Real time measurement of stress by electroencephalogram during contentious mouth opening

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Purpose: Dental treatment is a stressful event. The aim of this study was to evaluate the feasibility of electroencephalography (EEG) for the measurement of stress the stress of the patient's ongoing dental treatment. **Materials and Methods:** Real-time brain activity was measured for five healthy subjects (three males and two females) under contentious opening mouth conditions and compared with the relaxed conditions for 18 minutes. Brain activities were measured under the conditions that subjects were sited on the dental chair in horizontal situation. Electroencephalograph (EEG) were used to measure the five type of brain waves: θ, α_1, α_2, α_3, and β. **Results:** In θ wave, α_3 wave and β wave, widening gap between opening mouth condition and closing mouth conditions were observed with over the time course. This tendency was confirmed by autoregressive moving average (ARMA) model and mixed effect modeling. All of the coefficients of opening mouths were statistically significant, when closing mouth used as reference. EEG may be useful tool to measure the stress during dental treatment. Stress by sitting on dental chair in horizontal situation was depended on personality traits. **Conclusion:** Contentious opening mouth may be stressful; however, the amount of stress may be small. The changes can be seen within 18 min. Prolonged chair time for the dental treatment may not be recommended.

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Key Words: dental treatment, electroencephalograph, stress

Introduction

Dental treatment is a stressful event. Multiple factors that induce anxiety were summarized in previous review paper [1,2]: previous negative or traumatic experience, vicarious learning from anxious family members or peers, vulnerable position of lying back in a dental chair [3-5], sights of needles and air-turbine drills, sounds of drilling and screaming, the smell of eugenol and cut dentin, sensations of high-frequency vibrations in the dental setting [6-8], fear of pain, blood-injury fears, lack of trust or fear of betrayal, fear of being ridiculed, fear of the unknown, fear of detached treatment by a dentist or a sense of depersonalization, fear of mercury poisoning, fear of radiation exposure, fear of choking and/or gagging, a sense of helplessness on the dental chair, and lack of control during dental treatment [1,9]. These are all negative images of dental treatment. These images induce dental anxiety or phobia. The patients with dental anxiety or phobia refused the dental treatment. To recommend the dental treatment for these patients, information about stress levels ongoing dental treatment is necessary. However, there is little information about the stress levels of the patients. To measure the stress of the patient's ongoing dental treatment, non-invasive and real time monitoring system for measuring stress is necessary.

Electroencephalography (EEG) is an electrophysiological monitoring method to record electrical activity of the brain. It is typically noninvasive. EEG measures voltage fluctuations resulting from ionic current within the neurons of the brain [10]. In clinical contexts, EEG refers to the recording of the brain's spontaneous electrical activity over a period of time [10]. EEG is generally used to diagnose epilepsy, sleep disorders, depth of anesthesia, coma, encephalopathies, and brain death, tumors, and stroke [11,12]. It can applicable for the response for visual, somatosensory, or auditory stimulus. Therefore, it can applicable for cognitive science, cognitive psychology, and psychophysiological research. Therefore, EEG may be feasibility to measure the stress of the patient's ongoing dental treatment.

The aim of this study was to evaluate the feasibility of EEG for the measurement of stress the stress of the patient's ongoing dental treatment. To simplify this aim, this study evaluated the real-time brain activity by contentious opening mouth conditions and compared with the relaxed conditions.

Materials and Methods

Subjects

Five healthy subjects were participated in this study. They were three males and two female, and their ages were 45, 28, 40, 38, and 33, respectively. As study design was cross over design, brain activities were measured twice for every subject. The order to measure the stress conditions were randomly allocated. This study was approved by the Ethical Committee of Tsurumi University School of Dental Medicine (Approval Number: 1627). Written approval was obtained from the institution where the study was carried out. The participants were informed about the study, and written consent was obtained.

Stress measurement conditions

Brain activities were measured under the conditions that subjects were sited on the dental chair in horizontal situation. The operators advised the subjects to be relax and eyes should be closed. For the opening mouth conditions, Multiple Mouth Opener (Takasago Medical Industry Co., Ltd., Tokyo, Japan) were set in the right molar and opening distance were set as 4 mm. For the closing mouth conditions, operators advised the subjects to close the mouth. Brain activities were measured by Brain Pro FM-929 (Futek Electronics Co., Ltd., Yokohama, Japan). Sensor bands (2 electrodes) were attached to the forehead, and electroencephalograms were recorded for 3 min through ear grounding [13-15].

