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Enhanced perceptual, emotional, and motor processing in response to dynamic facial expressions of emotion[1]

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Abstract: Dynamic facial expressions of emotion constitute natural and powerful media compared with static ones. However, little is known about the processing of dynamic facial expressions of emotion. In this paper, we describe the results of our recent neuroimaging and psychological studies on this issue. A neuroimaging study was conducted to investigate brain activity while viewing dynamic facial expressions. The results revealed that the broad region of visual cortices, the amygdala, and the right inferior frontal gyrus were more activated in response to dynamic facial expressions than control stimuli, such as static facial expressions and dynamic mosaics. In corresponding with the characteristics of these brain activities, the results of three psychological studies indicated that the dynamic presentation: (a) intensified the perceptual image of the facial expression (perceptual enhancement); (b) enhanced the emotional feeling; and (c) elicited spontaneous and rapid facial mimicry. These results revealed that the dynamic property facilitates the perceptual, emotional, and motor processing of facial expressions of emotion.

Key words: dynamic facial expression, representational momentum, emotion elicitation, facial mimicry.

Dynamic facial expressions of emotion constitute indispensable media in real social interaction. They indicate moment-to-moment changes in the emotional state of other individuals. The importance of the dynamic properties of facial expressions has been emphasized in the psychological literature. For example, Ekman and Friesen (1975) have described various facial expressions from a dynamic perspective.

However, little is known about the psychological mechanisms used for processing dynamic facial expressions compared to that of static facial expressions, as the majority of previous studies have used static facial images. It is obvious that static images cannot reflect the liveliness of dynamic facial expressions as they occur in real-life communication.

A few psychological studies that investigated the effect of dynamic presentations of facial stimuli reported a facilitative effect on facial processing. For example, studies have shown that the dynamic presentation of facial expressions improves the emotional recognition of expressions (Frijda, 1953; Harwood, Hall, & Shinkfield, 1999; Wehrle, Kaiser,

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Schmidt, & Scherer, 2000). Other researchers reported that the dynamic presentation of facial stimuli facilitated age (Berry, 1990) and identity recognition (Bruce & Valentine, 1988; Lander, Christie, & Bruce, 1999) compared to static image presentations. These data suggest that compared to static presentations, dynamic presentations of facial stimuli facilitate the various types of face processing.

In this paper, we describe the results of our recent research investigating this issue. We conducted neuroimaging and psychological studies. The results of a neuroimaging study revealed the brain areas involved in the processing of dynamic facial expressions. Based on these neuroimaging data, we hypothesized that dynamic presentation facilitates various psychological processes and a series of psychological experiments were conducted. Our results are in line with, and extend the facilitative effect of, dynamic presentations of facial expressions reported in previous psychological literature. Specifically, the results revealed enhanced perceptual, emotional, and motor reactions in response to dynamic facial expressions, relative to static facial expressions.

Enhanced brain activity in response to dynamic facial expressions

To investigate the brain areas involved in processing dynamic facial expressions, we measured brain activity using functional magnetic resonance imaging when participants were observing dynamic emotional facial expressions (Sato, Kochiyama, Yoshikawa, Naito, & Matsumura, 2004).

Previous neuroimaging studies have indicated that some visual areas are more active in response to static facial expressions. These include the inferior occipital gyrus, fusiform gyrus, and superior temporal sulcus (STS; e.g., Kesler-West et al., 2001). The amygdala is also more active in response to static emotional expressions, especially in the case of negative emotions, such as fear or anger (e.g., Whalen et al., 2001). We focused on these brain areas when analyzing the neural activity in response to dynamic facial expressions and also tried to determine whether additional areas are involved.

We used a computer morphing technique to present the dynamic expressions (Figure 1). This method allowed us to strictly compare the

