Physiological manifestations of the modulation of post-stress recovery process by emotion-inducing stimulation of auditory and visual modality

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시각자극에 의해 유발된 스트레스 생리반응의 회복과정에 미치는 정서청각자극의 효과

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Abstract

Effects of the music and white noise on recovery of the autonomic and cortical responses evoked by aversive visual stimulation were analyzed in 20 subjects. It was suggested that the music is able to exert modulatory influence on the physiological activity resulted from exposure to unpleasant IAPS based stimuli. Spectral power of EEG, heart rate (HR), respiration rate (RSR) and electrodermal activity (EDA) were recorded and analyzed for each experimental condition. It was observed that affective visual pictures evoked HR and RSR deceleration, increased EDA and electrocortical activation expressed in decreased alpha power and increase of delta activity at occipital and frontal areas. Obtained results suggest that auditory stimulation both with pleasant and sad music lead to restoration of pre-stimulation activation levels of most physiological parameters during listening to music and in post-stimulation period. White noise evoked short-term physiological responses typical for orienting reaction and quite distinct from changes produced by music. Available data do not provide with sufficient information to differentiate effects among pleasant and sad music, due to qualitative similarities of physiological patterns, but support an assumption that music is capable to facilitate the process of recovery of physiological responses elicited by visual stimulation of negative valence, thus positively modulate post-stress state.

Key words: *EEG, autonomic activity, emotion-specific physiology, affective visual and auditory stimulation, recovery from stress*

Introduction

Physiological specificity of emotion is a concept that still requires validation in the different experimental designs [22]. It was shown in numerous psychophysiological studies that both auditory and visual affective stimuli are able to evoke emotional reactions accompanied by the autonomic and electrocortical responses [4,5,6,9,10,12,20]. It was also demonstrated that some physiological responses distinguish among the basic emotions elicited by different laboratory manipulations [1,2,3,8,11,14,16,19,23]. Nevertheless, no comprehensive studies were reported regarding the comparative analysis of physiological profiles (both ANS and CNS) during emotional auditory and visual stimulation and the interaction of effects if both modalities are used simultaneously or sequentially. Implied models were very often limited to analysis of ANS activity only [2,5,6,8,12,16,17,19,24], and much less CNS data are available on this topic [4,7,10,11,13].

There are also only few studies regarding systematic investigation of relationship between music and electrocortical activity [10,11]. One of their findings was that music evoked both calming and stimulating effects depending on ongoing general cortical activation level of subjects. Arousal modulatory effects of affective music on EEG activity and effects of repetitive exposure of music on subjective and physiological responses were reported by Iwaki et al. (1997), and functional relation between music and brain activation discussed.

Another important topic is understanding whether the emotionally positive auditory stimulation is able to affect the process of recovery from physiological arousal provoked by traumatic visual stimulation. According to proposal of Levenson (1994) "..the function of some positive emotional states might be in facilitation of restoration of pre-arousal levels than would be the case if the negative emotions were allowed to run their natural course"[17]. In our previous study [21] we tried to test this hypothesis applying visual stimulation with pictures from IAPS (International Affective Picture System)[14] and auditory stimulation with different emotional valence, but obtained controversial results: Autonomic and cortical arousal parameters were dissociated, demonstrating directional fractionalism [15] and complicating interpretation.

The issue remains an important one, since an ability to combine modalities is of crucial value because of potential practical outcome when stimuli are used for scientifically sound selection of audio-visual programs for stress management. Above experimental model addresses also such basic question of psychophysiology of emotion as whether the same emotions evoked by different modalities of stimulation are associated with similar profiles of the physiological responses [17]. Reproducibility of the physiological correlates of emotions, consistency of response in different research paradigms, and dependence on the situational context are all among the factors specially outlined in modern psychophysiological concepts [22]. In the emotion-specificity studies there should be taken into consideration the facts that physiological responses might be patterned, fractionated and arousal might also be differentiated at behavioral, central, autonomic and somatic levels, in order to the principle of a situation-specificity of physiological reactions.

