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From emotion perception to emotion experience: Emotions evoked by pictures and classical music

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Abstract

Most previous neurophysiological studies evoked emotions by presenting visual stimuli. Models of the emotion circuits in the brain have for the most part ignored emotions arising from musical stimuli. To our knowledge, this is the first emotion brain study which examined the influence of visual and musical stimuli on brain processing. Highly arousing pictures of the International Affective Picture System and classical musical excerpts were chosen to evoke the three basic emotions of happiness, sadness and fear. The emotional stimuli modalities were presented for 70 s either alone or combined (congruent) in a counterbalanced and random order. Electroencephalogram (EEG) Alpha-Power-Density, which is inversely related to neural electrical activity, in 30 scalp electrodes from 24 right-handed healthy female subjects, was recorded. In addition, heart rate (HR), skin conductance responses (SCR), respiration, temperature and psychometrical ratings were collected. Results showed that the experienced quality of the presented emotions was most accurate in the combined conditions, intermediate in the picture conditions and lowest in the sound conditions. Furthermore, both the psychometrical ratings and the physiological involvement measurements (SCR, HR, Respiration) were significantly increased in the combined and sound conditions compared to the picture conditions. Finally, repeated measures ANOVA revealed the largest Alpha-Power-Density for the sound conditions, intermediate for the picture conditions, and lowest for the combined conditions, indicating the strongest activation in the combined conditions in a distributed emotion and arousal network comprising frontal, temporal, parietal and occipital neural structures. Summing up, these findings demonstrate that music can markedly enhance the emotional experience evoked by affective pictures.

Keywords: EEG; Emotion; Perception; Feelings; Picture; Music; Psychophysiology

1. Introduction

Most of the published neuroimaging papers examining emotional processes have used visual stimuli in order to evoke emotions. In the majority of these studies either the Pictures of Facial Affect by Ekman and Friesen (1976) or the International Affective Picture System (IAPS) by Lang et al. (1995) have been used as stimulus material (e.g. Lee et al., 2004; Esslen et al., 2004; Hariri et al., 2002). This material is composed of stimuli using either facial expressions or scenes thought to evoke basic emotions (positive or negative). However, it is obvious that real-life emotional experiences mostly rely on the presence of combined stimuli coming from different modalities. For example, music is often used to enhance the emotional impact of movies. Although this enhancing effect of combined presentation of emotional music and visual stimuli is intuitive, modern neuroimaging research has mostly ignored the neurophysiological underpinnings of this enhancement effect. Even the neurophysiological study of emotional experiences associated with the perception of music has been understudied. Emotional appreciation of music is a new research avenue in neuropsychology and neurophysiology (Peretz, 2001). Nevertheless, the results of these few studies are remarkable. It has been shown that music elicits intense emotional responses that activate brain regions thought to be involved

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in reward/motivation, emotion and arousal, including ventral striatum, midbrain, thalamus, orbitofrontal cortex, anterior cingulate cortex and the insula (Brown et al., 2004; Blood and Zatorre, 2001). These brain structures are known to be active in response to other euphoria-inducing stimuli, such as food, sex, and drugs of abuse (e.g. Small et al., 2001).

Although these few studies have demonstrated that music is in fact a powerful elicitor of emotions and especially emotional feelings (Altenmuller et al., 2002; Krumhansl, 1997), there is (to our best knowledge) to date no neuro-imaging study which examined the influence of the combined presentation of emotional visual and musical stimuli on the central brain processing. Based on the subjective experience that combined presentation of congruent emotional musical excerpts and visual stimuli might enhance emotional experiences (as compared to the presentation of emotional stimuli from one modality) we designed the present study. In this study, we recorded EEG to measure the oscillatory brain activity while subjects were listening to emotional musical excerpts of fear, happiness and sadness and while they were viewing at emotionally laden visual pictures of the same emotional categories. In addition, psychometrical ratings and psychophysiological measures (skin conductance responses, heart rate, respiration and temperature) were collected after and during the experimental conditions, respectively. We hypothesized that activity in emotional brain structures are increased when the two emotional stimuli modalities are presented in combination compared to the separated presentation of the two modalities. Furthermore, we believe that this increased brain activation is accompanied by increased subjective and psychophysiological arousal and involvement measures because recent findings have strongly supported the idea that the subjective process of feeling emotions is partly grounded in neural maps which represent aspects of the organism's internal state (Damasio et al., 2000; Craig, 2002). Thus, measures from the autonomic nervous system can help to objectively discriminate processes of cognitively evaluating emotions on the one hand or strongly feeling and experiencing emotions on the other hand.

