Original Article

Analysis of physiological responses associated with emotional changes induced by viewing video images of dental treatments

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Since the understanding of emotional changes induced by dental treatments is important for dentists to provide a safe and comfortable dental treatment, we analyzed physiological responses during watching video images of dental treatments to search for the appropriate objective indices reflecting emotional changes. Fifteen healthy young adult subjects voluntarily participated in the present study. Electrocardiogram (ECG), electroencephalogram (EEG) and corrugator muscle electromyogram (EMG) were recorded and changes of them by viewing videos of dental treatments were analyzed. The subjective discomfort level was acquired by Visual Analog Scale method. Analyses of autonomic nervous activities from ECG and four emotional factors (anger/stress, joy/satisfaction, sadness/depression and relaxation) from EEG demonstrated that increases in sympathetic nervous activity reflecting stress increase and decreases in relaxation level were induced by the videos of infiltration anesthesia and cavity excavation, but not intraoral examination. The corrugator muscle activity was increased by all three images regardless of video contents. The subjective discomfort during watching infiltration anesthesia and cavity excavation was higher than intraoral examination, showing that sympathetic activities and relaxation factor of emotion changed in a manner consistent with subjective emotional changes. These results suggest that measurement of autonomic nervous activities estimated from ECG and emotional factors analyzed from EEG is useful for objective evaluation of subjective emotion.

Key Words: Emotion, Autonomic nervous activity, Electroencephalogram, Electromyogram, Dental treatment
maintenance of homeostasis, and the physiological and psychological stress elicits an increase in sympathetic nervous activity with a simultaneous decrease in parasympathetic nervous activity. Furthermore, we found that the autonomic nervous activities, especially sympathetic nervous activity is quite useful for continuous assessment for the internal stress of children during dental treatments, even when no expressed sign of unease are present. The EMG of the corrugator muscle, a facial expression muscle, would be a good objective measure because it can be activated by some emotions such as pleasure, anger and discomfort and its tensions were reported to be heightened during presentation of film clips showing dental drilling or injections. Thus, we measured the autonomic nervous activities as well as EMG of the corrugator muscle for the objective evaluation of emotional changes induced in the dental settings in the present study. In addition, we have applied a new technique of emotion analysis from electroencephalogram (EEG) developed by Musha et al. to this study. As EEG has been conventionally utilized to understand the psychological states by analyzing the power of alpha, beta and theta wave components, this new analyzing method enables us to estimate the level of four basic components of emotion, such as anger/stress, joy/satisfaction, sadness/disappointment and relaxation under a variety of situations.

In order to elicit unpleasant emotion associated with dental treatments in the subjects, we used the video of dental treatments, since several studies have used the film clips to induce emotional changes. The studies showed that the presentation of video could evoke a strong emotional response and the negative emotions were associated with stronger physiological responses than the positive emotions. Especially in the subjects with dental phobia, the scenes or sounds of dental treatments such as infiltration anesthesia, cavity excavation and excavation sound were reported to cause heart rate acceleration. Thus, we prepared video images of infiltration anesthesia, cavity excavation and intraoral examination and used for inducing emotional arousal prior to the study in the actual clinical setting.

Collectively, in order to search for appropriate objective indices reflecting internal emotion, we recorded ECG, EMG and EEG as physiological responses during watching video images of dental treatments which generally induce a negative emotion in the present study. In addition to the objective indices, we obtained the information about the strength of subjective discomfort during watching the video images by questionnaire using Visual Analog Scale (VAS). To obtain reliable answer about the subjective feelings, the young adult subjects rather than children were involved in this study.

Taking together these results, we analyzed the correspondence between the subjective discomfort and the objective physiological responses, and discussed about the significance of recorded physiological indices in assessing the internal emotion. The appropriate physiological index reflecting internal emotion obtained from the present study would be a quite useful measure to understand children’s emotion in the next step.

