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ScienceDirect
International Journal of Psychophysiology 68 (2008) 17–26
INTERNATIONAL JOURNAL OF PSYCHOPHYSIOLOGY
www.elsevier.com/locate/ijpsycho

Role of tempo entrainment in psychophysiological differentiation of happy and sad music?

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Received 4 July 2007; received in revised form 30 October 2007; accepted 19 December 2007
Available online 27 December 2007

Abstract

Respiration rate allows to differentiate between happy and sad excerpts which may be attributable to entrainment of respiration to the rhythm or the tempo rather than to emotions [Etzel, J.A., Johnsen, E.L., Dickerson, J., Tranel, D., Adolphs, R., 2006. Cardiovascular and respiratory responses during musical mood induction. Int. J. Psychophysiol. 61(1), 57–69]. In order to test for this hypothesis, this study intended to verify whether fast and slow rhythm, and/or tempo alone are sufficient to induce differential physiological effects. Psychophysiological responses (electrodermal responses, facial muscles activity, blood pressure, heart and respiration rate) were then measured in fifty young adults listening to fast/happy and slow/sad music, and to two control versions of these excerpts created by removing pitch variations (rhythmic version) and both pitch and temporal variations (beat-alone). The results indicate that happy and sad music are significantly differentiated (happy > sad) by diastolic blood pressure, electrodermal activity, and zygomatic activity, while the fast and slow rhythmic and tempo control versions did not elicit such differentiations. In contrast, respiration rate was faster with stimuli presented at fast tempi relative to slow stimuli in the beat-alone condition. It was thus demonstrated that the psychophysiological happy/sad distinction requires the tonal variations and cannot be explained solely by entrainment to tempo and rhythm. The tempo entrainment exists in the tempo alone condition but our results suggest this effect may disappear when embedded in music or with rhythm.

Keywords: Tempo; Emotion; Music; Skin conductance; Heart rate; Respiration rate; Diastolic blood pressure; Zygomatic activity

1. Introduction

Emotion has a particular status in music since music is well recognized to be an excellent mood inducer, and since emotion is the main reason behind most people's engagement with music (Juslin and Sloboda, 2001; Panksepp 1995). One way to explore the emotional responses to music is to consider both conscious emotional assessments in recognition task (emotion identification), for example, and automatic psychophysiological responses to stimuli that reflect emotional responses likely related to feeling. Several studies have supported the notion that psychophysiological responses may distinguish basic emotions such as fear, happiness, sadness, disgust, surprise and anger (Ekman et al., 1983; Levenson, 1992; Collet et al., 1997; Rainville et al., 2006).

Psychophysiological responses to music have been studied in the past (for review, see Bartlett, 1999; Nyclicek et al., 1997) with various methods involving different stimuli durations (few seconds to few minutes) and tasks (feel the emotion, or recognize it). These methodological differences may explain

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doi:10.1016/j.ijpsycho.2007.12.001

some of the contradictory results observed in the literature. For example, long musical excerpts (more than 20 s duration) have been found to induce moods (Krumhansl, 1997) when concentrating on emotion feeling, but a habituation effect may also be observed in physiological responses, thereby attenuating potential differences. In contrast, shorter excerpts (few-seconds duration) have been used to evoke transient emotions (Khalfa et al., 2002), with the advantage of producing less habituation, without compromising emotional responses, since it has been shown that less than 1 s in music allows emotional responses (Bigand et al., 2005). Nevertheless, several experiments have demonstrated clear physiological differentiations between happy and sad music. In general, happy excerpts elicit larger skin conductance responses (Khalfa et al., 2002), faster heart and respiration rates relative to sad excerpts. In a study where participants listened to 3 min of sad, fearful and happy music, happiness and sadness were differentiated by the electrodermal conductance level (reflecting activation of the sympathetic nervous system), and by cardio-respiratory responses (Krumhansl, 1997). The heart rate was slower during sad music than when listening to happy music, the diastolic blood pressure increased more for sad than happy excerpts, and the breathing rate increased less for sad than happy music. The review from Bartlett (1999), also indicates that heart and respiration rates were generally found to be larger during happy than sad excerpts, although no blood pressure differences were observed between the two emotions (Nyclicek et al., 1997). More recently, heart rate has again been reported to decrease more during negative than positive music, and to be higher during high-arousal compared to low-arousal music (Witvliet and Vrana, 2007). And the respiration rate has been confirmed to differentiate between happy and sad excerpts (Etzel et al., 2006).

This happy–sad music distinction may be the result of responses to the acoustical parameters responsible for this distinction. Indeed, on one hand, happy music is typically fast (and written in major mode) while sad music is typically slow (and written in minor mode) (Balkwill and Thompson, 1999; Gabrielsson and Juslin, 1996; Peretz et al., 1998). The happy/sad distinction relies on two major musical features: tempo (i.e. the number of beats per minute) (Gabrielsson and Lindstrom, 2001; Schellenberg et al., 2000), and mode (i.e. the specific subset of pitches used to write a given musical excerpt) (Krumhansl, 2001). The specific manipulation of musical tempo affects the perception of happiness and sadness (Dalla Bella et al., 2001; Khalfa et al., 2005). On the other hand, entrainment to tempo or rhythm which is not specific to music has been described. It is a phenomenon in which two or more independent rhythmic processes synchronize with each other (Clayton et al., 2005; Jones and Boltz, 1989). This is why Etzel et al. (2006) pointed out that the significant respiration rate difference between happy and sad excerpts they observed seems to be attributable to entrainment of respiration to tempo (Haas et al., 1986), and/or to rhythm (i.e. temporal patterning conveyed by tones' perception).