2. Materials and methods

2.1. Subjects

24 right-handed (tested with standard handedness tests revealing consistent right-handedness in all subjects) females (mean ± S.D. age, 26.1 ± 5.3) were examined in the experiment, most of them students of psychology, biology or medicine. Females were chosen because it is known that they show stronger emotional reactions than males. All subjects underwent a physical evaluation to screen out chronic diseases, mental disorders, medication, drug or alcohol abuse. Furthermore, depression, anxiety and alexithymia were assessed by the German versions of the Self-Rating Depression Scale (SDS; Zung, 1965), the State-Trait Anxiety Inventory (STAI; Laux et al., 1981) and the Toronto-Alexithymia Scale (TAS; Taylor et al., 1985). Two of the original 26 subjects had to be excluded because their score in these tests were not within the normal range for the general population. Each subject received 30 Swiss Francs for the participation. The study was carried out in accordance with the Declaration of Helsinki principles, approved by the ethics committee of the University of Zurich. All subjects gave written, informed consent and were informed of their right to discontinue participation at any time.

2.2. Stimuli and study design

The musical stimulus material consisted of excerpts of exactly 70 s duration and were taken from the following classical orchestral pieces: 1) Gustav Holst: Mars—*the Bringer of War* from *The Planets*, 2) Samuel Barber, *Adagio for Strings*, 3) Beethoven, *Symphony no.6 (3rd mvt)*. The excerpt by Holst was chosen to evoke fear, the one by Barber was chosen to evoke sadness, and the one by Beethoven was chosen to evoke happiness. Various psychological and psychophysiological experiments have shown that these excerpts are capable of evoking the mentioned three basic emotions (e.g. Krumhansl, 1997; Peretz et al., 1998). In order to avoid startling the participants, the beginning (2 s) and the end (2 s) of each stimulus were faded in and out, respectively. The visual stimulus material consisted of 48 pictures from the same three emotional categories as the musical stimuli: fear, happiness and sadness. The pictures were taken from the International Affective Picture System (IAPS) or had been collected by the author. The IAPS numbers for the stimuli included in the study are the following: happy pictures had the numbers 2030, 2040, 2091, 2165, 2303, 2345, 2352, 2530, 8120, 8350, 8370, 8380, 8461, 8496, 8497; sadness pictures had the numbers 2141, 2205, 2276, 2312, 2700, 2900, 6010, 9220, 9415, 9530; fear pictures had the numbers 3500, 6211, 6212, 6250, 6312, 6313, 6510, 6540, 6570, 6821, 6834, 6838, 6940. All pictures contained humans or human faces, were matched for complexity and rated for emotional content in a pilot experiment by 48 subjects on 9-point scales for valence and arousal. A "9" on the scales indicated that subjects felt very happy and aroused, respectively. The mean ratings (± S.D.) for the three picture categories were as follows: valence: 2.2 ± 0.76 (fear picture), 3.3 ± 0.69 (sadness picture), 7.8 ± 0.70 (happy picture); arousal: 6.5 ± 0.94 (fear picture), 5.2 ± 0.84 (sadness picture), 6.1 ± 0.81 (happy picture). Fear-inducing pictures depicted for example a man attacking a woman with a knife or a man pointing a pistol to the viewer. The "happiness" pictures showed for example a man holding his smiling baby, laughing children playing on the beach, or athletes in a victory pose. Sadness scenes consisted for example of a crying little boy standing in front of a destroyed house or a couple standing at a gravestone. The two stimuli modalities (auditory or visual) were presented for 70 s either alone or combined. Both the stimuli modalities and the three different emotions were presented in a counterbalanced and pseudo-random order to carefully control for order and habituation effects. Each emotional picture was shown for 4.375 s within a block consisting of 16 pictures of the same emotional category. The digitized pieces of music were played during the whole duration of the experimental conditions. The subjects were instructed to place themselves into the same mood as expressed by the presented emotional stimuli (similar mood induction methods were used by Schneider et al., 1994; Kimbrell et al., 1999; Esslen et al., 2004). The pictures were presented on a 17-in. computer screen and the design was programmed using the presentation software called "Presentation" (Neurobehavioral Systems, Version 0.70, 2003). Subjects were seated at 1.15 m distance from the screen with their head comfortably positioned in a chin rest.

2.3. EEG measures

The electroencephalogram (EEG) was recorded from 30 scalp electrodes using a Brain Vision amplifier system (BrainProducts, Germany). Silver–silver–chloride-electrodes (Ag/AgCl) were used in association with the "Easy Cap System" (International 10-20 system, FMS Falk Minow Services, Herrsching-Breitbrunn, Germany). The electrooculogram (EOG) was recorded from two additional electrodes placed below the outer canthi of each eye. BrainVision Recorder and Analyzer (BrainProducts, Germany) were used to record (electrode impedance <5 kΩ, 0.5–70 Hz, 500 samples/s) and analyze the data. All recorded EEG-epochs were carefully and individually checked for artefacts by visual inspection. When an artefact occurred in a given channel, data from all channels were removed. The artefact-free EEG material was recomputed to average reference and digitally band passed to 1.5–30 Hz. Artefact-free chunks of data were then extracted through a Hamming window, which reduces spurious spectral power estimates at the beginning and end of each chunk. A fast Fourier transform (FFT) algorithm was applied to all extracted artefact-free epochs of data (each epoch lasted 2.048 s). The conditions did not differ in the number of artefact-free epochs used in the analyses (mean = 25.6). Power density (μV^2/Hz) was then computed for the Alpha-band (8–13 Hz) because about 2 decades of work on Alpha power desynchronisation (for a review see Klimesch, 1999) as well as several recent combined EEG/fMRI and EEG/PET papers strongly indicate that power in the Alpha-band is inversely related to activity (Laufs et al., 2003a,b; Oakes et al., 2004) and is more strongly related to behaviour than power in other frequency bands (Davidson and Hugdahl, 1996). All power density values were log-transformed to normalize the distribution of the data. 16 electrodes were collapsed into 4 electrode clusters: anterior left (F7/F3/FT7/FC3), anterior right (F4/F8/FC4/FT8), posterior left (TP7/CP3/P7/P3) and posterior right (CP4/TP8/P4/P8). The average values across the respective electrode sites were calculated for all 9 conditions and 24 subjects.

