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Emotional valence contributes to music-induced analgesia

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Abstract

The capacity of music to soothe pain has been used in many traditional forms of medicine. Yet, the mechanisms underlying these effects have not been demonstrated. Here, we examine the possibility that the modulatory effect of music on pain is mediated by the valence (pleasant–unpleasant dimension) of the emotions induced. We report the effects of listening to pleasant and unpleasant music on thermal pain in healthy human volunteers. Eighteen participants evaluated the warmth or pain induced by 40.0, 45.5, 47.0 and 48.5 °C thermal stimulations applied to the skin of their forearm while listening to pleasant and unpleasant musical excerpts matched for their high level of arousal (relaxing–stimulating dimension). Compared to a silent control condition, only the pleasant excerpts produced highly significant reductions in both pain intensity and unpleasantness, demonstrating the effect of positive emotions induced by music on pain (Pairwise contrasts with silence: p's < 0.001). Correlation analyses in the pleasant music condition further indicated that pain decreased significantly (p's < 0.05) with increases in self-reports of music pleasantness. In contrast, the unpleasant excerpts did not modulate pain significantly, and warmth perception was not affected by the presence of pleasant or unpleasant music. Those results support the hypothesis that positive emotional valence contributes to music-induced analgesia. These findings call for the integration of music to current methods of pain control.

Keywords: Pain; Pain modulation; Music; Emotion; Psychophysics

1. Introduction

Since ancient times, humans have attributed to music the capacity to cast out the malignant spirits causing sickness and suffering (Gfeller, 2002). Music was an integral part of the healing process in many cultures and still is an important component of many primitive forms of medicine. Nowadays, music therapy is emerging as an evidence-based discipline with the explicit goal to re-introduce music into modern medical settings. Among the many alleged benefits of music, pain reduction is one that has spurred the most early and constant interest. In a seminal study, Gardner et al. (1960) reported that music was effective in reducing the pain of 90% of 5000 patients undergoing dental surgery. This original finding has since been replicated several times with a wide diversity of clinical populations (McCaffrey and Freeman, 2003; Phumdoung and Good, 2003; Voss et al., 2004; Good et al., 2005; Nilsson et al., 2005; Tse et al., 2005; Cepeda et al., 2006). In these studies, pain is reduced in patients receiving a musical intervention in addition to standard care, as compared to those receiving only standard care. Although this evidence supports the use of music in clinical settings, it does not demonstrate any specificity of this intervention

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and does not inform about the mechanisms of action. Because these clinical studies only compared the effects of music with a control condition without music, distraction appears to be the most parsimonious explanation of the observed analgesic effects of music.

Another account of the analgesic properties of music lies in its ability to induce strong positive emotions. Indeed, a recent meta-analysis on musical mood inductions procedures has revealed that musically induced emotions could influence a wide range of cognitive abilities (Vastfjall et al., 2002), placing music among the most effective inducers of emotion (Westermann et al., 1996). Thus, emotional reactions to music might be a key component explaining music-induced analgesia. Indeed, pain has been previously shown to be modulated by emotions induced by pictures (Meagher et al., 2001), films (Weisenberg et al., 1998), emotional sentences (Zelman et al., 1991), odors (Villemure et al., 2003), or hypnosis (Rainville et al., 2005). In these studies, pleasant emotions are generally found to reduce pain while unpleasant ones tend to increase it. These results can not be solely explained by an effect of distraction because unpleasant emotional stimuli, which are also distractive, do not reduce pain (reviewed in Rainville, 2004). We adopted the same logic here and studied the pain-modulating effects of positive and negative emotional reactions to music.

Here, the pain induced by thermal stimulations was assessed while participants listened to musical excerpts selected to differ on the valence dimension (pleasant vs. unpleasant) and carefully matched on arousal (relaxing vs. stimulating). Non-painful thermal stimuli were included to account for non-specific effects of distraction on thermal perception (Bushnell et al., 1985). Based on the hypothesis that the emotional valence of music contributes to changes in pain, we hypothesized that pleasant excerpts would reduce pain whereas unpleasant ones would increase it.

