Facial Part Effects Analysis using Emotion-evoking Videos: Smile Expression

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***Abstract*-This study specifically examines the expressive process of "happiness" related facial expressions after giving a stress stimulus. In addition, it presents a quantitative analysis of expressive tempos and rhythms using mutual information. By acquiring image datasets of facial expressions under states of pleasant–unpleasant stimulus for 20 participants, we calculated the information in three region of interests (ROIs): ROI 1, the whole face and the upper face; ROI 2, the whole face and the lower face; and ROI 3 between the upper face and the lower face. Additionally, we tried to express complexity and ambiguity objectively during facial expressions because of human psychological states. Results clarified the possibility of estimating the impression of facial expressions from the magnitude relation and order relation of mutual information of each ROI. More than male participants, female participants were able to create facial expressions of "happiness" easily and intentionally, and were less susceptible to discrepancy expressions.**

Keywords–Psychological measures, stress; Intentional facial expression; Machine learning approaches; Behavior modeling

I. INTRODUCTION

Attractive smiles attract people and represent a symbol of happiness, soothing another person's mind. Smiles are therefore effective as a lubricant of human communication. According to a study [1] that analyzed geometric features with respect to charming smiles, the most attractive part of smiles in both men and women is perceived as the eye, followed by the mouth. In addition, facial parts associated with the eyes and mouth, such as the corners of the eyes and mouth, are reportedly more important as attractive factors of smiles. In attractive smiles, the existence of a golden ratio was observed in the aspect ratio of the expression rectangle. Furthermore, Yamada et al. [2] investigated the relevance between the whole and partial impression formed from facial parts and pointed out the following points. Eyes play an extremely important role in forming impressions of others. It is possible to some degree to illustrate the overall impression by adding and coupling the partial impression formed from each part. However, they suggest that individual differences exist in the information of the parts which are expected to be related to emphasis. Assessing male and female viewpoints of smile expressions specifically, women are said to tend to expose smiles more than men [3]. Moreover, smiles are natural for women: women are better at making smiles than men. Particularly, women have excellent skills to adjust positive emotional expressions. Such natural expressions can elicit positive effects on a person viewing the smile (recipient). Nevertheless, for the creation of intentional facial expressions, different facial muscles are said to move in conjunction with natural facial expressions [4]. Particularly examining the expressive process, the deformation degree, and operation timing of facial parts creating smiles are expected to vary slightly.

To clarify the relevance between facial expressions and psychological states to date, as a result of verifying the relevance between psychological stress and facial expressions using the framework of Facial Expression Spatial Charts (FESCs), we demonstrated that the degree of stress accumulation can be easily ascertained from facial expression types and expressive processes [5] [6]. Additionally, we proposed a framework of rhythms and

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tempos that specifically examines actions to repeat intentional facial expressions after giving a stress stimulus [7]. We define one rhythm as one tempo repeated several times. In addition, regarding one tempo as the period during which facial expressions transform from a neutral face (i.e., expressionless) to the next neutral face, we found that the variation in unpleasant stimulus became greater than that in pleasant stimulus, addressing the variation of the number of frames constituting one tempo. Furthermore, using Bayesian networks, we constructed a graphical model of the relation between these three facial expressions and psychological stress factors. Results show that facial expressions displaying the effects of psychological stress easily were "happiness" and "sadness." Additionally, we showed the possibilities that facial parts (such as the eyes and mouth) easily differed by facial expression type [8] [9] [10].

In this study, particularly addressing the expressive process of "happiness" facial expression after giving a pleasant–unpleasant stress stimulus by emotion-evoking videos, we strove objectively to express complexity and ambiguity through facial expression because of human psychological states, by quantitative analysis of expressive rhythms from the viewpoint of mutual information.

This paper is presented as follows. We review related work to clarify the position of this study in Section II. Section III presents a definition of a new framework of exposed rhythms and tempos for analyzing relations of psychological stress and facial expressions. Section IV describes a method to capture facial expression images, in addition to preprocessing, classification of facial expression patterns with self-organizing maps, integration of facial expression categories with fuzzy adaptive theory, and quantification of expressive rhythms using mutual information. We explain our originally developed facial expression datasets including stress measurements in Section V. In Section VI, based on the calculation results of mutual information in a time-series change of ELs for each facial region, we analyze the respective trends exhibited by men and women. Additionally, we discuss the effects of a pleasant–unpleasant stimulus which would give the expressive rhythm of facial expressions from the perspective of mutual information. Finally, we present conclusions and intentions for future work in Section VII.

II. Related Works

In spite of increasing or decreasing attractiveness of a "smile" with changes in expressive process, many conventional studies have examined the shape of a post-expression face. Case studies examining the expressive process are few [11]–[14]. Regarding impression formation of friendly and thoughtful smile expressions, Ishi et al. [11] described the following. A continuous video presentation, such as expression levels from a neutral face become the maximum, is the most effective. Hanibuchi et al. [12] proposed a smile training method that specifically examines facial expressions process. Through impression evaluation experiments, they demonstrated the validity of goal setting with the actor's perspective. In addition, particularly addressing a natural smiling face, Fujishiro et al. [13] [14] investigated how eye, cheek, and mouth movements contribute to the impression formation of natural smiles in the expressive process. Results revealed moderate correlation between the behavioral termination of the eyes and cheek and the impression formation of natural smiles. Nevertheless, the authors did not report the psychological state of the actor when viewing a "natural smile" and "forced smile," such as a disagreement expression or expression suppression. Particularly, they were unable to come up to address impression formation based on the timing structure of facial parts.

