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ORIGINAL PAPER

Effects of Music on the Recovery of Autonomic and Electrocortical Activity After Stress Induced by Aversive Visual Stimuli

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Abstract The purpose of this study was to compare the effects of music and white noise on the recovery of physiological measures after stressful visual stimulation. Twenty-nine participants took part in the experiment. Visual stimulation with slides eliciting disgust was followed by subjectively pleasant music, sad music, and white noise in three consecutive sessions. The spectral power of the frontal and temporal EEG, skin conductance, heart rate, heart period variability, facial capillary blood flow, and respiration rate were recorded and analyzed. Aversive visual stimulation evoked heart rate deceleration, increased high frequency component of heart period variability, increased skin conductance level and skin conductance response frequency, decreased facial blood flow and velocity, decreased temporal slow alpha and increased frontal fast beta power in all three sessions. Both subjectively pleasant and sad music led to the restoration of baseline levels on most parameters; while white noise did not enhance the recovery process. The effects of pleasant music on post-stress recovery, when compared to white noise, were significantly different on heart rate, respiration rate, and peripheral blood flow. Both positive and negative music exerted positive modulatory effects on cardiovascular and respiratory activity, namely increased heart rate, balanced heart period variability, increased vascular blood flow and respiration rate during the post-stress recovery. Data only partially supported the "undoing" hypothesis, which states that positive emotions may facilitate the process of physiological recovery following negative emotions.

Keywords Music · Noise · Emotion · EEG · Autonomic activity

Introduction

Therapeutic applications of music

Music has been used as a therapeutic technique because it is considered to have stress reducing capabilities. Many clinical and nursing care studies indicate that music decreases anxiety, and reduces both blood pressure and heart rate in stressful situations associated with clinical laboratory procedures (Alien et al., 2001; Andrade & Bhattacharya, 2003; Hamel, 2001; Schneider et al., 2001; Sutoo & Akiyama, 2004; Thorgaard et al., 2004; Watkins, 1997). Music is commonly used to enhance coping with the stress of a painful medical procedure (Fauerbach et al., 2002). Furthermore, some clinical findings indicate that music attenuates symptoms in various disorders, such as epilepsy (Turner, 2004), Parkinson's disease (Bernatzky et al., 2004; Paccetti et al., 1998), and attention-deficit/hyperactivity disorder (Abikoff et al., 1996).

However, there still exists controversy in "music listening—stress reduction" research. For example, several comprehensive meta-analysis and review studies in the area of application of music intervention for the care of patients with dementia in elderly settings (Kneafsey, 1997; Lou, 2001; Roger, Chapin, & Brotons, 1999; Sherratt, Thornton, & Hatton, 2004) highlight several methodological weakness and limitations, and the mechanism by which music appears to modify physiological activity is not clear. It is obvious that more rigorous research designs are required to evaluate and understand psychological and physiological effects of music on behavior in distress and negative affect states. In

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addition, research is needed that will attempt to identify which properties of music are responsible for the psychophysiological effects. Thus, this study addresses issues concerning the emotion eliciting qualities of music. The ability of music to induce an emotional response is a universal phenomenon and studying music from an affective neuroscience perspective may help foster knowledge in the area of brain mechanism of emotional reactivity to music as well as lead to useful clinical applications (Blood & Zatorre, 2001; Kaiser et al., 1995; Panksepp & Bernatzky, 2002; Zatorre, 2003).

Physiological effects of affective visual and auditory stimulation.

Emotional responses can be induced by stimuli in different sensory modalities (Gomez & Danuser, 2004). Both auditory and visual stimulation have the property to elicit emotions detectable by means of central (CNS) and autonomic (ANS) nervous systems measures. No studies, however, have measured both CNS and ANS functioning during affective auditory and visual stimulation to examine the interaction of effects relevant to emotions when both sensory modalities are used sequentially. Studies are limited to the analysis of either ANS (Boiten, Frijda, & Wientjes, 1994; Hubert & de Jong-Meyer, 1990; Levenson, 1992; Lang, 1995; Nyklicek, Thayer, & van Doornen, 1997), or CNS (Koelsch et al., 2000; Iwaki, Hayashi, & Hori, 1996, 1997; Iwaki et al., 1995; Iwanaga, Doeda, & Iwaki, 1996; Iwanaga & Moroki, 1999; Ogata, 1992; Schmidt & Trainor, 2001) activity. Only a few authors report the results of simultaneously assessed autonomic and cortical variables during experimentally induced emotions (Amrheim et al., 2004; Baumgartner, Esslen, & Jancke, 2005; Brauchli, Michel, & Zeier, 1995; Cuthbert et al., 2000; Palomba, Angrilli, & Mini, 1997; Spence, Shapiro, & Zaidel, 1996).

Emotional reactions associated with the processing of affective pictures have been investigated more intensively, and results of these studies provide detailed information about associations between specific physiological measures (e.g., skin conductance, heart rate, facial electromyogram, brain activity parameters) and the two basic dimensions of emotion, valence and arousal, of pictorially induced emotions (reviewed in Hamm, Schupp, & Weike, 2003). The International Affective Picture System (IAPS, Lang, Bradley, & Cuthbert, 2001), which is a set of normative visual emotional stimuli, uses standardized pictorial stimuli for eliciting specific emotional states in an experimental setting. An important advantage of the IAPS is the availability of affective space mapping of emotion in the dimensions of arousal and pleasantness (Cuthbert, Bradley, & Lang, 1996; Lang, 1995; Witvlet & Vrana, 1995). A dimensional scaling of emotions induced by the IAPS slides is typically made using the self-assessment manikin (SAM, Hamm, & Vaitl, 1993; Lang, Bradley, & Cuthbert, 2001); this instrument is a pictorial rating form that enables a self-report assessment of arousal (calm vs. high aroused), valence (pleasant vs. unpleasant) and dominance dimensions (Lang, 1995).

Affective visual stimulation in a passive viewing mode evokes a transient physiological response pattern featured by a heart rate (HR) deceleration, skin conductance increase, slight decrease of respiration frequency, alpha-blocking and increase of delta and beta EEG activities at the occipital and frontal areas (Sohn et al.,1998cd; Sokhadze et al., 1998). However, evoked phasic (i.e., short-term) physiological responses varies across discrete emotions. For example, in a case of disgust, HR, heart period variability (HPV) and respiration rate (RESP) showed the least deceleration, and skin conductance response (SCR) yielded a lower amplitude but higher non-specific SCR (NS.SCR) frequency when compared to other negative emotions (Sohn et al., 1998c). The electroencephalographic (EEG) profile of disgust appears as a bilateral frontal slow alpha decrease which is less pronounced than in sadness or in positive emotions, and a significant theta power increase that is more profound at the right frontal side (Sohn et al., 1998d).

Other authors report similar ANS and CNS effects of negative affect-eliciting visual stimulation (Davidson, 1995; Hubert & de Jong-Meyer, 1990; Klorman, Weisberg, & Austin, 1975). Davidson et al. (1992) presented their participants emotionally charged film clips and found greater right-sided frontal activation during a disgust condition relative to a happiness condition. Other studies show that disgust elicits higher SCL but lower respiration amplitude than happiness, and lower HR changes and lower pulse volume than sadness (Levenson, 1992). Cacioppo et al. (1993) emphasized that the mean change scores of HR for disgust are quite moderate, and they discussed possible reasons why HR is not changing much in such a strong emotion as disgust.

Disgust is a particularly interesting negative emotion which possesses a moderate value on the arousal scale but a high value on the negativity scale when assessed by two-dimensional affective space (Lang, 1995). If categorized by type of associated motivational drive, disgust would be considered an emotion with a “withdrawal” behavioral tendency. Pathways mediating the physiological responses associated with this emotion could be considered as belonging to the behavioral inhibition system (Gray, 1982). Disgust represents an interesting model of “directional fractionation” (Lacey & Lacey, 1970), as the emotion is characterized by relatively low cardiovascular and respiratory activities but at the same time increased electrodermal (Boucsein, 1999) and electrocortical activities (Davidson, 1995, 1998). As outlined by Levenson (1994), several emotions (including disgust) are associated with low arousal and thus behaviors with low metabolic demands. These emotions produce less autonomic changes than an emotion such as anger, which is associated with high arousal and high metabolic demand behavior such as "fight-or-flight" type actions that require an increased autonomic support.

Studies on physiological effects of music

Studies of cardiovascular responses to music showed inconsistent results; these inconsistencies might be attributable to methodological differences in music selection. It was shown that HR and blood pressure were decreased by sedative music (Knight & Rickard, 2001) and by self-selected music (Alien et al., 2001; Miluk-Kolasa, Matejec, & Stupnicki, 1996; White, 1999). However, other studies indicate that music induced no changes in HR or blood pressure (Vanderark & Ely, 1994; Strauser, 1997) or induced stable increases of physiological responses (Iwanaga & Moroki, 1999).

McFarland (1985) studied the effects of music on skin temperature (TEMP). He found that arousing, negative emotion music (Mars, from G. Holst's "Planets") terminated TEMP increases and perpetuated TEMP decreases, whereas calm, positive emotion music (Venus, from G. Holst's "Planets") terminated TEMP decreases and perpetuated TEMP increases. However, the author noted that the effects of music may depend upon what music has been previously heard (McFarland, 1985). This notion is rather important, as the autonomic responses to music may be dependent on preceding tonic levels of arousal.

Burns et al. (1999) examined the effects of listening to classic, rock, and relaxation music on perceived and peripheral physiological indicators of relaxation. They found that classical and self-selected relaxation music increased subjective perceptions of relaxation. Unfortunately, the physiological measures (HR, TEMP and muscle tone) in this study did not show significant effects, a finding that may be due to less than optimal physiological measurement (e.g., HR measured by plethysmograph). Thus, the author's conclusion that listening to certain types of relaxation music for a short period may not have effects on level of physiological arousal must be considered tentative.