The aim of the present study was to evaluate the autonomic and electrocortical responses elicited by emotional visual and auditory stimulation and compare modulatory effects of pleasant (1/f) music, sad music and white noise on the process of physiological recovery from aversive visual stimulation in the same situational context.

Method

Twenty female college students (20-24 years old) participated in the study. None of the subjects had any neurological disturbances and they were not on any medication. All subjects passed psychological testing prior to the experiment, but they were not pre-selected on the basis of psychometric data. After brief introduction to experimental situation and attachment of the electrodes they were placed in a recliner-chair in the experimental room with dim light and were left for 10 min for adaptation and baseline recording. Visual stimulation was delivered by a Kodak slide-projector, while auditory stimulation through the stereo loudspeakers.

Experimental procedure consisted of 3 sessions of stimulation with following regime: pre-stimulation resting baseline recording (1 min), visual stimulation with IAPS pictures (3 slides with mutilated bodies, 20 s exposure of each) followed by 2 min long auditory stimulation, and post-stimulation resting baseline(1 min). In the first session 3 IAPS pictures (set of ##1113, 3051, 3170) were presented, followed by auditory stimulation with pleasant 1/f music ("Spring song", Victor Musical Industries). In the second session, pictures (IAPS ## 3140, 1300, 1120) were followed by by sad music ("Canon", Music Therapy, Erato, Inc.), while in the third (IAPS## 3071, 1301, 3130), were followed by by white noise (20Hz - 20 KHz, 35 dB). All subjects experienced the same order of stimuli presentation and the same time course of experiment.

Equipment and data reduction

Physiological signals were acquired by BIOPAC MP100 hardware with AcqKnowledge III (v.3.2) software. Three Ag/AgCl electrodes were attached for measurement of Lead I EKG; thoratic pneumogram was recorded with strain gauge transducer, electrodermal activity was recorded by Ag/AgCl electrodes filled with isotonic Unibase gel. Constant voltage technique was employed to measure skin conductance level (SCL) and skin conductance response (SCR). All signals were processed and heart rate (HR), respiration rate (RSR), both on per minute basis, and SCR amplitude and SCR rise time were calculated and averaged in 60 s windows. Minimal SCR amplitude was defined as 0.025 μs change of SCL. Also, mean number of SCR during each stimulation condition and SCL drift values (difference between pre- and post-stimulus SCLs) were obtained. Non-specific SCRs during baseline recording were not calculated separately. Monopolar EEG was recorded from frontal, temporal and occipital sites (F3,F4,T3,T4, O1,02 by 10/20 system, referent electrode on ipsilateral earlobe). EEG power values were calculated by using FFT for following bands: delta 0.5-3.9 Hz, theta 4.0-7.9 Hz, alpha 8.0-12.9 Hz (slow alpha 8.0-9.9 Hz; fast alpha 10.0-12.9 Hz); beta 13.0-30 Hz (slow beta 13.0-19.9 Hz; fast beta 20.0-30.0 Hz). Relative powers (RP) of each above band (percent to total power in 0.5-30.0 Hz) were calculated and compared for every recording site and experimental condition.

Statistical analysis was performed by SPSS package using Student's T-test for paired samples, one-way ANOVA and post-hoc Tukey test.

Results

Heart rate. Affective stimulation resulted in consistent HR deceleration in all 3 sessions. Mean HR changes was -1.22 bpm, most significant in second session (-2.44 bpm, $p< 0.001$) and least in the 1st one (-0.86 bpm, $p>0.05$). Pleasant (1/f) music evoked further deceleration of HR (-1.64 bpm as compared to IAPS condition) in the first minute of stimulation and to less extent in the second minute (-0.36 bpm), with full recovery of pre-baseline level when auditory stimulation was over. Sad music led to HR acceleration during the whole period of stimulation (mean change 2.59 bpm in comparison to visual stimulation, $p< 0.01$). In no sessions pre- and post-stimulation levels differed significantly. Comparison of effects of 1/f music and sad music revealed significant differences in HR both at the first and second minutes of stimulation (1/f vs. sad, respectively -2.30 and -3.20 bpm, $ps< 0.05$). HR was also significantly higher during listening to sad music than to white noise (1.76 bpm higher in sad music, $p<0.05$). White noise (WN) resulted in further HR decrease as compared to IAPS stimulation (-0.86, $p>0.05$) and baseline conditions (-2.34, $p<0.01$) in the first minute, habituation of HR response in the second minute was followed by almost total restoration in post-stimulation resting state. Mean HR values for all conditions are shown in Fig. 1.

