2006) and Nater et al. (2006). Moreover, the present findings are opposite to those generally observed with other emotional induction techniques such as mental imagery or the presentation of emotional movie clips for which SCL is higher during negatively valenced emotion (Cacioppo et al., 2000). This outcome suggests that skin conductance levels might be related to some aspects of the emotional response that are not directly linked to the perceived valence and arousal and may vary from one study to another. In the present case, the pleasant and arousing excerpts might have prompted motoric activity such as dancing or tapping of the foot. Finally, no differences in heart rate were found between pleasant and unpleasant excerpts. Taken together with the negative findings of Baumgartner et al. (2006) and Etzel et al. (2006), this lack of difference suggests that heart rate alone is not sufficient to differentiate pleasant from unpleasant musical conditions.

4.3. Implications

The present study supports the emotivist stance and provides some theoretical justifications for the use of music as a therapy. If music is able to induce emotions that can reduce the activity of the emotional defensive system, it can be used to alleviate some unpleasant emotional states, such as anxiety (Rudin et al., 2007), depression (Siedliecki and Good, 2006), or pain (Roy et al., 2008). In addition, the demonstration that emotions are indeed felt in response to music also opens up questions about how and why it does so. The combination of psychophysiological recordings with brain imaging techniques, in addition to self-reported measures of emotion and careful manipulation of the musical stimuli, will help to characterize how the brain and the body interact to create emotional feelings to music (Koelsch, 2005).

Acknowledgements

The work was supported by a grant from the Natural Science and Engineering Research Council of Canada (NSERC) to Isabelle Peretz, and by a doctoral scholarship from the NSERC to Mathieu Roy. We thank Amee Baird for English editing, Francine Giroux for statistical advice and Pierre Rainville for his suggestions on physiological signal analysis.

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