One of the most comprehensive studies on the cardiovascular differentiation of musically-induced emotions was carried out by Nyklicek, Thayer, and van Doornen (1997). These authors assessed a broad range of cardiovascular and respiratory variables to maximize the ability to distinguish among the effects of listening to 12 fragments of music. White noise was used as a neutral stimulus. The successful discrimination of emotions induced by music in this study was mainly due to respiratory and cardiac chronotropic components. The authors also found support for the hypothesis that a differentiation of basic emotions could be performed by arousal and valence dimensions.

There are several studies systematically investigating the relationship between music and electrocortical activity (Altenmuller et al., 2002; Brattico et al., 2003; Breitling, Guentner, & Rondot, 1987; Davidson & Schwartz, 1977; Iwaki, Hayashi, & Mori, 1996, 1997; Khalfa et al., 2005; Loui et al., 2005; Ogata, 1992; Walker, 1977, 1980). One of the findings was that music can evoke both calming and stimulating effects depending on the ongoing general cortical activation level of participants. Different types of emotion-eliciting music were found to modulate arousal in a study by Iwaki, Hayashi, and Mori (1997). This study also presented data on the subjective and physiological responses to the repetitive exposure to music. The functional relation between the music and brain activation was discussed. The music used in Iwaki et al. (1997) was previously employed by McFarland (1985), i.e., Mars and Venus, from G. Holst's "Planets." Iwaki et al. (1997) suggested that two processes occur during presentation of the music. One is the orienting response and habituation, while the other involves the attention to music accompanied by changes in emotion (Iwaki et al., 1995; Iwaki, Hayashi, & Mori, 1996, 1997; Iwanaga, Doeda, & Iwaki, 1996).

Walker (1977) analyzed associations between the subjective reaction to music and EEG frequencies over the occipital areas. He found that subjective attentiveness to music was positively correlated with alpha production, while beta activity showed large discrepancies during music. Davidson and Schwartz (1977) employed music as a task engaging primarily the right hemisphere; other studies in the EEG literature also report interhemispheric difference in alpha consistent with the hypothesis that music processing involves the right hemisphere more than the left one. Breitling, Guentner, and Rondot (1987) used an EEG brain mapping technique to assess the topographic distribution of EEG power during exposure to auditory stimulation with music. The authors concluded that perception of a melody involves integrative processes and recognition of higher melodic and tonal entities. These might be situated predominantly in the right hemisphere (i.e., in the right frontal and parietal multisensory association areas) in non-musicians. Perhaps listening to music requires a cognitive activity that occurs in response to musical information such as melody, harmony, rhythm, etc. (Janata & Petsche, 1993). Only a few systematic studies report on event-related brain activity elicited by the cognitive processing of music, and how music processing is influenced by a preceding musical context, unexpected chords, and the degree of expectancy violation of harmonic contexts both in musicians and non-musicians (Brattico et al., 2003; Janata, 1995; Koelsh et al., 2000; Koelsch & Siebel, 2005; Loui et al., 2005).

The results obtained by Iwaki et al. (1995, 1996, 1997) support the hypothesis that music influences arousal mechanisms and that different types of music can induce both stimulatory and sedative effects on the arousal level. In this series of studies, regardless of type of music, participants with high arousal were calmed while participants with low arousal were aroused while listening to music. One study demonstrated the modulating effects of music and noise on arousal during different stages of the sleep-wakefulness cycle (Iwaki et al., 1995). Similar modulation by music was shown in the experiments where EEG and autonomic arousal levels were manipulated by cognitive tasks and rest periods before exposure to calm or arousing music (Iwaki, Hayashi, & Mori, 1996).

The "undoing" hypothesis: Positive emotion as a facilitator of recovery from negative emotion

According to the "undoing" hypothesis of Levenson (1994), some positive emotional states are functionally able to facilitate the restoration of physiological activity shifted by negative emotional states. Positive emotions within this theoretical framework may speed recovery from the cardiovascular sequelae of negative emotions (Fredrickson & Levenson, 1998). One of the main arguments proposed by Levenson was that positive emotions may not be associated with behavior requiring much autonomic arousal. For instance, some pleasant emotions, such as contentment, might not be associated with any particular behavior, or if they are, the associated behavior would have little metabolic demand and thus moderate autonomic activation. Levenson (1994) also proposed that one of the primary functions of positive emotions might be associated with "unwinding" autonomic activation produced by the negative emotions.

This hypothesis was supported experimentally in studies using fear as negative emotion and contentment as a positive emotion. Results indicated that cardiovascular arousal associated with fear induced by an affective film dissipated more quickly when followed by the contentment as compared to the sad or neutral films (Fredrickson, 1997; Fredrickson & Levenson, 1998). Fredrickson, Branigan, and Tugade (1998) report that two distinct positive emotions advance recovery from the cardiovascular aftereffects of a negative emotion. The duration of cardiovascular reactivity (HR, pulse volume, pulse transit time, and blood pressure) elicited by a speech task recovered faster if participants viewed a contentment film, and slower if the film was neutral. The role of positive emotion as a means by which to "bounce back" from stressful experience was later elaborated to a broader theoretical framework of positive emotions and positive psychology which specifically emphasizes possible health-promoting functions of positive emotions (Dunn & Dougherty, 2005; Fredrickson, 1998, 2001; Tugade & Fredrickson, 2004). Thus, research shows that positive emotions may have advantageous physical and psychological health outcomes by serving a buffering function and providing thus a useful antidote to the problems associated with negative emotions and illness (Tugade, Fredrickson, & Feldmann-Barrett, 2004).

In a context of the "undoing" hypothesis, the ability of music to induce positive emotions could be used to facilitate the process of recovery from physiological arousal provoked by negative emotions (also referred to here as stress). In a pilot study intended to test the applicability of "undoing" theory with musically-induced positive emotions, fragments of music identified as pleasant as well as fragments of white noise were presented after a set of subjectively unpleasant visual stimulation (Sohn et al., 1998a). Facilitation of alpha rhythm restoration in the music group, when compared to the white noise and "no-music/noise" control groups, was found. However, autonomic responses obtained when participants were listening to pleasant music showed more signs of arousal than when negative emotions were elicited by passive viewing of affective pictures (Sohn, Sokhadze, Yi, & Lee, 1998a,b). One of the possible reasons for this mixed autonomic response pattern was that different sets of emotion-eliciting slides of the negative valence category (fear, sadness, disgust, anger) were used. Previous studies report that despite the similarity of the overall pattern of autonomic reactivity to affective visual stimuli with negative valence, significant differences in the magnitude of autonomic responses to pictures eliciting discrete emotional states were found. For example, disgust could be readily differentiated from sadness by autonomic responses (Sohn et al., 1998a,b,c,d).

Thus, these findings suggest the importance of testing the "undoing" hypothesis by using visual stimuli that induce only one emotional state, and analyzing recovery after this negative emotion (IAPS-stress) by using music to induce a positive emotional state during post-stress recovery. To improve interpretability, a second musical fragment ("sad" music) was employed as an emotional but not unpleasant contrast, with white noise serving as an unemotional control condition. For this study, disgust was selected as an unpleasant emotion with negative valence. Disgust has relatively low autonomic arousal, and thus the pleasant music was selected as a positive emotion also with moderate autonomic arousal. The main differences in the design of this study as compared to Sohn et al. (1998a) are as followings: a) only disgust-eliciting pictures are used to elicit negative emotion or stress (IAPS-stress); b) both subjectively "pleasant" and "sad" (i.e., less pleasant) music and white noise are used; c) participants were not divided in groups, but rather each participant is exposed to all three experimental conditions (IAPS-induced stress followed by pleasant music, sad music, and white noise, in a counterbalanced order).

The aim of the present study is to identify the effects of music on the process of recovery (and baseline restoration) of cardiovascular, respiratory, electrodermal and electrocortical activities after aversive visual stimulation. If subjectively pleasant music enhances post-stress recovery compared to "sad" music or white noise, support will be found for the "undoing" hypothesis. Thus, the hypothesis predicts a different post-stress recovery course for the conditions with pleasant versus sad musical fragments.

Methods

Participants

Twenty-nine undergraduate college students (females aged 20 to 24)) participated in the study. The students were provided with cafeteria vouchers (equivalent to approximately $10) for participation in the study. All participants reported they were in good health and had no history of neurological or psychiatric disorders. They also reported compliance with a requirement on the posted invitation, which was to refrain from drinking caffeine-containing beverages and smoking for at least 1 hour before experiment. All procedures were approved by the appropriate IRB, and written consent was obtained from each participant.

Experimental procedure

After an introduction to the experiment and attachment of electrodes, they were placed in a reclining chair for 10 min in the experimental room with dim light for adaptation and baseline recording. Visual stimulation was delivered by a Kodak slide-projector while auditory stimulation was presented through the stereo loudspeakers from a "Pioneer" high fidelity CD player system.

The experimental procedure consisted of three sessions of stimulation with the following regime: a pre-stimulation resting baseline recording (1 min), a visual stimulation with the International Affective Picture System [IAPS] (Lang et al., 1997) pictures (3 IAPS slides with mutilated bodies, 20 sec exposure of each slide), followed by a 2 min auditory stimulation and a post-stimulation resting baseline (1 min). In one session, a set of 3 IAPS pictures (IAPS #1113, #3051, #3170) was shown, followed by auditory stimulation with "pleasant" music (according to pilot subjective reports; "Spring song," Victor Musical Industries, Ltd., Japan). In another session a second set of aversive slides (#3140, #1300, #1120) was shown, followed by "sad" music (according to pilot subjective reports; "Canon," Johann Pachelbel, The Music Therapy Charity, Warner Classics, UK). In yet another session the IAPS slides #3071, #1301, #3130 were presented followed by a white noise (20 Hz–20 KHz, 55 dB; evaluated in another study citation to be non-emotional but alerting). The order of these three sessions was counterbalanced to avoid an order bias. White noise (WN) was delivered through the same loudspeakers as music and had comparable intensity and loudness.

