ORIGINAL ARTICLE

Characteristics of facial muscle activity during voluntary facial expressions: Imaging analysis of facial expressions based on myogenic potential data

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Abstract

Purpose: Facial expressions are formed by the coordination of facial muscles and reflect changes in emotion. Nurses observe facial expressions as way of understanding patients. This study conducted basic research using facial myogenic potential topography to visually determine changes in the location and strength of facial muscle activity associated with voluntary facial expression to examine relationships with facial expressions.

Methods: Participants comprised 18 healthy adults (6 men, 12 women; mean age, 24.3 ± 4.3 years). Facial myogenic potentials were measured from 19 electrodes arranged concentrically on the face, and topographic analysis was conducted. Using potential changes and topograms, the muscle activity associated with nonvoluntary facial expression and voluntary facial expressions of happiness and disgust were classified according to the characteristics of expressions. To classify homogeneous groups among the reaction of disgust, hierarchical cluster analysis was utilized.

Results: One characteristic of the facial expression of happiness was activity in areas including the greater zygomatic muscle. With the facial expression of disgust, characteristic changes were seen in areas including the corrugator supercilii. Cluster analysis of the expression of disgust showed four homogeneous subgroups.

Conclusion: With facial myogenic potential topography, facial expressions can be evaluated objectively without being influenced by face shape or countenance. Color changes in topograms showed subtle changes in expressions that could not be supplemented with statistical processing alone, and these were useful in identifying individuality. Topography is thus expected to be utilized to supplement basic knowledge of facial expressions for a better understanding of patients.

KEYWORDS
cluster analysis, electromyogram, facial expression, observation, topography

1 | INTRODUCTION

Facial expressions are formed by the coordinated actions of facial muscles and can reflect changes in emotion. A change in facial expression offers a nonverbal mode of communication established between the individual exhibiting the facial expression and those visually perceiving the expression.[1,2] Nurses observe facial expressions as way to deepen their understanding of patients. Florence Nightingale wrote of "throwing yourself into others' feelings," and "the very alphabet of a nursing is to be able to interpret every change which comes over a patient's countenance, without causing him the exertion of saying what he feels" in NOTES ON NURSING.[3]

Clinically, nurses not only assess the status of the patient based on basic facial expressions, but also need to assess complex changes exhibited through the face as a whole. In diseases associated with organic neuromuscular degeneration, such as intractable neurological disease or paralysis, weakness or partial deficits in facial expressions arise.[4] Because the disease course in a patient and its treatment may influence the emotions of the patient, attention must be paid to the extent of facial expressions and changes in them.[5,6] Moreover, in diseases associated with abnormal expressions or behaviors, perception of facial emotion is altered, and cognitive intervention may therefore be necessary in some cases.[7] Consequently, a multifaceted understanding that helps the subjective assessment of the observer is needed.

Observation of facial expressions in nursing has been based on assessments based on intuition and the experiences that individual nurses have acquired in the course of their lives, and has therefore relied on subjective verbal representations from nurses. However, in the field of nursing, little education or basic research on observation of facial expressions by nurses to subjectively judge expressions. Recently, resulting from research to objectively evaluate facial expressions, tools for analyzing the degree of pain in painful dementia patients have been introduced using direct analysis of facial images by machine learning.[8,9] Objective evaluation methods developed in a wide field should therefore be applied, to provide maximal utility for fundamental research into the observation of facial expressions.

Facial electromyography (fEMG) enables measurement of the myogenic potentials of typical facial muscles, such as the greater zygomatic and corrugator muscles. Previous studies have found decreased corrugator muscle activity and increased greater zygomatic muscle activity with positive emotional stimulation, and increased corrugator muscle activity and decreased greater zygomatic muscle activity with negative emotional stimulation.[10–12] Ohyama and Kobata used fEMG topography derived from neuromuscular unit potentials from 16 electrodes to grade facial movement loss and diagnose paralysis in patients with facial nerve palsy.[13,14] The focus to date has been on diagnosis and treatment based on methods such as assessing the countenances associated with various diseases, and we think it is possible to determine individual facial expressions based on facial muscle activity. Applying these techniques to nursing seems likely to allow objective assessment of changes in muscle activity associated with changes in facial expression, increasing the objectivity with which nurses understand their patients.

In recent years, myogenic potential topography (MPT) has emerged as a method of visually determining myogenic potential, and this approach is being used to physiologically assess muscle activity. With this method, the location and strength of myogenic potential activity can be determined based on color gradations, and muscle contraction force can be analyzed according to the firing frequency of motor neurons to a frequency band.[15,16] The objective of this study was to use facial MPT (fMPT) to visually determine changes in the location and strength of facial muscle activity associated with voluntary facial expressions of basic emotions and to examine relationships between those changes and facial expressions.

2 | METHODS

2.1 | Participants

Participants were 18 healthy adults (6 males, 12 females; mean age, 24.3 ± 4.5 years) who volunteered to participate. Exclusion criteria were as follows: regular drug use; or neurological or other underlying disorders. All participants were instructed to refrain from drug use before the experiment.
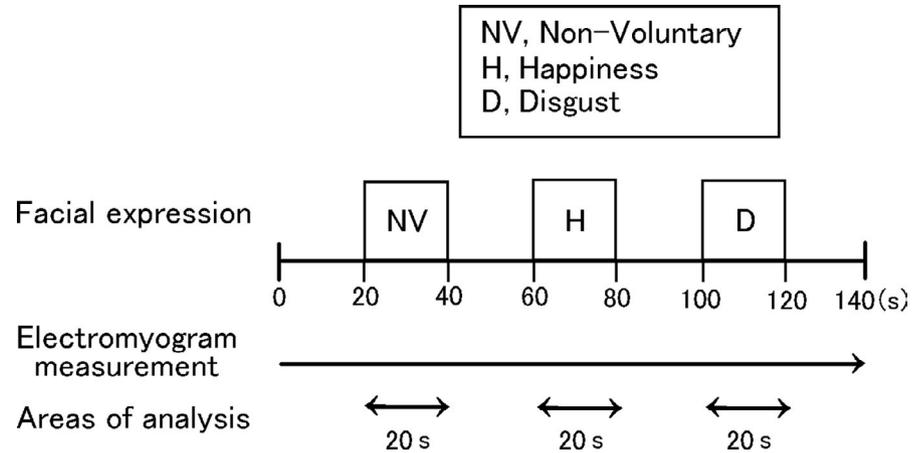
2.2 | Ethical consideration