2. Methods

2.1. Participants

Eighteen participants (9 men, 9 women), aged between 19 and 39 years (mean = 27, SD = 6) took part in this study. Subjects were recruited using ads posted throughout the campus of the University of Montreal. None of them had followed advanced musical training or had previously participated to other pain studies. Participants were also screened for the absence of skin problems, psychiatric or neurological disorders and chronic pain. Moreover, they had not consumed any analgesic medication in the 24 h preceding the experiment.

2.2. Musical excerpts

Three 5-min excerpts of pleasant music and three 5-min 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 dimension of valence (on a scale ranging from 0 to 9 with 0 – ‘pleasant’ and 9 – ‘unpleasant’) and arousal (with 0 – ‘relaxing’ and 9 – ‘stimulating’). Three highly pleasant and three highly unpleasant excerpts were selected that matched on their level of arousal. Since unpleasant excerpts were always judged to be arousing, all excerpts were selected on 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; $t\ (19) = 1.535$, $p > 0.05$, n.s.). All selected excerpts were normalized to equate loudness range across musical excerpts.

2.3. Thermal stimuli

The thermal stimulations were produced by a 3 × 3 cm contact thermode (TSA Neuro-sensory analyser, Medoc Ltd. Advanced Medical system, Israel). Four temperatures were selected: one non-painful (40 °C) and three painful (45.5 , 47, 48.5 °C). Subjects were not informed of the number of levels. Each stimulation consisted in a plateau of 6 s with a rise/fall time of 2 s from/to a baseline temperature of 32 °C, leading to a total stimulus duration of 10 s. Stimuli were applied alternatively on three spots on each forearm.

2.4. Measures

Thermal stimuli were evaluated using numerical rating scales (Rainville et al., 1992). After each stimulus, participants indicated whether the stimulation received was painful or not. Subjects then rated the stimuli on a scale ranging from 0 – ‘no heat’ to 100 – ‘extremely warm’ (not painful). Painful stimuli were rated on separate scales of pain intensity and unpleasantness ranging from 0 – ‘no pain’ to 100 – ‘extremely intense’ or ‘extremely unpleasant’. Subjects were allowed to give ratings higher than 100 on both pain scales if necessary (Rainville et al., 1992).

In order to verify that the selected excerpts induced the intended emotions in the experimental sample, participants were explicitly asked to rate the emotional state experienced on the dimensions of valence (0 – ‘pleasant’, 9 – ‘unpleasant’) and arousal (0 – ‘relaxing’, 9 – ‘stimulating’). The moods induced in each experimental condition were also assessed using the Profile Of Mood States (POMS) (McNair et al., 1992). The POMS is a questionnaire comprising 30 items, each consisting of an emotional adjective for which subjects have to rate to what extent it describes their current mood (0 – ‘not at all’, 4 – ‘extremely’). Six emotional sub-scales can be derived from the 30 items: Tension, Depression, Anger, Vigor, Fatigue and Confusion. Subjects also rated the perceived emotional intention conveyed by each musical excerpt separately, at the end of the experiment, on scales of sadness, happiness, fear, anger, peacefulness and surprise (0 – ‘not at all’ to 9 – ‘extremely’). While the valence, arousal and POMS scales were specifically used to measure the emotional states induced in the participants, ratings of perceived emotional intention were used to confirm that subjects could recognize consistently the emotions conveyed by each excerpt.