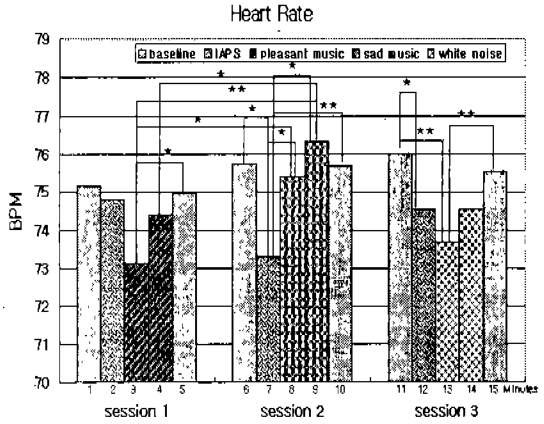


Figure 1. Dynamics of mean HR values in beats per minute (bpm) during sessions with different auditory stimulation (pleasant 1/f music, sad music, white noise) conditions after affective visual stimulation. *, $p<0.05$, **, $p< 0.01$

Respiration rate. Visual stimulation of negative valence evoked very slight and non-significant decrease in RSR. For example, RSR deceleration during the third session was only -1.06 breath per minute (bpm), $p<0.05$. Effects of both conditions with music stimulation were similar and can be described as RSR increase. Nevertheless, RSR acceleration was significant as compared to visual stimulation and resting states only when listening to sad music. Comparison of RSR responses across auditory stimulation showed that RSR in response to white noise was significantly lower (in the first minute of stimulation, WN vs. sad was -1.68 bpm, $p<0.01$; WN vs. 1/f music was even -1.94 bpm, $p<0.001$). White noise stimulation decreased RSR by -1.26 bpm ($p<0.05$) in comparison to pre-stimulation level. After WN RSR baseline was lower than both initial and third session pre-stimulation levels, but difference was not statistically significant. Mean RSR values are plotted in Fig. 2.

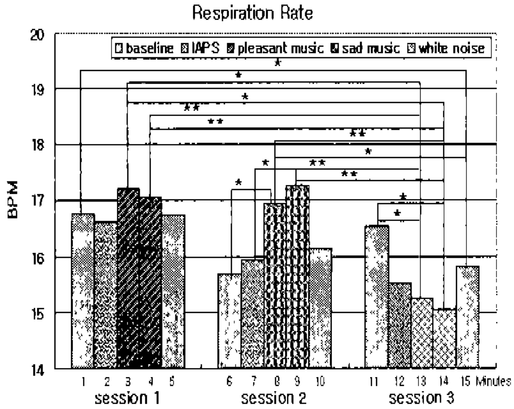


Figure 2. Mean respiration rate values in breaths per minute (bpm) during sessions with different auditory stimulation (pleasant 1/f music, sad music, white noise) conditions after affective visual stimulation. *, $p< 0.05$, **, $p< 0.01$

Electrodermal activity.

Skin conductance level. SCL reaction to IAPS-based stimulation in all 3 sessions was manifested in elevation of mean level (0.022 μs, $p< 0.05$). Presentation of auditory stimuli after visual stimuli induced SCL decrease (mean shift was -0.018 μs with respect to SCL during viewing negative pictures, $P<0.05$ for sad music), but this decrease was not significant when compared to pre-stimulation baselines. Furthermore, in a case of white noise SCL decrement was not significant even vs. visual stimulation SCL (-0.01 μs, $p> 0.05$). No difference was detected either in pre- and post-stimulation SCLs (Fig 3. a)