Affective pictures

Slides from the IAPS were selected on the base of a preliminary study. Ratings were obtained from 90 college students using the SAM and a separate scale of disgust (Lee et al., 1997). The nine IAPS pictures used in that study had been rated as eliciting disgust (Mean ± Standard Deviation [M ± SD] 3.91 ± 0.61 on 1–7 scale of disgust). SAM data for these slides were as follows: arousal, 4.89 (±0.38); valence, 2.67 (±0.49); and dominance 3.18 (±0.39). The normative means from the IAPS affective rating data base (Lang, Bradley, & Cuthbert, 2001) for the same nine slides on arousal, valence, and dominance for females are 6.57 (±0.64), 2.30 (±0.94), and 3.16 (±0.40), respectively. The arousal rating in our preliminary study was significantly lower (-1.68, $t = 6.69$, $p < 0.001$) than the normative values, while valence and dominance did not differ.

Music/noise

Musical fragments for this project were selected on the basis of subjective evaluations obtained from a college student sample matched by gender, age and socio-cultural parameters in the pilot studies (Sohn et al., 1998a,b). Pleasant music was selected from a typical relaxation CD ("Spring song") featuring natural sounds (bird song, surf of ocean, etc.) on a background of a piano melody. Manufacturers claim the music to be "1/f " music (Voss & Clarke, 1975, 1978), which is popular in Japan and Korea as a light relaxation music for meditation exercises. A musical pattern is called "1/f" ("one-over-f") when the power spectrum of sequences of musical notes is inversely proportional to the frequency on a log-log plot (Jeong, Joung, & Kim, 1998). According to Voss and Clarke (1978), the power spectra of the loudness and frequency fluctuations for Bach's music, averaged over piece, have a 1/f distribution. Several studies on music perception have employed music with a 1/f pattern to investigate the origin of a universal positive emotional response to music (Jeong, Joung, & Kim, 1998; Voss & Clarke, 1975; 1978). The selected fragment of 1/f "pleasant" music as used in this study was subjectively described as "soft, romantic, and cheerful, evoking relaxation," and most of the participants in the pilot study liked the melody, and rated it as a "pleasant" one (Sohn et al., 1998a). The second musical fragment ("sad" music) for this study was selected following results from our previous research series on affective auditory stimulation perception (Sohn et al., 1997; Sohn et al., 1998b; Sohn et al., 1999a,b; Sokhadze et al., 1998); selections were based on a familiarity with the preferences of music in young female students in Korea. Negative (in particular "sad") emotions were usually elicited by more dissonant sounding pieces of instrumental music in baroque and classic style, whereas positive emotions were usually induced by the compositions in the soft rock and pop-style. Similar habits and attitudes of music consumption with the slight variations were reported for undergraduate students in Germany by Altenmuller et al. (2002). "Sad" music ("Canon," Johann Pachelbel) in our study was a baroque piece of chamber music for three violins and bass performed in 1970 by Orchestre de Chambre (Jean-Francois Paillard). This melody was verbally described by participants in our previous studies as "sad, but not annoying, melancholic, etc." The literature on musically induced emotions typically finds that sadness is more likely to be induced by a musical excerpts characterized by a slow tempo and played in a minor mode (Khalfa et al., 2002; Peretz, 2001, 2006). Hereafter, based on pilot studies and references in musical perception research, the musical fragment "Spring song" will be referred to as "pleasant" music whereas the "Canon" will be referred to as "sad" music. White noise (55 dB) was subjectively described by participants in our previous experiments as "annoying, dizzy, uncomfortable, alerting, but not emotional at all" (Sohn et al., 1999a,b; Sohn, Sokhadze, Choi, & Lee, 2000; Sokhadze et al., 2000a). All participants in this study were not familiar with any of selected musical excerpts and never participated in pilot studies using affective auditory emotional stimulation.

Equipment and physiological variables

Physiological signals were acquired by a Grass Neurodata System and Laser Doppler Blood Flow Monitor (LASERFLO) BMP403A interfaced via BIOPAC MP100WS hardware with AcqKnowledge III (v.3.5) software. The sampling rate for all physiological signals was 512 Hz.

Electrocortical activity

The Grass Neurodata System was used to record occipital (O1, O2), temporal (T3, T4), and frontal (F3, F4) electroencephalogram (EEG) monopolarly referred to the linked earlobes. The EEG signal was interfaced to the BIOPAC MP100WS. The skin was prepared by abrasive OMNEPREP paste, and golden Grass electrodes were filled and fixed by adhesive TEN20 gel. Occipital EEG data are not reported in the present paper, since responses at O1 and O2 sites were more vulnerable to sensory stimulus-specific effects during visual stimulation.

EEG spectral power (Fast Fourier Transformation, Hanning window, linear) was analyzed for the frontal and temporal sites (F3, F4, T3, T4) and power was calculated for following frequency bands: delta (0.5–3.99 Hz), theta (4.0–7.99 Hz), slow alpha (8.0–9.99 Hz), fast alpha (10.0–12.99 Hz), slow beta (13.0–19.99 Hz), fast beta (20.0–30.0 Hz). Relative powers (RP) of each band were calculated and converted to percents: e.g., slow alpha RP = slow alpha power/total power.

Frontal asymmetry scores were measured for theta, slow alpha, fast alpha, slow beta, and fast beta bands. Frontal slow alpha asymmetry index (A-score), for instance, was calculated as follows: Frontal slow alpha A-score = Log (RP slow alpha F4) – Log (RP slow alpha F3).

Blood flow

The LASERFLO Model BMP403A Blood Perfusion Monitor (TSI Inc., USA) was used to non-invasively measure capillary blood perfusion parameters such as blood flow, volume, and velocity (Anderson, 1989). The LASERFLO device uses laser Doppler technology to measure: 1) blood flow (FLOW) in ml/min/100 *g* of tissue; 2) blood volume (BV) expressed as the average number of Doppler shifts per photon (maximal BV is 1.60 and is proportional to concentration of red blood cells (RBC's) in tissue); 3) blood velocity (VEL) proportional to average velocity of moving RBC's in capillaries and expressed as mean Doppler shift frequency (in KHz). The probe was attached to the forehead (1 cm above the left eyebrow) by adhesive material. The LASERFLO probe is factory-calibrated. It delivers a low power beam of laser light (wavelength ∼780 nm, Doppler update rate 188 Hz) to the facial tissue under study. The volume of tissue sampled by the light is in the order of 1 mm^3. The system measures hemodynamics of the vessels supplying the skin (e.g., assessment of the peripheral circulation parameters). The BMP 403A device was interfaced via BIOPAC 100WS.

Autonomic measures

Electrocardiogram (ECG), pneumogram (PNG), and electrodermal activity (EDA) were acquired by the ECG100A, RSP100A, GSR100A BIOPAC system modules and the EL501, TSD101, TSD103 sensors, respectively. Three Ag/AgCl electrodes (EL501 with Signa creme) were attached for the measurement of Lead I ECG. PNG was recorded with a strain gauge transducer (TSD101, attached with adjustable Velcro strap) that measures the changes in thoracic circumference as the subject breathes. EDA was recorded by Ag/AgCl electrodes (6 mm contact area) mounted in polyurethane housings with a 1.6 mm cavity to accommodate isotonic Unibase gel (prepared according to Boucsein, 1992). The TDS103 electrodes were attached to the distal phalanx of index and middle fingers of the left hand. The constant voltage (0.5 V) technique was employed to measure skin conductance level (SCL) and skin conductance response (SCR).

Physiological dependent measures

Electrodermal activity

Skin conductance level (SCL), skin conductance response magnitude (SCR-M, i.e., sum of all SCR with amplitude more than 0.05 μSiemens [μS] in 1 min epoch), and SCR number per minute (in other words, non-specific SCR frequency; NS.SCR) were measured as number of SCRs in 1 min.

Cardiovascular activity

Heart rate (HR), high frequency (HF) and low frequency (LF) components, and LF/HF ratio of heart period variability (HPV) were calculated as cardiac activity measures. Inter-beat intervals of ECG (R-R intervals) were visually screened for the presence of artifacts related to movement or spurious R-wave detection. Employing artifact processing methods recommended by Berntson et al. (1997), visually identified missed or incorrectly measured inter-beat intervals were replaced by interpolated measures derived from the neighboring R-peaks on ECG or from the relevant beats on blood flow variables recordings. Artifact-corrected 1-min long recording epochs were resampled at 10 Hz basis and analyzed with a Fast Fourier Transformation (FFT) to assess HPV using the Hanning window. Integrals of the spectrum in 0.039–0.146 Hz (LF component of HPV) and 0.146–0.400 Hz (HF component of HPV) bands were measured (in ms^2) in baseline and experimental conditions. The LF/HF ratio of HPV was calculated to measure the ANS balance index.[1]

Respiratory activity

Respiration rate (RESP) per minute and inspiration wave amplitude (IA) was calculated. PNG FFT analysis was used to identify Peak respiration frequency (PFRQ) as the maximum of a spectral curve in 0.14–0.50 Hz range. PFRQ was used to control HF peak related to respiratory frequencies in HPV (Grossman, Karemaker, & Weiling, 1991) and was not a primary dependent variable in this study. The IA was measured as a relative change of amplitude vs. baseline level (in %). Interpretation of associated changes in respiratory sinus arrhythmia (i.e., HF of HPV) can be problematic if experimental conditions show significant changes in respiration parameters (frequency, depth of respiration) (Task Force, 1996; Berntson et al., 1997). There are established methods of adjustment using respiratory frequency and depth as covariates in statistical analysis or removing these possible contributions by regression analysis. However, as it was demonstrated by Grossman et al. (Grossman, Karemaker, & Weiling, 1991; Grossman & Kollai, 1993), if experimental manipulations produce moderate changes in respiration parameters they may exert only minimal influences on the relationships between respiration and heart period variability, and consequently no adjustment was used here.

