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Enhanced facial EMG activity in response to dynamic facial expressions

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ABSTRACT

The suggestion that dynamic facial expressions of emotion induce more evident facial mimicry than static ones remains controversial. We investigated this issue by recording EMG from the corrugator supercilii and zygomatic major. Dynamic and static facial expressions of anger and happiness were presented. Dynamic presentations of angry expressions induced stronger EMG activity from the corrugator supercilii than static presentations, while dynamic presentations of happy expressions induced stronger EMG activity from the zygomatic major compared to static presentations. These results indicate that dynamic facial expressions induce facial EMG activity interpretable as facial mimicry more evidently than static expressions.

1. Introduction

Communication through facial expressions of emotion plays an important role in social coordination (Keltner and Kring, 1998). Throughout the evolutionary process, facial expressions have helped humans act collectively during times of danger and form close relationships with one another. Consistent with this idea, psychophysiological studies using facial electromyography (EMG) 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 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. This facial muscular activity can be interpreted as mimicking behavior or facial mimicry (Hess et al., 1999). Dimberg and Thunberg (1998) showed that facial EMG activity occurred rapidly after about 500 ms from the onset of facial pictures. Dimberg et al. (2000) reported that facial EMG activity occurred even without awareness of the specific facial expression. These data indicate that facial EMG activity interpretable as facial mimicry occurs rapidly and automatically in response to stimulus facial expressions.

Dynamic facial expressions of emotion are ecologically valid and powerful media for emotional communication compared to static expressions. Several lines of psychological studies have investigated the effect of dynamic presentations of facial stimuli and reported a facilitative effect on facial processing. For example, the dynamic presentation of facial expressions has been shown to improve the emotional recognition of expressions (Frijda, 1953; Harwood et al., 1999; Wehrle et al., 2000). Other research has found that the dynamic presentation of facial stimuli facilitated age (Berry, 1990) and identity recognition (Bruce and Valentine, 1988; Lander et al., 1999) compared to static image presentations. Therefore, it appears reasonable to expect dynamic facial expressions to elicit facial mimicry more evidently than static ones.

However, only a few studies have investigated this issue, and data are inconsistent. Weyers et al. (2006) presented dynamic and static facial expressions of anger and happiness using avatars, that is, computer-generated artificial faces. They took EMG recordings from the facial muscles of the corrugator supercilii and zygomatic major. Their results showed that dynamic presentations of happy expressions induced stronger EMG reactions for zygomatic major muscles compared to static presentations. This result is consistent with the idea that dynamic facial expressions induce more evident facial mimicry than static expressions. However, for angry facial expressions, they found no significant differences between dynamic and static presentations for corrugator supercilii muscle activity.

Sato and Yoshikawa (2007a) investigated this issue utilizing a different methodology. They presented dynamic and static facial expressions of anger and happiness, using computer-morphing techniques and videos of real people. The participants' facial reactions were unobtrusively videotaped and blindly coded using an objective criterion (Ekman and Friesen, 1978). In the case of dynamic, but not

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static, presentations, brow lowering and lip corner pulling were evident for angry and happy expressions, respectively. These results indicate enhanced facial mimicry for dynamic facial expressions, common to both anger and happiness.

The different results in these previous studies (Sato and Yoshikawa, 2007a; Weyers et al., 2006) may have been caused by differences in the stimuli that were presented. Whereas Weyers et al. (2006) utilized artificial avatars, Sato and Yoshikawa (2007a) applied representations of real peoples' faces. A recent neuroimaging study revealed that the activity of some social- and/or emotion-related brain regions, such as the amygdala, was lower when viewing avatars than when viewing real-person stimuli (Moser et al., 2007). The dynamic stimuli of real people may be more ecologically valid than dynamic avatars and hence, induce clearer facial mimicry. In this study, we utilized the stimuli of real people to test the hypothesis that enhanced facial EMG reactions could be induced by dynamic rather than static facial expressions of both negative and positive stimuli.