This study was approved by the ethics committee of the Faculty of Medicine at the University of Miyazaki. Participants were briefed on the details of the experiment and provided written consent before enrolment in the study. Participation in the study was voluntary, and subjects were informed they could refuse to participate or rescind consent to participate at any time. Protecting the confidentiality of the subjects was given thorough consideration when handling study data.
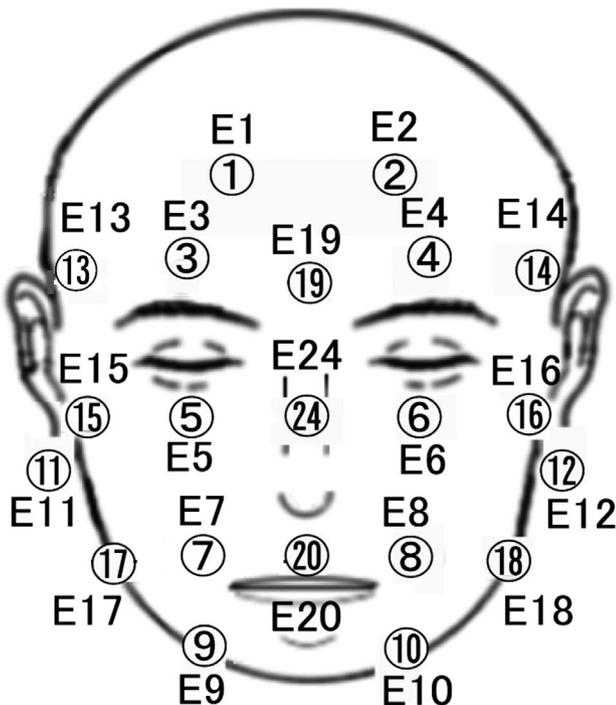
2.3 | Voluntary facial expressions

In infancy, emotions and facial expressions are generally expressed without inhibition. With the gradual effects of factors such as the social environment and interpersonal relations, inhibition of facial expressions is known to occur.[17] In a convalescent environment, changes in emotions may occur during the course of disease or its treatment. Nurses thus need to consider factors such as concealed facial expressions and emotions. To examine observations of facial expressions in the clinical setting, this study attempted to elucidate the characteristics of forced smiles and expressions of disgust by examining nonvoluntary and voluntary facial expressions of happiness and disgust. Subjects were given the following instructions when expressing the three facial expressions: nonvoluntary facial expression, "Do not make any facial expression, just look forward and relax"; voluntary facial expression of happiness, "Please smile"; and voluntary facial expression of disgust: "Please disgusting face."

FIGURE 1 Experiment procedure: electromyogram recording. The arrows indicate the analysis scope. Nonvoluntary facial expression, *NV*; voluntary facial expression of happiness, *H*; voluntary facial expression of disgust, *D*. Facial expressions were expressed for 20 s, with a 20-s interval between expressions

NV, Non-Voluntary
H, Happiness
D, Disgust

Facial expression | NV | H | D

0 20 40 60 80 100 120 140 (s)

Electromyogram measurement

Areas of analysis 20 s 20 s 20 s

(A)

(B)

Electrode code	Placement
E1	Position in right mid-frontal region perpendicular to right angulus oculi
E2	Position in left mid-frontal region perpendicular to left angulus oculi
E3	Middle of right eyebrow
E4	Middle of left eyebrow
E5	Middle of right infrapalpebral sulcus
E6	Middle of left infrapalpebral sulcus
E7	Position below E5 perpendicular to nasolabial fold
E8	Position below E6 perpendicular to nasolabial fold
E9	Middle of right border of mentalis
E10	Middle of left border of mentalis
E11	Right earlobe
E12	Left earlobe
E13	Right temple
E14	Left temple
E15	Top of right cheek bone
E16	Top of left cheek bone
E17	Hollow of right cheek
E18	Hollow of left cheek
E19	Glabella
E20	Nasolabial fold (or midway between E24 and nasion)
E24	Bridge of the nose
EZ	End of the nose

FIGURE 2 A, Mimetic diagram showing the arrangement of electrodes. Nos. 1 to 20 and 24 are electrode numbers for the EEG-9100. Electrodes arranged on the face are indicated by the letter E added before the number. B, Electrode codes and placement. EZ is not shown in Figure 2A

2.4 | Experimental environment

The experiment was conducted in a shielded room from which external electric waves and sound were blocked. Room temperature and relative humidity were controlled to 24°C and 55%-65%, respectively.

2.5 | Experimental protocol

Each subject was seated in a chair in the laboratory, and electrodes were arranged on the face. The investigators then instructed the participant to maintain nonvoluntary and voluntary facial expressions of happiness and disgust, in that order, for 20 seconds each.

