Physiological Evaluation of Music Effect for the Mental Workload

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Abstract: Studies of mental stress have become the more important topics recently. Various studies have been conducted on physiological effects of music, while the effects of music under stress condition is not revealed in detail. The purpose of this study is to investigate the effects of music on participants’ subjective and physiological response by mental workload. First, eight participants (mean age; 25.6) were requested to perform the Uchida-Kraepelin test, which was given as a simple mental calculation task, for 30 minutes. After that, participants were exposed to music (“Bolero”, M.Ravel) for 13 minutes, while they were exposed to noise or just stayed in silence as a control. State-Trait Anxiety Inventory (STAI), salivary Immunoglobulin A (sIgA), auditory event-related potentials (ERPs) and heart rate (HR) were assessed through the experiment. Results: 1) Before and after the calculation task: Saliva secretion rate and salivary IgA levels significantly decreased and increased (p<.01). P300 amplitude of auditory ERPs significantly decreased (p<.05). HR significantly increased (p<.01) during the calculation task comparing with before and after the calculation task. 2) After music (“Bolero”): Saliva secretion rate and salivary IgA levels significantly increased (p<.01) and decreased (p<.05). HR significantly decreased (p<.05). P300 amplitude significantly increased (p<.05). No significant physiological effect was found in noise and silence, while saliva secretion rate significantly increased (p<.05) in silence. Our results of salivary IgA and HR suggest that the calculation task activates immune and sympathetic nervous system and, in contrast, music alleviates such symptom. On the other hand, the result of P300 amplitude suggests that the central nervous system for the recognition information processing is inactivated by the calculation task, and it can be recovered by music. In this study, we introduced various types of physiological indices, and future works are promising to clarify the mechanism of physiological effects of music.

Key Words: Music Therapy, Salivary immunoglobulin A, Event-related potentials, Heart rate

1. Introduction

Stress has been considered an important research since it comes to be recognized that stress causes both physical and psychological malfunction. Mental workload is divided into mental stress and mental strain [1], and the research on mental workload increased in 1990's [2]. At the present day, the research on stress management has also become important. As one strategy for coping with stress, we are concerned with music therapy. Music has been used as a form of healing [3], while an individual difference seems to affect physiological reactivity, for example, Kansei for music, preference, and personality.

The effects of music for stress have been measured by heart rate (HR), blood pressure (BP), salivary immunoglobulin A (sIgA), questionnaires such as the State-Trait Anxiety Inventory (STAI) and so on. Knight and Rickard [4] found that listening to classical music prevents significant increases in subjective anxiety, systolic
blood pressure, and heart rate caused by a cognitive stressor. In addition, diastolic blood pressure and salivary IgA levels were not affected by the stressor, while classical music reduced diastolic blood pressure and salivary IgA levels. Similarly, Burns et al. [5] conducted a study to evaluate the effects of different types of music for stress reactivity. The state anxiety levels of healthy participants who listened to relaxing classical music, hard rock music, self-selected music (their own ‘relaxing’ music) or control (in silence) were lower than premusic anxiety levels. Moreover, the classical music group’s postmusic heart rates were lower than the control group’s and the self-selected music group’s postmusic, and the self-selected music group’s trait anxiety levels were higher than the hard rock music group’s and the classical music group’s. Satoh and Urakawa [6] found that the background music (BGM) prevents the suppression of immune system by stress. In a study of 16 college students, participants watched cruel video and photographs for 30 min. Half of the participants watched them with BGM, and another half without. The natural killer cells (NK cells) activity of participants who watched them with BGM increased between pre and poststressor, while the activity of participants who watched them without music decreased. In addition to this result, BGM did not affect the other chemical agents (adrenaline, noradrenaline, cortisol, etc.)

It is suggested that that music is effective on physiological and psychological components as mentioned above. While a considerable number of studies have been conducted on physiological effects of music, the effects of music were not revealed in detail. Furthermore, very few attempts have been made at a study which evaluated central nervous system, autonomic nervous system and immune system simultaneously. Therefore, it is necessary to investigate the effects of music under stress condition in detail. In this study we introduced the various physiological indices such as sIgA concentration, saliva secretion rate, heart rate, spectral analysis of heart rate variability (HRV) and event-related potentials (ERPs) of brain wave (see below for detail).