Materials and Methods

Subjects

Fifteen right-handed, healthy subjects (6 males and 9 females) aged 22.67 ± 2.89 years (the mean ± S.D.) participated in this study. To decide the number of subjects, we made use of the Power and Sample Size Calculation (William D. D. and Walton D. P. Jr., Department of Biostatistics Vanderbilt University School of Medicine). All subjects had no abnormality in the audio-visual functions and were not dental personnel because dental personnel are used to dental treatments and expected to cause poor response to it. The subjects were undergraduate and graduate students who had experiences of dental treatments such as infiltration anesthesia and cavity excavation, and recruited from our university and neighboring universities. They were asked not to take any alcohol, caffeine or medication on the day before the experiment and to refrain from eating or drinking anything at least 2 hours before the experiment.

All subjects were informed about the purpose and details of this study and voluntarily agreed to cooperate. This study was approved by the Ethics Committee of Tokyo Medical and Dental University (Approval number 739).

Audiovisual stimuli of dental treatments

For audio visual stimuli, three images of dental treatments such as infiltration anesthesia, cavity excavation and intraoral examination for 2 min were prepared in order to evoke emotions, based on the previous report that dental phobia patients feel fear especially with infiltration anesthesia, tooth extraction and cavity excavation. We used the audio and visual stimulations simultaneously in order to reproduce the situation more similar to actual clinics. The videos of
infiltration anesthesia, cavity excavation and intraoral examination included the image of liquid injection from an injection syringe, cutting by the dental turbine and contra-angle hand-piece and the assessment and tooth tapping examination, respectively. The video images were projected on a 60-inch screen located 2 m in front of the subjects.

Experimental procedures
The subjects were seated on a comfortable armchair and asked to relax their muscles during watching the videos. The electrodes for recording ECG, EEG and EMG were attached on the skin of respective parts of the body (Fig. 1a). A protocol of experiment was made up of 1) eye closure (2 min), 2) eye open with no image (2 min), 3) audiovisual stimulation with dental treatment video (2 min), 4) eye open with no image (2 min), 5) eye closure (2 min), and 6) answering questionnaire (VAS), and the whole procedure took about 10 min (Fig. 1b). This protocol was performed three times for three kinds of video images with 2 min recess between protocols. Thus, the interval of consecutive treatment videos was taken at least 10 min to avoid aftereffect from the previous treatment video. The presentation order of three videos was changed randomly among subjects.

The subjects closed their eyes in a relaxed state during eye closure period, and they watched the gray screen as background state during eye open period. The ECG, EEG and EMG was continually recorded from start to finish of experiment.

Data acquisition and analysis

Measurement of the autonomic nervous activity
ECG data were recorded continuously through the protocols with Active Tracer AC-301A (GMS Co., Japan). The recorded data were uploaded onto a computer and processed with the program (MemCalc/Win ver.2 Tawara, GMS Co., Tokyo, Japan) which analyzes fluctuations of separate R-R intervals and outputs the power of two specific frequency bands, high (HF: 0.15-0.40 Hz) and low (LF: 0.04-0.15 Hz). Since HF and LF is respectively considered to reflect the respiratory variation and the blood pressure regulation via baroreceptor, the area of HF was regarded as parasympathetic nerve activities and the area of LF was regarded as parasympathetic and sympathetic nervous activities. As an index of sympathetic nerve activities, LF/HF was calculated. The changes of each nervous activity were evaluated.

Figure 1  Experimental procedure
a: Diagram showing the recording system of ECG, EEG and EMG.
 b: Time course of the video stimulation protocol. The period of eye closure, eye opening with no image and watching video images was 2 min each. After viewing, the subjects marked discomfort level of the video using VAS.
 c: Configuration of EEG recording electrodes (larger circle) in the International 10-20 system.
compared with the levels (eye open period with no image) just before watching videos.

**Measurement of EEG**

Since EEG recording is non-invasive and has a quite high time resolution, we recorded EEG to observe brain activity in this study. Ten Ag-AgCl electrodes were placed on the scalp at positions FP1, FP2, F3, F4, T3, T4, P3, P4, O1 and O2 according to the International 10-20 Standard (Fig. 1c) and on a right earlobe as a reference electrode. The emotion analysis was performed by using the software of Emotion Spectrum Analysis Method (ESAM; Emotion Expert, Brain Functions Laboratory, Inc., Japan). In ESAM, 135 cross-correlation coefficients calculated from 45 electrode pairs in the theta (5-8 Hz), alpha (8-13 Hz) and beta (13-20 Hz) frequency bands in every 5.12 seconds, from which the four orthogonal emotional states (anger/stress, joy/satisfaction, sadness/depression and relaxation) were separated and their levels were evaluated. The levels of four factors of emotions during watching video images were compared with those just before videos (eye-open period with no image) after normalization with Z transformation.