Psychometric measures

Individual subjective ratings of perceived nervousness (anxiety), depression, and stress (7-point rating scale), and subjective evaluation of disgust elicited by IAPS-slides (7-point rating scale) were used. Questionnaires were given to participants after each auditory stimulation condition following the 1 min long post-music/noise resting condition recording. Instructions to the questionnaires requested the participants to rate how anxious, depressed, and stressed they felt at that moment, and also to rate the degree of disgust they experienced after presentation of the IAPS pictures.

Participants were not asked to rate their emotions induced by music nor comment on their like-dislike preferences regarding music/noise.

Statistical analysis

All physiological signals were processed and averaged in 60 s windows for baseline and stimulation conditions. The auditory stimulation data were measured on a per minute basis and then averaged for the 2 min long condition. Two participants were excluded from further analysis because they did not have all EEG and ANS parameters recorded. Therefore, the number of participants analyzed was 27. Data were analyzed by the SPSS (v.14.0) statistical package using one-way ANOVAs, post hoc Scheffe tests, and paired sample Student's *t*-tests. The significance level of the Scheffe test is designed to allow all possible linear combinations of group means to be tested, not just pairwise comparisons for post hoc tests, making the Scheffe test much more conservative than the Tukey or Bonferroni tests. This characteristic means that a larger difference between means is required for significance. In multiple post hoc comparisons (pleasant vs. sad vs. white noise) only significance (considered at the level of $p < 0.05$) from the Scheffe test is shown.

For the autonomic variables directly addressing hypotheses on recovery from stress level and restoration of initial baselines, repeated measures general linear model ANOVAs were performed on the within-group factor *Emotion* (pleasant, sad, noise) and the *Music-noise* (music, noise) factor. For

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[1] Based on the criteria for the selection of appropriate analytical epochs for HPV analysis, 1-min recording epochs used here are sufficient to assess the HF component of HPV. However, at least a 2 min recording epoch is recommended for the correct assessment of the power of LF band (Berntson et al., 1997). Thus, by these standards, the LF component of HPV in our study was recorded without sufficient accuracy due to shorter than recommended epoch.

the EEG variables the additional factors *Hemisphere* (left, right) and *Region* (frontal, temporal) were considered. In all ANOVAs, Greenhouse-Geisser corrected p-values were employed where appropriate. In such cases, the Greenhouse-Geisser epsilon (ε) is given.

Results

Effects of affective visual stimulation

The effects of lAPS-based visual stimulation yielded a rather consistent and reproducible pattern of ANS and EEG responses. A repeated measures ANOVA test showed that differences in all responses among the three sessions of visual stimulation were not significant, except theta response in the 3rd session. Data described below are presented as mean differences from baseline with standard deviations (SD) averaged across the three sessions of visual stimulation (Mean ± SD).

Autonomic responses

Visual stimulation evoked a deceleration of HR from baseline (-1.45 ± 1.44 BPM, $t = 5.27$, $p = 0.001$), an increase of HF power in HPV (0.10 ± 0.13 ms^2, $t = 2.97$, $p < 0.01$), and a decrease of the LF/HF ratio in the HPV (-0.32 ± 0.42, $t = 2.74$, $p = 0.018$). Facial capillary blood flow parameters demonstrated all signs of vasoconstriction which were expressed in decreased FLOW (-0.04 ± 0.03 ml/min/100 *g*, $t = 4.18$, $p = 0.002$), decreased peak of blood flow in each cardiac cycle (PKFL, -17.5 ± 15.94 %, $t = 3.64$, $p = 0.005$), and decreased blood flow velocity (VEL, -0.14 ± 0.13 KHz, $t = 3.76$, $p = 0.003$). Blood volume (BV) responses in all sessions were not significant and the BV reactivity in general was quite low.

Respiration rate and peak respiration frequency did not change significantly, while inspiration amplitude only tended to increase ($12.29 \pm 23.29\%$ from baseline, $t = 2.04$, $p = 0.06$). The correlation of PFRQ and peak of HF in HPV was high ($r = 0.89$, $p < 0.001$), thus emphasizing involvement of the respiratory sinus arrhythmia in the mediation of cardiac rhythm variability effects.

SCL increased from baseline (0.09 ± 0.16 μS, $t = 2.93$, $p = 0.007$). Mean SCR magnitude was 1.41 ± 1.01 μS, and NS.SCR freq. was 1.84 ± 1.43 per min.

Electrocortical responses

EEG responses to aversive visual stimulation were expressed in slow alpha RP decrease at frontal (F3, -2.32 ± 3.06, $t = 3.86$, $p = 0.001$; F4, -2.19 ± 2.78, $t = 4.00$, $p < 0.001$), and temporal areas (T3, -1.75 ± 2.45, $t = 3.65$, $p = 0.001$; T4, -1.72 ± 3.14, $t = 2.79$, $p = 0.01$). Fast alpha did not change significantly from baseline. Fast beta increased at both frontal sites (F3, 1.32 ± 1.99, $t = 3.39$, $p = 0.002$; F4, 1.27 ± 2.46, $t = 2.65$, $p = 0.014$), while slow beta increased only at the right side (F4, 0.72 ± 1.64, $t = 2.25$, $p = 0.033$).

The frontal slow alpha asymmetry index was not significant in all 3 sessions of visual stimulation. Other asymmetry indices (slow alpha temporal, fast beta frontal and temporal, theta temporal) were also not significantly different in visual stimulation sessions. Results of aversive visual stimulation, expressed in a form of changes of autonomic and EEG measures, are summarized in the upper boxes in Tables 1 and 2.

Time course of post-stress recovery in auditory stimulation

All physiological variables during the first and the second minute of stimulation were compared to assess the effects

Table 1 Effects of aversive affective visual stimulation (IAPS-stress) and auditory stimulation (Music and White Noise) on autonomic parameters

	HR BPM	HF ms^2	LF/HF Index	Peak Flow %	Velocity KHz	NS.SCR N/min
Changes of autonomic parameters in visual stimulation (IAPS-stress) vs. baseline (M ± SD) for 3 sessions						
IAPS-elicited						
stress (disgust)	−1.45 (1.44)**	0.10 (0.13)*	−0.32 (0.42)*	−17.51 (15.94)*	−0.14 (0.13)**	2.84 (1.25)**
Changes of autonomic parameters in auditory stimulation vs. IAPS-stress level						
Music/WN						
Pleasant Music	−0.55 (4.04)	−0.10 (0.19)**	0.21 (0.64)	49.06 (61.91)**	0.15 (0.23)*	−2.70 (1.71)*
Sad Music	2.26 (2.24)**	−0.01 (0.11)	−0.18 (0.70)	23.93 (47.60)*	0.08 (0.24)	−0.55 (1.86)
White noise	0.18 (3.83)	−0.06 (0.24)	0.07 (0.31)	−1.41 (2.09)*	0.08 (0.19)	−1.41 (2.07)
Changes of autonomic parameters in post-auditory stimulation period vs. IAPS-stress level						
Post-Music/WN						
Pleasant Music	0.28 (4.36)	−0.06 (0.25)	−0.04 (0.43)	59.31 (67.25)**	0.16 (0.23)*	−2.40 (1.54)**
Sad Music	2.27 (2.83)**	−0.02 (0.10)	0.07 (0.80)	35.27 (43.08)**	0.16 (0.19)**	−2.06 (1.30)**
White noise	1.31 (3.55)	−0.06 (0.25)	0.14 (0.41)	63.75 (106.85)*	0.14 (0.25)*	−1.41 (2.07)*

Note. Statistically significant changes are shown by asterisks (paired sample *t*-test, $^{*}p < 0.05$, $^{**}p < 0.01$).

Table 2 Effects of aversive affective visual stimulation (IAPS-stress) and auditory stimulation (Music and White Noise) on EEG parameters

	SAF3	SAF4	SAT3	SAT4	FBF3	FBF4
Changes of the EEG bands relative powers in affective visual stimulation (IAPS-stress) vs. baseline						
IAPS-stress	−2.32 (3.06)**	−2.19 (2.78)**	−1.75 (2.45)**	−1.72 (3.14)*	1.32 (1.99)**	1.27 (2.46)*
Changes of the EEG bands relative powers in auditory stimulation vs. IAPS-stress level						
Pleasant music	2.20 (2.71)**	2.74 (2.76)**	2.23 (2.19)**	2.32 (3.12)**	−3.07 (3.97)**	−3.32 (4.33)**
Sad music	2.04 (2.80)**	2.49 (3.02)**	1.80 (2.71)**	2.03 (2.99)**	−2.22 (3.74)**	−2.32 (3.95)**
White noise	−0.99 (9.29)	1.17 (3.92)	0.71 (3.86)	1.03 (4.28)	−2.06 (3.70)**	−1.67 (4.32)
Changes of the EEG bands relative power in Post-auditory stimulation vs. IAPS-stress level						
Pleasant music	3.16 (3.39)**	3.34 (3.22)**	2.75 (2.57)**	2.84 (2.64)**	−2.60 (4.46)**	−2.65 (5.84)*
Post Music/WN						
Sad music	3.78 (6.90)*	3.44 (5.76)**	3.78 (10.03)	3.18 (8.59)	−2.43 (4.38)**	−2.46 (4.63)*
White noise	−0.30 (10.23)	1.54 (4.65)	0.72 (4.28)	1.44 (4.82)	−1.75 (5.03)	−1.25 (5.83)

Note. Statistically significant changes are shown by asterisks (paired sample *t*-test, $^{*}p < 0.05$, $^{**}p < 0.01$). Abbreviations: SA – slow alpha relative power, FB – fast beta relative power. F3, F4 – left and right frontal sites, T3, T4 – left and right temporal sites of EEG recording.

of habituation on physiological reactivity during auditory stimulation. The most obvious effects of habituation were exhibited in lowered EDA on the second min of stimulation as compared to the first min in WN. A decrease of SCR magnitude (-0.95 ± 0.99 μS, $t = 3.12$, $p < 0.01$), of SCL (-0.08 ± 0.14 μS, $t = 2.92$, $p < 0.01$), and lower NS.SCR frequency (-0.77 ± 0.94, $t = 3.50$, $p = 0.003$) was observed. Adaptation to WN stimulation was also seen in cardiovascular parameters. HR acceleration during the 2nd min (1.16 ± 2.19 BPM, $t = 2.75$, $p < 0.05$) and termination of vasoconstriction resulted in increased FLOW, PKFL, and VEL during the 2nd minute when compared to the 1st min assessment (ps < 0.05 for all blood flow parameters in WN).