Spectral analysis of heart rate variability (HRV) in electrocardiograph (ECG) has been developed to evaluate autonomic nervous system [7]-[9]. Fujisawa et al. [10] explained: Heart rate is regulated by the balance between parasympathetic nervous system (PNS) and sympathetic nervous system (SNS) activity. Spectral analysis of HRV has shown at least two distinct regions of periodicity in heart rate. It has been showed that high frequencies (HF, >0.15 Hz) of HRV are associated with cardiac PNS activity. Lower frequencies (LF, <0.15Hz) of HRV are associated with both PNS and SNS activity. In addition, the ratio LF/HF selectively indicated SNS activity.

P300 components of event-related potentials (ERPs) reflect the cognition information processing. Previous studies suggested that P300 latency and amplitude are useful for the evaluation of mental fatigue [11][12]. Uetake and Murata [11] reported that the appearance of fatigue is reflected more strongly in P300 components than the α-band power and power peak frequency of electroencephalogram (EEG) obtained by a traditional spectral analysis. Kaseda et al. [12] reported that ERPs may be useful for the objective evaluation of mental fatigue. These studies suggest that mental fatigue affects P300 components.

Salivary immunoglobulin A (sIgA) has been chosen as a measure of stress and relaxation reactivity (see review [13]). S IgA is the dominant immunoglobulin in external secretions that bathe mucosal surfaces (respiratory and intestines) and is characterized as a component of the immune systems "first-line of defense" against pathogenic viruses, and bacteria [14]. Tsujita and Morimoto reported that sIgA in saliva can be a useful stress marker for the immediate stress effect (see review [15]). On the other hand, Kuhn [16] conducted a study to evaluate the effects of music activity as measured by sIgA. Kuhn found that sIgA concentration of the active groups increased greater than those of the control groups (in silence). It is suggested that music activity may increase immune system function.
The purpose in the current study was to investigate the effects of music on subjective and physiological response by mental workload. The effects of music were measured by self-ratings of the State-Trait Anxiety Inventory (STAI), sIgA concentration, saliva secretion rate, P300 components (latency and amplitude), heart rate (HR), LF/HF ratio and HF.

2. Method

2.1 Participants

Eight healthy participants (all males) were examined. Their average age was 25.6 (S.D. = 4.56) years. Informed consent for this study was obtained from all participants. All participants were investigated three kinds of music condition. Each day of week was assigned to each participant, and the experiment was conducted over three weeks. The order of music was randomly assigned among participants. At the day of experiment none of the participants reported symptoms of upper respiratory tract infection. Participants were asked refrain from consuming drinks containing caffeine and from smoking 30 min prior to experiment.

2.2 Materials

The calculation task (Stressor). We have chosen the calculation task to cause mental stress. Participants were requested to perform the Uchida Kraepelin test [17], which was simple mental arithmetic task for 30 min. The task was self-paced.

Music piece. Standard compact disc was used to present music to the participants. The Bolero by Ravel, performed by Simon Halsey, City of Birmingham Symphony Orchestra (ToshibaEMI) was used as the “Music” condition. The participants repeatedly listened to the section from the beginning to 6 min 50 sec. This section is a ‘sedative’ part in the Bolero. The sound recorded from building construction site was used as the “Noise” condition, and in “Silence” condition, participants are requested to keep quiet as a control. The maximum loudness of the Bolero in the room was adjusted to 65 dB sound pressure level, and the noise was adjusted to 85 dB. It was hypothesized that measurements of “Music” condition would be more relaxation effects than measurements of “Noise” and “Silence” condition.

Questionnaires. The State-Trait Anxiety Inventory (STAI) [18] was used to measure both state and trait anxiety levels. A demographic questionnaire was used to obtain information about the participant’s age and general health. Information was also obtained on whether participants were experiencing any cold symptoms within a week. After music listening, the questionnaires asked them to rate their level of relaxation and preference of music piece on Likert-type scale with 1 being “Not relaxed at all”, or “Not preference” and 5 being “Totally relaxed”, or “Preference” by circling the number that best described. Higher scores indicated the participants were more relaxed, and has a good impression to the music piece.