More recently, Gomez and Danuser (2007) found that tempo, accentuation and rhythm correlated with physiological responses (respiration, skin conductance, heart rate) to music. Previously, Scherer and Zentner (2001) also suggested that coupling between internal biophysiological oscillators and external auditory rhythms may underlie the physiological emotion-inducing effects of music and could be sufficient to induced distinctive patterns of physiological responses to happy and sad music.

This study thus intended to verify whether psychophysiological differences between happy and sad music may be attributable to entrainment to tempo or rhythm variations. We tested whether fast and slow rhythm, and tempo alone (versions without pitch variations) are sufficient to induce differential physiological effects, such as those expected in response to happy and sad music of the same rhythm and tempo (with pitch variations).

To this aim, we examined the effects of happy and sad music on emotional psychometrical ratings and psychophysiological responses. The same effects were measured in control conditions, including a 1) rhythm condition in which pitch changes were removed while preserving the original tempo and rhythm, and a 2) tempo condition, where both pitch and duration (i.e. rhythm) variations were removed, while keeping the tempo. The rhythm and tempo conditions served to test the hypothesis that physiological differences observed with happy and sad music result from entrainment to rhythm and tempo. The rhythm condition also allowed us to assess the role of pitch variations on the expected psychophysiological differentiation between happy and sad music.

The psychometric ratings were chosen considering that emotions are generally assessed according to their categories (i.e., happy vs. sad) and to two emotional dimensions: arousal (i.e., relaxing to stimulating) and valence (i.e., unpleasant to pleasant) (Bradley and Lang, 2000; North and Hargreaves, 1997; Thayer and Faith, 2001). This is all the more appropriate that the facial electromyographic activity of the corrugator supercilii has been shown to covary with the degree of unpleasantness of picture stimuli whereas the zygomatic major activity and the heart rate covary with the pleasantness level (Lang et al., 1998; Witvliet and Vrana, 1995). More recently, Witvliet and Vrana (2007) have also demonstrated that positive music prompted higher zygomatic electromyographic reactivity scores than negative music. As regards with the arousal dimension, the change in skin conductance typically increases with increasing arousal (Lang et al., 1998). Sad and happy excerpts which are differentiated along the valence and arousal dimensions were thus expected to be discriminated by physiological measures.

Therefore, in order to measure conscious perception of happiness or sadness we collected recognition judgments, and ratings of arousal and valence. To quantify automatic (unconscious) physiological responses to musical stimuli, we recorded measures of cardio respiratory responses (heart and respiration rates, blood pressure), facial electromyographic responses (zygomatic and corrugator muscles), and electrodermal responses to musical stimuli, with or without pitch and rhythm variations. We predicted physiological differences to occur between happy and sad music. Heart rate, skin conductance responses, zygomatic activity and blood pressure

were expected to increase during happy as compared to sad excerpts. The reverse was expected for the corrugator activity. Since happiness and sadness were differentiated in other sensory modalities (like the visual modality) in absence of tempo or rhythm variations, we hypothesized that the physiological differences between happiness and sadness cannot be reduced to an effect of entrainment to tempo or rhythm. Consequently, the psychophysiological differences between happy and sad excerpts should not be observed between the fast and slow excerpts in the rhythmic version (no pitch variation), and in the tempo version (no musical context).

2. Methods

2.1. Participants

Fifty healthy volunteers (21 women and 29 men, mean age: 21.6±2.7 years) were recruited among students at the University of Montreal. None of them had received formal musical training. All procedures were approved by the ethic committee of the University of Montreal and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All subjects provided written informed consent prior to their inclusion in the study.

2.2. Musical stimuli

Original versions of six musical excerpts from the classical music repertoire (Adagio from Albinoni; Concerto d'Aranjuez from Rodrigo; Peer Gynt's Suite n°2 from Grieg; Carnaval des animaux (Finale) from Saint-Saens; Concerto n°23 (3rd mvt) from Mozart; Eine kleine Nachtmusik (1st mvt) from Mozart) (15-s mean duration) taken from a previous study (Peretz et al., 1998) were selected. Three excerpts unambiguously conveyed happiness and the other three conveyed sadness (Peretz et al., 1998). The happy excerpts were written in a major mode at a fast tempo (average Metronome Marking=136 beats/min) (range: 110–154). In contrast, the sad excerpts were written in minor mode at an average slow tempo of 52.3 beats/min (Metronome Marking) (range: 40–69). Two other versions of the original excerpts were created with the Encore 3.0 software, by successively removing the pitch variations (rhythmic version), and pitch plus temporal variations (tempo version) in each melody (see sad and happy stimuli respectively in Appendix 1a and 1b). Six musical conditions, each comprising three excerpts, were presented to the participants: 1) 3 happy—original melodies (happy), 2) 3 sad—original melodies (sad), 3) 3 happy—rhythm (happy R), 4) 3 sad—rhythm (sad R), 5) 3 happy—tempo (happy T), 6) 3 sad-tempo (sad T).

Excerpts were repeated to create 1-min stimuli in such a way that the beat was maintained, and then all stimuli were computer-generated with a piano timbre via a synthesizer (Rolland Sound Canvas SC50). It is noteworthy that using computer-generated stimuli as compared to real performances does not affect the emotional judgments, as shown in previous study (Peretz et al., 1998). Moreover, since stimuli in all conditions were computer-generated, the absence of interpretation does not constitute a bias in the present experiment.

2.3. Procedure

Subjects were comfortably seated in a silent room. A glass dividing this room and the experimenter room allowed viewing the participants during the experiment. After the installation of electrodes and apparatus for physiological measurements, three example stimuli were presented to the subjects just before beginning the experiment in order to reduce the orienting response evoked by the first trials, and to verify that the subjects had understood how to use the verbal rating scales. Then, they were asked to relax for 5 min before starting the actual experiment. During the experiment, they were also instructed to concentrate on the stimuli, asked not to move or speak, and to try to feel the emotions evoked by the stimuli as much as possible. The MIDI files were presented to the participants with MDR-v200 Sony headphones according to a randomized latin-square design, at a comfortable loudness level adjusted individually. Each stimulus presentation was separated by a resting period in which the participants completed the emotional judgments, and then relaxed for at least 20 s to allow for physiological measures recovery to baseline.