TABLE 1 Medians with interquartile ranges of myogenic potentials for each electrode and comparison by facial expression

	Nonvoluntary			Happiness			Disgust (μVP)			P-value[a]		
	Median	[25%,	75%]	Median	[25%,	75%]	Median	[25%,	75%]	Happiness vs non	Disgust vs non	Happiness vs disgust
E1	6.3	2.9	13.2	12.3	6.5	17.2	10.8	4.3	18.0			
E2	5.7	2.5	12.3	11.1	4.8	17.9	6.5	4.2	11.6	0.039		0.043
E3	4.2	2.6	11.5	20.6	9.1	32.5	49.9	24.0	94.9	0.001	0.001	0.004
E4	5.1	2.4	12.0	13.8	9.0	21.1	54.7	35.6	115.4	0.003	<0.001	0.001
E5	2.2	1.6	4.6	58.5	24.2	122.5	5.8	4.2	9.5	<0.001	0.001	0.005
E6	2.6	1.4	6.3	62.5	24.3	176.3	5.6	3.1	8.6	<0.001	0.031	0.014
E7	2.8	1.1	4.7	111.9	59.9	308.3	4.4	2.6	12.7	<0.001		0.006
E8	3.0	1.3	11.3	108.8	67.2	185.0	5.5	3.4	11.7	<0.001		0.002
E9	5.7	3.1	11.1	252.5	55.7	603.8	9.8	4.9	25.3	<0.001	0.018	0.004
E10	5.4	2.1	12.3	172.3	60.5	508.1	7.5	4.8	30.3	<0.001	0.031	0.002
E13	2.7	1.4	4.3	23.9	11.6	36.7	7.3	3.7	16.5	<0.001	0.001	0.006
E14	2.0	1.6	4.3	21.0	8.6	33.4	6.9	3.5	17.9	<0.001	0.004	0.016
E15	1.9	1.3	3.2	165.1	44.0	516.2	4.7	2.8	7.2	<0.001	0.005	0.002
E16	1.9	1.0	5.3	132.9	56.8	577.2	5.2	2.6	9.1	<0.001		0.003
E17	2.2	1.1	4.2	399.0	86.9	565.0	5.7	2.4	12.8	<0.001		<0.001
E18	3.5	1.3	5.0	268.8	125.3	469.2	4.4	2.7	10.9	<0.001		<0.001
E19	2.8	1.7	4.3	10.0	4.4	19.5	21.3	12.4	46.8	<0.001	<0.001	0.008
E20	2.4	1.5	8.5	117.6	27.1	335.6	7.2	3.8	9.8	<0.001		0.011
E24	1.8	1.3	3.0	24.6	6.1	73.3	10.0	2.9	16.6	<0.001	0.001	

[a]Wilcoxon's signed-rank test.

An interval of 20 seconds was inserted between each of nonvoluntary facial expression, voluntary facial expression of happiness, and voluntary facial expression of disgust. Electromyographic measurements were performed continuously from the start of the experiment to completion. Protocols for instructions on facial expression and electromyographic measurements, and the scope of analysis are indicated in Figure 1.

2.6 | Electromyogram recordings and analysis

2.6.1 | Administration of fMPT recording electrodes and recording method

An EEG-9100 monitor (Nihon Kohden) was used to measure myogenic potentials related to facial muscle activity and create a topogram. We improved electrodes that fit easily onto the face. Electrodes were small Ag disks (diameter, 6 mm; thickness, 2 mm). Electrodes were placed on the skin of the face, avoiding the eyes and mouth. Inter-electrode distance was carefully monitored to ensure homogeneity of the electric field (Figure 2A). The recording electrodes were numbered E1 to E20 and E24. Electrode placements are listed in Figure 2B. The recording electrodes were monopolar leads in electrodes E1 to E10 and E13 to E20.

Myogenic potential data are displayed on a monitor with the following settings: vertical resolution, 20 µV/mm; horizontal resolution, 100 mm/s; and low-pass filter, 60 Hz.

2.6.2 | Statistical analysis

Myogenic potentials for each electrode by facial expression are reported as medians, with interquartile ranges, and these distributions are shown in box-and-whisker plots. Values of myogenic potentials for the three facial expressions were compared with each other using Wilcoxon's signed-rank test for each electrode.

To reduce the dimensionality of the 19 separate variables, and to identify important variables devoid of collinearities, principal component analysis (PCA) was utilized. Resulting factor scores were shown in scatter plots and used in subsequent cluster analyses. To classify homogeneous groups for the expression of disgust, hierarchical cluster analysis using a between-group linkage method with Euclidean distance was utilized.[18] Values of $P < 0.05$ were considered statistically significant. All statistical analyses were based on two-tailed probabilities. IBM SPSS Statistics for Windows software was used for statistical analyses.[19]