Stress measurement

Electroencephalograph (EEG) were used to measure the five type of brain waves: θ, α_1, α_2, α_3, and β. These five brain waves are denoted that: θ, 4-6 Hz, idling, sleepy [16,17]; α_1, 7-8 Hz, relax [18]; α_2, 9-11 Hz, relax and concentrated [18], α_3, 12-13 Hz, drowsy [18]; β, 14-23 Hz, active thinking, focus, high alert, anxious so-called stress wave [19,20]. These five were recorded every second. It is generally known that observed values of brain waves varies between subjects, data is commonly expressed as the percentage of each waves. In this study, data were expressed by the percentage of each wave in the total of five waves.

Statistical analysis

Data of recorded brain wave every second were transformed into moving average for 3 min. Time series analysis were carried out to construct autoregressive moving average (ARMA) model. As the recorded data were nested in subjects, and time, mixed effect modeling was carried out to find out the effect of stress under opening mouth. Then, average value of every 3 min of five waves described above was used for the outcome variable. These analyses were carried out by IBM SPSS Statistics ver 24.0 (IBM, Tokyo, Japan).

Results

Five brain waves obtained by the average five subjects were graphically illustrated in Fig. 1. Red line denoted opening mouth and blue line denoted closing mouth conditions. Solid line denoted the observed values of 3 minutes' moving average of each brain wave. In θ wave, α_3 wave, and β wave, widening gap between opening mouth condition and closing mouth conditions were observed with over the time course.