After listening to each stimulus, participants were asked to verbally judge if the excerpt was happy or sad (emotion recognition), then to rate the valence (0—unpleasant to 9—pleasant) and arousal (0—relaxing to 9—stimulating). The rating scales were placed in front of the participants, who responded through a microphone. The experimenter followed their responses by loudspeaker in a separate room. The overall duration of the experiment was about 1 h.

2.4. Physiological measures

Heart rate, blood pressure, respiration rate, skin conductance, zygomatic and corrugator muscles activity was recorded throughout the experiment in each participant. Heart rate (HR), and muscle activities were acquired at 1000 Hz, whereas skin conductance (SC), blood pressure (BP) and respiration rate (RespR) were acquired at 125 Hz, using the MP 150 system and Acqknowledge software 3.6.7 (Biopac Systems Inc.). Electrocardiogram (ECG) was recorded using a standard 3 leads montage (Einthoven lead 2 configuration) (Biopac EL503). Blood pressure was recorded on the radial artery of the left wrist, using a non-invasive continuous blood pressure monitoring system (Colin medical instrument, model 7000). Respiration was indexed by relative changes in thoracic/abdominal expansion monitored using a tension transducer (Biopac SS5 L) attached to a strain-gage belt placed over the lower floating rib and adjusted individually to produce the maximal deflection during 10 normal breathing cycles in the pre-experimental set up phase. SC was recorded on the palmar surface of the left hand (Biopac EL503), at the thenar and hypothenar eminences according to the recommendations of Fowles et al. (1981), with a pair of Ag–AgCl electrods (0.8 cm

diameter), and filled with a 0.050 molar NaCl paste. Finally, facial electromyograms of the right zygomatic major (EMGz) and right corrugator supercilii (EMGc) were recorded using 4 mm Ag–AgCl electrodes positioned according to the guidelines from Fridlund and Cacioppo (1986), and Cacioppo and Tassinary (1990), with the nose as a common reference, and a passband filtering limited to 30–500 Hz to increase signal-to-noise ratio. As the average amplitude of the EMG signal is required to quantify the EMG responses (Fridlund and Cacioppo, 1986), the root mean square of the EMG signal measured in μV, was calculated using 20 samples of data from the EMG source channel.

2.5. Physiological signals processing

All physiological measures were continuously monitored during the experiment and visually inspected off-line. Recording artefacts were identified and corrected by intrapolation or else discarded. The musical stimulus duration was recorded within the same file to insure precise alignment of target recording epochs. Some subjects showed no skin conductance variations or moved (rarely) or spoke (rarely) during the recordings. In addition, the blood monitoring system sometimes stopped during the experiment, and the electrodes for the facial electromyograms did not have a good contact with the skin at the end of the experiment. The corresponding data were eliminated from the analysis. The final data set was complete in 39 subjects for blood pressure, 49 for heart rate (which is less sensitive to artefacts due to movements than blood pressure), 48 for respiration rate, 40 for skin conductance, 32 for zygomatic muscles (a sensitive measure to speaking and movements), and 40 for corrugator muscles. Given that it was not always the data belonging to the same participants that were eliminated from the analyses for each measure, it would have considerably reduced the number of participants if we had conducted our analyses with the same number of participants. Instantaneous R–R intervals were calculated from the ECG using a peak detection algorithm to obtain a continuous RR tachogram. Careful examination of the ECG and the tachogram insured that the automatic R-wave detection procedure had been performed correctly. The respiratory signal was smoothed using the mean of a 1-s moving window and transformed to obtain instantaneous respiration rate (RespR) measurements. The respiration cycle detection was also visually verified. SC was also smoothed at 0.5 s and biopac peak detection function allowed to detect and count skin conductance responses (SCRs) that were superior to 0.02 μSiemens/s. Diastolic blood pressure (DBP) was measured using the biopac peak minimum detection function. The acknowledged software also allowed calculating the root mean square (RMS) of the EMGz and EMGc. According to previous studies that used dynamic stimuli such as naturally occurring sounds (Bradley and Lang, 2000) or music (Krumhansl, 1997; Etzel et al., 2006) instead of static pictures, our psychophysiological responses required analyses over time. In Etzel et al. study (2006) in which physiological responses to music were analyzed by 1-s or 5-s steps, significant changes lasted 10 to 30 s. This is why the mean RMSs of the EMGz and EMGc, as well as HR, RespR, SCR, and DBP were calculated by 15-s steps of the 60-s duration stimuli. The values obtained for each stimulus were averaged according to time by stimulus categories (happy, happy R, happy T, sad, sad R, sad T). In addition, for each subject, the mean values obtained during the baseline periods (15 s duration) preceding the stimuli were subtracted from the mean values obtained during each stimuli.

2.6. Statistics

Data analyses were then performed on the difference values obtained in order to verify whether psychophysiological parameters distinguish between happy and sad music and to test whether the rhythm and tempo alone are sufficient (i.e. if pitch variations are necessary) to produce these psychophysiological differences.

To analyze ratings, two-way RM (Repeated-Measures) ANOVAs were performed on the percentage of emotion recognition, the Valence and Arousal ratings taking Tempo (slow and fast), and Type of stimulus (music, rhythm, tempo) as within-subjects factors. Pairwise comparisons (paired *t*-test with Bonferroni-corrected *p*-values) were performed when effects reached significance ($p < .05$).