2.6.3 | Image analysis

EEG-9100 with analysis software (QP-220A; Nihon Kohden) has a multichannel analyzer and creates the myogenic potential topogram with 6-bit resolution. Analysis encompassed the period from the start of facial expressions to the completion of expression. Physiologically relevant changes to the electric potentials in the face are captured by frequency analysis of the myogenic potentials.
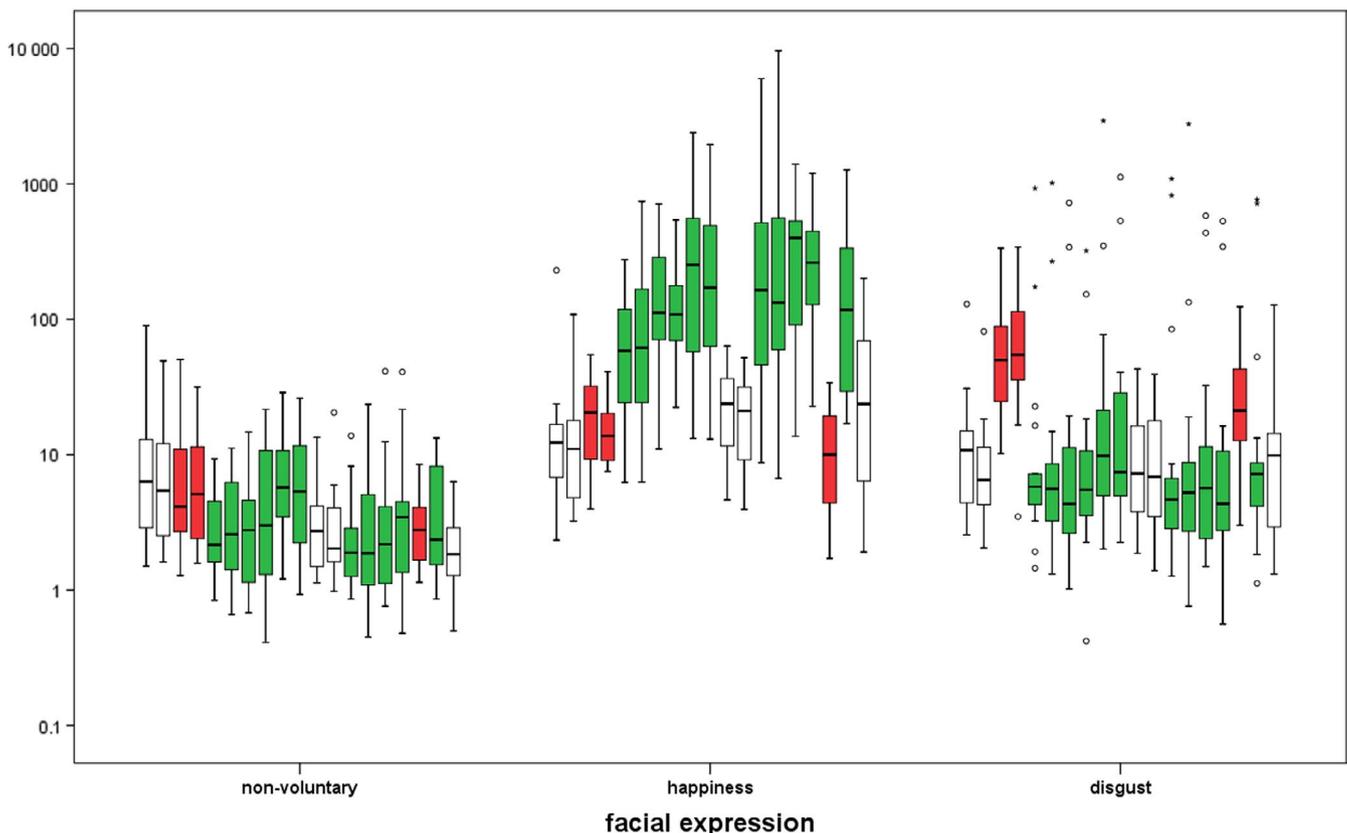

FIGURE 3 Box-and-whisker plot of myogenic potentials in each electrode by facial expression. Changes in myogenic potential are shown in order from the left: E1-E10, E13-E20, and E24. Green: E5-10, E15-18, E20; red: E03, E04, E19; white: the others

Myogenic potential data were analyzed using a fast Fourier transform (FFT) with the following settings to obtain the power spectrum. Data from approximately 200 ms before and after eye blinks or eye movements were deleted.

Maximum potential of the myogenic potential topograms was set at 200 μV^2 and subdivided into the following five bands: 1-10 Hz, 10-20 Hz, 20-30 Hz, 30-40 Hz, and 40-50 Hz.

3 | RESULTS

3.1 | Descriptive statistics, PCA, and cluster analysis

Table 1 and Figure 3 show the distribution of the myogenic potentials in each electrode by facial expression. High myogenic potentials were measured at locations E5-10, E15-18, and E20 during the voluntary facial expression of happiness, and these are shown in green. High myogenic potentials were measured at locations E3, E4, and E19 during the voluntary facial expression of disgust, and these are shown in red. No other locations showed much difference compared to other locations, and these are shown in white (Figure 3).

Principal component analysis demonstrated the existence of a three-factor structure that jointly accounted for 89% of the variation in the 19 original variables. The estimated factor loadings are shown in Table 2. The first principal component, "Factor 1," displayed a general trend in which quantities increased for increasing values of all 19 original variables. The second principal component, "Factor 2,"

was associated with E3, E4, and E19, as the electrodes showing disgust-specific myogenic potentials. The third principal component was associated with E1 and E2. Resulting factor scores are shown in Figure 4.

According to the scatter plot, the data for voluntary facial expression of happiness were clustered in a group. However, the data for voluntary facial expression of disgust were scattered, and cluster analysis using three factor scores was thus conducted. Four
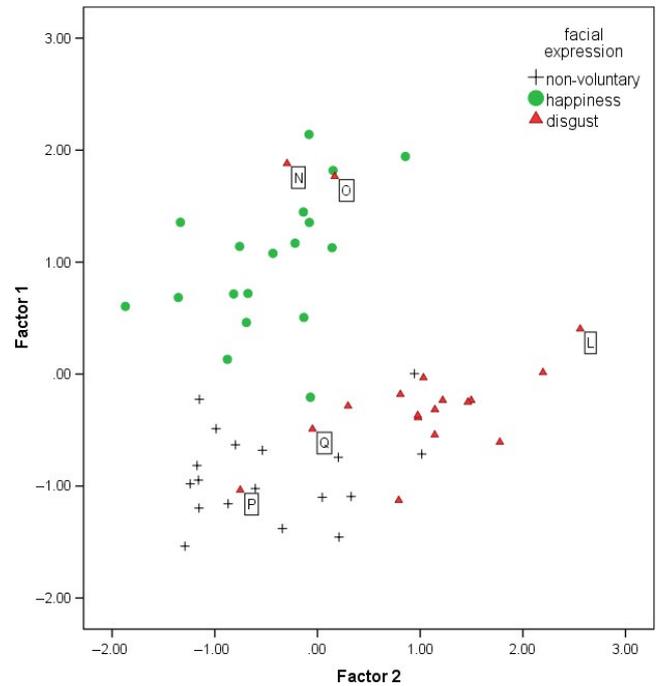