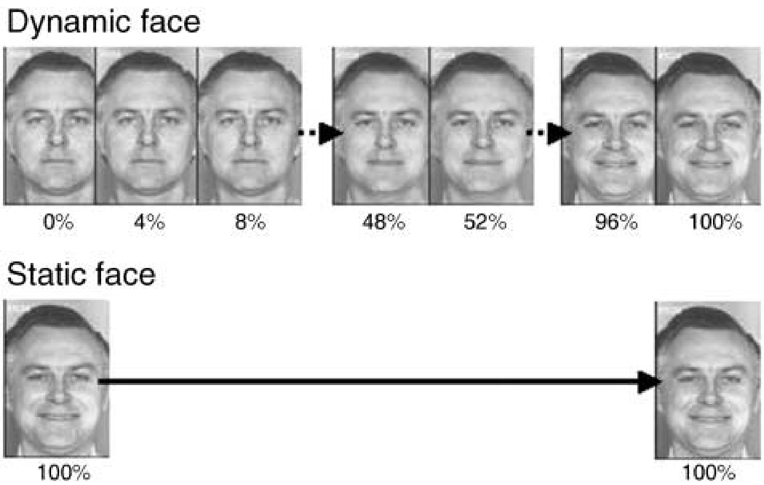

Figure 1. Stimulus presentations in the dynamic facial expression condition (upper) and static facial expression condition (lower).

dynamic and static presentation of facial expressions relative to other methods, such as comparison between videotaped films and frames cut from the films. In addition, because this method enabled us to implement motion on static images chosen from a stimulus set frequently used in previous studies (Ekman & Friesen, 1976), the results can be properly compared with previous findings. The presentation speed was adjusted to closely reflect natural changes in the dynamic facial expressions of emotions, which has been shown in a previous study (Sato & Yoshikawa, 2004).

The facial expressions were morphed from neutral to fearful or happy expressions. For comparison with the dynamic expressions, two types of conditions were prepared. In the primary condition, participants viewed static fearful or happy expressions. In the other condition, participants observed dynamic mosaic images. This condition was included to test whether higher brain activity for dynamic facial expressions, as compared to static expressions, was simply a result of the processing of dynamic visual information. Participants passively viewed these stimuli.

As a result, the broad region of occipital and temporal cortices showed higher activation while viewing the dynamic facial expressions than while viewing either of the control stimuli (Figure 2). The clusters included the activation foci of the inferior occipital gyrus, fusiform