Psychophysiological measures were analyzed using three-way RM-ANOVAs. Three within-subjects factors were considered: Tempo (slow and fast), Type of stimulus (music, rhythm, and tempo), and Time (4 epochs of 15 s). Pairwise comparisons (paired *t*-test with Bonferroni-corrected *p*-values) were performed when effects reached significance ($p < .05$).

3. Results

3.1. Verbal responses

The analyses of the percentages of correct emotion recognition (Fig. 1) showed that emotions (main effect of Type: $F(2, 98) = 25.4$, $p < .0001$) were better recognized in the musical selections

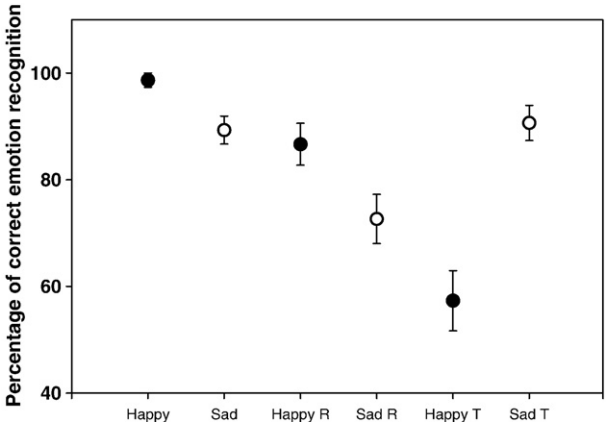


Fig. 1. Means and standard errors of the percentage of emotion recognition according to each stimuli categories. Black filled circles represents fast tempo stimuli and white filled circles represents slow tempo stimuli.

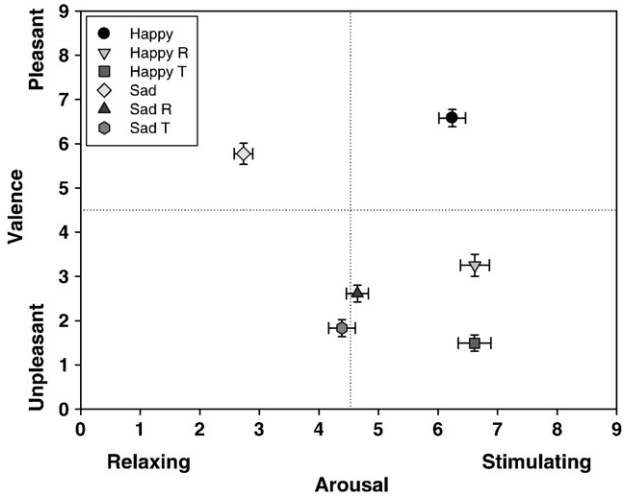


Fig. 2. Bi-dimensional representation of means and standard errors bars of the arousal and valence assessment of the stimuli.

than in rhythm ($p<.001$) and tempo stimuli ($p<.001$). Besides this main effect, there was a significant Tempo × Type interaction ($F(2, 98)=26.1$, $p<.0001$) explained by superior emotion recognition of happy than sad excerpts ($p<.001$), better recognition of happy melodies and happy R compared to happy T ($p<.001$), and better recognition of sad T compared to sad R and sad melodies ($p<.001$).

Results of statistical analysis on valence ratings showed significant main effects of Tempo ($F(1, 49)=10.8$, $p<.005$), with fast stimuli (happy, happy R and happy T) being more pleasant than slow stimuli (sad, sad R, sad T), and Type ($F(2, 98)=452.9$, $p<.0001$), with musical stimuli (either happy or sad) being more pleasant than sad and happy R stimuli ($p<.0001$) which were more pleasant than happy and sad T stimuli ($p<.0001$). There was also a significant Tempo × Type interaction ($F(2, 98)=11.1$, $p<.0001$). As represented in Fig. 2, sad music was less pleasant than happy melody ($p<.01$), and similarly, sad R stimuli were less pleasant than happy R stimuli ($p<.01$). In addition, sad melody was also more pleasant than sad R and sad T ($p<.001$) and happy music was more pleasant than happy R and happy T ($p<.001$).

As expected, there were significant main effects of Tempo ($F(1, 49)=201.9$, $p<.0001$), Type ($F(2, 98)=13.4$), and of Tempo × Type interaction ($F(2, 98)=21.5$, $p<.0001$) on arousal ratings. This is illustrated in Fig. 2, showing that fast stimuli were more stimulating than slow ones, with happy, happy R, and happy T stimuli being respectively more stimulating than sad, sad R, and sad T stimuli (all $p<.001$). The sad excerpts were also more relaxing than the sad R and sad T stimuli (all $p<.001$) but happy excerpts, happy R and happy T were equally stimulating (p's >0.05, ns).

3.2. Facial muscles

The mean values of zygomatic and corrugator RMSs across conditions and time are given in Table 1. Major significant results are given in Fig. 3(a and b). Statistical analysis of zygomatic muscles RMS differences shows no significant main effects of the three factors, but significant Tempo × Type × Time ($F(6, 204)=2.25$, $p<.05$) interaction. As represented in Fig. 3a, happy musical excerpts caused larger zygomatic activity than sad musical excerpts in the last 30 s ($p<.05$) of stimulation. Zygomatic activity increased more during happy excerpts than during sad excerpts ($p<.05$), but no such differences were observed between happy R–sad R, and happy T–sad T. The happy/sad excerpts distinction was thus not found when the tempo or rhythm factors were examined in isolation. The zygomatic activity was also significantly larger in response to happy music than to happy R and happy T stimuli in the last 15 s (all $p<.05$), and than to happy R stimuli at 30 s ($p<.05$). In contrast, no significant difference was demonstrated between the three types of slow tempi stimuli.