**Measurement of EMG**

EMG activity was recorded with the electromyography system (Bagnoli2-EMG system, Delsys Co., USA) equipped with a recording electrode having a pair of silver bars spaced 10mm apart. The recording electrodes placed on the skin over the right corrugator muscle. The electrical activity of the muscle was amplified 1000-fold with hum noise filter set to 50Hz. The data were stored in PC by data acquisition system (Unique Medical Co., Tokyo) for further analysis. The EMG signal was subjected to smoothing processing at 11 sampling points after rectification by using analytical software (LabChart 5 for Windows, AD INSTRUMENT Co, New Zealand). The mean amplitudes of processed activities for 20 sec around the peak were calculated and used for comparison of the muscle activity between the periods of video watching and previous eye opening.

**Subjective evaluation**

Degree of subjective discomfort for watched video was assessed by VAS method. The subject marked the level of discomfort on 100 mm line in which 0 means ‘no feeling’ and 100 means ‘extremely uncomfortable’. The mean value of VAS was compared between three video images. Although the strength of stress felt during viewing videos varies depending on individual dental history, we considered the subjective discomfort level with VAS as the reflection of their dental histories.

**Statistical analysis**

Statistical analyses were performed using Dr. SPSS II for Windows (Japan IBM Co., Japan). Wilcoxon rank-sum test was used for analysis of the changes in autonomic activities, emotional levels and EMG activities and Friedman test was used for comparison between three types of videos. The level of \( P < 0.05 \) was considered as statistically significant in all analyses.

**Results**

**Autonomic nervous activities during video viewing**

A typical example of autonomic nervous activity change during watching the video of infiltration anesthesia is shown in Fig. 2a. In this case, sympathetic nervous activities increased and parasympathetic nervous activities decreased during watching the video. The changes of sympathetic and parasympathetic nervous activities by watching three types of video images in all subjects are summarized in Fig. 2b. The activities during video watching are expressed in relative value to those during eye opening with no image. The sympathetic nervous activity was significantly elevated by watching video of infiltration anesthesia \( (P = 0.02) \) and cavity excavation \( (P = 0.011) \) compared with each activities during previous eye open, but no significant change was observed by intraoral examination video \( (P = 0.394) \). In the parasympathetic activities, no statistically significant changes were observed by watching any videos \( (P > 0.05) \) compared to each during eye open, though the levels tended to decrease by watching cavity excavation and intraoral examination \( (P < 0.1) \).

**Emotional changes during video viewing**

An example of changes in four emotional factors during viewing the infiltration anesthesia video is shown in Fig. 3a. In this case, anger/stress and sadness/depression level was elevated and relax level was lowered during watching the video. The changes in levels of 4 emotional factors in all subjects are summarized in Fig. 3b. The values indicate the difference between the levels during watching video and eye opening. A significant decrease in relaxation level was observed by watching the video of infiltration anesthesia \( (P = 0.017) \) and cavity excavation \( (P = \)
0.015), but no significant changes were observed in other emotional factors such as anger/stress, joy and sadness ($P > 0.05$). No significant changes in all emotional factors were observed by watching the video of intraoral examination ($P > 0.05$).

**Change in the corrugator muscle activity by video viewing**

An example record of the corrugator muscle activity during viewing the infiltration anesthesia video is shown in Fig. 4a. The activity of corrugator muscle was greatly increased compared to that during eye opening. The changes in corrugator muscle activities in all subjects are summarized in Fig. 4b, which showed that the activities were significantly increased by watching all videos (infiltration anesthesia: $P = 0.001$; cavity excavation: $P = 0.004$; intraoral examination: $P = 0.023$). The rates of increment in EMG activities did not
Subjective evaluation by questionnaire

As shown in Fig. 5, the averaged VAS value of subjective discomfort was 56.7 mm for infiltration anesthesia, 46.0 mm for cavity excavation and 20.0 mm for intraoral examination. The subjective discomfort was significantly higher during the video of infiltration anesthesia ($P = 0.020$) and cavity excavation ($P = 0.033$) than intraoral examination video, but there was no significant difference between infiltration anesthesia and cavity excavation ($P > 0.05$).