We measured facial EMG reactions while participants passively viewed dynamic and static facial expressions. To present dynamic facial expressions, we used videos of real people's facial expressions, which had been used in a previous behavioral study and were shown to elicit automatic facial mimicry more evidently than static facial images (Sato and Yoshikawa, 2007a). We prepared facial expressions of anger and happiness to represent the positive and negative emotional valence. We used the apex images of the dynamic facial expressions under static conditions. After the facial EMG recordings, we presented the stimuli again, and required the participants to rate the experienced emotion and recognized emotion of the stimuli. We predicted that specific facial EMG reactions, interpretable as facial mimicry, would occur more evidently for dynamic rather than for static facial expressions of emotion.

2. Method

2.1. Participants

Twenty-nine volunteers (18 females and 11 males; mean ± SD age, 20.9 ± 0.9 years) participated in this experiment. All of the participants had normal or corrected-to-normal visual acuity. Although an additional male volunteer actually participated, his data were not analyzed due to outlier properties (see Data analysis). Informed consent was obtained from all participants in written form after the experimental procedures had been explained.

2.2. Experimental design

The experiment was constructed as a within-participants two-factorial design, with presentation condition (dynamic/static) and expression (angry/happy) as the factors.

2.3. Stimuli

The stimuli were the same as those used in a previous study (Sato and Yoshikawa, 2007a). The materials were video clips of angry and happy facial expressions of four females and four males. These stimuli were selected from a video database of facial expressions of emotion composed from more than 50 Japanese models. None of the faces was familiar to any of the participants. Preliminary ratings from 14 participants who did not take part in this experiment confirmed that the stimuli clearly displayed the target emotions relative to other basic emotions. In addition, a trained coder of the Facial Action Coding System (FACS; Ekman and Friesen, 1978) evaluated the stimulus facial actions, and the FACS data were subjected to the Facial Action Coding System Affect Interpretation Dictionary (FACSAID; Ekman et al., 1998). The results confirmed that the emotional meanings of the stimulus facial actions could be recognized as intended. Specifically, all of the selected angry and happy expressions showed action units 4 (brow lowering) and 12 (lip corner pulling), respectively. The expressions contained few artifacts irrelevant to emotional expressions.

For the dynamic expression stimuli, 38 frames from neutral to emotional expressions were presented. Each frame was shown for 40 ms, and each clip was presented for 1520 ms.

The frames of the apex emotional expressions in the dynamic condition were prepared for the static expression stimuli and presented for 1520 ms.

2.4. Apparatus

Experimental events were controlled by a program written in Visual C++5.0 and implemented on a computer (Inspiron 8000, Dell) with a Microsoft Windows operating system. The stimuli were presented on a 19 in. CRT monitor (HM903D, Iiyama; 480 vertical × 640 horizontal pixels resolution, 16 bit color, 75 Hz refresh rate) from a viewing distance of about 0.6 m. The stimuli were presented at 300 pixels in height × 200 pixels in width, subtending a visual angle of about 16.5° in height × 11° in width.

2.5. Procedure

Experiments were conducted individually in an electrically shielded room. Upon arrival, participants were told that the experiment concerned sweat gland activity while evaluating some faces, which was the cover story to conceal our real purpose for making facial EMG recordings.

After electrode placement, the participants were asked to fill out dummy questionnaires for about 10 min, which were aimed at enhancing the participants' general adaptation to the experimental settings. After completing the questionnaires, the participants were told that they would be first viewing and then evaluating all of the stimuli.

The EMG recordings were conducted while the participants passively viewed the stimuli. In total, 32 trials were conducted, consisting of eight trials each of dynamic angry, dynamic happy, static angry, and static happy expressions. The order of stimulus presentation was randomized.