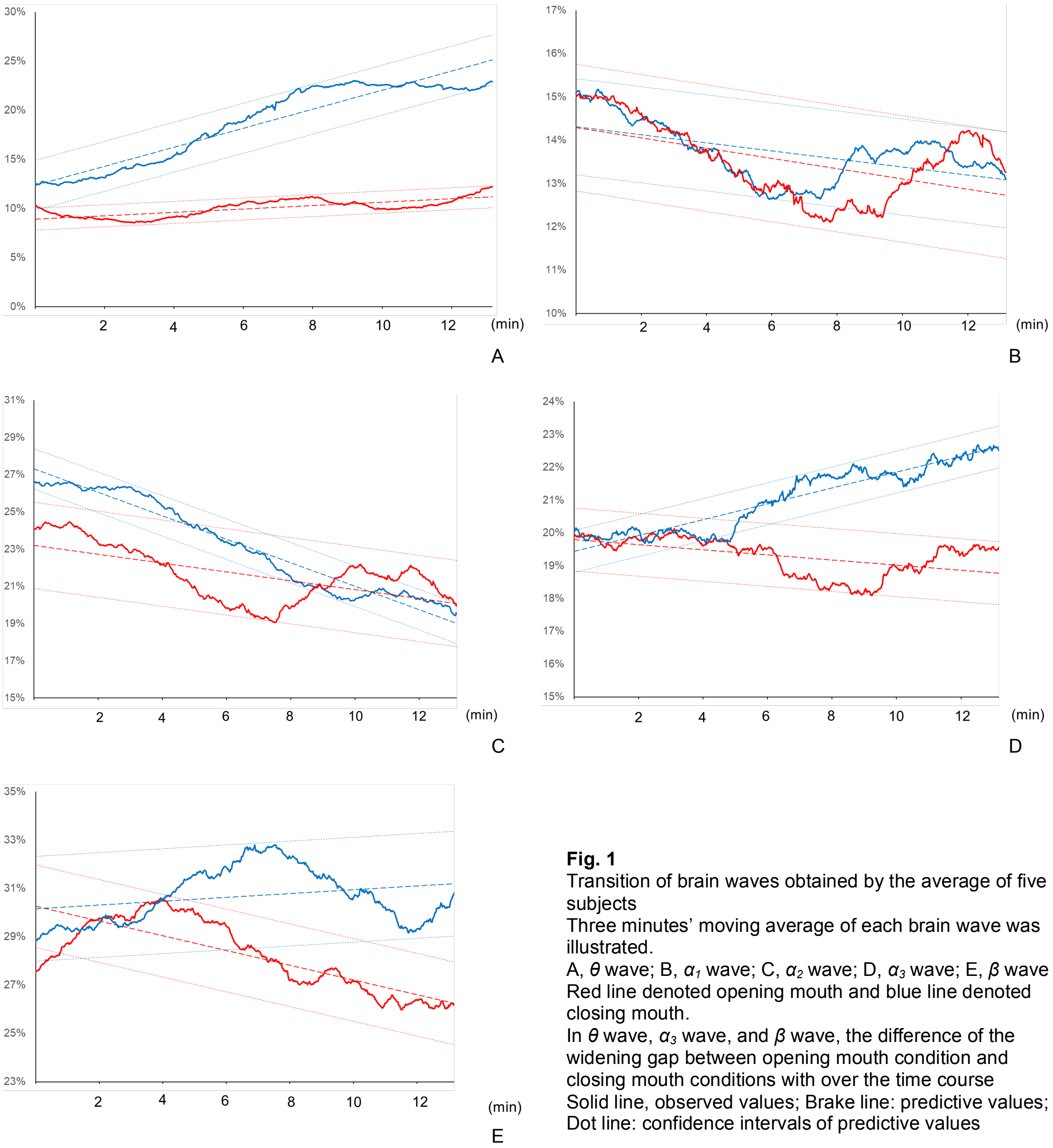

Fig. 1
Transition of brain waves obtained by the average of five subjects
Three minutes' moving average of each brain wave was illustrated.
A, θ wave; B, α_1 wave; C, α_2 wave; D, α_3 wave; E, β wave
Red line denoted opening mouth and blue line denoted closing mouth.
In θ wave, α_3 wave, and β wave, the difference of the widening gap between opening mouth condition and closing mouth conditions with over the time course
Solid line, observed values; Brake line: predictive values; Dot line: confidence intervals of predictive values

These time series data were applied for the time series analysis model to calculate the predictive values of the transition of brain waves. Autoregressive moving average (ARMA) model, which consisted of the combination of autoregressive and moving average, was applied in this study. The results of the fitness index were shown in Table 1. All of the data were significantly fitted for the models, and the p-values were all less than 0.01. Predictive values by the results of ARMA models were overwritten on Fig. 1. Broken lines and dot lines denoted the predictive values and their upper and lower limit of the confidence intervals. Predictive values were also indicated that widening gap between opening mouth condition and closing mouth conditions were observed with over the time course in θ wave, α_3 wave, and β wave.

Table 1 Estimated parameters and fitness indexes for the transition of brain waves by autoregressive moving average model (ARMA model)

		Model fit		Parameter of ARMA model			
		SRSquare	*p*-value	Parameter	Estimate	SD	*p*-value
θ	Close	0.573	<0.001	Intercept	0.08	0.001	<0.001
				Time	3.50×10^{-5}	1.17×10^{-6}	<0.001
	Open	0.891	<0.001	Intercept	0.09	0.001	<0.001
				Time	1.90×10^{-4}	2.64×10^{-6}	<0.001
α_1	Close	0.283	<0.001	Intercept	0.15	0.001	<0.001
				Time	-1.90×10^{-5}	1.15×10^{-6}	<0.001
	Open	0.27	<0.001	Intercept	0.15	0.001	<0.001
				Time	-2.40×10^{-5}	1.52×10^{-6}	<0.001
α_2	Close	0.95	<0.001	Intercept	0.3	0.001	<0.001
				Time	-1.30×10^{-4}	1.13×10^{-6}	<0.001
	Open	0.371	<0.001	Intercept	0.24	0.001	<0.001
				Time	-4.70×10^{-5}	2.41×10^{-6}	<0.001
α_3	Close	0.27	<0.001	Intercept	0.2	0.001	<0.001
				Time	-1.60×10^{-5}	9.99×10^{-7}	<0.001
	Open	0.889	<0.001	Intercept	0.19	0	<0.001
				Time	4.80×10^{-5}	6.66×10^{-7}	<0.001
β	Close	0.641	<0.001	Intercept	0.31	0.001	<0.001
				Time	-6.10×10^{-5}	1.78×10^{-6}	<0.001
	Open	0.069	<0.001	Intercept	0.3	0.001	<0.001
				Time	1.60×10^{-5}	2.26×10^{-6}	<0.001

Data were significantly fitted for the models, and all *p*-values were less than 0.01.