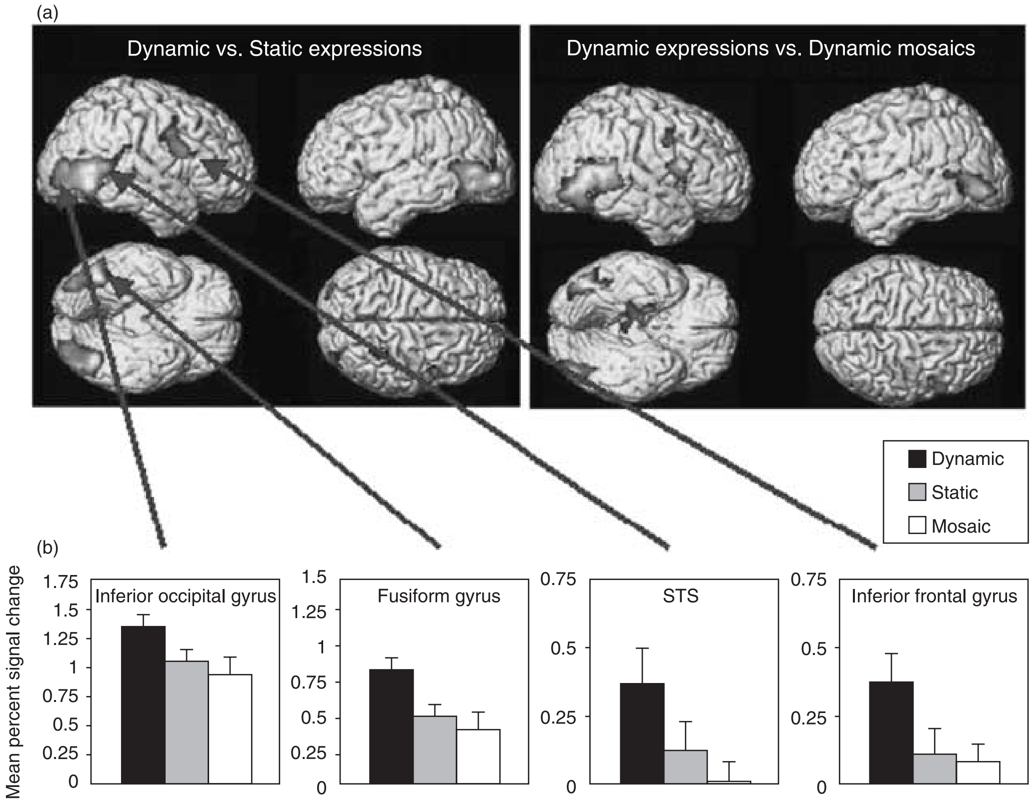

Figure 2. (a) Statistical parametric maps showing brain regions activated in response to dynamic fearful expressions compared to static fearful expressions (upper) and dynamic mosaics (lower). The areas of activation are rendered on spatially normalized brains.(b) Mean percentage signal changes (with standard error) of the representative brain regions highly activated for dynamic fearful expressions. Data for dynamic fearful expressions, static fearful expressions, and dynamic mosaics are shown. From Sato et al. (2004). Reprinted with permission from the publisher.

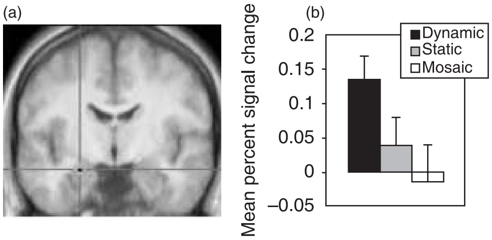

Figure 3. (a) A statistical parametric map showing left amygdala activity for dynamic fearful expressions compared to static fearful expressions. (b) Mean percentage signal changes (with standard error) of amygdala activity. Data for dynamic fearful expressions, static fearful expressions, and dynamic mosaics are shown. From Sato et al. (2004). Reprinted with permission from the publisher.

gyrus, and STS. The left amygdala was highly activated in response to dynamic facial expressions when compared with both control stimuli (Figure 3). The right amygdala also showed modest activation. In addition to these regions, the pars opercularis of the inferior frontal gyrus in the right hemisphere was activated in the same manner as the occipital and temporal cortices (Figure 2).

In summary, the broad region of visual cortices, the amygdala, and the right inferior frontal gyrus were more activated in response to dynamic facial expressions than control stimuli. These neuroscientific data, indicating that dynamic properties of facial expressions of emotion yield higher activation in various brain areas, provides the possibilities that psychological processes for dynamic facial expressions could also have facilitative effects compared with the processing for static expressions in various ways. A series of our psychological experiments examined this expectation.

Enhanced perception of dynamic facial expressions

In the first psychological study, we examined how the dynamic presentations of facial expressions influence the perceptual processes of facial images (Yoshikawa & Sato, submitted).

Our neuroimaging data showed that the clusters in the visual cortical areas were activated to a greater extent when observing dynamic facial expressions compared with static ones. The cluster included the inferior occipital gyrus, fusiform gyrus, and STS. These areas have been proposed to comprise the core system for the visual analysis of faces (Haxby, Hoffman, & Gobbini, 2000). These data suggest the possibility that the presentation of dynamic facial expressions could facilitate the perceptual processes of facial images compared with those of static facial expressions.

In the psychological literature on motion perception, the representational momentum (RM; Freyd & Finke, 1984; Freyd, 1987) has been reported. RM is a phenomenon in which the final position of an object, when seen to be actually moving or changing position in a way that implies continuous motion, shifts in the perceiver's mind in the direction of the observed transformation (Freyd & Finke, 1984; Hubbard, 1990). Since its discovery, this effect has been found in several types of implied change of object shape (Kelly & Freyd, 1987). However, whether the RM effect emerges when perceiving dynamic facial expressions of emotions remains unknown. Based on the aforementioned neuroscientific data indicating higher activation of visual areas for dynamic facial expressions, we hypothesized that the RM could occur for dynamic facial expressions of emotions. Specifically, we predicted that when a person perceives a dynamic facial expression changing from a neutral state to a particular emotional expression, such as anger or happiness, the last image of the dynamic sequence will be perceived in an exaggerated form, showing stronger emotional intensity.