Only a few effects of physiological adaptation were manifested during pleasant music conditions. Relatively higher values of FLOW and PKFL were observed on the 1st min of pleasant music condition, but none of other parameters significantly differed between the 1st and the 2nd min of music exposure.

Sad music showed an opposite HPV effect. The power of HF component was significantly higher on the 2nd min than on the 1st min ($p < 0.05$), however, HR only tended to be higher at the 2nd min of sad music ($p = 0.062$). The EEG parameters did not show differences between the 1st and 2nd min of music/noise.

Recovery of physiological parameters

To assess the effects of music/noise on recovery after stress induced by aversive visual stimulation, the post-stress period responses were divided into: 1) recovery during music/noise vs. IAPS-stress, 2) recovery during music/noise vs. initial baseline, 3) post-music/noise resting period vs. IAPS-stress, and 4) post-music/noise resting period vs. initial baseline (restoration).

Recovery of parameters during music and noise conditions vs. IAPS-stress levels

HR acceleration was significant only in the sad music condition ($t = 6.00$, $p < 0.001$). The HF component of HPV decreased significantly only in the pleasant music condition ($t = 2.43$, $p = 0.026$). Figure 1 shows differential changes of the HF component of HPV in response to IAPS, music and WN. Pleasant music was characterized by a decrease in NS.SCR freq. ($t = 3.21$, $p = 0.005$), and significant increases in FLOW ($t = 3.93$, $p = 0.001$), blood VEL ($t = 2.65$, $p = 0.02$) and peak of blood flow ($t = 3.16$, $p = 0.006$). PKFL increased marginally in the sad music condition ($t = 2.13$, $p = 0.048$), and decreased in WN ($t = 2.25$, $p = 0.047$). BV did not vary as a result of music valence (positive vs. negative).

One-way ANOVAs showed differences between music (both pleasant and sad as one music condition) and WN effects in FLOW (music vs. noise, $F[1,48] = 4.89$, $p = 0.032$, see Fig. 2a) and RESP (music vs. WN, $F[1,79] = 4.19$,

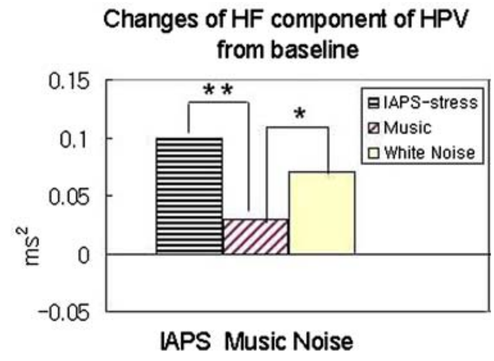

Fig. 1 Heart period variability (HPV) changes in affective visual stimulation, music and white noise. HF component of the HPV significantly increased during IAPS-stress and was lower in music (mean for both pleasant and sad music) than in white noise conditions. $^{*}p < 0.05$

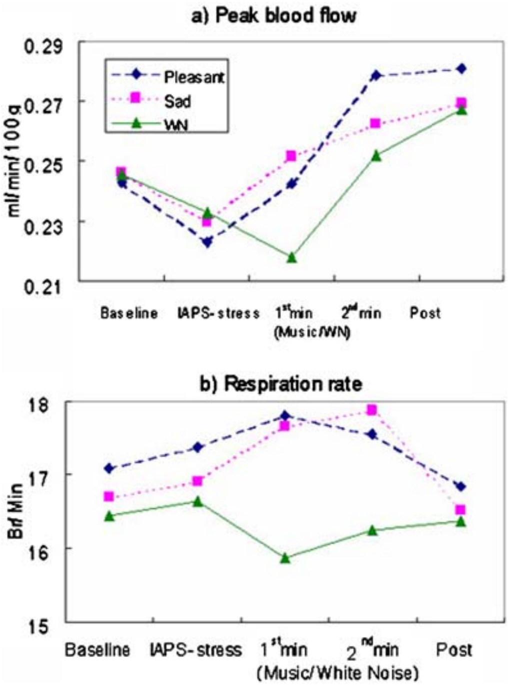

Fig. 2 Dissociation of peak blood flow and respiration rate in music and white noise at the 1st minute of auditory stimulation. (a) Peak blood flow which was decreased in all 3 IAPS-stress conditions continued to decrease at the 1st min of white noise, whereas increased in both music conditions. The 1st min tonic values of PKFL were significantly different for WN-sad music pair ($p = 0.029$). The 2nd min of auditory stimulation and post-stimulation period did not yield differentiation of PKFL levels. (b) Respiration rate increased in both music conditions, whereas decreased at the 1st min of white noise. Differentiation of music and noise condition in post IAPS-stress recovery period was significant ($p = 0.044$). However, in post-stimulation period RESP recovered in all conditions and did not differentiate effects of music and noise. PKFL and RESP decreases at the 1st min of white noise followed by habituation of the responses on the 2nd min along with similar habituation effects observed in SCR (SCR magnitude and NS.SCR frequency) suggests occurrence of orienting response at the 1st min of white noise exposure

$p = 0.044$, see Fig. 2b). Multiple comparisons of pleasant, sad music and WN conditions showed differences between pleasant music and WN in FLOW ($p = 0.048$). Heart rate differentiated conditions ($F[2,78] = 6.20, p = 0.003$); in particular, HR increased during sad music when compared to other conditions (post hoc Scheffe test: sad vs. pleasant, mean difference 3.17 bpm, $p = 0.005$; sad vs. WN, 2.49 bpm, $p = 0.041$). Stated differently, HR recovery in sad music was significantly different from both other conditions. Figure 3 shows these HR data.

Repeated measures ANOVA of HR recovery vs. stress level with *Emotion* (pleasant, sad, WN) and auditory stimulation *Condition* (music/noise, post-music/noise) factors showed only marginal main effect of condition ($F = 3.92$, $p = 0.051$) and a trend to 2-way interaction ($F[2,78] = 2.80$, $p = 0.067$, $\varepsilon = 0.612$).

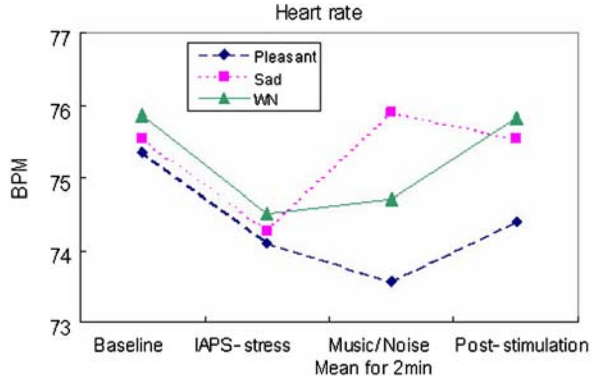

Fig. 3 Heart rate in experimental conditions. HR deceleration was significant in all 3 sessions of the IAPS stimulation ($t = -5.27, p < 0.001$). In post-IAPS recovery period sad music evoked HR acceleration and changes from IAPS-stress level ($t = 6.00$, $p < 0.001$), significantly different from both pleasant music and white noise ($F_{2,78} = 6.20$, $p = 0.003$). Multiple comparisons showed differentiation of HR effects between sad and pleasant music ($p = 0.003$), and between sad music and white noise ($p = 0.031$). Post-stimulation resting periods did not differentiate conditions

Both pleasant and sad music led to similar increases in slow alpha power at the right frontal site only (pleasant music, F4, $t = 2.99$, $p = 0.006$; sad, $t = 3.08$, $p = 0.005$), while white noise evoked bilateral increases (F3, F4, $ps < 0.05$). Fast beta relative power at the frontal and temporal sites significantly decreased bilaterally in both pleasant (F3, F4, T3, T4; $ps < 0.05$) and sad music (F3, F4, T3, T4; $ps < 0.05$). White noise resulted in fast beta decrease at both frontal sites (F3, F4; $ps < 0.01$), but only at the left temporal side (T3, $t = 2.15$, $p = 0.041$).

One-way ANOVA analysis revealed differences between music (pleasant and sad music as one group) and WN conditions in left slow alpha power changes (music vs. noise, $F[1,76] = 5.03$, $p = 0.028$). No significant differences were found among the multiple comparisons of EEG changes in post-IAPS-stress recovery process in pleasant music, sad music, and WN.