2.4. Psychophysiological measures

In addition to EEG, heart rate (HR), skin conductance response (SCR), respiration (Resp), and skin temperature (Temp) at the volar surface of the left little finger's distal phalanx (in degrees Celcius) were collected using a commercially available device (PAR-PORT manufactured by Hogrefe Company, Germany). It is well-established that emotion experiences are accompanied by physiological changes that occur automatically without voluntary control. Musical emotion is no exception. On the contrary, music seems to be particularly powerful in eliciting such changes (e.g. Krumhansl, 1997; Khalfa et al., 2002). For SCR recording, electrodes were attached to the thenar and hypothenar areas on the palm of the left hand. Quantitation of SCR's entailed measurement and summation of the SCR amplitude during the 70 s experimental period. Log-transformation (log[SCR + 1] was used to normalize the SCR amplitude data.

2.5. Psychometrical measures

After every experimental condition psychological measures were assessed on a computer-based 5-point scale, ranking from "1 = not at all" to "5 = very strongly". For this purpose two questionnaires were used: First, three scales of the German version of the Differential Emotion Scale (DES; Izard et al., 1974) with three adjectives per scale measuring the three basic emotions of happiness, sadness and fear; and second, three items of the ITC-Sense of Presence Inventory (Lessiter et al., 2001) measuring how much the subjects were involved or engaged in the different emotional experiences.

2.6. Statistical analysis

The Alpha-Power-Density values were analyzed in a four-way repeated-measures ANOVA with the following factors: "emotion" (fear, happiness, sadness), "modality" (combined, picture, sound), "region" (anterior, posterior), and "hemisphere" (left, right). For each psychophysiological measurement (SCR, HR, Respiration, Temperature) and the psychometrical involvement scale, two-way repeated-measures ANOVAs were performed with the following factors: "emotion" (fear, happiness, sadness) and "modality" (combined, picture, sound). For three other psychometrical scales (Fear, Sadness and Happiness scales) non-parametric Wilcoxon tests were performed because some of the scales violated the normality assumption necessary to conduct parametric statistical tests. As effect size measure

ETA^2 is reported. All statistical analyses were performed using the statistical software package SPSS PC (version 11.5). Results were considered as significant at the level of $p<0.05$. In case of a significant multivariate effect post hoc paired *t*-tests were computed using the Bonferroni correction according to Holm (1979).

3. Results

The psychometrical results clearly showed that the subjects were able to experience the presented emotions as evidenced by their ratings of the experienced quality of the emotions. Stimuli chosen to evoke happiness showed the highest scores on the "happiness" scale, and the lowest scores on the "fear" and "sadness" scales, respectively (all significant at $p<0.001$, paired Wilcoxon tests). For those stimuli chosen to evoke fear, subjects reported the highest values on the "fear" scale in every modality, intermediate values on the "sadness" scale and together with the evoked emotion of sadness the lowest values on the "happiness" scale, demonstrating no significant differences between sadness and fear on the "happiness" scale (all at $p<0.001$). Finally, stimuli evoking sadness revealed in every modality the highest values on the "sadness" scale and intermediate values on the "fear" scale (all at $p<0.001$).

More important, as can be inferred from the significant effects presented in Fig. 1 (a,b,c), the emotional experience of the presented emotions was most accurate and pronounced in the combined conditions, intermediate in the picture conditions and lowest in the sound conditions. In order to estimate and quantify the distinctiveness of the subjective emotional experiences, we calculated ETA^2 as a mean variability score between each DES-scales separately for each emotion and modality conditions. A high ETA^2 indicates strong differences between the three emotion scales, whereas a low ETA^2 indicates reduced emotional distinctiveness regarding the "happiness", "sadness" and "fear" scales. Concerning the evoked emotion of happiness, the ETA^2 for all three modalities were very similar (combined: 0.97, picture: 0.95, sound: 0.97) and paired Wilcoxon tests between the three modalities revealed only one significant difference between the combined and the picture conditions, demonstrating a slightly increased rating on the "happiness" scale in the combined condition ($p<0.01$, Fig. 1b). The differences concerning the negative emotional conditions were more extreme (especially for the sound conditions) which is clearly shown by the differences in the ETA^2 measures (combined: 0.93 for the fear condition and 0.95 for the sad condition, picture: 0.89 and 0.88, sound: 0.46 and 0.68). Paired Wilcoxon tests showed that the sound conditions alone evoked less distinctive emotional