RM-ANOVA performed on RMS values of the corrugator showed a significant Tempo × Type × Time interaction ($F(6, 222)=2.19$, $p<.05$). Contrary to the zygomatic, the corrugator tended to be more activated by the sad than the happy music especially in the 30 last seconds as shown in Fig. 3b, but its effect did not reach statistical significance ($p=.2$). Despite the significant Tempo × Type × Time interaction, post hoc comparison tests did not reach significance, and the EMGc did not confirm the differences between happy and sad music.

3.3. Electrodermal activity

The RM-ANOVA applied to the number of electrodermal responses revealed a significant main effect of Time ($F(3, 102)=3.6$, $p<.05$) with more SCRs at 45 and 60 s than at 15 and 30 s (all $p<.05$), and a significant Tempo × Type interaction ($F(2, 68)=3.9$, $p<.05$) (see Table 2). As shown in Fig. 3c, happy excerpts evoked more SCRs than sad excerpts ($p<.05$), and than happy R and happy T (Table 2). In contrast, the number of SCRs did not differ between the three slow-sad stimuli. As for the EMGz, the number of SCRs allowed to distinguish between happy and sad excerpts ($p<.05$) but neither between happy R and sad R, nor between happy T and sad T. The pitch

Table 1
Means (SD) changes in RMS values of the zygomatic and corrugator muscles from the pre-stimulus baseline during the 60-s of all stimuli categories listening

Mean RMS (±SD)	Conditions	60 s	Mean RMS (±SD)	Conditions	60 s
Zygomatic (10^{-1})	Sad	−0.43 (±1.52)	Corrugator (10^{-4})	Sad	6.25 (±7.82)
	Happy	1.13 (±3.00)		Happy	4.19 (±4.02)
	Sad R	−0.27 (±3.55)		Sad R	5.87 (±4.44)
	Happy R	−0.54 (±2.73)		Happy R	4.55 (±5.86)
	Sad T	0.59 (±3.68)		Sad T	3.56 (±10.62)
	Happy T	−0.10 (±3.24)		Happy T	2.80 (±14.08)

Changes of facial muscles activity.

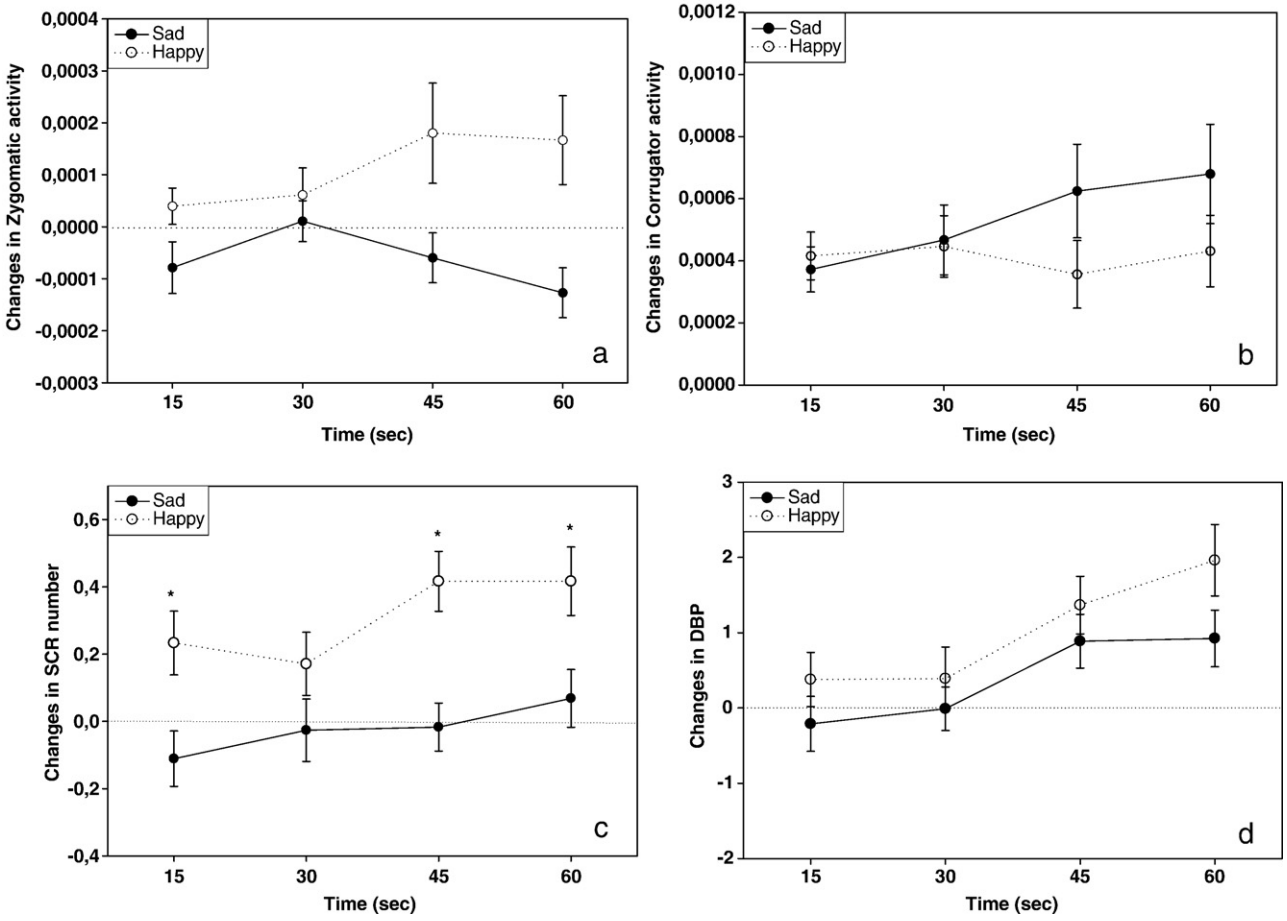


Fig. 3. Means (and standard errors) changes in zygomatic activity (a), corrugator activity (b), skin conductance responses (c), diastolic blood pressure (d) from the pre-stimulus baseline ($y=0$) during successive 15-s epochs of happy and sad excerpts. * indicates statistically significant differences ($p<.05$).

variations appear to be necessary for the music differentiation by SCRs.