We presented dynamic facial expressions created by a morphing technique, as in our neuroimaging study. In order to examine the participants' perception of the images, we used an interactive image selection task (Benson & Perrett, 1991). In this task, participants observed a short animation stimulus of a facial expression moving from neutral to one of the six basic emotions. Immediately after viewing the stimulus, participants were asked to select the last image perceived by using a slider on the computer display. This procedure made it possible to produce the images that participants thought they had perceived with little constraint. When the images had been selected, participants viewed the animation stimuli again and had the opportunity to modify their original choice of image. Unlike typical RM paradigms, in which participants match their internal image with a limited number of predetermined images, this interactive image selection procedure enabled us to obtain participants' internal images more precisely. A potential drawback of this procedure might have been the decay of perceived images over time. To avoid this procedural shortcoming, we presented the same dynamic stimulus twice. In the second exposure, participants perceptually matched the image they had selected with the last image of the stimulus and modified their choice if they thought the two images did not match exactly.

As shown in Figure 4, the RM effect emerged. This means that when seeing a dynamic facial expression changing at a fast enough velocity, the participants perceived a more intensified emotional image than actually presented.

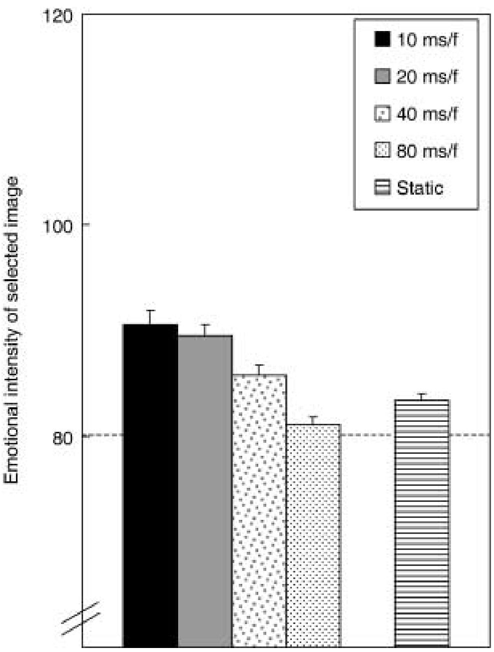

Figure 4. Mean percentage (with standard error) of the images perceived in each condition. The images actually presented were of 80% intensity.

The RM effect suggests that we possess a perceptual mechanism that efficiently catches sudden changes of emotional state in others in a very short period of time. Perceiving stronger emotion from rapid changes of facial expression has high ecologic value and is beneficial for social interaction.

Enhanced emotional elicitation of dynamic facial expressions

In the second psychological study, we examined participants' subjective emotional experience while viewing the dynamic or static facial expressions of emotion (Sato & Yoshikawa, 2006a).

Previous neuroimaging studies have revealed that amygdala activity is associated with subjective emotional feelings elicited in response to aversive olfactory and gustatory stimuli (e.g., Zald & Pardo, 1997). A recent neuroimaging study showed that this is also the case for facial expression processing (Sato, Yoshikawa, Kochiyama, & Matsumura, 2004). In this study, angry or neutral expressions looking toward or away from the participants were presented. The results showed that the left amygdala was more active in response to angry expressions looking toward the participants than angry expressions looking away from them. More importantly, the results showed the positive relationship between amygdala activity and the intensity of negative emotional experience while viewing the expressions.

Emotion elicitation in response to others' emotional expressions is proposed as being one of the most basic components of expression processing and social communication (Frijda, 1988). Previous psychological studies have consistently found that a subjective emotional experience is elicited by static presentations of facial expressions of emotions (e.g., Dimberg, 1988). We hypothesized that that the dynamic presentations of emotional expressions induce more intense emotional experience than the corresponding static presentations.

We presented dynamic and static facial expressions of fear and happiness, and dynamic and static mosaic images. For the dynamic facial expression condition, we used the same stimuli as our neuroimaging study. The participants rated their emotional experience while viewing the stimuli in terms of valence and arousal. Valence, which ranges from positive to negative, represents the qualitative component. Arousal, which ranges from high to low, reflects the experienced intensity of either positive or negative emotions (Lang, Bradley, & Cuthbert, 1998).

Figure 5 shows the mean ratings for valence and arousal. The valence ratings indicated that participants experienced a negative emotion in response to fearful expressions and a positive emotion in response to happy expressions. However, dynamic presentations had no effect on valence ratings, although dynamically presented facial expressions of both fearful and happy emotions were rated as highly arousing, relative to static expressions of those same emotions.