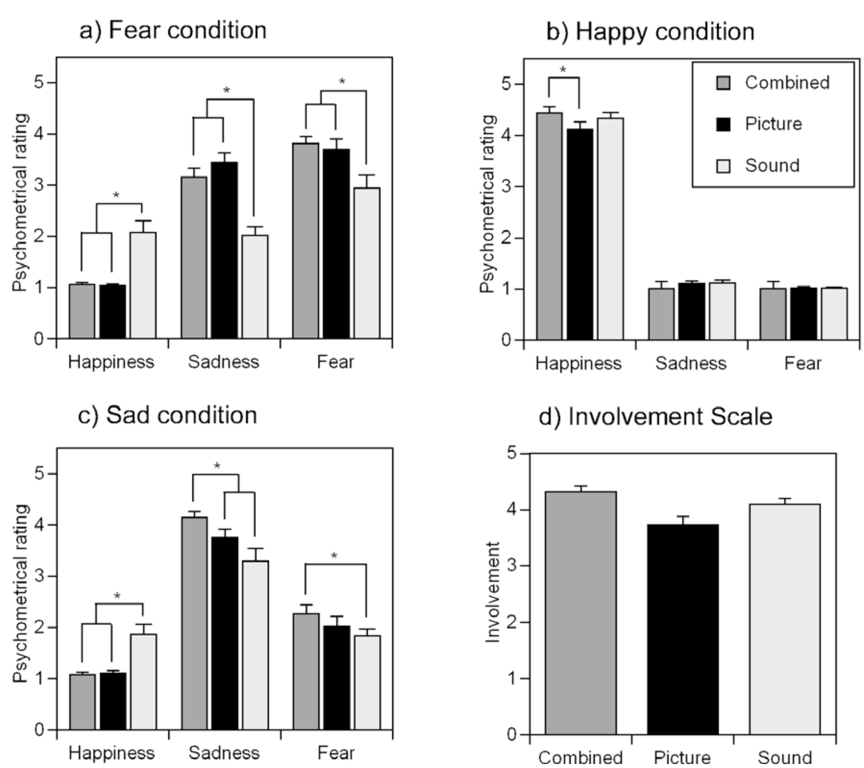

Fig. 1. Mean psychometrical ratings (±S.E.M.) of the fear conditions (a), happy conditions (b) and sad conditions (c). Note that subjects had to rate every emotion on a scale for happiness, sadness and fear (5-point scales, ranking from "1 = not at all" to "5 = very strongly"). Significant statistical differences between the different modalities (combined, picture, sound) are depicted (all at $p<0.01$). (d) Significant main effect of modality regarding the involvement scale is shown demonstrating an increased involvement experience both in the combined and the sound conditions compared to the picture conditions ($p<0.001$).

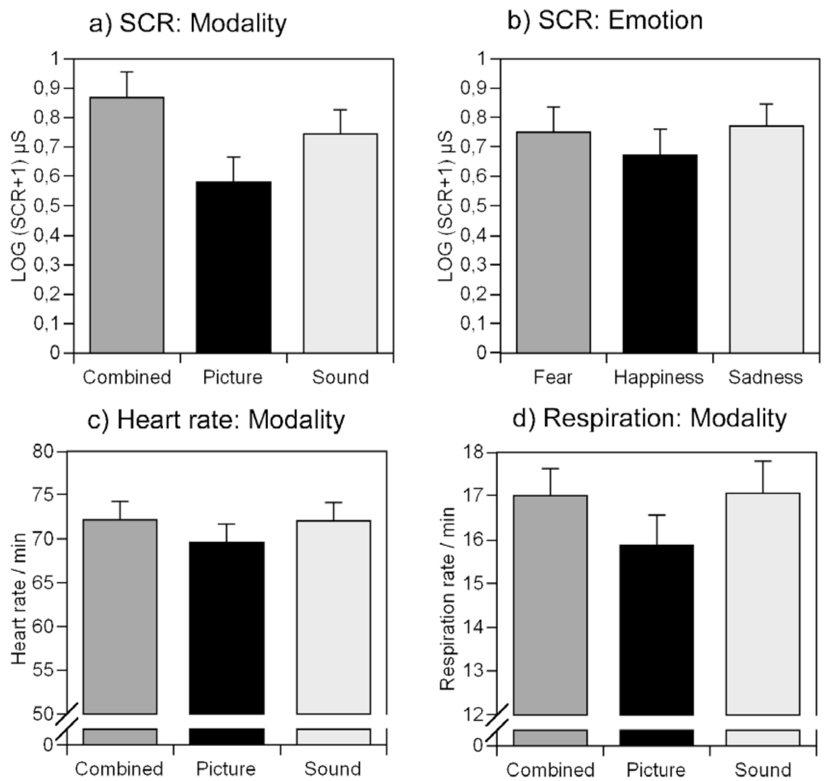

Fig. 2. Physiological results of SCR (a) and (b), heart rate (c), and respiration (d). Depicted are means and standard error of the means. (a) Findings demonstrate the largest SCR for the combined conditions, intermediate for the sound conditions and lowest for the picture conditions ($p < 0.001$). (b) Negative emotional conditions have larger SCR than the positive emotional conditions ($p < 0.05$). (c, d) Both heart rate ($p < 0.001$) and respiration ($p < 0.01$) have increased values in the combined and sound conditions in comparison with the picture conditions.