For a good impression on the face of a conversation partner, Kampe et al. [15] revealed that the good impression was more emphasized with matching of each other's eye-gaze. Using anthropomorphic agents, Kuroki et al. [16] indicated the following. The combination of eye-gaze and facial expressions affects emphases of impressions. The impressive transmission of friendship properties can be emphasized particularly. Moreover, by analyzing brain activities using functional magnetic resonance imaging (fMRI) as physiological indices, an activation is observed in the prefrontal cortex responsible for higher cognitive functions such as emotional processing, motivation, and reasoning. Furthermore, the same activation is observed in the amygdala associated with emotions and rewards. Therefore, the formation of a good impression shows that the prefrontal cortex and the amygdala play mutually important roles [17]. However, impression evaluation has not been done subjectively for overall impressions of the face. Moreover, dealing with impression formation based on the timing structure of facial parts has not been achieved.

III. Framework of Exposed Rhythms and Tempos

As an index for quantifying individual facial expression spaces, we proposed a framework of expression levels (ELs) [5]. The ELs include both features of the pleasure and arousal dimensions based on the arrangement of facial expressions on Russell's circumplex model [18]. Specifically, we extract the dynamics of topological changes of facial expressions of facial components such as the eyes, eyebrows, and mouth. Topological changes show the structure defining the connection form of the elements in the set. The ELs obtained in this study are sorted to categories according to their topological changes in intensity from expressions that are regarded as neutral facial expressions. As discussed above, the ELs in this study include features of both pleasure and arousal dimensions. In Russell's circumplex model, all emotions are constellated on a two-dimensional space: the pleasure dimension of pleasure–displeasure and arousal dimension of arousal–sleepiness. In

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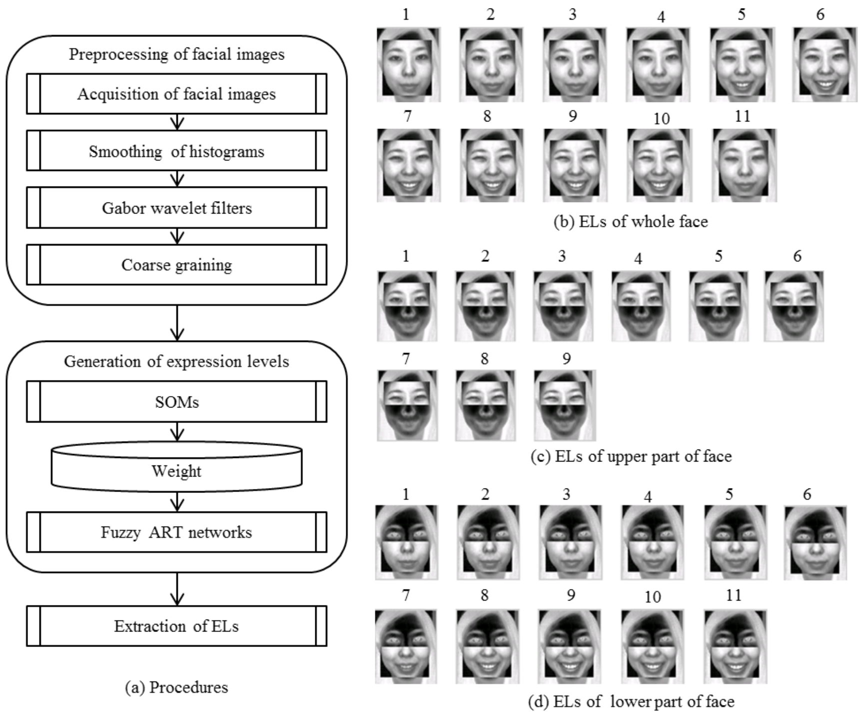

Figure 1. Overview of the procedures used for our proposed method.

the intentional facial expressions covered in this study, direct handling of the facial expressions for the influence of pleasure dimension is difficult. Therefore, as a method of measuring transitory stress response, we conduct an evaluation using the salivary amylase test. As a method of measuring the transitory stress response, we conduct an evaluation using the salivary amylase test during the task of watching emotion-evoking videos causing a pleasant–unpleasant state. Specifically examining the values of salivary amylase activity before and after watching videos, we can effectively perform stress measurements using salivary amylase tests to assess the stress state transiently. Consequently, we target the intentional facial expressions under pleasant and unpleasant stimulation states.

In this study, using temporal variation of ELs, we intend to visualize rhythms and tempos of facial expressions that humans create. We defined one rhythm as a tempo that is repeated several times. One tempo is the period during which facial expressions are transformed from a neutral state to the next neutral state. Facial expressions exhibited intentionally by humans form an individual space based on the dynamic diversity and static diversity of the human face. Facial expression dynamics can be regarded as "topological changes in time-sequential facial expression patterns that facial muscles create." Static diversity is individual diversity that is configured by the facial component position, size, and location, consisting of the eyes, nose, mouth, and ears. In contrast, dynamic diversity denotes that a human can move facial muscles to express internal emotions unconsciously and sequentially or to express emotions as a message. After organizing and visualizing topological changes of face patterns by ELs, we attempt to use the framework of rhythms and tempos with expressions to examine ambiguities and complexities of facial expressions attributable to a psychological state.