Recovery of parameters during music and noise conditions vs. initial resting baseline

Sad music was the only condition where RESP increased and exceeded the baseline level (1.77 ± 2.52 breath/min, $t = 3.65, p = 0.001$). White noise resulted in decreased RESP as compared to baseline (−0.96 ± 2.23 breath/min, $t = 2.24$, $p = 0.034$). HPV parameters in WN were also different from baseline, namely the power of HF component was higher (0.07 ± 0.15 ms^2, $t = 2.19$, $p = 0.04$), while LF/HF ratio of HPV was lower (-0.45 ± 0.78, $t = 2.71, p = 0.013$).

One-way ANOVAs (music vs. WN) showed marginally significant differences in the increase of HF from baseline in WN compared to music, $F(1,53) = 4.11$, $p = 0.048$, as well as more profound decrease of LF/HF ratio in WN compared to music, $F(1,52) = 6.92$, $p = 0.011$. Recovery of RESP vs. initial baseline by auditory stimuli was significantly differed ($F[2,78] = 10.76, p < 0.001, \varepsilon = 0.977$). Multiple post hoc comparisons with Scheffe corrections showed that respiration rate changes compared to baseline significantly increased during sad music and were significantly different from WN ($p = 0.001$). However, in the WN condition RESP was not statistically different from the pleasant music condition. Music in general led to an increase of RESP, while WN led to a decrease of RESP as compared to baseline. The difference between music and WN was substantial ($F[1,79] = 16.17$, $p < 0.001$, Fig. 2b). A repeated measures ANOVA showed an interaction of RESP recovery by auditory stimulation type [(pleasant, sad, WN) X *Condition* (music/noise, post-music/noise)], both when compared to baseline ($F[2,78] = 5.36$, $p = 0.007$, $\varepsilon = 0.827$), and stress level ($F[2,78] = 5.50$, $p = 0.006$, $\varepsilon = 0.838$). Repeated measures ANOVAs of HR recovery relative to initial baseline level with auditory *stimulation type* (music vs. WN) and auditory *condition* (music/noise, post-music/noise) factors showed a main effect of condition ($F = 5.52$, $p = 0.021$) with no interactions.

The relative power of frontal (F3, F4) fast beta decreased significantly from baseline in all 3 conditions (in a range from −0.98 to −1.34, $p < 0.05$). Right temporal fast beta (T4) decreased significantly in both music conditions (pleasant vs. baseline, −2.11 ± 4.51, $t = 2.36$, $p = 0.025$; sad vs. baseline, −2.09 ± 8.82, $t = 2.43$, $p = 0.018$). Only sad music showed a marginal fast beta RP decrease from baseline at T3 site (−1.41 ± 3.41, $t = 2.11$, $p = 0.044$).

One-way ANOVAs (music vs. WN) found differences between changes of slow alpha (F3) in music and WN compared to baseline ($F[1,76] = 4.83$, $p = 0.031$). Slow alpha was more blocked in WN at F3 site (−3.57 ± 10.81). A three-way ANOVA of slow alpha power recovery vs. initial baseline was performed with following factors: *Music/noise* (music, noise), *Hemisphere* (left, right), *Region* (frontal, temporal). A main effect of *Hemisphere* was significant ($p = 0.036$), however, *Music/noise* X *Hemisphere* interaction did not reach significance level ($F[2,78] = 3.40$, $p = 0.068$, $\varepsilon = 0.445$). This trend can be described as more pronounced alpha blocking effect on the left hemisphere in WN compared to music and post-music resting conditions. Other post hoc multiple comparisons did not demonstrate any further differences in the EEG parameters changes vs. baseline between pleasant music, sad music and white noise.

Restoration of parameters in post-music/noise resting period vs. IAPS-stress levels

HR recovered from stress level and exceeded the baseline level only in the sad music condition ($t = 4.16$, $p < 0.001$). Blood flow parameters (FLOW, PKFL, and VEL) fully recovered and demonstrated rebound in all auditory stimulation conditions without significant differentiation of the effects of pleasant music, sad music and white noise. The dynamics of peak blood flow changes are shown in Fig. 2a.

Slow alpha power recovered vs. IAPS-stress level in the post pleasant music period at all frontal and temporal sites, however during sad music recovery occurred only at frontal sites (ps < 0.05). In the post WN resting period slow alpha was not different from the lAPS-stress level. Fast beta recovered from the lAPS-stress during the post music period at all sites except during the pleasant music condition, where the left temporal fast beta did not decrease significantly from the lAPS-stress level.

The only difference between music and noise conditions was found in the left frontal slow alpha (F3, $F[1,76] = 4.57$, $p = 0.036$, see Fig. 4); in particular, the post-music slow alpha was higher than in IAPS-stress (3.46 ± 5.39) but lower than in post-WN condition (−0.30 ± 10.23).

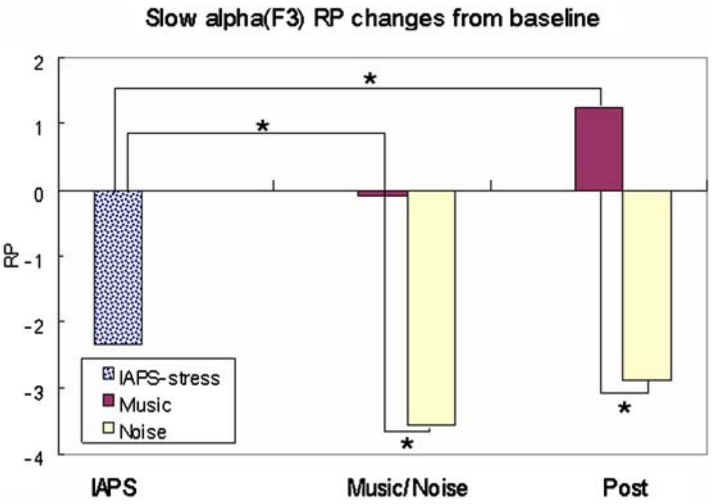

Fig. 4 Slow alpha (F3) relative power (SAF3) changes from baseline in affective visual and auditory stimulation and in post-stimulation resting period. IAPS-based stimulation evoked SAF3 power decrease from baseline. Music led to recovery of baseline level during stimulation and rebound in post-stimulation, whereas WN did not. Post- vs. pre-stimulation SAF3 changes differentiates effects of music and white noise. Changes of SAF3 relative power from IAPS-level in music condition were also different from those elicited by white noise. $^*p < 0.05$

Restoration of parameters in post- music/noise resting period vs. initial baseline

Peak blood flow exceeded initial baseline levels only in the post-pleasant music condition (32.12 ± 49.11%, $t = 2.50, p = 0.025$). SCL in the post-WN condition remained marginally higher than in initial baseline (0.04 ± 0.09 μS, $t = 2.05$, $p = 0.05$). Differences were not found for pleasant music, sad music or WN conditions in the recovery of autonomic parameters.

Fast beta power was lower in the post-music period as compared to initial baseline at the temporal sites (pleasant music T4, −2.07 ± 4.58, $t = 2.30$, $p = 0.030$; sad music, T3, −1.74 ± 2.93, $t = 3.03$, $p = 0.006$). After sad music, fast beta decreased compared to the initial baseline bilaterally at the frontal sites (F3, $t = 2.27$, $p = 0.032$; F4, $t = 2.34$, $p = 0.027$). There were no differences in the EEG for the post-WN condition compared to baseline, except for fast beta at T4 site (which was lower than in baseline). Differences in EEG measures were not found between pleasant, sad music and white noise conditions when these were compared to measures taken during the initial baselines.

Post music/noise psychometric data

Subjective ratings of perceived negative affect (disgust, anxiety, depression, and stress) were obtained immediately after the 1-min long post-auditory rest period. Disgust induced by the IAPS slides was not significantly changed after pleasant music (4.83 ± 1.39), sad music (4.97 ± 1.32), and WN (4.72 ± 1.27). The same was true for the subjective rating of anxiety (mean ± SD: following pleasant music, 3.38 ± 1.72; sad music, 3.72 ± 1.68; and WN, 3.52 ± 1.67), depression (2.97 ± 1.47; 3.28 ± 1.88; 2.86 ± 1.41, respectively), and stress (4.00 ± 1.64; 4.24 ± 1.55; 4.34 ± 1.63, respectively). Thus, subjective state (self report) of disgust, anxiety, depression, and stress was not improved by pleasant music, sad music, and white noise.

Discussion

The effects of aversive visual stimulation

Repetitive aversive visual stimulation with the IAPS pictures in all sessions evoked reproducible physiological responses. HR deceleration, accompanied by increased electrodermal activity and beta activity in the EEG during passively viewed pictures or films of negative valence, was found in the present study and has previously been reported in the literature (Lang, 1975; Spence, Shapiro, & Zaidel, 1996). The co-occurrence of phasic cardiac responses (e.g., HR deceleration) and SCR was used to determine the actual occurrence of an emotion, taking into consideration that skin conductance is assumed to be more reactive to arousal (Boucsein, 1992, 1999; Khalfa et al., 2002), while HR is believed to be more sensitive to the valence dimension of affective visual stimulation (Cuthbert et al., 1996; Bradley & Lang 1995; Lang, 1995; Lang, Bradley, & Cuthbert, 1997; Sokhadze et al., 2000b). The HF peak of HPV and peak of respiration frequency were strongly correlated, suggesting that HF reflected respiratory sinus arrhythmia related coupling and that HF power could be considered a parasympathetic index. Using this reasoning, the lAPS-elicited disgust increased parasympathetic activation that resulted in HR deceleration.

The decrease of facial capillary blood flow parameters during aversive visual stimulation (e.g., face paling) can be assumed to be a result of vasoconstriction mediated by α-adrenergic sympathetic influences (Anderson, 1989; Papillo & Shapiro, 1990). Other obvious signs of the sympathetic activation were manifested in an increased electrodermal activity because sweat glands are innervated solely by the sympathetic system (Boucsein, 1992).