experiences indicated by increased happiness experiences in both the fear and sad conditions and reduced fear and sadness experiences in the fear and sad conditions (compared to the combined and picture conditions), respectively (all at $p < 0.01$, Fig. 1a,c). Regarding the evoked emotion of sadness, the picture condition alone also showed reduced sadness experience compared to the combined condition ($p < 0.01$, Fig. 1c). Finally, both the "sadness" scale in the evoked emotion of fear as well as the "fear" scale in the evoked emotion of sadness were increased in the combined conditions compared to the sound conditions (all at $p < 0.01$, Fig. 1a,c). Taken together, the sound conditions showed a reduced emotional clarity compared to the combined and the picture conditions.

On the other hand, both the psychophysiological (SCR, HR, Resp) and the psychometrical involvement measures showed a different pattern. Four two-way repeated-measures ANOVA revealed in all these arousal measurements a highly

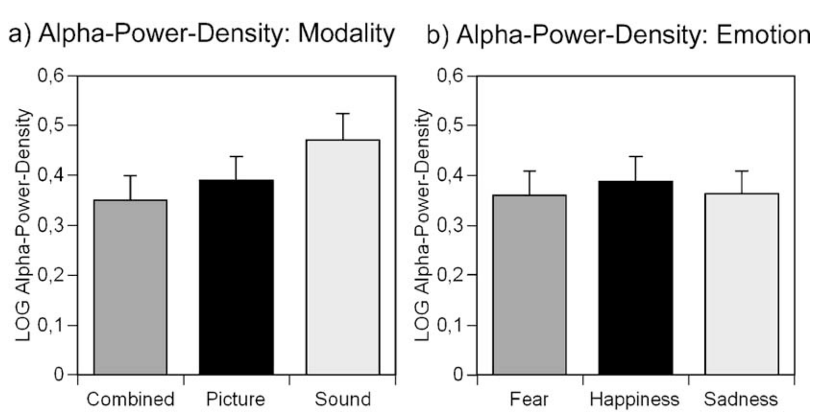

Fig. 3. Means (±S.E.M.) of log Alpha-Power-Density (8–13 Hz). (a) Depicted is the highly significant main effect of modality ($p < 0.001$) indicating the largest Alpha-Power-Activity for the sound conditions, intermediate for the picture conditions and lowest for the combined conditions. (b) Additional four-way repeated-measures ANOVA excluding the sound modality factor (please see text for explanation) revealed a significant main effect of emotion ($p < 0.01$) demonstrating increased Alpha-Power-Activity in the happy conditions (combined+picture) compared to the fear and sad conditions.

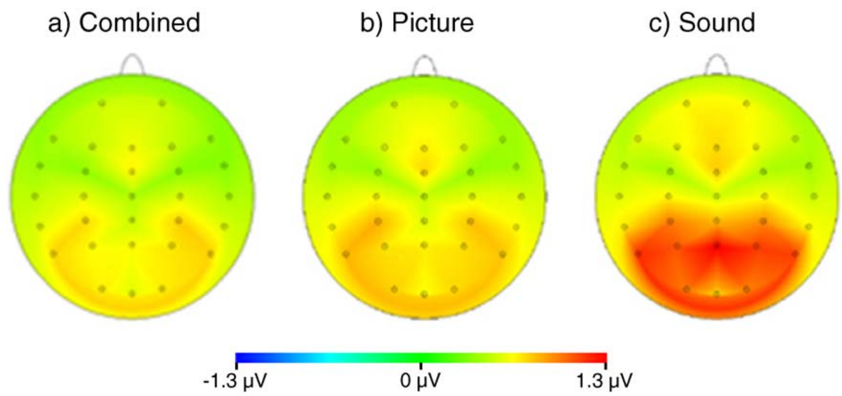

Fig. 4. Scalp Maps of Alpha-Power-Density (8–13 Hz) in the combined (a), picture (b), and sound conditions (c).