2.5. Procedure

At their entrance in the laboratory, participants were briefly told that the study investigated the effects of music on pain and that they would be asked to evaluate the sensations induced by heat stimulations, while listening to music. Then, they were familiarised with the thermal stimuli and evaluation scales by rating eight thermal stimuli (two per temperature) on the warmth or pain scales. After this practice block, the musical excerpts were presented using headphones (SONY MDR-CD370) at a comfortable, individually adjusted, intensity level that remained constant across pleasant/unpleasant music conditions. Each silence, pleasant music, and unpleasant music conditions lasted 15 min. In order to create audio-clips of 15-min of pleasant music and 15-min of unpleasant music, the three 5-min excerpts of the same type were presented successively. The order of presentation of the 15-min blocks of pleasant music, unpleasant music or silence was counterbalanced between subjects so that each condition occurred in the first, second or third position for an equal number of subjects.

The stimulation paradigm is described in Fig. 1. During each 5–min musical excerpt or each 5-min period of silence, the subjects first listened passively to the music or sat in silence for 140 s. During the next 160 s, they received a series of eight thermal stimulations. The presentation orders of the thermal stimuli were counterbalanced so that, in each experimental condition, each spot of skin received all four temperatures and no spot was stimulated in successive trials. Participants rated the warmth or pain intensity and unpleasantness in the 10-s window after each thermal stimulus. After each musical excerpt and each 5-min silent period, participants also rated the valence and arousal of the emotions felt in the condition. After each 15-min experimental condition, participants rated their mood using the POMS. At the end of the experiment, participants listened again to each of the 5-min musical excerpts to rate the emotional intention expressed in the music.

3. Results

We first verified that the musical excerpts had the expected effects on arousal and valence and we further describe their effects on moods and the perceived emotional intention. Then, we report the effect of the pleasant and unpleasant excerpts on pain. Finally, we explore the potential mediator of the observed effect using correlation analyses. Partial eta-squared (η^2) was used as the effect size for ANOVAs and Cohen's d was used for pairwise contrasts (adjusted for r and using Hedges' bias correction (Hedges and Olkin, 1985). Cohen (Cohen, 1988) provides guidelines for interpreting η^2 (small = .01, medium = .06, large = .14) and d (small = .2, medium = .5, large = .8).

3.1. Mood induction

The mean valence and arousal ratings of the pleasant music, unpleasant music and silence conditions were first compared to assess the efficacy of the induction of emotion by music. The analysis confirmed that the chosen excerpts induced the expected emotions. The pleasant and unpleasant excerpts differed significantly on the dimension of valence (pairwise contrast: $F(1,17) = 86.24$, $p < 0.001$, $d = 3.02$, confidence interval: 2.06–3.97) (Table 1). Pleasant and unpleasant excerpts were also respectively more (pairwise contrast: $F(1,17) = 8.67$ $p < 0.01$, $d = 1.22$, confidence interval: 0.51–1.93) and less (pairwise contrast: $F(1,17) = 26.01$, $p < 0.001$, $d = 2.58$, confidence interval: 1.69–3.46) pleasant than the silence condition. In contrast, pleasant and unpleasant musical excerpts did not differ from each other on the dimension of arousal (pairwise contrast: $F(1,17) = 2.41$, $p > 0.05$, n.s., $d = 0.41$, confidence interval: −0.25 to 1.07) but both conditions were felt as significantly more stimulating than the silence condition (pairwise contrast for pleasant music: $F(1,17) = 17.37$, $p < 0.001$, $d = 1.33$, confidence interval: 0.61–2.05; pairwise contrast for unpleasant music: $F(1,17) = 32.62$, $p < 0.001$, $d = 1.58$, confidence interval: 0.83–2.33).

Music also had some effects on reported moods as measured by the Profile of Mood States questionnaire (POMS; Table 1) completed at the end of each 15-min condition. The effects of each experimental condition on participants' mood were assessed by conducting separate analysis of variance on each of the six subscales (Anger, Depression, Fatigue, Anxiety, Vigor, Confusion). Only the anger and anxiety scales were found to vary across experimental conditions (Anger:

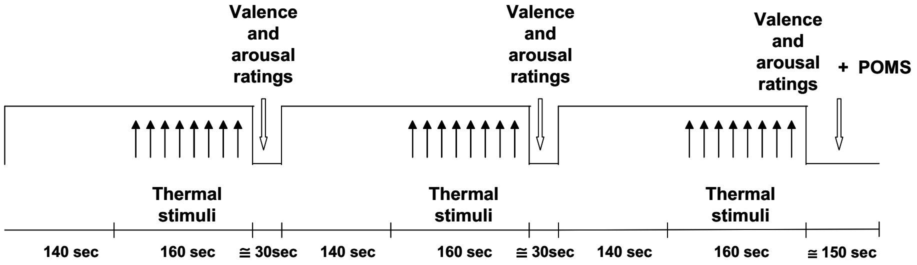

Fig. 1. Time course of audio and thermal stimuli in one experimental condition. Participants listened passively to either music or silence for 300 s. In the last 160 s of each period, they rated the pain or warmth induced by each of eight thermal stimulations (arrows). Emotions induced by music or silence were evaluated at the end of the 300 s period. Emotional state was evaluated at the end of the whole experimental condition with the Profile of Mood States (POMS).

Table 1
Within-subject comparison of the mean (SD) ratings of the emotional states experienced in the three experimental conditions and of the emotional intention conveyed by pleasant and unpleasant music

Dependent variable	Result of statistical test	Pleasant music[*]	Unpleasant music[*]	Silence
Emotional dimension				
Valence	$F(2,34) = 32.40$, $p < 0.001$	2.25[ab] (±1.87)	7.04[bc] (±1.76)	3.97[ac] (±1.32)
Arousal	$F(2,34) = 17{,}30$, $p < 0.001$	5.36[b] (±2.33)	6.31[b] (±1.92)	2.85[ac] (±1.37)
POMS subscales				
Anger	$F(2,34)= 5.32$, $p < 0.01$	3.10[a] (±2.29)	4.09[c] (±3.86)	3.72 (±3.05)
Depression	$F(2,34) = 0.80$, $p =$ n.s.	3.18 (±1.64)	3.03 (±1.58)	1.71 (±3.21)
Fatigue	$F(2,34) = 0.50$, $p =$ n.s.	2.54 (±3.87)	2.50 (±3.61)	3.16 (±3.88)
Anxiety	$F(2,34) = 3.36$, $p < 0.05$	2.35[b] (±1.71)	2.87 (±2.81)	2.80[c] (±3.06)
Vigor	$F(2,34) = 077$, $p =$ n.s.	4.38 (±4.59)	3.91 (±4.82)	4.75 (±4.93)
Confusion	$F(2,34) = 0.79$, $p =$ n.s.	2.18 (±3.93)	2.46 (±4.22)	4.34 (±2.45)
Emotional intention				
Sadness	$t(17) = 5.07$, $p < 0.001$	0.61 (±0.60)	3.29 (±2.39)	–
Happiness	$t(17) = 5.33$, $p < 0.001$	6.53 (±1.84)	2.51 (±2.01)	–
Fear	$t(17) = 5.24$, $p < 0.001$	0.47 (±0.61)	4.45 (±3.11)	–
Anger	$t(17) = 5.11$, $p < 0.001$	0.75 (±1.21)	3.49 (±2.02)	–
Peacefulness	$t(17) = 4.62$, $p < 0.001$	3.63 (±2.19)	0.78 (±1.13)	–
Surprise	$t(17) = 0.21$, n.s.	3.65 (±2.00)	4.37 (±2.34)	–

a–c, follow-up pairwise contrasts. a, significantly different from unpleasant music; b, significantly different from silence; c, significantly different from pleasant music.

[*] Pleasant excerpts are taken from *Love and Happiness* by Emst Ranglin, *William Tell Overture* by Rossini, and *French Cancan* by Canissimo; Unpleasant excerpts are taken from *Pendulum music* by Sonic Youth (Steve Reich), *The threshold of deafening silence* by Paul Dolden, and *Fassicles* by The thirteen ghosts with D. Bailey and T. More.