IV. PROPOSED METHOD

Facial expression processes differ among individuals. Therefore, adaptive learning mechanisms are necessary for modification according to individual characteristic features of facial expressions. In this study, our target is intentional facial expressions. We use self-organizing maps (SOMs) [19] to extract topological changes of facial expressions and for normalization with compression in the direction of the temporal axis. After classification by SOMs, facial images are integrated using Fuzzy ART [20], which is an adaptive learning algorithm with stability and plasticity. In fact, SOMs perform unsupervised classification input data into a mapping space that is defined preliminarily. In contrast, Fuzzy ART performs unsupervised classification at a constant granularity that is controlled by the vigilance parameter. Therefore, using SOMs and Fuzzy ART, time-series datasets showing changes over a long term are classified using a certain standard. Figure 1 presents an overview of the procedures used for our proposed method. In the following, we describe extraction of time-sequential

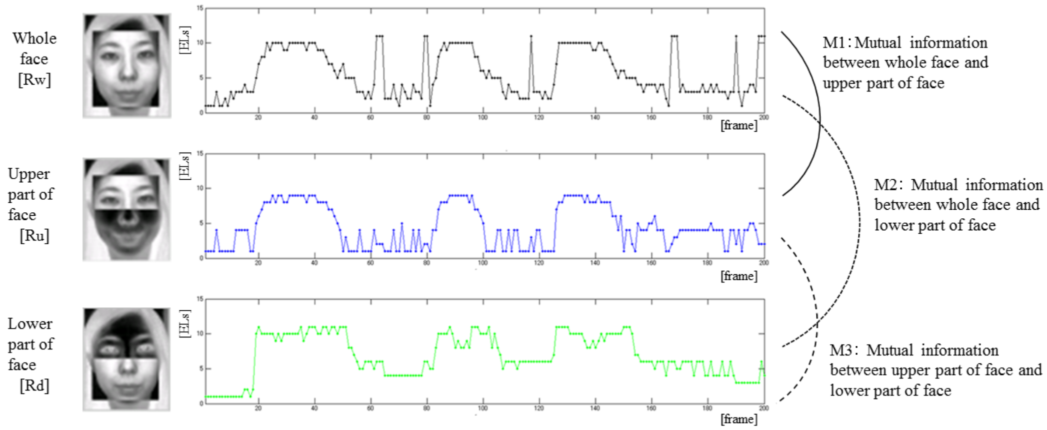

Figure 2. Each mutual information among time-series changes of facial parts.

changes of ELs, and also explain quantification of expressive tempos and rhythms by mutual information.

A. Acquisition of Time-series Variation of ELs

We set the region of interest (ROI) to 90 × 80 pixels, including the eyebrows, which all contribute to the impression of a whole face as facial feature components. With preprocessing, brightness values are normalized for time-series images of facial expressions. The influence of brightness values attributable to illumination conditions is thereby reduced. Moreover, smoothing the histogram is useful to adjust contrast and clarify the images. In addition, using the orientation selectivity of Gabor Wavelets filtering as a feature representation method, the facial parts characterizing the dynamics of facial expressions are emphasized, such as the eyes, eyebrows, mouth, and nose. By down-sampling (i.e., 10 × 10 pixels) time-series facial expressions converted with Gabor Wavelets filtering [21], the effects of a slight positional deviation when taking facial images were minimized. Then data size compression was conducted.

First, SOMs are used to learn the time-series images of facial expressions with down-sampling. The face images showing topological changes of facial expressions that are similar are classified into 15 mapping units of SOMs. Next, similar units (i.e., Euclidean distances of the weight vectors are close) among 15 mapping units of SOMs are integrated into the same category using Fuzzy ART. By sorting the facial expression categories integrated by Fuzzy ART from neutral facial expression to the maximum of facial expression, we obtain ELs labeled as expressive intensities of facial expressions quantitatively. The integrated category sorting procedure is based on the two-dimensional correlation coefficient of the average image of the facial expression images classified into each category. Finally, we conduct correspondence of ELs with each frame of the facial images to assess a time-series dataset of variation of ELs.

B. Quantification of Exposed Rhythms using Mutual Information

Mutual information [22] [23] can express changes between signals with the entanglement and synchrony. It can be regarded as an amount that represents linear and nonlinear dependence between the two time-series datasets. Moreover, it represents information flows and dynamically coupled rings between two signals. Mutual information between these two signals is zero if the two systems for observation target differ completely from independent ones. Applying this scheme to the facial expression process, it is possible to quantify the synchronicity and functional connectivity between facial parts. Figure 2 presents one example of time-series changes of ELs in the "Whole face," "Upper part of face," and "Lower part of face" obtained in Section 4.A. In this study, three ROIs listed below are calculated as the mutual information among facial parts in the expressive process. The time-series changes of ELs with respect to the "Whole face," "Upper part of face," and "Lower part of face" respectively represent $R_w = R_w(t)$, $R_u = R_u(t)$, and $R_d = R_d(t)$. Then, mutual information of each ROI is obtained as described below.