FIGURE 4 Scatter plot of factor scores 1 and 2 for the three facial expressions

TABLE 2 Estimated factor loadings onto the three factors in PCA

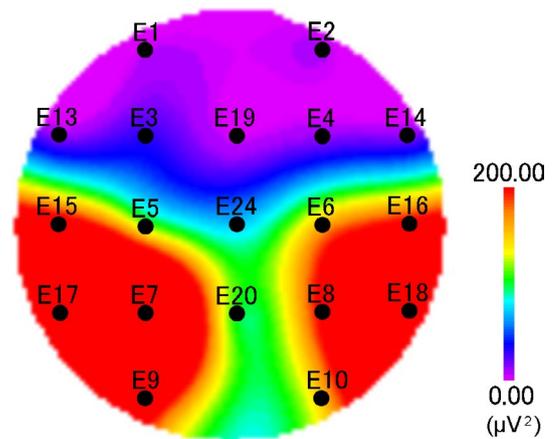|	Factors		
	1	2	3
E1	0.404	0.496	0.704
E2	0.510	0.437	0.660
E3	0.342	0.845	−0.213
E4	0.335	0.856	−0.213
E5	0.957	−0.076	−0.054
E6	0.951	−0.132	−0.030
E7	0.937	−0.208	0.002
E8	0.910	−0.267	−0.024
E9	0.896	−0.203	0.021
E10	0.920	−0.214	−0.001
E13	0.863	0.197	−0.084
E14	0.890	0.221	−0.105
E15	0.955	−0.096	0.057
E16	0.933	−0.193	−0.038
E17	0.920	−0.234	−0.008
E18	0.925	−0.303	0.038
E19	0.461	0.736	−0.293
E20	0.946	−0.107	−0.030
E24	0.873	0.203	−0.129

FIGURE 5 Relationship between the topogram and electrode arrangement. The bar on the right indicates electrode power with colors. The upper base is 200 μV^2 (red) and the lower base 0 μV^2 (purple). In this example, a range from red to yellow is seen near E5, E6, E7, E8, E9, E10, E15, E16, E17, and E18, indicating specific potential activity

homogeneous subgroups were identified. The first cluster, labeled "strong general types," comprised L. The second cluster, labeled "no change type," comprised P and Q. The third cluster, labeled the "lower facial type," comprised N and O. The others, labeled "general types," comprised A to K, M, and R.

3.2 | Topograms in fMPT

An example of a topogram and the arrangement of electrodes are shown in Figure 5. Topograms showed clear changes in the range of 30-40 Hz when the upper limit was set at 200 μV^2. Topograms were created for all participants, with low myogenic potential shown from purple to blue, moderate myogenic potential shown in green, and high myogenic potential shown from yellow to red.

3.2.1 | Myogenic potential changes with nonvoluntary facial expression

Figure 6 is a topogram obtained when the instructions were for non-voluntary facial expressions. For all subjects, the color of the entire
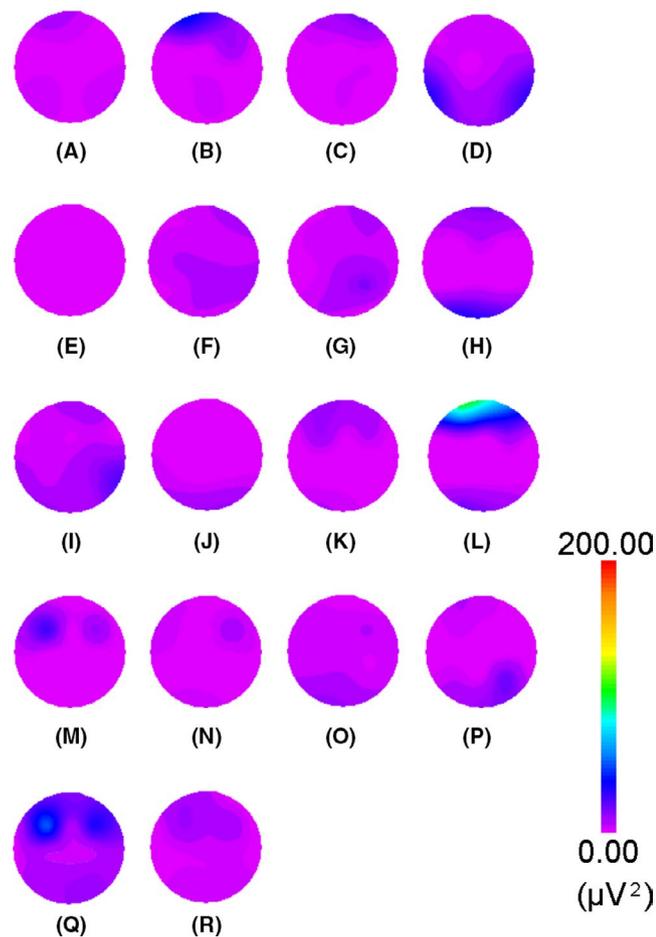
topogram was purple or blue, indicating no changes in potential (Figure 6).

3.2.2 | Myogenic potential changes with voluntary facial expression of happiness

Figure 7 is a topogram obtained when the instructions were for a voluntary facial expression of happiness. Changes in high potentials were observed in 14 subjects (A, C, D, F, H, I, J, K, L, M, N, O, P, and Q), indicated by a change in color to red near E5, E6, E7, E8, E9, E10, E15, E16, E17, E18, and E20. No high potential changes were seen in 4 subjects (B, E, G, and R), although a change to yellow or green was seen for E17 and E18 in some subjects (Figure 7).