3.4. Cardiovascular measures

Results of statistical analysis of HR evidenced a significant main effect of Time ($F(3, 129)=7.9$, $p<.001$), HR being superior at 45 s than at 15, 30 and 60 s, and a significant Tempo × Type × Time interaction ($F(6, 258)=2.3$, $p<.05$). Despite this significant 3-way interaction, and although the HR tended to be larger in response to happy than to sad excerpts in the last 15 s of the stimuli ($p=.18$), no post hoc comparison tests were statistically significant.

DBP was found to vary according to the Type of stimuli ($F(2, 58)=3.9$, $p<.03$), original melodies eliciting larger DBP than tempo stimuli ($p<.01$). It also varied according to the Time ($F(3, 87)=7.5$, $p<.001$), the DBP being significantly higher at 60 s than at 45 s, and both being higher than DBP at 15 and 30 s. The DBP was thus globally increasing over time during the stimuli. In addition, there was a significant Tempo × Type interaction ($F(2, 58)=3.8$, $p<.03$) which indicated that happy excerpts evoked larger DBP ($p<.05$) than sad excerpts (Fig. 3d) whereas comparable DBP were found between happy R vs sad R, and happy T vs sad T. Larger blood pressure was also recorded for happy music than happy R stimuli ($p<.05$) and happy T stimuli ($p<.0001$). In contrast, no such differences were evidenced with sad stimuli whatever their type. The happy/sad distinction by DBP was only observed when the excerpts were not modified (no pitch removal). The same analysis were also conducted on Systolic Blood Pressure but only yielded nonsignificant trends in the same direction.

3.5. Respiratory

The mean values of the respiration rates (RespR) are given in Table 2. The RM-ANOVA performed on these RespR indicates a significant main effect of Time ($F(3, 132)=15.2$, $p<.001$) with a significant increase in RespR at 45 and 60 s compared to 15 and 30 s ($p<.001$), and a significant Tempo × Type interaction ($F(2, 88)=4.3$, $p<.05$). Happy and sad music were not distinguished by RespR values but happy T stimuli increased RespR values compared to sad T stimuli ($p<.001$) (Fig. 4). Then, contrary to the other physiological recordings, RespR only differentiated between slow and fast tempo in the tempo condition. In addition, no Type effect was evidenced on 'happy' stimuli although it was for 'sad' stimuli with sad and sad R stimuli eliciting higher RespR than sad T stimuli (all $p<.05$).

4. Discussion

4.1. Emotional judgments

As expected from previous studies on tempo variations (Dalla Bella et al., 2001; Gabrielsson and Lindstrom, 2001; Peretz et al., 1998), happy and sad music were clearly identified with emotion recognition rates superior to 89%. However, the happy/sad distinction ability decreased when the pitch variations were removed, and more importantly, the stimuli became less pleasant. However, the emotion originally intended for the sad Tempo-only stimuli remained well recognized (superior to 90%). This latter finding parallels previous results (Schellenberg et al., 2000), and supports the hypothesis that equating tone durations in sad excerpts give them a special "funeral" quality making them sound very sad. Moreover, since the sad Rhythm, and sad Melody stimuli were found to be more pleasant than the sad Tempo stimuli, it may also explain why sad Tempo stimuli were more easily associated to the negative (sadness) than the positive (happiness) emotion.

Therefore, the musical excerpts evoked the intended emotions, but eliminating pitch variations dramatically modified their emotional characteristics by diminishing their valence, and by reducing the arousal differences between fast and slow tempi. However, fast/slow tempo distinction (in rhythm and tempo conditions) mainly relies on the superior stimulating aspect of the fast stimuli as compared to the slow. The tempo and rhythm conditions could not evoke real happy or sad emotions, nor pleasant emotions. They just allow distinguishing between relaxing and stimulating stimuli.

On the contrary, in agreement with a previous study (Khalfa et al., 2002), happy melodies were considered pleasant and stimulating whereas sad melodies were less pleasant and more relaxing. Sad music, contrary to sad stimuli in other domains (Witvliet and Vrana, 1995) was not rated as unpleasant. Nevertheless, happy excerpts were rated slightly more pleasant than sad excerpts.

Table 2
Means (SD) changes in the number of skin conductance responses, the heart rate (HR), the diastolic blood pressure (DBP), and the respiration rate (RespR) from the pre-stimulus baseline during the 60-s of all stimuli categories listening

Mean (±SD)	Conditions	60 s
SCR (number)	Sad	−0.013 (±0.41)
	Happy	0.31 (±0.44)
	Sad R	0.023 (±0.50)
	Happy R	−2.08e-3 (±0.44)
	Sad T	0.012 (±0.40)
	Happy T	−0.09 (±0.48)
HR (beats/min)	Sad	−55.2 (±57.1)
	Happy	−72.5 (±233.5)
	Sad R	−88.4 (±55.9)
	Happy R	63.3 (±86.9)
	Sad T	−51.4 (±26.9)
	Happy T	−143.2 (±74.9)
DBP (mm Hg)	Sad	0.1774 (±1.66)
	Happy	1.36 (±1.91)
	Sad R	0.33 (±1.74)
	Happy R	0.11 (±1.50)
	Sad T	0.14 (±1.77)
	Happy T	−0.038 (±1.63)
RespR (cycles/min)	Sad	0.12 (±0.36)
	Happy	0.09 (±0.41)
	Sad R	0.07 (±0.46)
	Happy R	0.09 (±0.31)
	Sad T	−0.04 (±0.45)
	Happy T	0.18 (±0.53)

Changes of electrodermal and cardiorespiratory activities.