Table 2 Results of mixed effect modeling

		Fixed effect model			Random effect model		
		Coefficient	95% CI	*p*-value	Coefficient	95% CI	*p*-value
θ	Intercept	0.15	0.143 - 0.156	<0.001	0.15	0.066 - 0.233	0.008
	Opening mouth	−0.087	−0.012	<0.001	−0.087	−0.008	<0.001
	Time	1.0×10^{-4}	1.0×10^{-4} -1.0×10^{-4}	<0.001	1.0×10^{-4}	-2.0×10^{-4} - 4.0×10^{-4}	0.359
α_1	Intercept	0.142	0.138 - 0.146	<0.001	0.142	0.031 - 0.253	0.024
	Opening mouth	0.002	−0.008	0.329	0.002	0.001 - 0.003	<0.001
	Time	-2.0×10^{-5}	-3.0×10^{-5} - -1.0×10^{-4}	<0.001	-2.0×10^{-5}	-9.0×10^{-5} - 4.0×10^{-5}	0.419
α_2	Intercept	0.245	0.241 -0.249	<0.001	0.245	0.207 - 0.283	<0.001
	Opening mouth	0.015	0.012 -0.019	<0.001	0.015	0.013 - 0.018	<0.001
	Time	-9.0×10^{-5}	-1.0×10^{-4} - -8.0×10^{-5}	<0.001	-9.0×10^{-5}	-2.0×10^{-4} - 5.0×10^{-5}	0.155
α_3	Intercept	0.205	0.202 - 0.208	<0.001	0.205	0.156 - 0.254	<0.001
	Opening mouth	−0.017	−0.006	<0.001	−0.017	−0.003	<0.001
	Time	2.0×10^{-5}	9.0×10^{-6} - 2.0×10^{-5}	<0.001	2.0×10^{-5}	-9.0×10^{-5}- 1.0×10^{-4}	0.68
β	Intercept	0.314	0.308 - 0.320	<0.001	0.314	0.145 - 0.483	0.007
	Opening mouth	−0.024	−0.01	<0.001	−0.024	−0.004	<0.001
	Time	-2.0×10^{-5}	-4.0×10^{-5} - -9.0×10^{-6}	0.001	-2.0×10^{-5}	-2.0×10^{-4} - 1.0×10^{-4}	0.648

For opening mouth, closing mouth was used as reference. The coefficients of brain waves were statistically significant.

The results described above were depended on time series analysis. By the time series analysis, factors that affected on the transitions could not be statistically evaluated. Therefore, multilevel modeling was applied to calculate the effect of opening mouth for the transitions of brain waves. The results were shown in Table 2. For fixed effect models, coefficients of opening mouth of all of the brain waves were statistically significant. Then, random effect models were constructed by using time for random variable. The coefficients of opening mouth of all of the brain waves were also statistically significant.

Discussion

In this study, opening mouth clearly affected the brain waves. Dental anxiety and phobia are a frequently encountered problem in dental offices. These patients need to be identified and their concerns should be addressed. The etiologies of dental anxiety and phobia are consisted of multiple factors: previous negative traumatic experience or lack of understanding, and the vulnerable position of lying back in a dental chair etc. [1-6]. Stress during the dental treatment can be the trigger of dental anxiety or phobia, the stress under the dental treatment should be minimized. The objective assessment of stress has been developed. Blood pressure, pulse rate, pulse oximetry, finger temperature, and galvanic skin response can greatly enhance the diagnosis and enable categorization of these individuals as mildly, moderately, or highly anxious or dental phobic [1,21]. These devices take advantage of measuring the subtle changes vital reactions. Among them, galvanic skin response has been validated as an accurate method in measuring dental anxiety. In addition to these devices, Electroencephalography (EEG) are also available to measure the stress [22-24]. The advantage of EEG is that it can measure and monitor real time changes of the stress during dental treatment. And it can measure simultaneously stress and relaxation.

As shown in Fig. 1, α_1 and α_2 waves, which denote the relaxation status, were decrease in accordance with the laps of time when compared with the baseline. However, ranges of changes of these waves were small. For θ wave, which also denote the relax conditions, changes of opening mouth conditions were almost stable. In contrast, changes of closing mouth condition were clearly increased. These results indicated that sitting on dental chair in horizontal situation were not so stressful. Previous report had shown that the vulnerable position of lying back in a dental chair was the etiology of dental anxiety [3]. The difference of the results may derive from personality traits. For α_3 and β wave, even the ranges of changes were small, the difference between opening mouth conditions and closing mouth conditions were clear. In addition to these graphical analyses, these results were confirmed by statistical modeling. All of the coefficients were statistically significant. Therefore, contentious opening mouth may be stressful, however, the amount of stress may be small.

Electroencephalography (EEG) may be useful tool to measure the stress during dental treatment. Stress by sitting on dental chair in horizontal situation was depended on personality traits. Contentious opening mouth may be stressful; however, the amount of stress may be small. The changes can be seen within 18 min. Prolonged chair time for the dental treatment may not be recommended.

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Conflict of Interest
The authors declare no conflict of interest exists.

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