$F(2,34) = 5.96$, $p < 0.001$, $\eta^2 = 0.445$; Anxiety: $F(2,34) = 3.35$, $p < 0.05$, $\eta^2 = 0.165$). Anger was lower after the pleasant music condition than after the unpleasant music (pairwise contrast: $F(1,17) = 13.62$, $p < 0.01$, $d = 1.37$, confidence interval: 1.10–2.67). Anxiety was lower after the pleasant music condition compared to the silence condition (pairwise contrast: $F(1,17) = 4.32$, $p < 0.05$, $d = 1.03$, 0.33–1.72).

Ratings of the emotional intention conveyed by the music were consistent with the valence of the excerpt (Table 1). Positive emotional intention, like happiness and peacefulness, were rated higher for pleasant excerpts than for unpleasant ones (Happiness: $t(17) = 5.33$, $p < 0.001$, $d = 2.53$, confidence interval: 1.65–3.40; Peacefulness: $t(17) = 4.62$, $p < 0.001$, $d = 1.75$, confidence interval: 0.99–2.52). Conversely, negative emotions, comprising Sadness, Fear and Anger, were higher for the unpleasant excerpts (Sadness: $t(17) = -5.07$, $p < 0.001$, $d = 1.89$, confidence interval: 1.10–2.67; Fear: $t(17) = -5.24$, $p < 0.001$, $d = 1.81$, confidence interval: 1.03–2.59; Anger: $t(17) = -5.11$, $p < 0.001$, $d = 1.67$, confidence interval: 0.92–2.43). Finally, surprise, which can be either positive or negative, was found to be equally present in pleasant and unpleasant excerpts (Surprise: $t(17) = 0.21$, $p > 0.05$, n.s., $d = 0.43$, confidence interval: −0.22 to 1.09).

3.2. Pain and warmth ratings

The warmth, pain intensity and pain unpleasantness ratings were averaged separately for each of the four temperatures and in each condition. When a stimulus in the noxious range of temperature (⩾45.5 °C) was not felt as painful (i.e. rated on the warmth scale), a pain rating of 0 was attributed to that stimulation. This happened in 47% of the 45.5 °C stimulations, 27% of the 47.0 °C stimulations and 9% of the 48.5 °C stimulations. The mean ratings of pain intensity and unpleasantness were then compared across experimental conditions and painful temperatures (Table 2). As expected, pain ratings increased with temperature (Intensity: $F(2,34) = 62.50$, $p < 0.001$, $\eta^2 = 0.786$; Unpleasantness: $F(2,34) = 41.39$, $p < 0.001$, $\eta^2 = 0.709$), indicating that the participants could discriminate the thermal stimuli. More importantly, pain ratings differed significantly across the music conditions (Intensity: $F(2,34) = 6.15$, $p < 0.001$, $\eta^2 = 0.266$; Unpleasantness: $F(2,34) = 6.11$, $p < 0.01$, $\eta^2 = 0.264$). Both intensity and unpleasantness ratings were lower during pleasant music compared to unpleasant music (pairwise contrasts – Intensity: $F(1,17) = 6.01$, $p < 0.05$, $d = 0.89$, confidence interval: 0.21–1.58; Unpleasantness: $F(1,17) = 6.63$, $p < 0.05$, $d = 0.69$, confidence interval: 0.02–1.37) and compared to silence (pairwise contrast – Intensity: $F(1,17) = 18.69$, $p < 0.001$, $d = 1.66$, confidence interval: 0.90–2.42; Unpleasantness: $F(1,17) = 19.29$, $p < 0.001$, $d = 2.02$, confidence interval: 1.21–2.82). In contrast, pain ratings did not differ significantly between the unpleasant music and the silence condition (pairwise contrasts – Intensity $F(1,17) = 0.39$, $p > 0.05$, n.s., $d = 0.12$, confidence interval: −0.53 to 0.77; Unpleasantness: $F(1,17) = 0.12$, $p > 0.05$, n.s., $d = 0.21$, confidence interval: −0.45 to 0.86). Examination of Table 2