significant main effect of modality (SCR: $F_{(2,20)}=19.14$, $p<0.001$, $ETA^2=0.657$; HR: $F_{(2,22)}=20.07$, $p<0.001$, $ETA^2=0.646$; Resp: $F_{(2,21)}=10.67$, $p<0.01$, $ETA^2=0.504$; Involvement scale: $F_{(2,22)}=13.48$, $p<0.001$, $ETA^2=0.551$), demonstrating increased arousal and involvement experiences both subjectively and psychophysiologically in the combined and sound conditions compared to the picture conditions (see Figs. 1d and 2a,c,d). Regarding SCR, paired *t*-tests additionally showed a significant difference between the combined and sound conditions, indicating increased amplitudes in the combined conditions in comparison with the sound conditions. Furthermore, SCR measures showed a significant main effect for emotion (SCR: $F_{(2,20)}=3.98$, $p=0.035$, $ETA^2=0.285$) which was qualified by reduced SCR's in the happy conditions compared to the negative emotional conditions (Fig. 2b). Regarding respiration, besides the main effect of modality, a significant main effect of emotion ($F_{(2,21)}=15.19$, $p<0.001$, $ETA^2=0.591$) as well as a significant interaction of emotion and modality ($F_{(4,19)}=5.990$, $p<0.01$, $ETA^2=0.558$) was revealed, which clarifies that the increased respiration rate in the combined and sound conditions is only apparent for fear and happiness and could not be found for sadness. Finally, temperature measurement of the left little finger showed a significant main effect of emotion ($F_{(2,22)}=3.626$, $p=0.044$, $ETA^2=0.248$), revealing decreased temperature in the fear conditions in comparison with the happy conditions. No other significant temperature differences between the three emotions could be observed. Taken together and most important for this study, the psychometrical and psychophysiological measures of involvement clearly demonstrated higher arousal levels in the combined and sound conditions compared to the picture conditions.

Regarding the brain activation pattern, the four-way repeated measure ANOVA revealed a highly significant main effect of modality ($F_{(2,22)}=15.55$, $p<0.001$, $ETA^2=0.586$), indicating the largest Alpha-Power-Density for the sound conditions, intermediate for the picture conditions, and lowest for the combined presentations of auditory and visual emotional stimuli. A linear trend describes the relationship between the three modalities ($p<0.001$, $ETA^2=0.527$; see Figs. 3a and 4). Furthermore, all conditions yielded topographically larger Alpha-Power-Density values over posterior than anterior sites (Region: $F_{(1,23)}=141.05$, $p<0.001$, $ETA^2=0.860$) and this effect was more pronounced for the sound conditions (Modality * Region: $F_{(2,22)}=6.724$, $p<0.01$, $ETA^2=0.379$). The nearly significant main effects of emotion ($F_{(2,22)}=3.33$, $p=0.054$) and hemisphere ($F_{(1,23)}=3.418$, $p=0.077$) indicated tendencies for an increased Alpha-Power in the happy conditions compared to the negative emotional conditions and for a greater extent of Alpha-Power in every emotional condition over the left hemisphere, respectively. No other significant effects or tendencies could be observed. Because the emotional experience was significantly less accurate and pronounced in the sound conditions (see psychometrical results above), we conducted additionally a post-hoc four-way repeated-measures ANOVA excluding the sound modality factor. This analysis showed no additional significant results except the expected significant main effect for emotion ($F_{(2,22)}=8.96$, $p<0.01$, ETA2=0.449), demonstrating an increased Alpha-Power in the happy conditions (combined and picture) compared to the fear and sad conditions (see Fig. 3b). However, we are reluctant to make strong arguments with regard to this finding because no a priori hypothesis has been made.

4. Discussion

The results of the psychological ratings clearly showed the subject's ability to experience the presented emotions. More important, the emotional experience of the evoked emotions was most accurate and pronounced in the combined conditions, intermediate in the picture conditions and lowest in the sound conditions. This is substantiated by the clearest difference between the three basic emotions in terms of the emotional ratings. Both the psychological (involvement scale) and the physiological (SCR, HR, Respiration) intensity measurements revealed increased measures in the combined and sound conditions compared to the picture conditions. Finally, statistical analysis revealed the largest Alpha-Power activity (note that higher Alpha-Power reflects reduced brain activity) for the sound conditions, intermediate for the picture conditions and lowest for the combined presentations of auditory and visual emotional stimuli at all 4 electrode clusters of the brain. Taken together, the combined conditions showed the largest emotional clarity and intensity together with the lowest Alpha-Power-Activity (i.e. stronger cortical activation), indicating the strongest activation over occipital, parietal and frontal, temporal electrode clusters of the brain. Besides the activation increase due to the crossmodal integration of two sensory stimuli (for a discussion of this point, please see limitations of the study), this strongest activation suggests enhanced activation in a distributed neuronal network for emotion and arousal processing. The results of the picture conditions suggest a markedly reduced emotion experience both subjectively and physiologically—despite of conserved emotion clarity (perception). The sound conditions on the one hand led to reduced emotional clarity and brain activity (largest Alpha-Power = lowest brain activity) but on the other hand to an emotional intensity comparable with the combined conditions.