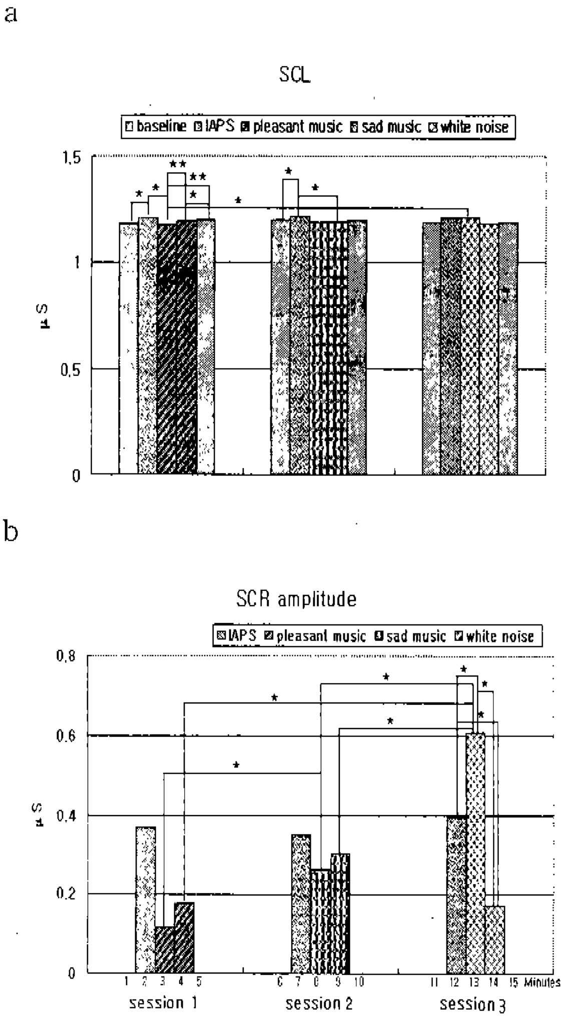


Figure 3. Electrodermal activity during affective visual and auditory stimulation. Skin conductance level (mean values in μs for each minute) dynamics in experimental session with auditory stimulation (pleasant, sad music and white noise) after IAPS-based negative emotion provoking stimulation (a). Skin conductance response amplitude (mean values in μs) during visual and auditory stimulation conditions with significance of differences of means between sessions. Baseline values of spontaneous non-specific SCR are not shown (b).

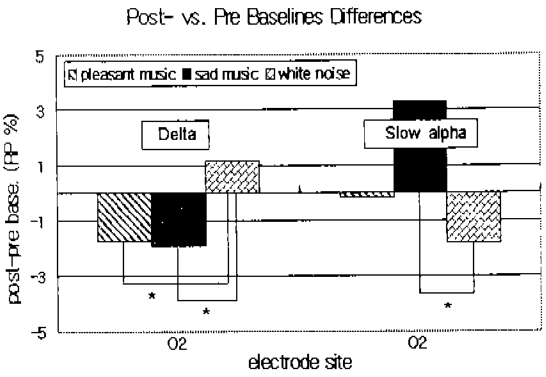
*, $p<0.05$, **, $p< 0.01$

Skin conductance response. Mean amplitude of SCR to aversive IAPS-based stimulation was characterized by similarity and reproducibility of values in all 3 sessions (mean SCR amplitude 0.37 μs, mean number of SCRs 2.39). Pleasant music presented after negative visual stimulation evoked significantly lower SCR amplitude (0.11 μs, $p<0.01$) in the first minute, but in second minute SCR amplitude (0.18 μs) failed to continue show significant difference with SCR to visual stimulus. Pleasant (1/f) music, at the same time, elicited SCR amplitude significantly lower than that in sad music stimulation conditions (0.28 μs, mean number of SCRs 1.33/per min). White noise evoked SCR (mean N=1.34 per minute) with the highest amplitude in the first minute (mean SCR amplitude 0.61 μs, N=1.58) which habituated in second minute (0.17 μs and 1.2/min) becoming significantly lower in amplitude (difference between 1st and 2nd min. SCR amplitude is -0.44 μs, $p< 0.01$). Figure 3.2. exhibit that amplitude of SCR to WN in first minute was significantly higher than those in sad or pleasant music stimulation conditions regardless time course of SCR to music (e.g. both 1st and 2nd minute of listening to music). Despite existence of some obvious tendencies in differences of SCR amplitude rise time across conditions (for example, longer SCR in sad vs. 1/f music and WN), none of them proved to be statistically significant.