Mutual information between the "Whole face" and "Upper part of face" is $I(R_w; R_u)$:

$$I(R_w; R_u) = H(R_w) + H(R_u) - H(R_w, R_u) \quad (1)$$

Mutual information between the "Whole face" and "Lower part of face" is $I(R_w; R_d)$:

$$I(R_w; R_d) = H(R_w) + H(R_d) - H(R_w, R_d) \quad (2)$$

Mutual information between the "Upper part of face" and "Lower part of face" is $I(R_u; R_d)$:

$$I(R_u; R_d) = H(R_u) + H(R_d) - H(R_u, R_d) \quad (3)$$

In that equation, $H(R_w)$, $H(R_u)$, and $H(R_d)$ respectively represent the entropy of $R_w(t)$, $R_u(t)$, and $R_d(t)$. $H(R_w, R_u)$, $H(R_w, R_d)$, and $H(R_u, R_d)$ respectively denote the joint entropy of both.

V. DATASETS

For this study, we constructed an original and long-term dataset for the specific facial expressions of participants. Details of the experimental protocols are the following. One experiment comprises three steps: step 1 is conducted under a normal state; step 2 is done during viewing of a pleasant video; and step 3 is done during viewing of an unpleasant video. We gave participants the task of watching emotion-evoking videos, causing a pleasant–unpleasant state, and took stress measurements by salivary amylase tests to assess the stress state transiently. In addition, the watching time is about 3 min for each emotion-evoking video. We prepared unpleasant videos (i.e., implant surgery and cruel videos) and pleasant videos (i.e., comedy videos of three types). The subjective assessment of five stages was also conducted at watching videos. For all participants, we fully explained the experiment contents in advance, based on the research ethics policy of our university, and also obtained the consent of experiment participants in voluntary writing of participants. Moreover, from each, we received agreement to publish facial images as part of their experimental participation.

A. *Facial Expression Images*

Open datasets of facial expression images are open to the public through the internet from universities and research institutes. However, the specifications vary among datasets because of imaging with various conditions. As static facial images, the dataset presented by Ekman and Friesen [24] is a popular dataset comprising collected various facial expressions used for visual stimulation in psychological examinations of facial expression cognition. As dynamic facial images, the Cohn–Kanade dataset [25] and Ekman–Hager dataset [26] are used widely, especially in experimental applications. In recent years, the MMI Facial Expression Database presented by Pantic et al. [27] and the CK+ dataset [28] have become a widely used open dataset containing both static and dynamic facial images. These datasets contain a sufficient number of people as horizontal datasets. However, facial images are taken only once for each person. No dataset exists in which the same person has been traced over a long term. Therefore, we created original and longitudinal datasets that include collections of the specific facial expressions of the same person during a long term.

The six basic facial expressions proposed by Ekman et al. [24] are "happiness," "anger," "sadness," "disgust," "fear," and "surprise." Among those six basic facial expressions, we specifically examined the facial expression of "happiness," which is believed to be most likely to be exhibited spontaneously. As the target facial expression of "happiness" under pleasant and unpleasant stimulation states, we acquired the facial expressions of 20 people. As a stimulation method, we pre-selected emotion-evoking videos that elicit pleasant or unpleasant emotions, with all participants expressing facial expressions of "happiness" immediately after viewing them. Participants, all of whom were university students, were 10 men, whom we designated as A–J (J was 20 years old; B, G, H, and I were 21; A, E, and F were 22; C and D were 23) and 10 women whom we designated as K–T (K, M, O, and P were 20 years old; L, Q, R, S, and T were 21; N was 23). The imaging period was three weeks at one-week intervals for all participants. The imaging environment for facial expressions was an imaging space partitioned by a curtain in the corner of the room. We took frontal facial images with conditions including the head of the participant in each image. In advance, we instructed each participant to expose the facial expression with no head movement. Consequently, imaging the face region to fit within the scope was possible. However, with respect to extremely small changes caused by body motion, we used template-matching methods to trace the face region by setting the initial template to include facial parts. By consideration of the application deployment and ease of imaging in future studies, we used commercially available USB cameras (QcamOrbit; Logicool Inc. [29]). When taking images of each facial expression, the same expression was repeated three times based on the neutral facial expression during the image-taking period of 20 s. We had previously instructed all participants to express an emotion three times at their own timing according to a guideline for 20 s. One dataset consisted of 200 frames with the sampling rate of 10 frames per second.

B. *Stress Measurement Method*

Because types of psychological stress are regarded as affecting facial expressions, we assessed transient stress and chronic stress. Chronic stress is that which humans have on a daily basis, whereas transient stress is that caused by a temporary stimulus. To assess transient stress stimulus to the participants in this study, we applied the salivary amylase test, which measures transient stress reactions. As a biological reaction, salivary amylase activity is detected as a low value if one is in a pleasant state. In contrast, the value is high if one is in an unpleasant state. As stress reactions when subjected to external transient stimulus, Yamaguchi et al. [30] confirmed that salivary amylase activity is an effective means of stress evaluation. For this study, using emotion-evoking videos as an external transient stimulus, we used the salivary amylase test method to measure stress reactions immediately after participants watched the videos.