3.2.3 | Myogenic potential changes with voluntary facial expression of disgust

Figure 8 is a topogram obtained when the instructions were for a voluntary facial expression of disgust. High potential changes were observed in 2 subjects (K and D), as indicated by an expansion of red
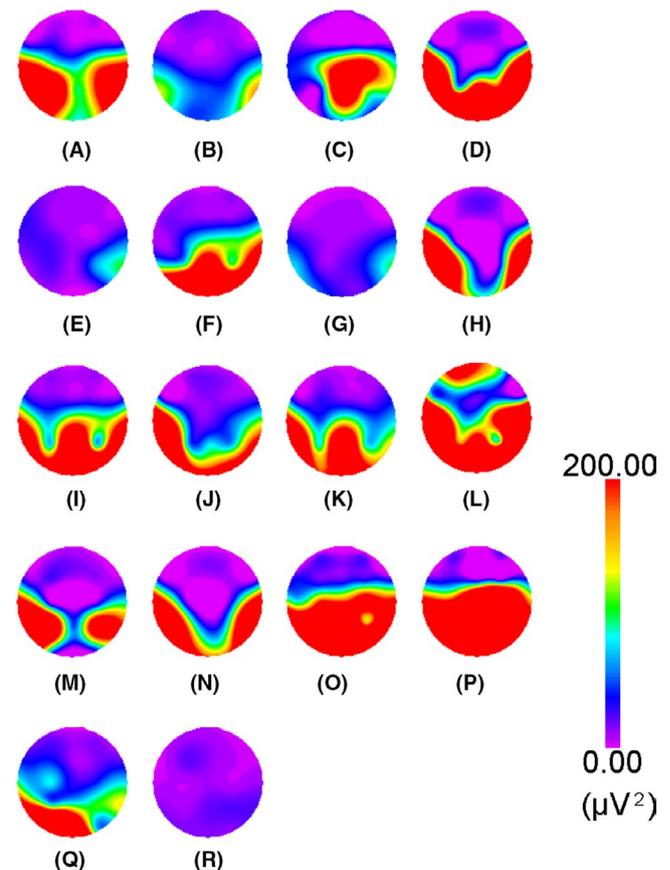

FIGURE 6 Myogenic potential topograms of participants A to R for nonvoluntary facial expression: topograms in the range of 30-40 Hz when the upper limit was set at 200 μV^2. A range from purple to bluish-purple is seen, indicating no specific changes

FIGURE 7 Myogenic potential topograms of participants A to R for the voluntary facial expression of happiness: topograms in the range of 30-40 Hz when the upper limit was set at 200 μV^2. Participants A, C, D, F, H, I, J, K, L, M, N, O, P, and Q, red spread from the bottom of the topogram. Low potential changes are seen in participants B, E, G, and R
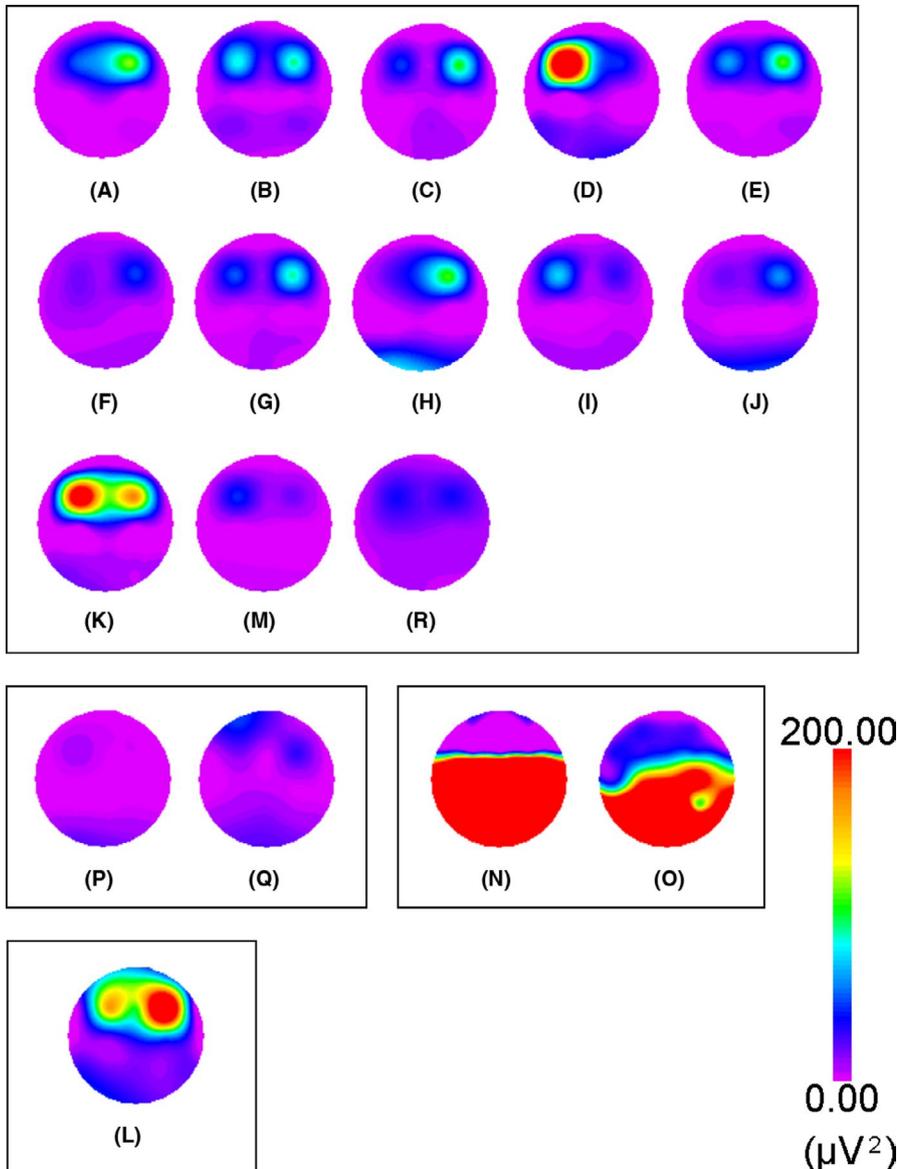
FIGURE 8 Myogenic potential topograms of participants A to R for the voluntary facial expression of disgust: topograms in the range of 30-40 Hz when the upper limit was set at 200 μV². In participants D and K, colors ranging from red to light blue expand centering on E3 and E4. In participants A, B, C, E, F, G, H, I, J, M, and R show changes of colors from light blue to green centering on E3 and E4. In participants N and O, red occupies most of the lower part of the topogram. Four groups are categorized based on cluster analysis with PCA. The same group is enclosed in a square. General types: A, B, C, D, E, F, G, H, I, J, K, M, and R, no change type: P and Q, lower facial type: N and O, strong general types: L