2.3 Salivary immunoglobulin A measurement

Saliva sample was obtained using cotton swabs (Salivettes, SARSTEDT Aktiengesellschaft & Co.). Participants were instructed to place a swab in their mouth for 3 min and not to swallow during that time. Swab was then placed in a Salivette tube and kept on icebox for the duration of the procedure. The volume of saliva secretion was determined by weight. Each collection tube was weighed before and after saliva collection. At the end of the procedure, saliva was extracted from the cotton by centrifugation at $3 \times 10^3 \text{ rpm}$ for 5 min. The samples was then frozen at $-20 \, ^\circ \text{C}$ for later analysis. On thawing, the concentration of IgA in saliva was determined by a Enzyme Immune Assay (E.I.A kit; MBL CO., Ltd.). Each 3 min sample provided a measure of saliva secretion rate.
(ml/min) and sIgA concentration (µg/ml).

### 2.4 Heart rate, LF/HF ratio and HF measurements

The surface ECG was recorded from standard lead $\ddagger U$. We calculated R-R interval by peak-to-peak on the ECG data. For HR, R-R intervals were translated to beat per minute (bpm). We also calculated LF/HF ratio and HF (msec$^2$) with spectral analysis of R-R interval variability.

### 2.5 Event-related potentials (ERPs) measurement

ERPs of brain wave were recorded using auditory odd-ball paradigm (Frequent; 1000 Hz; 80 %, Rare; 2000 Hz; 20 %, 72 $\pm$ 3 dB). The inter-stimulus interval was 2.0 sec. The participants were asked to count number of the rare stimuli. Thirty responses induced by rare stimulation were recorded continuously. Active electrodes were placed on Cz, referred linked earlobe electrodes. Impedance was below 5 k$\Omega$. The analysis time was 700 msec including a 100 msec pre-stimulus period. P300 components, latency (msec) and amplitude (µV), were determined by adaptive filter analysis [19].

### 2.6 Apparatus

Apparatus used to present the music were a Marantz CDR630 CD player, a Sony TA-FA70ES amplifier and Tannoy GRF-Memory/HE speaker systems. ERPs and ECG were measured using SYNAFIT2500 (NEC Medical Systems). Analog output of ERPs and ECG data were recorded by KCR-000 (KISSEI COMTEC CO., Ltd.). Recording frequency was 2K Hz for ERPs and ECG.

### 2.7 Procedure

On entering the testing rooms, the participant was asked to sit in a recliner, and participant completed demographic questionnaires. Then the sensors were attached and the procedure was explained to the participant. A series of the experiment is divided into following three phases.

**Before the calculation task phase.**

First, the participants filled out both forms of the STAI. Second, each participant’s first saliva sample was obtained, then ERPs and ECG were measured. Participants were instructed not to strain themselves, and to keep eyes closed while ERPs and ECG were being taken. After the measurement of physiological indices had been finished, the participants were requested to perform the calculation task for 30 min.

**After the calculation task phase.**

Second saliva sample was collected exactly in the last 3 min of the calculation task. This action did not affect the calculation task. Immediately after the stressor, each participant’s ERPs and ECG recording were conducted. After the measurement of physiological indices had been finished, the participants were exposed to music, or just stayed in silence for 13 min.

**After music listening phase.**

Third saliva sample was collected exactly in the last 3 min of music listening. Immediately after music listening, the psychological rating of relaxation and preference of music piece was carried out, and then each participant’s ERPs and ECG were again measured. Finally, the participants filled out both forms of the STAI.

The experiments were carried out in the afternoon between 1.00 p.m. and 5.00 p.m.. The procedure is summarized in Figure 1.

### 3. Results and Discussions

#### 3.1 Results
Before the calculation task phase

- Rating of STAI
- Saliva sample was obtained (3 min)
- Measurements of ERPs and ECG (5 min)

The calculation task (30 min)
- The Uchida Kraepelin test

After the calculation task phase
- Saliva sample was obtained (3 min)
- Measurements of ERPs and ECG (5 min)

Music listening (13 min)

After music listening phase
- Saliva sample was obtained (3 min)
- Rating of subjective feeling of relaxation and preference of music piece
- Measurements of ERPs and ECG (5 min)
- Rating of STAI

Table 1. Means and standard deviations of measured parameters of all conditions

<table>
<thead>
<tr>
<th>Variables</th>
<th>Prestressor Mean (S.D.)</th>
<th>Poststressor Mean (S.D.)</th>
<th>Stressor effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salivag A concentrations (µg/ml)</td>
<td>4.02 (2.57)</td>
<td>5.82 (3.26)</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>Saliva secretion rate (ml/min)</td>
<td>0.52 (0.19)</td>
<td>0.43 (0.15)</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>P300 latency (msec)</td>
<td>326.4 (12.8)</td>
<td>328.4 (16.1)</td>
<td>n.s.</td>
</tr>
<tr>
<td>P300 amplitude (µV)</td>
<td>22.2 (6.7)</td>
<td>18.7 (5.3)</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>Heart rate (bpm)</td>
<td>75.8 (10.6)</td>
<td>74.3 (10.3)</td>
<td>n.s.</td>
</tr>
<tr>
<td>LF/HF ratio</td>
<td>1.18 (0.99)</td>
<td>1.81 (1.44)</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>HF (msec²)</td>
<td>1203.1 (2007.0)</td>
<td>991.3 (1166.4)</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