4.1. Comparison between the combined and the picture conditions

Modern neuropsychological theories of emotion propose the following processes occurring after the initial presentation of an emotive stimulus (Phillips et al., 2003; for similar models see Scherer, 2000): (1) the appraisal and identification of the emotional significance of the stimulus; (2) the production of a specific affective state, including autonomic, neuroendocrine, and somatomotor responses, as well as conscious emotional feeling; (3) the regulation of the affective state and emotional behaviour. In addition, recent neuroimaging studies (Damasio et al., 2000; Anders et al., 2004; for a review see Craig, 2002) have provided strong evidence that cortical activations in brain areas representing somatic and visceral states of the body (e.g. insula, somatosensory association areas) constitute an important part of the basis of emotional feelings. Thus, increased somatic and visceral reactions of the body can be interpreted as strong indicators of increased emotional feelings or experiences. In our study, we found highly significant and consistent increases in somatic (SCR, HR, Resp) and psychometrical involvement measures in the combined compared to the picture conditions, clearly indicating enhanced emotional feelings in the combined conditions of the experiment. Furthermore, this enhanced emotional feeling was associated with increased cortical activation (indexed by reduced Alpha-Power) at anterior and posterior electrode clusters of the brain. The increased cortical activation at posterior clusters (measured at left- and rightsided occipital and parietal electrodes) in the combined conditions compared to the picture conditions is in line with findings from neuroimaging and electrophysiological studies showing that this part of the cortex is implicated in the modulation of emotion-related arousal (Davidson et al., 2000; Heller et al., 1997) and is recruited by emotional visual stimuli (compared to neutral stimuli, Beauregard et al., 1998; Lane et al., 1997; Davidson et al., 2000), in particular, when these stimuli are highly arousing (Lang et al., 1998; Taylor et al., 2000). In addition to parietal and occipital structures, functional imaging papers consistently also reported activation in temporal and frontal cortical structures during emotional processing of positive and negative emotional stimuli, including the hippocampus, insula, orbitofrontal cortex, anterior cingulate, dorsolateral and dorsomedial prefrontal cortex (in addition to subcortical structures as the amygdala, thalamus, ventral striatum and brainstem nuclei, for a review see Phillips et al., 2003; Phan et al., 2002). Thus, the increased activity in the combined conditions (indexed by reduced Alpha-Power) in the anterior and posterior electrode clusters of the brain can be interpreted as enhanced emotional processing in several of the aforementioned cortical structures, suggesting increased activity in a distributed emotion and arousal network in the combined compared to the picture conditions. However, future studies are needed to more precisely localize the involved cortical and subcortical structures of this emotional enhancement effect because electrical fields measured at particular electrode sites are too inaccurate to infer the underlying intracerebral cortical activations. Moreover, the increased brain activation in the combined compared to the single modality conditions is at least partly caused by the crossmodal integration of two sensory stimuli coming from different modalities. We discuss this point in more detail in a separate section of the paper (please see limitations).

Taken together, the results of this study strongly confirm the idea that music is in fact a powerful elicitor of emotions and can markedly enhance the emotional experience in the context of the presentation of affective pictures. This finding of a synergistic effect of music and pictures fits perfectly with the observation in a recent study by Koelsch et al. (2004) who showed that music and language prime a common semantic network. Moreover, this study shows that emotional reactions (e.g. emotional experiences or feelings) are relatively weak if only visual stimuli are used. Therefore, we believe that this stimulation mode will in most cases not evoke emotional feelings (or at least in a markedly reduced way) but rather a more cognitive, less arousing emotional perception process. We hypothesize that this finding could be one of the reasons for the often discrepant findings in emotion research (e.g. experimental results relative to hemispheric lateralization of emotional processing and differential activation during different emotions diverge in multiple ways), indicating that different emotion induction methods lead to different activations of the three emotional processes in the model by Phillips et al. (2003) mentioned above. We suggest that in particular the production of a specific affective state (including autonomic, neuroendocrine, and somatomotor responses as in process 2 of the described model) varies widely between different induction methods as has been shown in this experiment between the picture and the combined conditions.

4.2. Musical emotion: a paradox?

A further interesting finding of our study is the relatively strong Alpha-Power during listening of emotional musical excerpts. Although these stimuli evoked strong emotional reactions (indicated by increased SCR, HR, Resp and psychometrical measures) the cortical activation substantially decreases compared to both the combined and the picture conditions. Whereas the increased Alpha-Power activity (note that higher Power reflects reduced brain activity) in occipital and parietal electrode clusters of the brain can easily be explained by the reduced visual input in this condition (fixation cross versus emotional pictures), the increased Alpha-Power activity in frontal and temporal electrode clusters requires another explanation.

One explanation could be that the neural electrical activity is reduced because the sound stimuli are overall more pleasant as indicated by the valence ratings which showed that the ratings of the negative musical stimuli (sad and fear sound) were significantly less negative compared to both the negative combined and picture conditions. In line with this interpretation, several recent neuroimaging and electrophysiological studies have demonstrated reduced brain activation during positive compared to negative emotional stimuli (Carretie et al., 2001; Northoff et al., 2000; Schmidt and Trainor, 2001). However, this interpretation can not fully explain the finding of our study because the main effect of modality clearly indicates that musical stimuli irrespective of valence evoked reduced brain activation compared to the combined and picture conditions. Therefore, we favour another explanation. We hypothesize that the dissociation between the involvement measurements and the brain activity (in posterior and anterior electrode clusters of the brain) support the notion that emotional musical excerpts activate an internal mode of brain function. This internal mode is characterized by cognitive and emotional processes revolving around the subject's internal state instead of current external events or circumstances (Gusnard et al., 2001; Raichle et al., 2001). Accordingly, fronto-parietal attention networks (Corbetta and Shulman, 2002) preparing the subject to react adequately to external events or circumstances show diminished activations, leading to reduced cortical brain activation indexed in our study by increased Alpha-Power-Activity.