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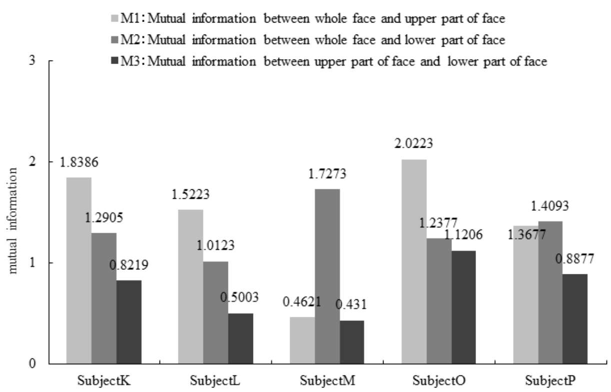
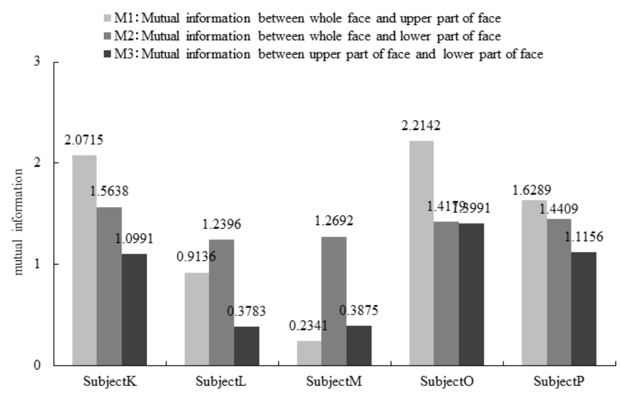
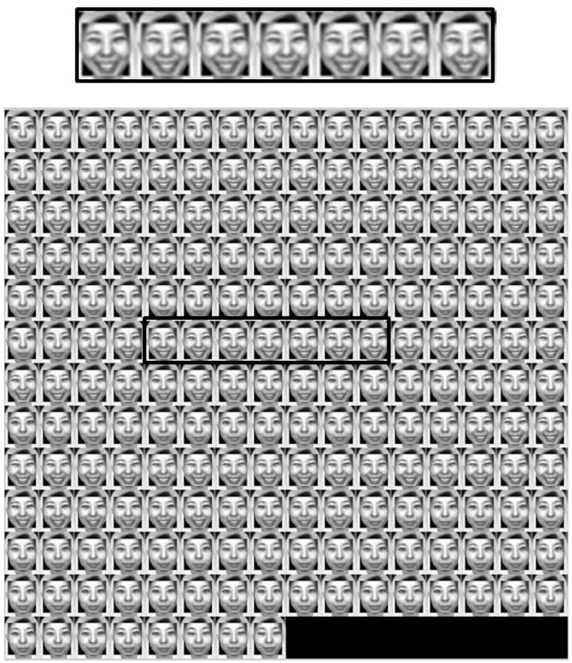


(a) Pleasant stimulus with emotion-evoking videos

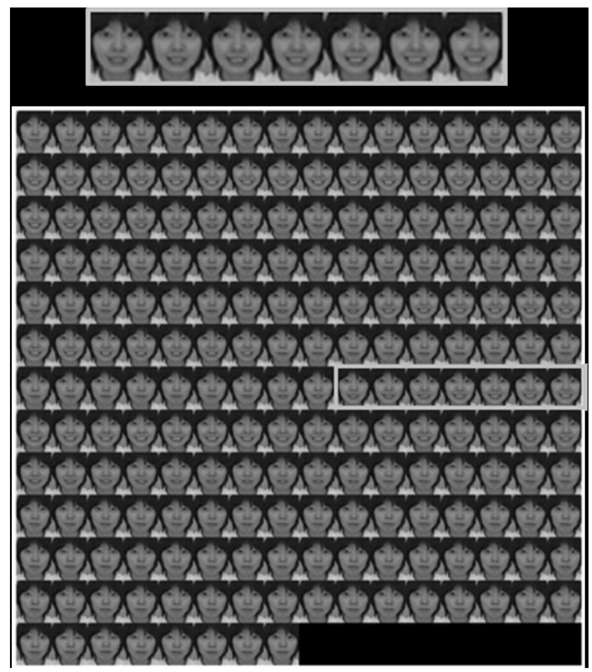


(b) Unpleasant stimulus with emotion-evoking videos

Figure 3. Mutual information results among each facial part for female.