Note. n.s. = not significant; Prestressor = Before the calculation task phase; Poststressor = After the calculation task phase.

The efficacy of stressor.

The efficacy of stressor were assessed by comparing before and after the calculation task in all conditions. The means and standard deviations of sIgA concentration (µg/ml), saliva secretion rate (ml/min), P300 latency (msec) and amplitude (µV), HR (bpm), LF/HF ratio, and HF (msec²), are shown in Table 1. It can be seen that the stressor increased sIgA concentration and LF/HF ratio, and the stressor decreased saliva secretion rate and P300 amplitude. The nonparametric test was used for the statistical testing in this study, because some indices such as LF/HF ratio...
Fig. 2  Means and standard deviations of: (a) sIgA concentration difference; (b) saliva secretion rate difference; (c) P300 amplitude difference; (d) heart rate difference; (e) state anxiety difference.

Fig. 3  Means and standard deviations of: (a) the score of relaxation; (b) the score of preference of music piece

**: p<0.01
and HF could not assume the normality. Wilcoxon’s Paired Signed Rank test revealed that significant effects for sIgA concentration ($p<0.01$), saliva secretion rate ($p<0.01$), P300 amplitude ($p<0.05$) and LF/HF ratio ($p<0.01$). Stress reactivity was similar for all conditions. No significant differences were found between “Music”, “Noise” and “Silence” conditions, while “Noise” condition’s P300 latency was prolonged than “Music” and “Silence” condition’s P300 latency.

**The effects of Music on Stress Response.**

The effects of music were assessed by comparing after the calculation task and after music listening in “Music”, “Noise” and “Silence” condition respectively.

**Music condition.** Wilcoxon’s Paired Signed Rank test revealed that music significantly increased saliva secretion rate ($p<0.01$) and P300 amplitude ($p<0.05$), and significantly decreased sIgA concentration ($p<0.05$), HR ($p<0.05$) and state anxiety ($p<0.01$). Figure 2 shows that the difference which were calculated by subtracting after the calculation task measures from after music listening measures.

**Noise and Silence condition.** Noise and silence had no significant effect on physiological and psychological indices, while only saliva secretion rate significantly increased ($p<0.05$) in “Silence” condition. The result also appears in Figure 2.

**Subjective evaluations.** Wilcoxon’s Paired Signed Rank test revealed that the self-rating of relaxation in “Music” condition and “Silence” condition were higher than “Noise” condition ($p<0.01$), and rating of preference in “Music” condition was higher than “Noise” condition ($p<0.01$). The result appears in Figure 3.

**3.2 Discussion**

Several studies reported that music contributes to be more relaxation effects than silence [4][6]. The results of our study support this hypothesis.

We will now discuss the efficacy of the stressor in detail. Our results of sIgA concentration and LF/HF ratio were increased by the calculation task. There are some other studies where sIgA concentration increased in response to mental arithmetic task [20][21]. However, the mechanism whereby stressful events affect sIgA is not yet clear. It has been hypothesized that stress affects immune system through its impact on the hypothalamic-pituitary-adrenal axis and sympathetic-adrenal medullary system [13]. The sympathetic-adrenal medullary system involves activation of the autonomic nervous system. In fact, the result indicated an increase in LF/HF ratio. On the other hand, stress tends to decrease saliva secretion rate via sympathetic nervous system [22]. The results of this study also indicated a decrease in saliva secretion rate. Therefore, it was found from the results that the calculation task activates immune and sympathetic nervous system. Moreover, our result of P300 amplitude was decreased by the calculation task. In previous studies, Uetake and Murata [11][23] found that P300 amplitude was decreased in response to mental arithmetic task. These findings suggest that the participant’s attention level was decreased after the calculation task, and the central nervous system for the recognition information processing is inactivated because of distress.

The focus of the current study was to investigate the effects of music on stress reactivity. Having the efficacy of the stressor, we will now discuss the effects of music.