In each trial, a fixation point (the picture with a small "+" in a gray color on a white background and of the same size as the stimulus) was presented at the center of the screen for 1520 ms. Then, the stimulus was presented for 1520 ms. After stimulus presentation, the screen was filled with a gray color as an intertrial interval, which was controlled to vary randomly from 6000 ms to 9000 ms. Throughout the data acquisition, the participants' motion artifacts were monitored through an oscilloscope and a video monitor, and the stimulus presentations were suspended when the participants showed temporal movements.

After EMG recordings, the stimuli were again presented to the participants, and they evaluated each stimulus for the experienced emotion (i.e., the strength of the emotion that subjects felt when perceiving the stimulus models' expression) and the recognized emotion (i.e., the strength of the emotion that subjects recognized from the stimulus models' expression) using the affect grid (Russell et al., 1989), which graphically assessed the two dimensions of pleasure and arousal on 9-point scales. Russell et al. (1989) showed that the affect grid is suitable for assessing both recognized and experienced emotion. The two types of evaluation were presented in blocks, the order of which was counterbalanced across participants. The order of stimulus presentation was randomized in each block.

Finally, the participants were interviewed to determine whether they had been aware of the purpose of the experiment. This process confirmed that all of the participants had been unaware.

2.6. EMG recording

EMG recordings were taken for the corrugator supercilii and zygomatic major muscles using Ag/AgCl electrodes. The electrodes were placed according to the guidelines of Fridlund and Cacioppo (1986). A ground electrode was placed on the forehead. Impedances were balanced and maintained below 15 kΩ. Data were amplified and filtered online (band pass: 5–1000 Hz; notch: 60 Hz) by a polygraph (NEC, Synafit 1000), and sampled by a digital converted system (MP100, BIOPAC Systems) at 2000 Hz. For the purpose of artifact rejection, a video recording was unobtrusively conducted using a digital video camera (DSR-PD150, SONY).

2.7. Data analysis

2.7.1. Preprocessing

EMG data were analyzed using Psychophysiological Analysis Software 3.3 (Computational Neuroscience Laboratory of the Salk Institute) implemented in MATLAB 6.5 (Mathworks). The data were sampled for 3500 ms in each trial, which consisted of pre-stimulus baseline data for 1000 ms (the fixation point was presented) and the data for 2500 ms after stimulus onset. The time window of the poststimulus period was identical to a previous behavioral study (Sato and Yoshikawa, 2007a) that detected facial muscle reactions in response to dynamic facial expressions. Our preliminary analyses of raw EMG data confirmed that most responses were detected in these time ranges.

Because participants were not told that their facial EMG data were being recorded, the data included various types of motion artifacts (e.g., mumbling). One of the authors blindly checked the videotapes and raw EMG data and rejected the artifact-contaminated trials. To evaluate the artifacts in the video data, we used the artifact lists of a previous study (Sato and Yoshikawa, 2007a) with a slight modification for the application to EMG data. The artifact lists included resting the chin on the hand (this prevented the movement of the lower face), swinging the head, yawning, eye closing, mumbling, and displaying facial expressions in the pre-stimulus period. The artifacts in the EMG data were evaluated according to guidelines (Gerleman, 1992; Soderberg, 1992). The frequencies of artifact-contaminated trials ($M \pm SD = 0.9 \pm 1.2, 0.9 \pm 1.1, 1.5 \pm 1.6, 1.2 \pm 1.7$, for dynamic anger, dynamic happiness, static anger, and static happiness, respectively) showed no significant systematic differences among the four experimental conditions (Friedman's one-way analysis of variance (ANOVA) by ranks, $P > 0.1$). The artifact-contaminated data were rejected from the following analyses. To further eliminate artifacts, the data were filtered off-line (band pass: 50–500 Hz).

For each trial, the differences in the mean absolute amplitudes between the pre- and poststimulus periods were calculated as the EMG data.