(a) Subject K



(b) Subject M

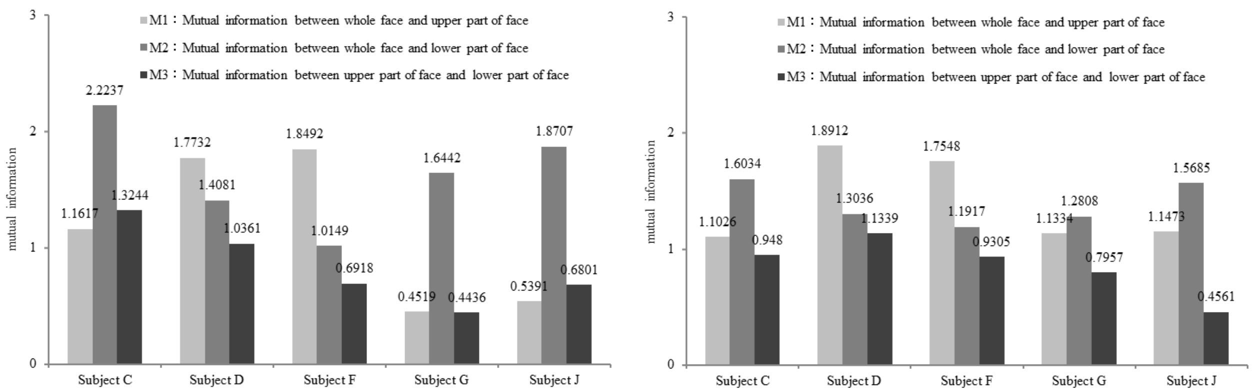
Figure 4. Time-series changes of smile facial expression with pleasant stimulus for specified subjects of female.

VI. EXPERIMENT

Based on the calculation result of mutual information in a time-series change of ELs for each facial region, we analyzed the respective male and female trends. Finally, we discussed the effects of a pleasant–unpleasant stimulus which would give the expressive rhythm of facial expressions from the perspective of mutual information.

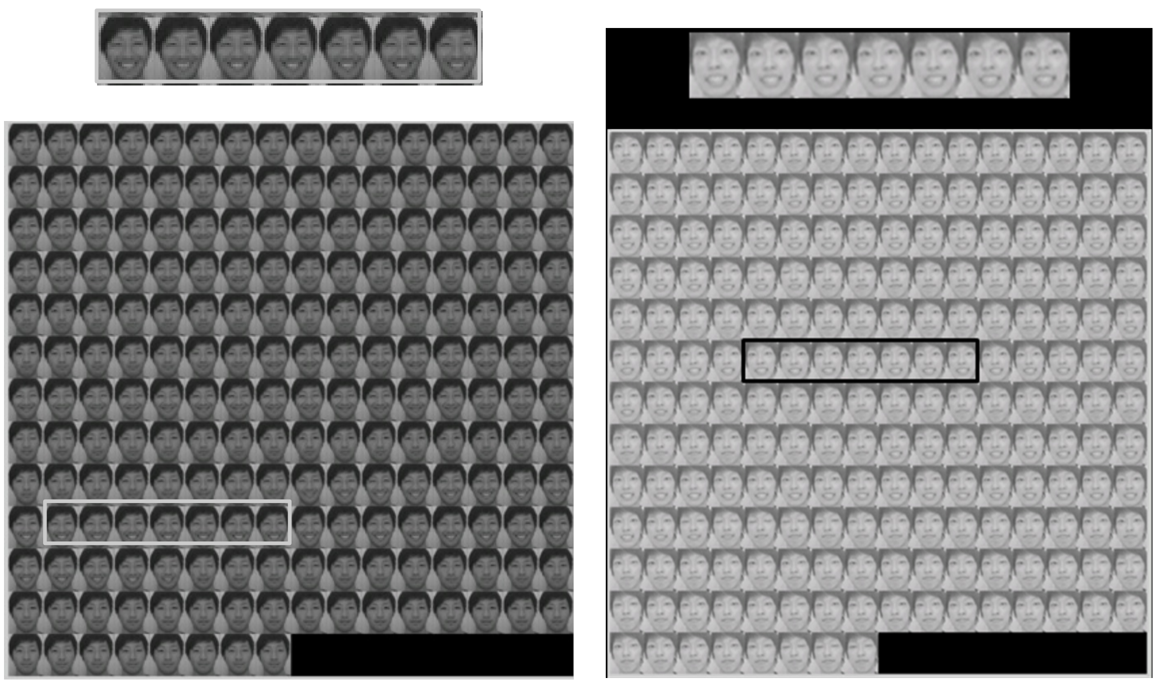
A. *Analysis of Female Participants*

Figure 3 depicts the calculation results of mutual information of five cases of female participants K, L, M, O, and P. The results show the mutual information of the time-series variation of ELs in each face region described in Section 4.B. Figure 3-(a) presents the calculation results obtained after giving a pleasant stimulus. Figure 3-(b) shows calculation results obtained after giving unpleasant stimulus. As an overall trend of female participants, we confirmed the following. For K, L, O, and P, the value of the mutual information is reduced to the order of "ROI 1: between the whole face and upper face," "ROI 2: between the whole face and lower face," and "ROI 3: between the upper face and lower face." The value of "ROI 2: between the whole face and lower face" is clearly larger than those for other ROIs in M. For K, M, and O, we were unable to recognize a marked change in the trend of mutual information by pleasant–unpleasant stimulus. However, for



(a) Pleasant stimulus with emotion-evoking videos (b) Unpleasant stimulus with emotion-evoking videos

Figure 5. Mutual information results among each facial part for male.



(a) Subject D (b) Subject J

Figure 6. Time-series changes of smile facial expression with pleasant stimulus for specified subjects of male.