**Autonomic nervous system and immune system.** The result of this study showed that the classical music reduced sIgA concentration. In previous study, Knight and Rickard [4] also found that music reduced salivary IgA levels. Watkins [24] proposed mechanisms for the effects of music on the hypothalamic-pituitary-adrenal axis system. The proposed mechanism is as follows: Auditory stimuli may decrease corticotropin releasing hormone (CRH)
being produced in the hypothalamus. Stimulation of the basolateral amygdaloid region may decrease CRH release directly by inhibition of hypothalamic nuclei and indirectly by preventing stimulation of the centromedial amygdaloid region. Inhibition of hypothalamic nuclei decreases CRH release, which decreases adrenocorticotrophic hormone (ACTH) release from the anterior pituitary and results in decreased plasma cortisol levels. A feedback loop allows plasma cortisol levels to also influence the rate of CRH release (see Figure 4). From the reasons mentioned above, it was suggested that the activation of immune system suppressed by music, while whether this hypothesis can be proved or not is open to discussion.

Saliva secretion rate tends to increase via parasympathetic nervous system [22]. Our result of saliva secretion rate was increased under “Music” and “Silence” condition. In this study, indices of parasympathetic nervous system indicate that music and silence did not affect HF, while heart rate was only decreased under “Music” condition. Recent researches suggest that CRH activates sympathetic-adrenal medullary system [25]. Given that music may decrease CRH release, sympathetic nervous system will be inactivated. Therefore, it is inferred from this hypothesis that the increase of saliva secretion rate and the decrease of heart rate result from inactivation of sympathetic nervous system. Although silence may inactivate sympathetic nervous system, the effect is smaller than music.

Central nervous system. Our result of P300 amplitude suggests that the central nervous system for the recognition information processing is recovered under “Music” condition, and it is indicated that the participant’s attention level turned to odd-ball paradigm increased. Since there are few studies which showed that P300 amplitude was recovered by music, the result of this study gives a useful suggestion to future.

STAI and subjective evaluations. Previous studies suggested that music reduced state anxiety levels [5][24]. Our finding of STAI also showed that the classical music would decrease participants’ perceived level of state anxiety levels. It is indicated that music is more effective for the reduction in state anxiety than noise and silence.
The score of preference in “Noise” condition was lower than the score of preference in “Music” condition. Additionally, the score of relaxation in “Noise” condition was lower than “Music” and “Silence” condition. Thus, it is likely that the noise was an unpleasant stimulus for participants. Music is composed of various elements (melody, harmony, rhythm, pitch, etc.), while relaxing or ‘sedative’ music, which is characterized by slow tempo, repetitive rhythm, gentle contours and strings, has typically been used in previous studies [4]. Therefore, it is suggested that the noise was induced unpleasant feeling, and the relaxation effect did not appear.

In “Silence” condition, the score of relaxation was almost equivalent to “Music” condition, while the relaxation effects of physiological and psychological indices were showed in only saliva secretion rate. From this point, it is indicated that music stimuli is an important element for the relaxation effects.

These results lead us to the conclusion that the listening to classical relaxation music has effective for stress. In contrast, Noise had no significant effect on physiological and psychological indices. In “Noise” condition, stress condition seemed to continue by the effect of unpleasant feeling.

There are other things to note. There was a participant who showed the relaxation effect regardless of the type of music. It is likely that the participant can recover with progress of time, or can take no notice of the noise. The other participant showed the relaxation effect in “Music” and “Noise” condition, or “Music” and “Silence” condition. These findings suggest that Kansei for music is various in human. The further investigation will be required in this point.

4. Conclusions

In this study, we evaluated the effects of music under stress condition using various physiological and psychological indices. Our results suggested that the listening to music is useful for the stress management, and participant who listened to classical music is recovered quickly than those who listened to noise and silence. An important point to emphasize is the result that P300 amplitude was increased under “Music” condition. Further research on this type study would clarify the mechanism of physiological effects of music.

Acknowledgment

The authors would like to thank the volunteer who participated in the experiment. The authors are also grateful to Dr. Yoshiyuki Kusunoki in SVBL Muroan Institute of technology and Assistant Shusaku Nomura in Shimane Univ. who provided many valuable comments of this research.

References

4. Wendy E.J. Knight, Nikki S. Rickard. Relaxing Music Prevents Stress-Induced Increases in Subjective Anxiety,