areas centering on E3, E4, and E19. No high potential changes were seen in 11 subjects (A, B, C, E, F, G, H, I, J, M, and R), while weak potentials indicated by colors of light blue to green were observed in E3, E4, and E19. These thirteen topograms were grouped to the same cluster by cluster analysis, as "general types." In the topogram of Subject L, not only E3, E4, and E19, but also E1 and E2 showed a high potential change, grouped as "strong general type." High potential changes were observed in 2 subjects (N and O), indicated by a change in color to red near E5, E6, E7, E8, E9, E10, E15, E16, E17, E18, and E20, grouped "lower facial type." Topograms in Subjects P and Q showed no change (No change type).

4 | DISCUSSION

4.1 | Statistical analysis

The distribution of myogenic potential showed the following characteristics. For happiness, increased myogenic potential was observed

in electrodes E5-10, E15-18, and E20 located in areas of the mouth and cheeks. For disgust, increased myogenic potential was seen in electrodes E03, E04, and E19 located in areas of the eyebrows and between the eyebrows.

After the data for 19 variables were grouped into three principal component scores (approximately 11% information loss), characteristic myogenic potential patterns were extracted using PCA. The first principal component, Factor 1, which had large factor loading associated with E5-E18, E20, and E24, contained information on happiness. The second principal component, Factor 2, which had a large factor loading associated with E3, E4, and E19, contained information on disgust.

4.2 | Image analysis of voluntary facial expressions based on myogenic potential data

In this study, facial muscle activity associated with voluntary facial expressions for the face as a whole was clearly determined from

topograms obtained under conditions of 30-40 Hz and 200 μV^2. The process of facial expression formation involves excitation of the motor cortex and contraction of the facial muscles via the facial nerves.[4] Because contractions of the facial muscles are accompanied by potential changes, they are reflected in topograms as color changes. In actual practice, color changes occur in localized areas in association with voluntary facial expressions, and the differences in color and the pattern in which colors expand are thought to indicate muscle contraction force, as reflected in changes such as increases and decreases in potential.

In the process of generating the topogram, frequencies of 1-50 Hz were divided into five bands. Eye blinks or eye movements had a large effect on frequency bands up to 5 Hz. An earlier fEMG study reported that high-pass filtering at 20 Hz was essential because of the strong effect of low-frequency artifacts such as motion potentials, eye movements, eye blinks, and activity of neighboring muscles, respiration, and swallowing on the EMG signal.[12] Although not mentioned in the Result2.6s section, in 1 to 20 Hz topograms, high potential changes in the region of the eyes were seen when subjects blinked. Except for waveform components <30 Hz, topograms generated with frequency bands ≤40 Hz were thought to reflect the extraction of pure voluntary facial muscle activity and to exclude artifacts such as noise other than facial muscle movement. In addition, fMPT methods are unrelated to facial shape and configuration, and so have the advantage of recording personal information while maintaining personal privacy.

4.3 | Characteristics of facial myogenic activity in voluntary facial expressions of happiness and disgust

With nonvoluntary facial expression, PCA suggested that no subjects showed specific potential changes (Figures 3 and 5, Tables 1 and 2). No color changes indicating high potential changes were seen in topograms of any subjects, suggesting a lack of individuality in nonvoluntary expression. In the absence of emotional, sensory, or other stimulation, no changes in facial expression were seen in most cases. Consequently, subjects showed no changes in stimulation associated with nonvoluntary facial expression, and this condition was therefore concluded to have shown the status with no activity of the facial muscles.

According to the findings of the statistical analysis, E5-10, E15-18, and E20 were shown to have high myogenic potential during voluntary facial expression of happiness. These locations included the greater zygomatic, lesser zygomatic, buccinator, risorius, and levator labii superioris muscles. An increase in zygomatic muscle activity has been reported when emotions are aroused by presenting pleasant images.[10-12] The characteristics of color changes in the topograms with the voluntary facial expression of happiness showed a tendency for expansion of specific changes from the left and right of the bottom semicircle of the topogram to the center. The topograms obtained in the present study showed the characteristics of muscle activity involved in forming a smile, such as elevation of the oral angle and cheeks. In addition, because muscles such as the

orbicularis oris and depressor labii inferioris were located near E9, E10, and E20, changes in these areas reflected movements such as pulling of the lower lip laterally and inferiorly and extending the lips to the side.

In the scatter plot of the PCA, clustering was observed with the myogenic potential. Facial expressions are said to be universal, going beyond cultures and ethnicities, with the smile being a facial expression indicative of happiness.[1] According to the results from this study, the facial expression of happiness showed marked changes from the middle to the lower edge of the topogram. Pronounced changes in the lower part of the face may be a feature of forced smiles. On the other hand, although low potential changes were seen in a few subjects (B, E, G, and R), facial expressions were found to be very weak.