In summary, our results showed that dynamic presentations of emotional facial expressions enhanced the overall emotional experience without a corresponding qualitative change in that experience. Eliciting emotion is an important component in processing facial expressions (Frijda, 1988). Specifically, emotional elicitation plays an important role in social interactions (Keltner & Kring, 1998). Daily communication via dynamic facial expressions may be more emotionally toned, and subsequently more socially interactive, than researchers have previously proposed.

Enhanced facial motor reactions in response to dynamic facial expressions

We investigated the participants' facial motor reactions while viewing dynamic or static facial expressions of emotions (Sato & Yoshikawa, 2006b).

Our neuroimaging study showed that the inferior frontal gyrus is more active in response to dynamic facial expressions than static facial expressions. This area has been proposed to be a human homolog of the monkey ventral premotor cortex (Rizzolatti & Arbib, 1998). Neurophysiological studies in monkeys have shown that some neurons in the ventral premotor cortex are active both when a monkey performs specific hand actions and when it observes experimenters performing similar actions (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). A recent study on monkeys revealed that the neurons in this region also discharge during the observation of communicative facial actions (Ferrari, Gallese, Rizzolatti, & Fogassi, 2003). Researchers proposed that this neural activity

Figure 5. Mean ratings (with standard error) for (a) valence and (b) arousal. From Sato and Yoshikawa (2006a in press). Reprinted with permission from the publisher.

might reflect the "mirror" functions; that is, matching observed others' actions with one's own execution of actions (e.g., Rizzolatti & Arbib, 1998).

Consistent with this idea, psychophysiological studies using facial electromyography indicate that facial expressions elicit facial muscular activity congruent with the presented facial expressions. For example, Dimberg (1982) showed that mere photographic presentations of angry and happy facial expressions induced spontaneous corrugator supercilii muscle activity (brow lowering actions, prototypical in angry facial expressions) and zygomatic major muscle activity (lip corner pulling actions, prototypical in happy facial expressions), respectively. One could expect that the dynamic presentations of emotional expressions induce more intense spontaneous facial reactions in response to the expressions.

In addition to this, a previous psychological study described that participants' facial reactions in response to others' facial expression stimuli were externally observable in the case of film stimuli, but not in the case of photo stimuli (Frijda, 1953). This issue is crucial because if overt facial mimicking occurs when perceiving facial expressions of emotions, then this facial motor activity could function not only in intraindividual processing, such as empathic understanding, but also in interindividual communication. We hypothesized that the dynamic presentations of emotional expressions elicit externally observable facial reactions in response to the expressions.

We video-recorded participants' facial reactions while they were passively observing dynamic and static facial expressions of anger and happiness. For the dynamic facial expression condition, we used almost the same temporal parameters as our neuroimaging study. In this experiment, Japanese faces were used. To videotape the participants' facial reactions, a video prompter system was used. The prompter system is an apparatus usually used in television studios. It allowed us to videotape the participants' facial expressions while they were unaware of the presence of a video camera. To analyze the participants' facial reactions, two scorers blindly scored the facial movements within 2.5 s from the stimulus onset using a facial action coding system (Ekman & Friesen, 1978). Action unit (AU) 4 (i.e., the action of lowering the brows) and AU 12 (i.e., the action of pulling the lip corners) were evaluated. In addition to analyses of the occurrence of participants' facial reactions for each trial, we also analyzed the facial reactions frame by frame for latencies.

Representative examples of the participants' facial reactions are shown in Figure 6, and the results of mean percentage occurrence for each AU are shown in Figure 7. Specific facial action patterns were elicited in response to dynamic facial expressions of anger and happiness. Brow lowering actions, which are prototypical facial movements in angry expressions, occurred more frequently in response to angry expressions than to happy expressions, and lip corner pulling actions, which are prototypical facial actions in happy expressions, occurred more frequently in response to happy expressions than to angry expressions. Because the participants passively viewed the stimuli, these facial actions reflected spontaneous processes.

In summary, our results indicated that dynamic facial expressions elicited more frequent spontaneous and rapid facial motor actions, interpretable as overt facial mimicry, compared with static facial expressions. Together with our neuroimaging data, we speculate that the mirror neuron system in the right inferior frontal gyrus may play an important role in facial mimicry. Externally observable facial behaviors that follow those of other individuals probably facilitate interindividual communication and social coordination; this neuro-cognitive mechanism may be of critically adaptive significance for social primates, including humans.