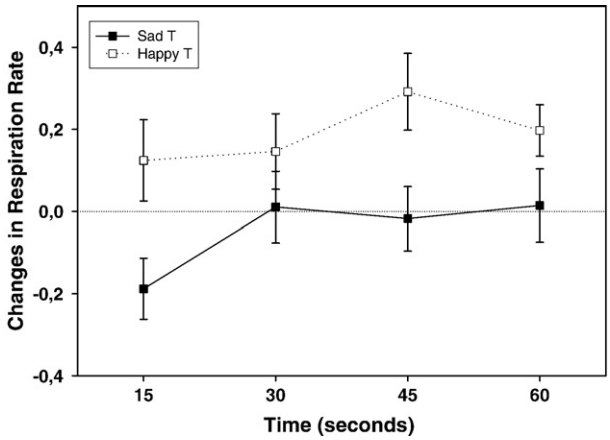


Fig. 4. Means (and Standard errors) changes in Respiration Rate from the pre-stimulus baseline ($y=0$) during successive 15-s epochs of happy T and sad T excerpts.

4.2. Psychophysiological happy/sad distinction

At a psychophysiological level, we also found a clear differentiation between happy and sad music. EMGz activity, SCRs, and DBP increased when participants were listening to happy compared to sad excerpts. Contrary to Nyclicek et al. (1997), but in accordance with Krumhansl (1997), DBP was higher during happy than sad music. The Zygomatic

Electromyogram increased while listening to happy music but not when listening to sad music. This result is consistent with effects of happy visual scenes and naturally occurring affective auditory stimuli (e.g., erotica) (Lang et al., 1998; Bradley and Lang, 2000), and with findings of a recent study using musical excerpts (Witvliet and Vrana, 2007). Despite the close pleasantness ratings for happy and sad excerpts, the zygomatic activity clearly distinguished between those two conditions suggesting an effect of the specific emotion conveyed rather than the valence. By contrast, the corrugator activity only tended to distinguish happy from sad music even if sad music is less pleasant than happy music it remains pleasant. Concerning the electrodermal measures, the finding of higher number of SCRs to happy than to sad music also parallels our previous observation of greater SCRs to happy than sad short musical excerpts (Khalfa et al., 2002). However, contrary to some previous experiments (Bartlett, 1999; Krumhansl, 1997; Nyclicek et al., 1997) using longer and musically more complex stimuli, we did not confirm any differences in respiration and heart rates between sad and happy music. These discrepancies may thus be explained by the characteristics of the excerpts. Our results have shown that the musical emotions were more differentiated after 30 s. Longer and more emotional (musically more complex) excerpts are then more likely able to induce different respiration and heart rates in response to happy and sad music.

Consequently, our results do not completely replicate previous results on psychophysiological responses to music. Due to experimental requirements, we used less complex and shorter excerpts which certainly elicited less intense emotions than the orchestral music used in some of the previous studies (e.g. Krumhansl, 1997; Nyclicek et al., 1997). Neverthless, clear psychophysiological differentiations between happy and sad excerpts were evidenced with EMGz, SCR, and DBP.

4.3. Importance of the pitch variations in psychophysiological differences

Our aim was to verify with the tempo and rhythm conditions that the happy/sad distinction would rely upon the melodic content rather than solely upon entrainment to tempo and/or rhythm. We verified our hypothesis since the happy/sad music distinction by SCRs, EMGz, and DBP was not found for the happy R/sad R (rhythm preserved), and happy T/sad T (beat-alone) conditions. This happy/sad distinction mainly relies upon the strong physiological reactions to happy pleasant excerpts that were clearly different from the happy R and happy T stimuli. The physiological effects of happy melodies can not be explained only be their stimulating properties since comparable levels of arousal were reported for the happy, happy R and happy T conditions. Pitch variations thus appear to be necessary for the psychophysiological happy/sad distinction.

In addition, even if tempo and/or rhythm drive changes in respiration (Haas et al., 1986), with fast tempo (in the beat-alone condition) significantly increasing the respiration rate, the tempo contribution was only observed in the tempo condition, and it did not modify the other psychophysiological parameters. Contrary to the results of Etzel et al. (2006) demonstrating differences in respiration rate between happy and sad excerpts of longer duration, the original musical excerpts including rhythm and pitch variations did not produced the expected changes in respiration rate in our experiment. Respiration rate may require more time (longer excerpts) to exert its effect when embedded into a more complex musical sequence. The tempo contribution is thus insufficient in the present study to explain the psychophysiological happy/sad distinction.

Consequently, this study provides evidence for the existence of three psychophysiological indices distinguishing happy from sad music: the DBP, the number of SCRs and the zygomatic activity. Moreover, it further demonstrates that the psychophysiological happy/sad distinction requires the tonal variations and cannot be explained solely by different entrainment to tempo and rhythm. The tempo entrainment exists in the tempo alone condition but our results suggest this effect may disappear when embedded in music or with rhythm. Further studies should elucidate whether this absence of tempo entrainment is related to an attention shift towards rhythmic and tonal variations, or whether the effect of tempo entrainment is more subtle or complex when the tempo is embedded within a multidimensional (true) musical context. In addition, the study was limited to two emotions, and did not explore whether pitch is sufficient to induce distinct emotional states. Pitch variations are important in Western music since its syntactic rules are related to its system of tonality (Schellenberg et al., 2005). The use of major mode was more associated to happiness and minor mode to sadness (Balkwill and Thompson, 1999; Peretz et al., 1998). Other musical emotions as well as the effects of pitch variations with and without rhythm should thus be explored. One would expect that the combination of pitch and rhythm may be more effective to elicit psychophysiological responses than the sum of pitch and rhythm alone. Further experiments should also verify whether the musical expertise in musicians modifies the psychophysiological differentiation of musical emotions, and whether this differentiation can be generalized to more musical excerpts.