Table 2
Mean (±SD[*]) ratings of warmth or pain for each temperature and experimental condition

Experimental condition	Warmth ratings (40 °C)	Pain intensity ratings			Pain unpleasantness ratings		
		45.5 °C	47 °C	48.5 °C	45.5 °C	47 °C	48.5 °C
Pleasant music	34.26 (±25.65)	16.86[b] (±16.35)	34.03[b] (±22.16)	57.68[ab] (±27.71)	12.82[b] (±14.59)	27.06[b] (±18.64)	47.84[ab] (±27.59)
Unpleasant music	38.07 (±25.24)	22.29 (±23.89)	39.13 (±23.39)	68.62[c] (±23.05)	17.93 (±21.56)	32.26 (±21.84)	60.10[c] (±26.26)
Silence	36.70 (±27.10)	25.05[c] (±23.37)	39.13[c] (±25.99)	69.66[c] (±30.43)	20.74[c] (±22.42)	32.65[c] (±24.42)	59.96[c] (±31.93)

a–c, follow-up pairwise contrasts. a, significantly different from unpleasant music; b, significantly different from silence; c, significantly different from pleasant music.

[*] Note that SD reflect the between-subjects variance within each condition whereas the results of the statistical test reflect the within-subject contrast across experimental conditions.

indicates very small reductions in pain compared to silence, infirming the hypothesized pain-enhancing effect of unpleasant music. Taken together, these results provide very strong evidence in favor of the main hypothesis of an effect of the valence of music on pain; however, only the analgesic effect of pleasant music was confirmed.

For all temperatures and conditions, pain unpleasantness was always lower than pain intensity ($F(1,17) = 16.90$, $p < 0.001$, $\eta^2 = 0.498$). However, no interaction was found with the pain dimension (intensity or unpleasantness), suggesting comparable effects of music and temperature on pain intensity and pain unpleasantness (interaction with temperature: $F(2,34) = 2.65$, $p > 0.05$, n.s., $\eta^2 = 0.135$; interaction with condition: $F(2,34) = 1.05$, $p > 0.05$, n.s., $\eta^2 = 0.029$).

Finally, warmth ratings obtained for the innocuous temperature (40 °C) were also averaged for each experimental condition. In 12% of the 40 °C stimuli, the innocuous heat was rated as painful and a warmth rating of 100 was attributed to those trials. The warmth ratings were then compared across the three experimental conditions. No effect of experimental condition was found on warm sensation intensity ($F(2,34) = 0.51$, $p > 0.05$, n.s., $\eta^2 = 0.029$).

3.3. Correlation analyses

In order to examine the influence of inter-individual differences in the emotions induced by the pleasant music on pain modulation, each subject's changes in pain ratings for the most painful temperature (48.5 °C) were correlated with changes in their valence ratings. These correlations were not performed on the 45.5 and 47 °C stimulations because of the high percentage of stimuli not rated as painful within those temperature conditions (see Section 3.2). The change scores were calculated by subtracting the ratings obtained during the silence condition from the ratings of the pleasant music conditions. Inter-individual differences in valence ratings significantly predicted pain ratings, independently from differences in arousal ratings (partial correlations on valence controlling for arousal ratings – Intensity: $r = 0.58$, $p < 0.05$; Unpleasantness: $r = 0.63$, $p < 0.05$). Thus, the analgesic effects of pleasant music were most effective in participants that reported feeling highly pleasant emotions in response to music. In addition, inter-individual differences in arousal ratings also predicted pain rating, independently from differences in valence ratings (partial correlations controlling for valence ratings – Intensity: $r = 0.59$, $p < 0.05$; Unpleasantness, $r = 0.49$, $p < 0.05$). This means that the participants that felt the least stimulated while listening to the arousing pleasant music showed the largest reductions in pain. Similar analyses performed on the effects of unpleasant excerpts did not reveal any significant effect of valence or arousal (all ps > 0.05). Taken together, those effects are consistent with the reduction of pain observed specifically in the positive valence condition.