EEG

Delta. Occipital and frontal (O2, F3,F4 sites) and at less extent temporal (T3) demonstrated significant increase of delta RP values when subjects were exposed to IAPS aversive pictures in all 3 sessions, the highest increase in the first session (e.g. at O2 delta RP increased at 5.45 to baseline, $p < 0.001$). Effects of music stimulation on delta waves was exhibited in delta decrease and were quite similar, with some differences in distribution among recording sites. Namely, occipital (O2) and right frontal (F4) sites had the same delta decrease response with post-stimulation levels lower than those of relevant pre-stimulus baselines (Fig.4. a), while effect was similar but less obvious at left frontal (F3) and temporal (T3) sites (Fig. 4.2). Furthermore, no significant differences were found in delta power between sad music and pleasant music condition at other sites. White noise effects on delta RP values was modest, still significant decrease at occipital site, but only when compared to visual stimulation levels (Fig 5.1.). Differences of delta responses to white noise and music were significant for WN-1/f music (F4) and WN-sad (O2) pairs, emphasizing distinction of delta RPs in music and white noise conditions.

a



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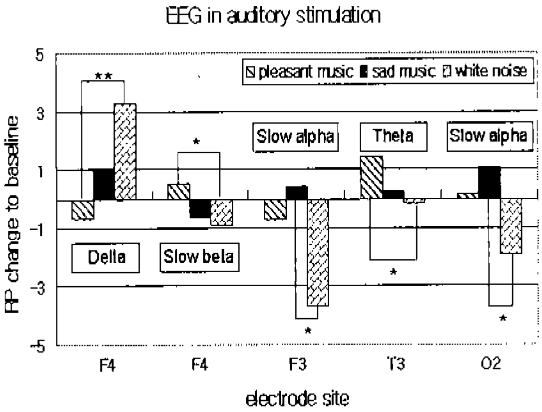
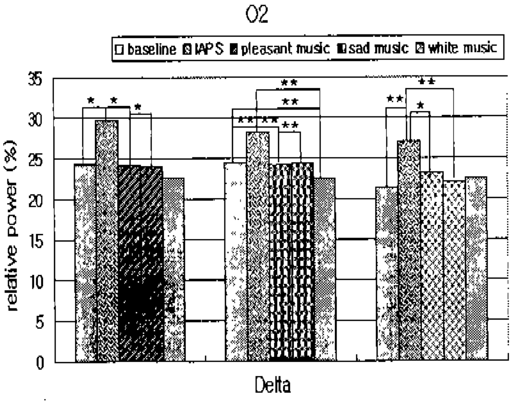


Figure 4. Comparison of differences between pre-stimulation and post-stimulation resting baselines of occipital delta and slow alpha relative powers (RP in percents) after sessions with auditory stimulation presented during recovery from effects of negative visual stimulation (a). Comparison of changes of the relative powers of delta, slow alpha and theta with respect to initial pre-visual stimulation baseline levels at frontal, temporal and occipital areas during 1st minute of auditory stimulation (b).
*, $p < 0.05$, **, $p < 0.01$

a



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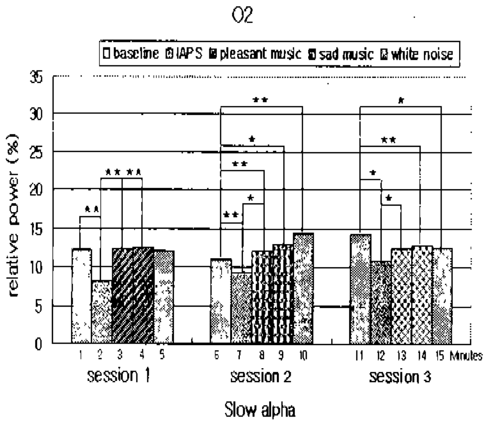