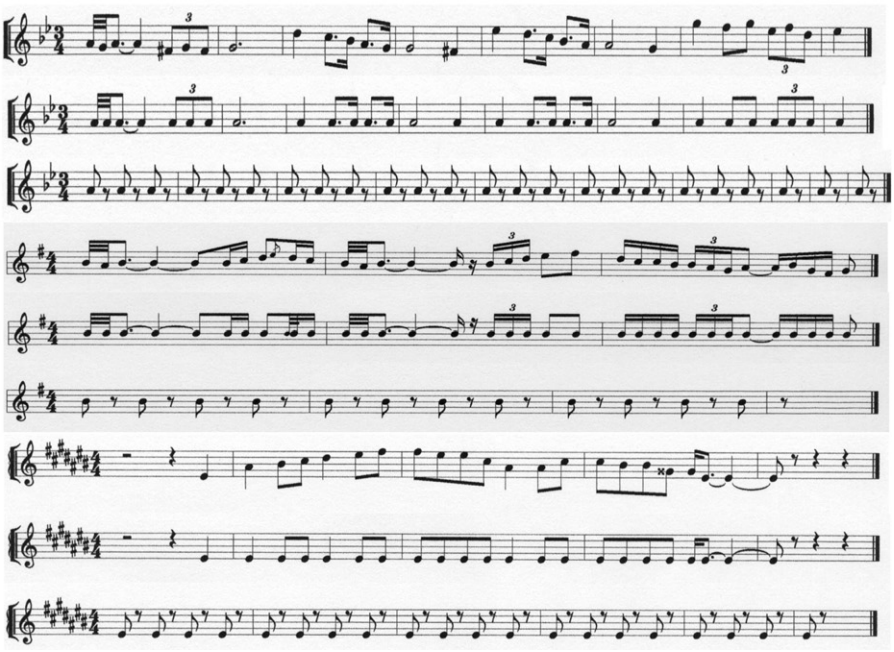
Acknowledgments

We thank Leo Tenbokum for his valued help in material assembly and testing, Manon Robert for her assistance in testing patients, and Krista Hyde for assistance with the English revision. This work was supported by a postdoctoral fellowship from the Canadian Institutes of Health Research to S. Khalfa.

Appendix A

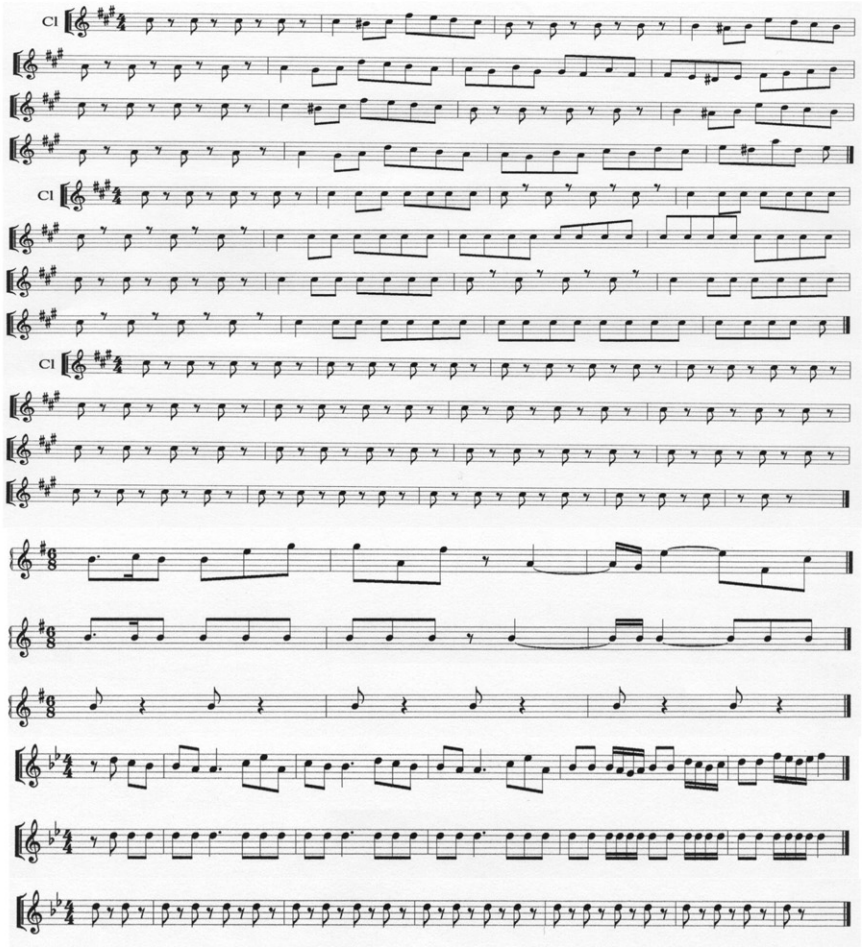
Appendix 1a: Sad original excerpts modifications by removing the pitch variation (Sad R) and the pitch plus rhythm variations (Sad T).

Work	Composer	Type
Adagio	Albinoni	Sad
		Sad R
		Sad T
Concerto d'Aranjuez	Rodrigo	Sad
		Sad R
		Sad T
Peer Gynt's Suite no2	Grieg	Sad
		Sad R
		Sad T



Appendix 1b: Happy original excepts modifications by removing the pitch variation (Happy R) and the pitch plus rhythm variations (Happy T).

Work	Composer	Type
Carnaval des Animaux (Le Cygne)	Saint-Saens	Happy
		Happy R
		Happy T
Concerto no23 (3rd mvt)	Mozart	Happy
		Happy R
		Happy T
Eine kleine Nachtmusik (1st mvt)	Mozart	Happy
		Happy R
		Happy T



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