4. Discussion

The results show that music induces emotions and modulates the experience of pain. The pleasant and unpleasant excerpts induced the corresponding emotional valence and similar levels of arousal. Participants also felt less anxiety and anger after listening to pleasant music. Finally, the perceived emotional intention conveyed in the excerpts was consistent with their emotional valence. These results confirmed that the selected pleasant and unpleasant musical excerpts conveyed positive and negative emotions and induced the corresponding emotional states in the participants, while adequately controlling for the arousal dimension.

Pleasant music was found to reduce pain compared to both unpleasant music and silence. Moreover, subjects reporting larger increases in valence also reported the largest decreases in pain. In contrast, unpleasant music did not affect pain and there was no correlation between variations in pain and valence in this condition. Those results therefore confirmed that the analgesic effect of pleasant music is associated with positive valence but did not confirm the hypothesised effect of unpleasant music on pain perception.

Secondary analyses also suggested an implication of arousal in the modulation produced by music. In addition to the analgesic effect of positive valence, partial correlation analyses performed between-subjects in the pleasant music condition indicated that participants reporting being less stimulated on the arousal scale also reported less pain. This was again not true for unpleasant excerpts. However, because our pleasant musical stimuli were all in the stimulating range, to match with highly arousing unpleasant excerpts, we cannot draw conclusion about a broader range of music-induced arousal. Future studies should include a comparison between pleasant-relaxing and pleasant-stimulating music to test the full extent of this effect.

The alternative explanation of music-induced analgesia in terms of attentional mechanisms appears insufficient to explain the present finding. First, the participants were instructed to direct their attention to the thermal stimuli in order to evaluate them. This procedure differs considerably from those used in studies examining the effects of distraction on pain and in which subjects are typically asked to ignore pain in order to process competing stimuli and perform a difficult task (Miron et al., 1989; Valet et al., 2004). Furthermore, in divided attention conditions where subjects are required to process both pain and a competing stimulus, the distraction effect on pain perception has been found to disappear (Miron et al., 1989). This is consistent with the primacy of pain processing in the absence of explicit demand to direct attention away from pain. In our experiment, music excerpts are likely to have acted more as a background inducer of emotion than as an active distractive task. A second argument is the absence of effect on warmth perception. Comparable effects of attention have been previously reported on the perception of painful and non-painful thermal sensations (Bushnell et al., 1985). Here, the absence of changes in warmth perception is unlikely to be due to a lack of power as the effect size was modest compared to the very large effects of pleasant music on pain. The emotional valence of the music, rather than its distractor value, appears to be the most likely mediator of the analgesic effect of the pleasant music.

Additional factors that may contribute to the analgesic effect observed include expectations (e.g., Price et al., 1999; Charron et al., 2006; Goffaux et al., 2007) Here, multiple temperatures were administered to minimize the predictability of the pain sensation, thereby reducing (although not eliminating) this potential confounding effect. The robust stimulus–response function demonstrates that subjects did rely on their sensation to rate pain. Furthermore, contrary to the hypotheses there was a slight (non-significant) *decrease* in pain during unpleasant music; a finding inconsistent with a widespread effect of expectations induced in favor of the hypotheses. Nevertheless, it is possible that expectations contributed specifically to the analgesic effect in the pleasant music condition. Interestingly, a structural equation modeling approach recently suggested that expected pain partly depends upon the emotional state of the patient before a painful dental procedure (Gedney and Logan, 2007). The relative contribution of emotion and expectation and their interaction should be addressed in future experimental studies.