Figure 5. Dynamics of relative powers of occipital delta (a) and slow alpha (b) during sessions where IAPS-based visual stimulation was followed by 3 different types of auditory stimulation (pleasant and sad music, white noise). Significance of intra-session differences of values are shown for both rhythms.
*, $p < 0.05$, ** $p < 0.01$

Theta. Visual stimulation had practically no impact on theta RP values at most recording sites, but at temporal area (T3) there was a tendency to non-significant decrease. Pleasant music stimulation evoked significant increase of theta RP at temporal site (T3) with respect to visual stimulation (1.49, $p<0.01$) and pre-stimulation baseline (1.42, $p< 0.01$) conditions and resulted in higher value of theta in post-stimulation resting state (0.91 with respect to pre-stimulation, $p<0.05$). Theta RP at T3 during 1st minute of sad music was higher than in post-stimulation period. Other changes of theta band were not significant (Fig 6.1.).

Beta. Visual stimulation did not elicited reproducible and significant changes of slow beta RV values in any session, while sad music only led to decrease of temporal (T3) slow beta RP values during auditory stimulation and post-stimulation resting state. However, during listening to sad music temporal slow beta was significantly lower only in the second minute with respect to pre-stimulation baselines (Fig 6.2.) The absolute values of temporal beta in WN and music did not differ significantly.

Alpha. Most prominent changes in alpha waves were detected in slow alpha band. That is significant slow alpha blocking effects as a result of aversive visual stimulation were expressed at all recording site, most profound in occipital (02) area (mean decrease of slow alpha RP for 3 sessions was −3.11 vs. baseline, $p<0.01$, Fig. 5.2). Pleasant 1/f music resulted in slow alpha enhancement and restoration to pre-stimulation level. However, at most of the recording sites post-stimulation slow alpha RP was not significantly different from initial baselines, but significant as compared to affective visual stimulation levels at F3,F4 and O2 sites (Figures 4.,5.,7.). On its turn, sad music evoked increase of slow alpha at all sites and RP values were significantly higher as compared to visual stimulation. Slow alpha exceeds baseline level during the second minute of stimulation with sad music at occipital sites of recording (1.06, $p<0.05$) and the right frontal F4 site (1.09, $p<0.01$). At the same time it was found that after sad music slow-alpha remains significantly higher during post-stimulation resting state when compared to the pre-stimulation level at most of recording sites (3.31 higher vs. baseline at O2; 1.8 at F3 and 1.76 at F3).

Other bands of occipital, frontal and temporal EEG did not yield significant information. Brain asymmetry data were not specially analyzed in this study, nevertheless in Fig 7. it can be traced a tendency of hemispherical lateralization of frontal slow alpha.