The number of subjects was 15 eventually, since 3 out of 18 subjects were excluded from the analyses because of noise problem in recording EEG. Thus, the order of three videos was not completely equally distributed, no significant influence of presentation order was observed in all physiological responses and subjective evaluation ($P > 0.05$).

Discussion

It is generally recognized that emotion induced by pain and noise accompanied with dental treatments is associated with changes in autonomic nervous system, endocrine secretion and muscle activity via the neuronal activities of amygdala and thalamus. In the present study, we measured the change in the brain, autonomic nervous system and muscle tone induced by unpleasant stimulation with dental treatment video, and investigated the correspondence between physiological responses and subjective discomfort feelings. We found that the sympathetic nervous activity was significantly elevated by watching videos of infiltration anesthesia and cavity excavation for 2 min, which showed higher subjective discomfort compared with oral examination. Ekman et al. showed that changes of autonomic nervous system induced by emotions occurred in a short period of time\textsuperscript{32}, and most studies regarding fear/
anxiety reported that fear can be characterized by sympathetic activation and vagal deactivation, together with faster and shallow breathing.\textsuperscript{7,8,23} The parasympathetic activities largely vary with individuals and no significant changes by video viewing was observed in the present subjects. In child patients of our previous study\textsuperscript{9}, however, remarkable differences of parasympathetic activities were observed between uncooperative and cooperative conditions in the same patients, which indicates that the activities may be more susceptible to mental conditions in children. In consistent with the previous studies, the present result suggested that autonomic nervous activity is useful for an indicator of internal stress which the patients feel to dental treatment.

In addition, we used the ESAM that can estimate the levels of four basic emotional states (anger/stress, joy/satisfaction, sadness/depression and relaxation) from EEG, and the significant decrease of relaxation level was observed during watching the video of infiltration anesthesia and cavity excavation compared with resting eye open state. However, unexpectedly the stress level did not change significantly by these videos. One possible reason is that the discomfort was not high enough to change anger/stress level, because the average value of subjective discomfort was 56.7 mm for infiltration anesthesia, and 46.0 mm for cavity excavation, which were around middle level. Using the ESAM analyses, Kikuchi\textsuperscript{18} and Nishiyama et al.\textsuperscript{19} reported that mounting of poor fitting dental prosthesis caused stress elevation and relax reduction accompanied with strong subjective discomfort. These results suggest that ESAM is one of useful tools to evaluate emotion induced by various stimulations.

On the other hand, regarding the corrugator muscle activities, all three videos induced increment of EMG activity. Several previous studies measured the corrugator muscle activities as an expression of emotional discomfort\textsuperscript{27,28}. However, the present study showed no differences between three types of videos, although the subjective discomfort level of infiltration anesthesia and cavity excavation was significantly higher than intraoral examination. Thus, there is a possibility that higher tension of corrugator muscle as shown in Fig. 4 was elicited by watching the video itself regardless of video types. Although any differences between three videos was not observed in video viewing of dental scene, the EMG of corrugator muscle might still be a useful index in the clinical settings because it is easy to record and suitable for real time monitoring. Though several muscles such as the corrugator muscle, zygomaticus major muscle and sternocleidomastoid muscle can be activated by emotional changes, the activation of these muscles except corrugator muscle could not be observed by video viewing in the present subjects (data were not shown) because they voluntarily control muscle activities. In case of children, the emotional changes may directly result in these muscle activities and these physiological responses could be used for objective measures of internal emotion.

In conclusion, the present results indicated that the sympathetic nerve activity and emotional relaxation level have demonstrated roughly consistent changes with subjective discomfort level felt with videos of dental treatments, which suggests that these objective parameters can be utilized for assessment of internal discomfort and stress. Further EMG study of other muscles as well as the corrugator muscle in the pediatric clinical situation is required to find the suitable muscle to evaluate internal stress. Since the video scenes of dental treatments used for emotional arousal may not be enough to elicit remarkable emotional changes in the healthy subjects, the investigation using autonomic nerve, EEG and EMG measures at actual clinical setting will be required.

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