According to the findings of the statistical analysis, E3, E4, and E19 were shown to have high myogenic potential during voluntary facial expression of disgust. In fEMG studies, activity of the corrugator muscle varies inversely with the emotional valence of stimuli by unpleasant pictures.[10-12] Although the present study examined an experimental method for voluntary facial expressions, a similar trend was seen. That is, activity common to areas that include the corrugator muscle was seen, suggesting that an expression of disgust may be able to be assessed by observing the area around the eyebrow.

In the present study, cluster analysis of changes in myogenic potentials with the voluntary facial expression of disgust identified four groups. In the topograms of most subjects (A, B, C, E, F, G, H, I, J, M, and R) as the general type, an expansion of specific changes was seen centering on areas near E3, E4, and E19. Moreover, cases were seen in which high potentials that encircled the orbicularis oculi muscle were present (subjects D and K). This was thought to be a case that reflected an expression that involved movements such as elevating the lower eyelid. In the strong general type (subject L), characteristic changes in E1 and E2 were seen and were considered to represent a general type. Muscles such as the frontalis, corrugator, and depressor supercilii were located in these colored areas. Possible facial expressions include creating wrinkles on the forehead, furrowing brows, and creating horizontal wrinkles between the eyes by drawing the eyebrows downward.

In lower facial type (subjects N and O), specific changes accounted for roughly the lower half of the topogram. Because muscles such as the buccinator, orbicularis oris, and mentalis were included in the lower part of the topogram, this was thought to reflect, in addition to the effects of the orbicularis oculi muscle, strong facial expression movements such as clamping the teeth together and elevating the lips and cheeks. The Facial Action Coding System involves observing facial expressions, focusing on facial movements visible to humans. This system is known as a method for assessing emotions by visually observing small changes in facial expression. Characteristic movements of the lips and cheeks have been found to be associated with facial expressions of disgust, and the results of the present study were suggested to reflect similar movements.[20-22]

In the change of myogenic potentials, facial expressions of disgust were also often weak, compared with the facial expression of

happiness (Table 1). Relationships with other people are known to affect facial expressions.[23,24] Moreover, reports have suggested that the mode of emotional expression in social settings varies according to the type of emotion.[25] The results of the present study suggested that facial expressions associated with unpleasant emotions tend to be readily inhibited, and we concluded that attention should be paid to such events in clinical settings.

In topograms, recorded potentials refer to the sum of potentials from different muscles near the electrode location and thus cannot be assigned to specific muscles. Consequently, a few subjects with the smiling facial expression and lower facial type showed high potential changes concentrated in the lower part of the topogram that were therefore highly similar. In the present study, the facial expression of happiness was the same as what we commonly refer to as a smile, as an expression of "happiness" and pleasant emotion. On the other hand, when simply instructed to make a facial expression of disgust, subjects recalled a number of negative emotions such as "sadness" or "anger." This may have been the cause of changes in expression being categorized into multiple groups by cluster analysis. Although not performed in this study, such similarities could potentially be evaluated in greater detail by matching findings with subjective expressions such as those obtained in interview surveys.

4.4 | Limitations of the study

In terms of limitations, this study was conducted under laboratory conditions. The degree of change in performance and sleepiness varies from actual working conditions, which greatly depend on differences in strain due to the nature of the work or the timing of busy work periods. Intervention studies in actual workplaces are required to clarify measures effective for reducing sleepiness and fatigue tailored to the conditions of specific professions and workplaces. A second possible limitation was that we did not use measurements of brain waves using polysomnography in this study, and the sleep stage of subjects during naps was not clearly determined. A third possible limitation was that the study focused on younger individuals, and no findings pertaining to middle-aged or elderly individuals were obtained.

Facial expressions have been found to be associated with developmental changes.[17] However, subjects in this study were in their 20s and 30s, placing them at a specific developmental stage that corresponds to early adulthood according to Erikson's stages of psychosocial development. Consequently, comparisons with other developmental stages are needed. In addition, these methods and results of analyses are useful as a basic approach to obtaining data on facial expression, helping medical staff to assess patients, rather than using experimental protocol directly in patients in clinical situations.

In this study, fMPT showed activity in a region that included the greater zygomatic muscle and at the inferior margin of the face as characteristic of voluntary facial expressions of happiness. With a voluntary facial expression of disgust, characteristic movements were observed in the region that included the corrugator muscle, and

all myogenic potential changes were classified into four groups by introducing cluster analysis with PCA. Moreover, facial expressions associated with unpleasant emotions were readily inhibited, indicating clear differences in the strength of individual expressions. Evaluating facial expressions by fMPT enables the location and strength of the variety of facial muscle activity that produces facial expressions to be determined visually. Furthermore, color changes in topograms showed subtle changes of expressions that cannot be supplemented with statistical processing alone, and they were useful in identifying individuality. This approach may thus contribute greatly as a scientific basis for nurses' observations and assessments of the facial expressions ascribed to the various emotions of patients.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTION

All listed authors meet the authorship criteria and are in agreement with the content of the manuscript.

DATA REPOSITORY

We cannot make the raw data open to the public. Disclosure of personal data was not planned in the research protocol approved by an Institutional Reviewer Board.

APPROVAL OF THE RESEARCH PROTOCOL BY AN INSTITUTIONAL REVIEWER BOARD

The protocol for this research project has been approved by a suitably constituted Ethics Committee of the institution and it conforms to the provisions of the Declaration of Helsinki. Committee of the Faculty of Medicine, University of Miyazaki. All informed consent was obtained from the subjects and/or guardians.

INFORMED CONSENT

Participants were briefed on the details of the experiment and provided written consent before enrollment in the study.

REGISTRY AND THE REGISTRATION NO. OF THE STUDY/TRIAL

Committee of the Faculty of Medicine, University of Miyazaki, Approval No. 1065.

ANIMAL STUDIES

N/A.

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