It should be noted that in the present study the evidence that the lAPS-based visual stimulation resulted in an emotional state was implied rather than measured. An experimental manipulation known to induce disgust was used to set the condition from which affective (music) or unemotional (WN) auditory stimulation might result in a differential post-stress recovery. Lee, Sokhadze, Youn, and Sohn (2000) found in a prior study that the self report of disgust was induced by these IAPS pictures. While self report of disgust was not collected as a part of the present study, the physiological outcome of the emotion induction supported the notion that a negative emotion had been created. Increased frontal beta, decreased frontal alpha, decreased cardiac activity, increased skin conductance responses and peripheral vasoconstriction was found.

The effects of music and white noise on recovery from lAPS-elicited disgust

Autonomic measures

Administration of auditory stimulation after the aversive visual stimulation resulted in a short-term HR decrease in white noise condition (1st min only), followed by a gradual HR acceleration in the sad music. This finding is consistent with results from an exploratory study by Krumhansl (1997), who found that the sad musical excerpts produced the larger changes than fear or happy music in HR. Initial baseline resting HR levels were restored in all sessions. The HF component of HPV decreased in pleasant music but increased in WN. Blood flow parameters increased in both music conditions, whereas they decreased under white noise. However, in the post-stimulation period all vascular blood flow measures recovered fully, even after WN (Fig. 2a). Furthermore, the peak of blood flow showed rebound effects in that baseline values were exceeded in the post-pleasant music period.

In addition, sad music evoked an increase in respiration rate, whereas WN led to decreased respiration frequency. Skin conductance activity was lower during music than during affective visual stimulation, however, white noise evoked the highest SCR magnitudes after the onset of stimulation (the 1st min). This finding was followed by a rapid habituation of electrodermal activity, both in terms of frequency and magnitude characteristics of SCR.

EEG measures

Electrocortical modulatory effects of music restored frontal slow alpha both in music and post-music conditions. It should be mentioned that pleasant music turned out to be more effective in term of alpha recovery, since post-stimulation alpha power increased relative to the initial pre-stimuli baselines of both temporal and frontal areas. In the sad music condition, however, the temporal slow alpha did not differ from the lAPS-level in post-stimulation period.

Frontal asymmetry

The "approach/withdrawal" motivational model of emotion and frontal brain asymmetries suggests that "approach" emotions such as happiness are associated with relatively greater left frontal brain activity, whereas "withdrawal" emotions such as sadness and disgust are associated with relatively lower left frontal brain activity (Davidson, 1992, 1995, 1998; Silberman & Weingarten, 1986; Spence, Shapiro, & Zaidel, 1996). In the present study there were no asymmetries in the frontal EEG bands of auditory stimulation conditions, although the frontal alpha recovered slightly better at the left hemisphere (F3) during music than WN. This may be partially attributed to the specific effects of music, because more profound effects of music should be observed in the right cortex given the data about functional brain lateralization and dominance of right hemisphere in music processing (Davidson & Schwartz, 1977; Walker, 1980). Thus, frontal asymmetry related to emotional experience could be masked by lateralized effects of music processing. One study claimed the ability to distinguish valence and intensity of musical emotions by frontal EEG measures (Schmidt & Trainor, 2001). The authors found that the pattern of frontal asymmetry did not distinguish the intensity of emotions, but the pattern of overall frontal EEG activity did, with the amount of frontal activity decreasing from happy to sad excerpts. The frontal asymmetry distinguished only valence of musical excerpts in that study, being greater at the left frontal sites during happy music and greater at the right frontal sites during sad musical excerpts. Cortical lateralization effects at the temporal areas was expressed by increased EEG activity on the left during emotionally positive musical excerpts and affective sounds have been reported as well (Altenmuller et al., 2002). However, recent functional magnetic resonance study of brain regions during recognition of happiness and sadness in music (Khalfa et al., 2005) show that emotional processing of sad excerpts activated the left orbital and mid-dorsolateral prefrontal cortex, a finding that does not confirm the valence lateralization model. No differences in neocortical activation of the two hemispheres related to the perceived pleasantness or unpleasantness were detected in a PET study (Blood & Zatorre, 2001).

Modulatory effects of music on the restoration of the baseline

Selectivity of modulation vs. non-specific arousal hypothesis

Reflection on the findings of the present study suggests that music selectively facilitates recovery of the pre-stimulation levels when aversive visual stimulation results in a decrease of activity of some physiological systems (i.e., cardiac), and an activation of other systems (i.e., electrodermal, vascular, cortical etc.). Affective auditory stimulation with music was able to selectively modulate physiological activity evoked by preceding negative valence visual stimulation. On the other hand, physiological responses to white noise, which does not posses emotion-eliciting capabilities at the applied intensity of stimulation, evoked responses typical of orienting reactions. The orienting response was followed by habituation expressed by responses that differed during the first and the second minute of exposure. During the first minute of the WN presentation, the physiological response pattern was typical of an orienting reflex accompanied with SCR, phasic HR deceleration, vasoconstriction and short-term EEG desynchronization. Repeated or continuous presentation of WN with similar acoustical characteristics (loudness, tonality, etc.) resulted in a gradual adaptation and habituation of physiological responses was found during the second minute of WN of this study. After the habituation process, however, orienting responses may reinstate the changes in stimulus intensity, modality, duration, frequency, sequence, complexity, and significance (Sokhadze & Sohn, 2000). In the present study, the WN condition was intentionally kept constant to avoid initiation of the orienting response. Continuous white noise background with constant psychoacoustic parameters has been a traditional tool employed in psychophysiology to affect the non-specific arousal level, and is commonly used for manipulations intended to modulate activation during a cognitive task performance. The effect is due to the WN influence on selectivity of attention (Boucsein & Ottman, 1996; Poulton, 1979). The intensity of background noise significantly affects both the subjective evaluation of stress level and the physiological arousal associated with a noisy environment.

In previous studies on short-term and long-term behavioral and psychophysiological effects of WN with different intensities (55, 70, and 85 dB), we found that auditory stimulation with WN of mild intensity (55dB) evokes an orienting response mediated primarily by phasic parasympathetic activation. This stimulation can be tolerated by participants for at least 2–3 minute without signs of excessive physiological arousal that are accompanied by subjective distress (such as found with the sympathetic dominance; Sokhadze et al., 2000a). Therefore, these physiological responses to WN are consistent with our previous data by showing that, at the selected intensity WN, a state of prolonged non-specific physiological arousal, and/or a generalized stress response, is not found.

Responses to affective stimuli: Orienting, attention or emotion?

One may argue that the physiological responses evoked by our affective manipulations in both visual (IAPS) and auditory (music) modalities may reflect an orienting reflex rather than emotional reaction; some of the physiological response patterns show HR deceleration, a result which is typically mediated by the parasympathetic activation. It should be noted that an orienting of attention is accompanied as well by a short-term sympathetic activation best captured in specific stimulus-locked SCR and vasoconstriction (e.g., sharp changes in blood flow or peripheral pulse volumes). The issue concerns the ability to separate attentional from emotional components of psychophysiological responses to affective stimuli, and this remains an important question in cognition and emotion research. Analysis of cardiac responses to affective stimuli is especially important for the elucidation of potential autonomic neural mechanisms of attentional and emotional processes, for the following reasons. The heart is an end-organ innervated both by the parasympathetic and sympathetic branches of the ANS. Cardiac chronotropic reactivity represents a quite sensitive measure capable to detect the timing of the moment when the orienting process (attention and perception of the stimulus) primes relevant motivational response (emotion with approach or avoidance tendencies).

Further initiation and development of the emotion-specific physiological responses is dependent as well on the experimental context (Stemmler, 1992). Passive viewing of affective pictures without any additional task demands (e.g., judging emotion category or responding to a specific target feature of affective stimuli) was found to elicit a short-term HR decrease related to valence (more deceleration to negative picture) and SCR (amplitude proportional with arousal rating of the picture; Lang, 1995; Cuthbert, Bradley, & Lang, 1996 Sohn et al., 1998d; Sokhadze et al., 1998). As it was predicted, the disgust emotion, which was elicited in a passive visual stimulation mode, resulted in a HR deceleration and an increased HF component of HPV (both indexing parasympathetic activation), and at the same time was accompanied with significant manifestations of sympathetic arousal such as decreased blood flow and velocity and increased non-specific SCR rate.

The specific stimulus may be a factor. Music may evoke attentional and cognitive processes specifically related to musical signal perception and processing. Music is a complex signal composed according to the rules of tonality and harmony, and the human brain is thought to implicitly form expectations in accordance with traditional musical styles and cultural preferences (Loui et al., 2005). In recent years cognitive neuroscience and psychophysiology studying musically-evoked EEG responses in musicians and nonmusicians have found electrophysiological markers of musical expectancies such as effects of congruent (i.e., expected) and incongruent notes, and harmonies that either obey or violate the theoretical and practical norms of melodic expectations (Braticco et al., 2003; Janata, 1995; Koelsch et al., 2000; Koelsch & Siebel, 2005; Loui et al., 2005; Peretz, 2006). The current study limited its scope of interest by using the well-known universal ability of music to induce an emotional response and to investigate whether this musically induced emotional response is capable of facilitating recovery from experimentally elicited stress. As music perception involves complex brain functions underlying responses to acoustical characteristics, auditory memory and associative processes, higher level processing of musical semantics and syntax (Koelsch & Siebel, 2005), and many factors could not be taken into consideration in this study need further study. Only those factors directly impinging on the focus of the research—testing the hypothesis that musical perception is affecting emotional state, and therefore may positively influence recovery of stress manifested in the central and autonomic nervous systems measures—were controlled.