Evidence for this interpretation comes from a PET study of Blood and Zatorre (2001) which demonstrated that intensely pleasant responses to music correlated positively with activations almost exclusively in subcortical structures, whereas strong negative correlation were found in the prefrontal and posterior neocortical regions (precuneus/cuneus), clearly indicating that strong and arousing emotional experiences can be evoked without strong activation in cortical brain regions. Accordingly, Damasio et al. (2000) demonstrated during the feeling of self-generated emotions widespread activation decreases in neocortical brain regions, including frontal, temporal, parietal and occipital areas. In contrast, primarily subcortical brain areas were strongly activated along with enhanced psychophysiological as well as psychometrical arousal measures. Therefore, we believe that these findings strongly indicate that reduced activation in cortical regions and increased psychometrical and psychophysiological arousal measures are not a paradox. We hypothesize that subcortical regions, such as for example the amygdala, the striatum, the thalamus are activated in the musical condition of our experiment leading to strong emotional experiences and somatic and visceral body reactions. However, as well-established, EEG can not detect such subcortical brain activation patterns.

The reduced cortical brain activation in the sound conditions found in our study should also not be seen as being in contrast to the excellent study of Altenmuller et al. (2002) which revealed widespread bilateral fronto-temporal brain activations during listening to musical excerpts of different valence. In this study, the authors recorded direct current (DC) potentials for relatively short events. In addition, they also compared the DC potentials obtained in these conditions to a pre-stimulus interval during which no stimulation occurred. In our study, we used cortical oscillation within the Alpha band and conducted between-conditions comparisons. Therefore, both studies substantially differ in terms of methodology, experimental design, and statistical analysis. Moreover, the finding of our study of reduced cortical brain activation in the musical compared to the picture and combined conditions does not necessarily indicate that the musical stimuli did not evoke fronto-temporal brain activations per se. It only indicates that the fronto-temporal brain activation is markedly increased in the picture as well as in the combined conditions compared to the sound conditions. Thus, we suggest that picture and combined conditions activate an emotional perception process characterised by focussing attention to external events, whereas musical excerpts activate an emotional perception process characterised by focussing attention to internal events and circumstances.

4.3. Limitations

Due to the lack of a neutral control condition (neutral music does not exist, for an explanation see Krumhansl, 1997; Peretz et al., 1998; Cooke, 1959), one could argue that the increased brain activation in the combined conditions is simply produced by multimodal cortical networks known to be involved in the integration of simultaneously presented auditory and visual information (Downar et al., 2000; Calvert et al., 2001; Beauchamp et al., 2004). However, we do not think that the modality effects of this study can be fully explained by such neutral crossmodal integration processes. The following reasons speak clearly against such an interpretation. First, and most obvious, the subjects consistently reported an increased emotional involvement along with enhanced somatic reactions of the body in the combined conditions. Second, in addition to the modality specific effects, valence specific effects in physiological measures in good agreement with the literature were found implying that the emotion induction procedure used in this study was successful and that the observed change in the brain activation pattern between the different modalities is influenced by the emotional valence of the stimuli. Regarding brain activations and SCR, we observed in the combined and the picture conditions but not in the sound conditions (note that the sound conditions were characterized by reduced emotional clarity) significant valence specific effects, demonstrating increased emotional brain processing and SCR levels in the negative emotional conditions (sad and fear) and a markedly reduced overall brain activation and SCR level in the positive conditions (Carretie et al., 2001, 2004; Northoff et al., 2000). In addition, reduced skin temperature of the left little finger in the fear conditions compared to the happy conditions as well as reduced respiration rates in the sad conditions compared to the happy and fear conditions were found (Krumhansl, 1997; Stemmler et al., 2001), further indicating successful emotion induction in the happy, fear and sad conditions. Nevertheless, we do not question that the activation of the crossmodal integration areas contribute to the observed emotional enhancement effect. Future studies are needed to clearly differentiate between a neutral crossmodal integration process and an emotional enhancement process.

5. Conclusion

Summing up, this is the first neurophysiological study demonstrating a strong emotional enhancement effect by simultaneous presentation of congruent emotional pictures and music regarding subjective ratings, peripheral and central physiological measures. Moreover, this study implies that strongest emotional reactions (experience) cannot be evoked by presenting emotional pictures alone (at least in most cases), but only by simultaneous presentation of congruent emotional musical excerpts. Therefore, we believe that this emotion induction method can make an important contribution to an improved understanding of the neural structures involved in emotional feelings and psychiatric disorders as depression and anxiety.

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