L and P, we detected a specific change in the trend of the mutual information after giving pleasant–unpleasant stimulus. Particularly, the tendency of L is remarkable. In pleasant stimulus, the value of the mutual information is reduced to the order of "ROI 1: between the whole face and upper face," "ROI 2: between the whole face and lower face," and "ROI 3: between the upper face and lower face." Otherwise, "ROI 2: between the whole face and lower face" shows a large value for the unpleasant stimulus. In the unpleasant stimulus, the value of the mutual information is reduced to the order of "ROI 1: between the whole face and upper face," "ROI 2: between the whole face and lower face," and "ROI 3: between the upper face and lower face." However, in pleasant stimulus, the order relation of mutual information of P is reversed with L because the value of "ROI 1: between the whole face and upper face" is reduced.

Next, although the same trend is apparent for both pleasant and unpleasant stimuli, we compare K to M, for which the order relation of the mutual information in each facial region is markedly different. For K in both pleasant and unpleasant stimuli, the mutual information value of "ROI 1: between the whole face and upper face" is larger than "ROI 2: between the whole face and lower face." In addition, particularly addressing "ROI 3: between the upper face and lower face," the value of K is larger than M. However, for M with both pleasant and unpleasant stimuli, the mutual information value of "ROI 2: between the whole face and lower face" is markedly larger than others. Furthermore, particularly addressing "ROI 1: between the whole face and upper face" and "ROI 3: between the upper face and lower face," the values of M are clearly smaller than those of K. For K and M, thumbnail images representing the time-series changes of "happiness" in pleasant stimulus are shown in Figure 4. Figures 4-(a) and 4-(b), respectively present thumbnail images of K and M. The top of each figure shows the characteristic section during exposed facial expression of "happiness." Comparing the thumbnail images shown in Figure 4 to the calculation result of mutual information shown in Figure 3, for K exposed "happiness," we can recognize the change of facial expression in the upper face such as the brow and the area around the eyes, and in the lower face such as the mouth. Otherwise, for M, we can not observe any change of facial expression in the upper face. However, only the corner of mouth in the lower face has changed significantly. Actually, K has the characteristics which the upper part and lower face change both synchronized during facial expressions. Staying on the subjective impression of the experimenter, the result for "happiness" looks more natural facial expressions. In contrast, for M, only the corner of the mouth in the lower face has been changed. Therefore, we have an uncomfortable feeling about the unnatural facial expression of "happiness."

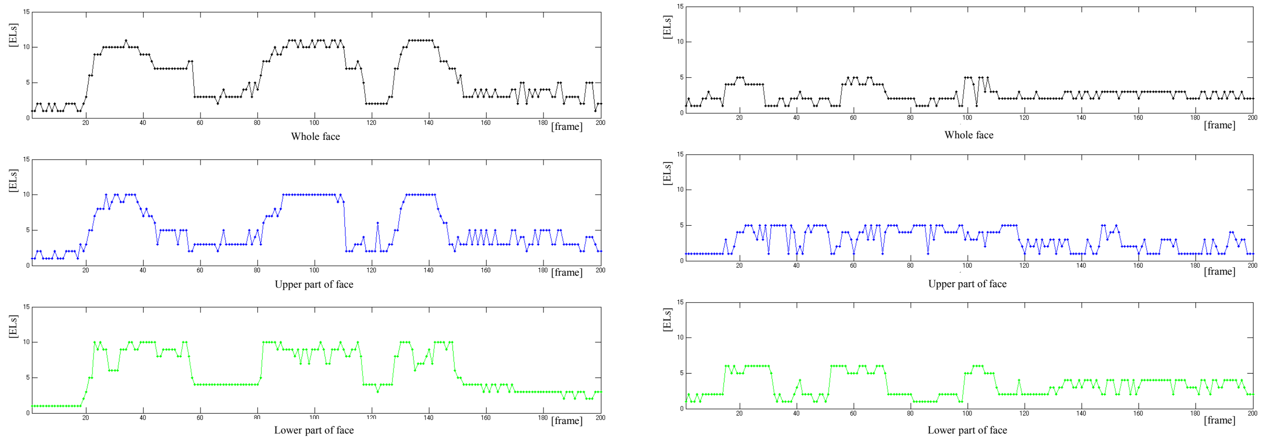
B. *Analysis of Male Participants*

Figure 5 presents calculation results of mutual information of five cases of male participants. Figure 5-(a) presents the calculation results after giving pleasant stimulus. Figure 5-(b) shows the calculation results after giving unpleasant stimulus. As an overall trend of male participants, we confirmed the following. For D and F, the value of the mutual information is reduced to the order of "ROI 1: between the whole face and upper face," "ROI 2: between the whole face and lower face," and "ROI 3: between the upper face and lower face." The value of "ROI 2: between the whole face and lower face" is markedly larger than those of other ROIs in C, G, and J. For male participants C, D, F, G and J, we were unable to recognize a marked change in the trend of mutual information by pleasant–unpleasant stimulus.