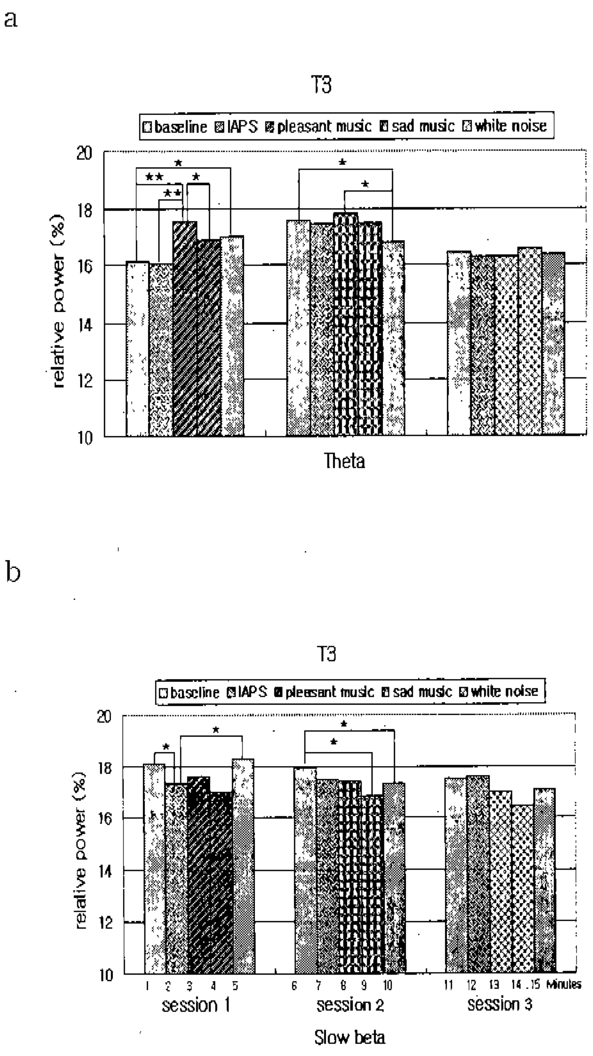

Figure 6. Dynamics of relative powers of temporal theta (a) and slow beta (b) during sessions where IAPS-based visual stimulation was followed by 3 different types of auditory stimulation (pleasant and sad music, white noise). Significance of intra-session differences of values are shown for both rhythms. White noise stimulation failed to evoke significant changes of theta or beta rhythms.
*, $p < 0.05$, ** $p < 0.01$

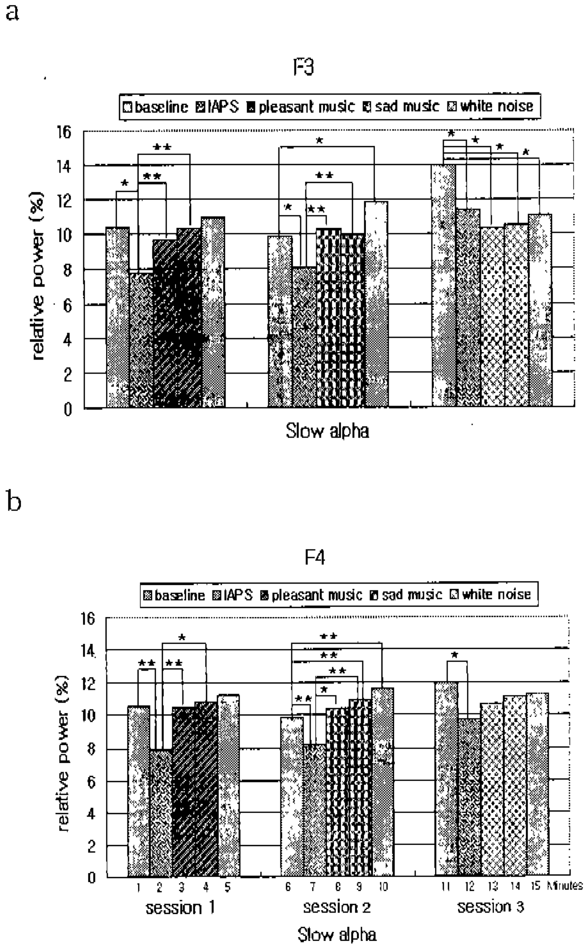

Figure 7. Relative power of frontal (F3, F4) slow alpha band during negative emotion inducing IAPS stimulation and subsequent auditory stimulation (pleasant, sad music and white noise). Significance of changes in each session only are presented. Alpha blocking effect was

significant in every session of affective visual stimulation.
*, $p < 0.05$, **, $p < 0.01$