In comparing the effects of pleasant and unpleasant music at similar levels of arousal, our study is the first to highlight the role of emotional valence in music-induced analgesia. The only two studies that have used a similar experimental design have not controlled for arousal. In one prior study (Hekmat and Hertel, 1993), an advantage of preferred music over non-preferred music was obtained in music-induced analgesia. However, the analgesic effect could be due to inter-individual differences in arousal. Moreover, the possibility to choose the music in the preferred music condition leads to a heightened sense of control. In the other study where the possibility to choose the music was controlled for (Perlini and Viita, 1996), the superiority of the pleasant music could be ascribed to differences in arousal and distraction. By controlling the arousal of the musical excerpts and by adding a non-painful control condition, our study provides a more direct demonstration of the involvement of emotional valence in music-induced analgesia. Of course, the present results should not be interpreted as an absence of potential effects of arousal or attention but rather as a demonstration of a specific contribution of emotional valence to music-induced analgesia. Future studies should further examine the potential interaction between arousal and valence and the potential contribution of expectation in music-induced analgesia.

Overall, our results are consistent with previous studies on the effect of pain-unrelated emotional stimuli, including the fact that the unpleasant music condition did not increase pain significantly (see Rainville, 2004). This is a common finding. Negative emotional stimuli produce inconsistent pain-modulating effects (Villemure and Bushnell, 2002). Several studies have observed little or no augmentation of pain during the presentation of unpleasant emotional stimuli (Weisenberg et al., 1998; de Wied and Verbaten, 2001). The reasons for these unstable pain-modulating effects of unpleasant stimuli remain speculative. One possibility is that unpleasant music was insufficient to induce negative moods. Although the participants reported feeling more unpleasant emotions after the unpleasant excerpts, most POMS sub-scales were not affected by this musical condition. Another possibility is that unpleasant stimuli might trigger both inhibitory and facilitatory pain processes (Rhudy and Meagher, 2000). In that perspective, stimuli that induce moderate levels of stress or negative emotions might produce a moderate activation of inhibitory mechanisms which may counteract pain enhancing effects of negative emotions.

Contrary to prior studies (Villemure et al., 2003; Rainville et al., 2005), unpleasantness ratings were not more affected than intensity ratings by the emotions conveyed by music. This may be due to the short time our participants had to evaluate each thermal stimulation (approximately 10 s). In order to speed up their ratings, participants might have judged intensity and unpleasantness in parallel. In the other two studies, participants had unlimited time. However, previous studies did not compare the effects of emotion on pain intensity and unpleasantness statistically. We thus provide a stricter test of the differences between pain intensity and unpleasantness. Another possibility is that the slower and more global retrospective ratings used in previous studies have introduced an additional memory dimension to the rating process which may differentially affect the sensory and affective evaluation of pain.

At a broader level, our results fit partly with the model of motivational priming (Lang et al., 1998). According to this theory, responses of the defensive emotional system, will be inhibited by pleasant stimuli and enhanced by unpleasant ones. For example, the amygdala and the periacqueductal gray matter (PAG) appear to be key structures mediating the affective modulation of the startle reflex, a defensive reaction to a strong and sudden stimulus (usually a loud white noise; (Vrana et al., 1988; Walker et al., 1997). Activation of this system by emotional stimuli may further activate descending pathways as suggested by the modulation of the spinally mediated nociceptive (RIII) reflex reported in a recent study (Rhudy et al., 2005). Interestingly, emotional reactions to music may also activate the PAG and other brain structures related to pain modulation such as the amygdala, the prefrontal cortex or the cingulate cortex (Blood et al., 1999; Blood and Zatorre, 2001; Koelsch et al., 2005). Moreover, there is evidence that emotional reactions induced by music involves endogenous opioids (Goldstein, 1980) and that music listening can increase the expression of mu opiate receptors (Stefano et al., 2004) and the secretion of serotonin (Evers and Suhr, 2000). These mechanisms may contribute to the analgesic effect of pleasant music.

By its ability to induce strong positive emotions, music is more than just a distraction. In our study, pleasant music relieved pain by up to 18% for the most painful temperature, which is comparable to some effects of classic analgesic drugs such as NSAIDs (Tanabe et al., 2002). Considering the availability, simplicity, and low cost, of musical interventions combined with the absence of any side effect, music appears to be of particular interest for pain management.

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