Next, regarding male participants, we compare D to J, for whom the order relation of the mutual information in each facial region is significantly different. For D in both pleasant and unpleasant stimuli, the mutual information value of "ROI 1: between the whole face and upper face" is larger than "ROI 2: between the whole face and lower face." In addition, particularly addressing "ROI 3: between the upper face and lower face," the value of D is larger than that of J. However, for J in both pleasant and unpleasant stimulus, the mutual information value of "ROI 2: between the whole face and lower face" is markedly larger than others. In addition, particularly addressing "ROI 1: between the whole face and upper face" and "ROI 3: between the upper face and lower face," the values of J are clearly smaller than those of D. For D and J, the thumbnail images representing the time-series changes of "happiness" in pleasant stimulus are portrayed in Figure 6. Figures 6-(a) and 6-(b) respectively present thumbnail images of D and J. The top of each figure shows the characteristic section during exposed facial expression of "happiness." Comparing the thumbnail images shown in Figure 6 to the calculation result of mutual information shown in Figure 5, for D exposed "happiness," we can recognize the change of facial expression in the upper face such as the brow and around the eyes, and in the lower face such as mouth. Otherwise, for J, no change of facial expression can be observed in the upper face. Only the corner of the mouth in the lower face has changed substantially. Actually, D has characteristics by which the upper part and lower face change at the same time during facial expressions. Therefore, the exposing result of "happiness" looks more natural facial expressions. In contrast, for J, only the corner of the mouth in the lower face has been changed. Therefore, we have an uncomfortable feeling about the unnatural facial expression of "happiness." These results underscore a common tendency between male and female participants and can be anticipated as a new index for quantification of the impression during facial expressions based on the mutual information of the time-series change of each face region.

C. *Effects of Pleasant–unpleasant Stimulus on Mutual Information*

The discrepancy expression in facial expressions means to expose the emotions that do not match one’s own feelings when experiencing certain emotions, such as having a smile, even though one might be in a sad mood. In previous studies, being positive emotional expressions during negative emotional experiences has been shown to engender the following: an amplification of actor’s sympathetic nerve activities [31], an increase of subjective emotional experiences, and some memory loss [32]. The discrepancy expression can easily take cognitive loads for expressive person. Additionally, it can potentially give bad effects to the mental health of actors. Furthermore, the expressive suppression in facial expressions indicates an emotional suppression by facial expressions when experiencing a certain emotion, such as to stifle crying when in a sad mood. Expressive suppression is reportedly associated with social support, closeness with others, and reduction in social satisfaction [33]. In comparison to men, women are more skilled at making smiles and excellent adjustments of positive emotional expressions. Moreover, women show similar effects such as natural expressions to recipients [3].



(a) Subject K (b) Subject M

Figure 7. Comparison of time-series changes of ELs with unpleasant stimulus.

Exposing facial expressions related to "happiness" after viewing an unpleasant video is equivalent to a discrepancy expression. In contrast, exposing the facial expression of "happiness" after viewing a pleasant video is a matching expression. For female participants K and M, such order of mutual information was markedly different; Figure 7 presents their facial expression rhythms. In the impression analysis of Section 6.B, the smile of K gave us a natural impression. In contrast, we received an unnatural impression from the smile of M. Focusing on an expressive rhythm of each facial part, the expressive rhythm of K indicates a time-series change such as to work together in each facial part. In contrast, we were unable to recognize cooperative movements at all in the expressive rhythm of M because the upper face and the lower face are independent. The mutual information of the ROIs (i.e., ROI 1, ROI 2, and ROI 3) effectively expresses the degree of similarity and synchronization of signal waveforms in facial expression rhythms. These mutual information values can be interpreted as quantified indices of the timing structure indicating the synchronization between the upper face (e.g., the eyebrows and eyes) and the lower face (e.g., mouth), which contribute the impression formation to the whole face. We should comprehensively consider the analysis results of Sections 6.B and 6.C. By particularly addressing the magnitude relation between ROI 1 and ROI 2 with respect to the mutual information, we were able to interpret "Eyes say things sufficient to mouth" quantitatively. Around the value of ROI 3 quantifying the timing structure between the upper face and the lower face, noting the magnitude relation and order relation between the values of ROI 1 and ROI 2, it is effective as an index for quantifying the degree of spontaneity and artificiality in facial expressions. Furthermore, more than male participants, the female participants easily created facial expressions of "happiness" intentionally. Then we assumed that result was only slightly affected by the discrepancy expression.

VII. CONCLUSION AND FUTURE WORK

In this study, to acquire image datasets of facial expressions under the states of pleasant–unpleasant stimulus for 20 participants (i.e., 10 men, 10 women), we used salivary amylase tests to validate emotional factors when viewing emotion-evoking videos. Additionally, by quantitative analysis of expressive rhythms from the viewpoint of mutual information, particularly addressing expressive processes of "happiness" facial expression after giving a pleasant–unpleasant stress stimulus by emotion-evoking videos, we objectively strove to ascertain complexity and ambiguity when making facial expressions because of human psychological states. Using evaluation experiments examining 10 participants (i.e., 5 men, 5 women), we analyzed the information of time-series changes in ROIs (i.e., ROI 1, ROI 2, and ROI 3), revealing the following points. By particularly addressing the expressive rhythm of each face region, one can estimate the impression of facial expressions from the magnitude relation and order relation of mutual information of each ROI. Additionally, the mutual information of expressive rhythms is effective as an index for measuring degree of spontaneity and artificiality during facial expressions. Female participants were better able to create facial expressions of "happiness" easily and intentionally than male participants were. Moreover, they were less susceptible to discrepancy expressions. In future work, by quantifying fluctuations of expressive tempos in facial parts upon the impression formation, and analyzing their timing structure, we intend to clarify differences of expressive paths between intentional and spontaneous facial expressions.

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