Discussion and conclusions

Repetitive aversive visual stimulation with IAPS pictures (mutilated bodies) in passive viewing situation in all sessions evoked surprisingly reproducible physiological responses: significant HR deceleration, moderate respiration rate (RSR) decrease, increase in SCL, relatively high amplitude SCRs, and EEG shifts in a form of increase of delta Relative power (RP) values in occipital, frontal and temporal areas, slight decrease of theta RP and significant slow alpha blocking effect in occipital and frontal areas. Decrease in HR and RSR, accompanied by increased electrodermal activity and EEG activation during passive viewing of pictures or films of negative valence, was reported in literature [7,9,12,13] and may be attributed to orienting reaction and "freezing" type behavioral response with lowered metabolic demands. However, it should be noted that such stimulation leads to lowering of cardiorespiratory activity, whereas electrodermal and electrocortical responses show increased arousal features [13,15,21]. In the given experimental context subjects had not any chance to avoid aversive stimulation, and they were neither involved in any other cognitive or motor tasks (e.g. motor response, immediate rating, mental task etc.). Subjective reports acquired after this kind of visual stimulation usually are associated with experiencing disgust or surprise emotions, and also evaluated shown pictures as unpleasant, stressful ones [13,21]. Our finding in this study was that above responses do not habituate over affective visual stimulation sessions, since neither signs of adaptation nor lowered reactivity were observed. Thus, that was a background state on which auditory stimulation was delivered, namely physiological pattern featured by the decreased alpha activity, decreased cardiorespiratory activity and increased skin conductance.

Obtained data showed that administration of auditory stimulation after aversive visual stimulation (which on its turn had led to HR deceleration) resulted in phasic and short-term HR deceleration followed by further HR acceleration in 1/f music, HR deceleration in white noise conditions and to HR acceleration in sad music. However, initial baseline HR levels were totally restored during post-stimulation period in all sessions. The process of HR recovery proceeded more effectively and in a different way in a case of listening to sad music. Meanwhile, both kinds of music stimulation evoked increase of respiration rate. Post-stimulation RSR resting values did not differentiate significantly among sessions. Skin conductance level was lower during listening to music, however, white noise evoked highest SCR amplitude after onset of stimulation followed by rapid habituation of electrodermal activity, both in terms of frequency and magnitude characteristics of SCR.

Electrcortical modulatory effects of music were expressed in total restoration of slow alpha RP in both stimulation and post-stimulation conditions. It should be mentioned that sad music happened to be more effective with regard to alpha recovery, and post-stimulation alpha power increased in comparison to the initial pre-stimuli baseline in occipital and frontal areas. Difference between visual and auditory stimulation occipital delta power was significant only in the pleasant music condition. Influence of auditory stimulation on post-stimulation resting state occipital delta was significant only in terms of differences between RP in music (both 1/f and sad) and white noise, namely post-WN delta increased vs. baseline, while in music conditions RP of delta band decreased. Another interesting finding was that temporal theta rhythm power significantly increased both in pleasant and sad music stimulation and post-stimulation periods, being slightly higher in sad music condition, but at the same time, theta was not affected at all by white noise. RP values of beta bands lowered during listening to sad music, but only as compared to pre-stimulation level, while post-stimulation slow beta RP lowered vs. baseline significantly only at the temporal area.

Analysis of physiological patterns described above may lead to conclusion that music facilitates recovery of the pre-stimulation arousal levels even when visual stimulation resulted in decrease of activity of some physiological systems (i.e. cardiovascular, respiratory etc.), and activation of other systems (i.e. electrodermal, cortical etc.). Thus, affective auditory stimulation with music is able to selectively modulate physiological activity evoked by preceding negative visual stimulation, even if changes elicited by the latter were manifested in a form of directionally fractionated and patterned response (for example, HR decrease, SCL increase and alpha blocking). On other hand, physiological responses of white noise, which does not posses emotion eliciting capabilities at the applied intensity of stimulation, evokes response typical for orienting reaction followed by pronounced habituation. Comparison of 1/f music and sad music effects revealed some quantitative differences (i.e. in direction of HR response, magnitude of RSR response etc.), but general pattern of responses was quite similar.

Further studies should be carried out to reliably differentiate both cortical and autonomic emotion-specific responses using more complicated behavioral manipulations, namely, more variable situational context and other models of stress, for example that one when all monitored physiological parameters demonstrate invariant activation. In that case it would be available much more opportunities to test the impact of the positive valence of emotional sensory stimulation on dampening physiological consequences of stress elicited by negative stimuli.

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