Conclusion

Summarizing the main results of our series of studies revealed that dynamic facial expressions of emotions elicit higher activation in various brain areas, such as visual cortices, the amygdala, and the ventral premotor cortex. In accordance with this evidence, our psychological studies on processing dynamic facial expressions of

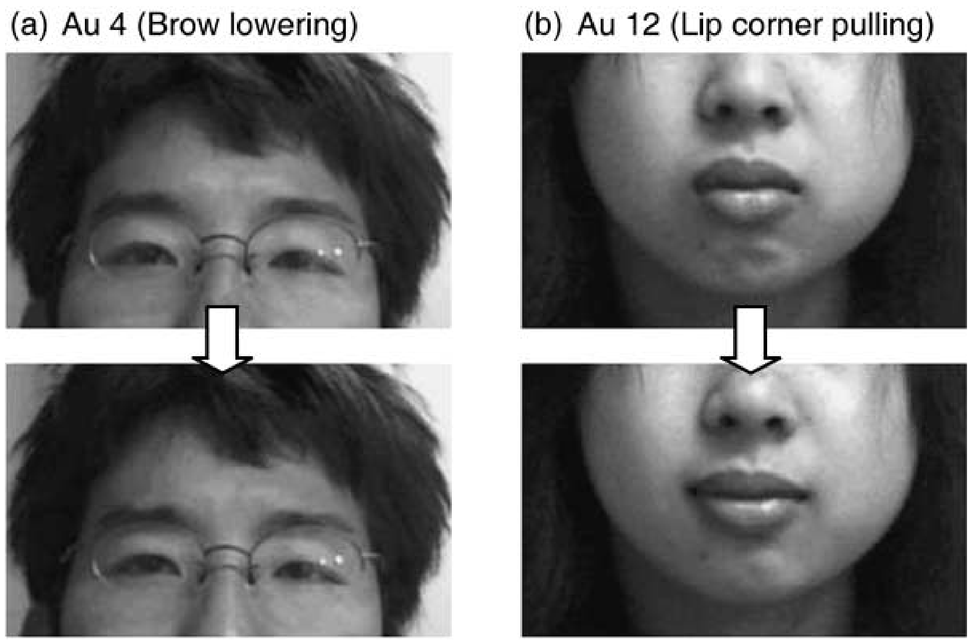

Figure 6. Representative examples of participants' facial reactions to the dynamic facial expression stimuli. Each figure presents the participant's brow lowering action in response to the (a) angry expression and the lip corner pulling action in response to the (b) happy expression. From Sato and Yoshikawa (2006b in press). Reprinted with permission from the publisher.

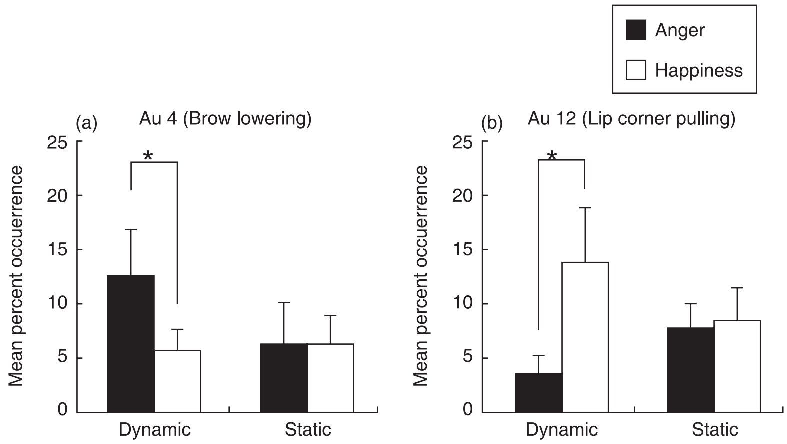

Figure 7. Mean (with standard error) percentage occurrence of (a) action unit (AU) 4 and (b) AU 12.

emotions revealed that dynamic presentation: (a) produces intensified perceptual images of facial expressions (perceptual enhancement); (b) enhances the emotional feeling; and (c) elicits spontaneous and rapid facial mimicry. These results revealed that dynamic facial expressions facilitate perceptual and emotional processing as well as motor reactions.

There is no doubt that real facial expressions are dynamic. We believe that our results contribute to the understanding of communication via facial expressions in daily life.

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