A comparison of pleasant and sad music effects revealed some differences (i.e., in HR response, magnitude of RESR response during recovery, etc.), but the general pattern of responses was quite similar. Subjective reports also did not show significant differences in ratings of experienced anxiety, depression and stress after the exposure to musical fragments. However, the affective significance of music stimuli (feelings associated with listening to music) might have had primary importance in the course of changes due to music independently of the differences in the emotional valence (pleasant vs. sad). These data are partially consistent with the findings of Iwaki, Hayashi, and Mori (1997), who found that frontal EEG alpha band amplitude increased during both stimulating and calming music, and that the direction of change was dependent on the ongoing cortical activity level.

The negative valence emotion (disgust) elicited by the pre-selected affective slides (mutilated bodies, victims of accident etc.) was accompanied with such autonomic changes as HR deceleration, heart rate variability changes, vasoconstriction, and high tonic electrodermal activation. The correspondent subjectively experienced emotion should be located in moderate arousal, low pleasantness position of a two dimensional map of affective space. Subsequent music exposure led to a physiological response characterized by change in the direction of activation—namely, an increase in cardiovascular and respiratory activity and a decrease of electrodermal activity—thereby resulting in a restoration of the pre-stress baseline autonomic profile. In future studies it would be a challenging task to test whether music is capable to lower arousal and negative emotions and accompanying physiological response pattern elicited by a strong emotion with approach motivational tendency (such as anger). Unfortunately, it was not feasible to include anger as a contrast to disgust in this study. In our pilot studies we found that anger was not as readily elicited as disgust by IAPS stimulation in a passive viewing mode (Sokhadze et al., 2000c).

Physiological manifestations of emotional states

Emotional states induced by music were predicted to be characterized by a shift in affective space. Higher arousal and more positive states were predicted for the pleasant music, and higher arousal and less positive states were predicted for the sad music. Physiological changes were found not only during the music condition, but also in the post-music resting period. White noise did not exert any significant influences on recovery; instead, WN elicited an orienting response after the onset of noise—with subsequent habituation.

Autonomic and EEG response patterns associated with music can be clearly distinguished from those induced by white noise. Analysis of several autonomic and EEG variables demonstrate differences between music conditions and noise. Both music conditions had different outcomes on the recovery of physiological parameters, as compared to WN condition. One reason for the use of music is to induce emotions; white noise can be employed as an "emotionally neutral" control condition (reviewed in Nyklicek, Thayer, & van Doornen, 1997). The EEG effects of music were expected to be more present in the right hemisphere, however, no significant changes in frontal asymmetries were detected.

Comparing effects of pleasant vs. sad music on post-stress recovery

Subjectively "pleasant" music, more than sad music, was expected to restore the initial resting baseline physiological levels during both the post-aversive stimulation period and the post-auditory stimulation (i.e., exhibit more obvious "undoing" effect). However, in this study differences between the pleasant and sad music effects on autonomic measures were observed only in HR and respiratory rate (i.e., an increased cardiorespiratory activity in sad music). Differences in EEG between musical fragments were observed only in terms of a more profound decrease of fast beta power during pleasant music. Thus, differences in the physiological responses between two musical excerpts by valence (pleasant vs. sad) were minimal in this study. Both "pleasant" and "sad" music had a comparable positive recovery outcome, with only few physiological differences. The most obvious beneficial effect of music—restoration of initial baselines after visually elicited negative emotions—were seen in comparison to white noise. Thus, these data are not sufficient to claim that only emotionally positive music enhanced post-stress recovery process.

Therefore, the obtained results cannot be considered as strongly supporting the "undoing" hypothesis. However, the data do support the effectiveness of music as a means to facilitate recovery from disgust elicited by aversive visual stimulation. The modulatory effects of music altered the physiological measures in directions opposite from those induced by aversive visual stimulation. Post-stress positive facilitatory influences of music were significantly more effective than those of white noise, suggesting that the effects of music might vary according to affective content, as opposed to effects simply due to an auditory modality of stimulation.

Limitations of the study

There are several limitations that need to be mentioned. The data on participant's health and medication status were based exclusively on self-reports. No formal neurological or psychiatric evaluations were conducted in the study. Initial baseline, visual stimulation, and post-stimulation recovery periods were recorded for 1-min long epochs, suggesting that all data on the low frequency (LF) component and LF/HF index of HPV may not be sufficiently reliable as a 2-min long epoch is recommended for more accurate assessment of HPV (Task Force, 1996; Berntson et al., 1997). Future research designs should have windows of at least 2 minutes for baseline and emotion conditions to be able register accurate HPV indices.

A subjective rating of disgust elicited by visual stimulation was not obtained immediately after presentation of the pictures, but only after the auditory stimulation. The ratings did not include assessment of valence and arousal as had been done in the pilot studies (with the SAMS, to assess emotional response to IAPS slides). The absence of significant differences between the subjective ratings of perceived stress following auditory stimulation is surprising given the statistically significant changes observed in physiological measures. There are several possible explanations for this finding. One explanation is that subjective ratings were obtained not immediately after auditory stimulation but only after the post-auditory resting period. The elicited emotions may have faded out by that time. Another possible explanation is that the participants underrated (or perhaps exaggerated) their experienced stress (nervousness, depression, stress) intensity ratings. Previous work has shown that the efficacy of musical mood induction procedures is strongly dependent on instructions to the participants (Hermans, De Houwer, & Eeelen, 1996; Lenton & Martin, 1991). Lenton and Martin (1991) investigated the contribution of instructions on the intensity of musically induced moods or emotions. They compared the ability of music of normal volumes as well as "subliminal" music to induce moods under two different sets of instructions. Lenton and Martin found that instructions containing references to mood were necessary for successful music-based emotion induction detectable by psychometric measurements. The instructions provided to the participants in our study did not include guidance on how to react to the emotional contents of music. It is possible that the participants responded to the questionnaire based more on a cognitive appraisal of the feelings they felt expected of them (such as appreciation of the exposure to music), as opposed to the emotion they actually felt. Previous research has shown that such declarative cognitive process do not necessarily lead to correct descriptions of experienced emotion (Altenmuller et al., 2002).

An alternative explanation is that participants experienced minor subjective emotional responses during affective auditory stimulation, and the cortical and autonomic physiological measures used in this study were sufficiently sensitive to detect subtle changes in arousal level. Interestingly, some data reviewed by Hagemann, Waldstein, and Thayer (2003) suggest that the co-occurrence of EEG and autonomic activity during experimentally induced emotions may be mediated by the arousal component of emotional stimuli rather than by the valence component.

Despite the fact that individual physiological variables (e.g., HR, HF of HPV, SCR, relative power of slow alpha in the EEG etc.) were sufficiently sensitive to differentiate among the effects of experimental manipulations, musically induced emotions as such distinguished one from another better when using all physiological variables together as discriminators (Nyklicek, Thayer, & van Doornen, 1997). Again, participants in our study were not asked to rate their subjective experience while they were listening to music along valence and arousal dimensions of emotional space. This procedure created another limitation; affective ratings were not obtained that could be comparable with the normative affective ratings values database from the International Affective Digitized Sounds (IADS, Brady & Lang, 1999). Participants were not requested to evaluate the emotional category of musical excerpts so as to avoid biasing physiological responses by introducing additional cognitive task (i.e., categorization) during experimental manipulations of affect. The minimal psychometric evaluation of emotional context of the music is nevertheless a limitation of the study that must be taken into account in future research. It is possible, however, that certain physiological measures are differentially sensitive to valence and arousal dimensions of emotions induced by music, and yet do not necessarily correlate with subjective categorization of emotion. As was reported in a study by Khalfa et al. (2002), subjective ratings of the emotional clarity for four musical excerpts (fear, happiness, sadness, and peacefulness) did not parallel the corresponding SCR magnitudes. The study raises a question that certain physiological parameters (e.g., SCR) can be modulated by musical emotional arousal, but at the same time are not sensitive to perceived emotional clarity of musical clips. Recently, Baumangartner, Esslen, and Jancke (2005) reported that EEG activation (indexed by the power of alpha rhythm density) and SCRs showed valence specific effects in response to visual stimulation (IAPS pictures) as well as to combined visual and congruent music conditions, but not in music-only condition. The music condition in that study was also characterized by reduced subjective emotional clarity when compared to visual or combined emotionally congruent audio-visual conditions. It should be noted that emotional experiences associated with the perception of music have not been sufficiently explored, and emotional appreciation of music is still a new research avenue in psychophysiology (Peretz, 2001).

Practical implications

Because music led to the restoration of pre-stress baseline levels in most physiological parameters under study, evidence supporting the use of music to restore psychological and physiological functioning following stressful visual stimulation, and perhaps following other types of stress, has been obtained. Additional research on modality and situation-specific effects of stressful stimulation is clearly needed. However, the possibility exists that music could be useful in various settings in which people must deal with visually stressing material as part of their daily jobs. Using music in this way would certainly be healthier than taking medication (or drinking, using drugs, and so forth), and presumably music is also less expensive. The present study adds to current literature by suggesting that music may affect physiological response before subjective state.

The present study may also contribute to further developments in these applied areas by having identified sensitive physiological measures. Although this study did not find substantial differences between pleasant and sad music, further research is needed to verify the importance of affective valence on modulatory effects. Previous research has shown that emotional reactions to music vary based on history, culture, associations, age, personality, and other factors. The importance of the valence of music in modulating physiological response will need specific examination in the context of the specific disorder or condition in question. In other words, optimal treatment for post-stress anxiety may differ from general clinical practice when music is being used as a part of relaxation training, as the individual differences in emotional reactivity to music may influence therapeutic efficacy.

In general, the many practical advantages of using music to facilitate post-stress recovery suggest various applications in clinical settings. Basic research such as the present study will aid in the identification of mechanisms through which music may affect physiological change.

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