To test the assumption of a normal distribution for the parametric analyses, the mean EMG data across all trials were calculated for each muscle and each participant. One participant was found to be a deviant case from the group mean for both muscles (>5 SD), and thus the data from this participant were eliminated. However, preliminary analyses including this participant produced the same patterns of results.

2.7.2. Facial EMG

The EMG data were averaged for each condition of each participant, and then analyzed by a two-way repeated-measures ANOVA with presentation condition and expression as factors. For the significant interactions, we analyzed the simple effects of presentation condition.

In addition, to confirm that the EMG activity changed compared to the baseline, the EMG data of each condition was tested for a difference from zero using one-sample t-tests (two-tailed).

2.7.3. Psychological ratings

The valence and arousal ratings of recognized and experienced emotions were separately analyzed using ANOVAs of the same design as the EMG analysis.

3. Results

3.1. Facial EMG

For the corrugator supercilii muscle (Fig. 1, left), the ANOVA showed an interaction between presentation condition and expression, $F(1, 28) = 9.55$, $P < 0.005$. The main effect of emotion was also significant, $F(1, 28) = 4.85$, $P < 0.05$. Follow-up analyses of the interaction revealed that the simple main effect of presentation condition, indicating stronger corrugator supercilii activity for dynamic than for static presentations, was significant only for angry expressions, $F(1, 56) = 6.36$, $P < 0.05$.

The one-sample t-tests revealed that significantly higher corrugator supercilii activity was observed for the dynamic angry expressions than for the baseline, $t(28) = 2.00$, $P < 0.05$, and significantly lower corrugator supercilii activity was seen for the dynamic happy expressions than for the baseline, $t(28) = 3.08$, $P < 0.01$. The activity for static angry expressions was not significant, $t(28) = 0.74$, n.s.

For the zygomatic major muscle (Fig. 1, right), the interaction between presentation condition and expression was significant, $F(1, 28) = 4.42$, $P < 0.05$. The main effect of emotion was also significant, $F(1, 28) = 10.96$, $P < 0.005$. Follow-up analyses of the interaction revealed that the simple main effect of presentation condition, indicating stronger

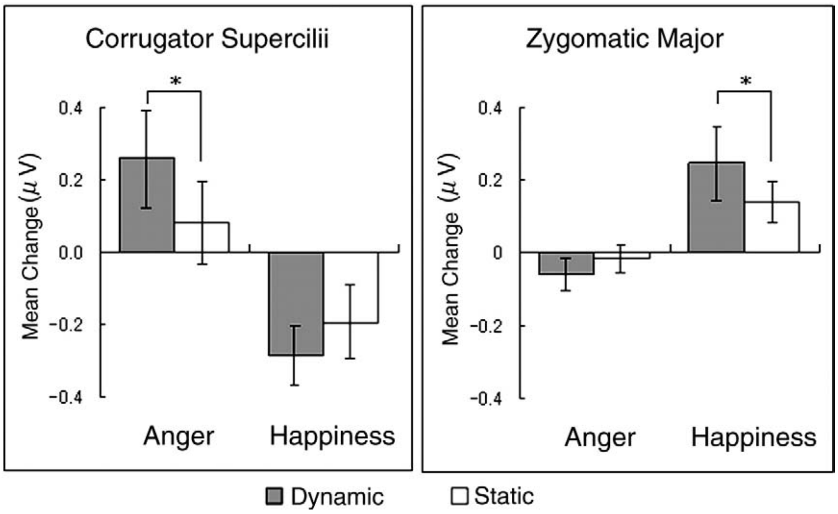

Fig. 1. Mean (±SE) EMG change activity for corrugator supercilii (left) and zygomatic major (right) muscles. Asterisks indicate the significant simple main effects of presentation condition, indicating higher activity for dynamic presentations than for static presentations.

Table 1
Mean (with SE) ratings of valence and arousal for experienced and recognized emotions

Measure		Experienced emotion				Recognized emotion			
		Anger		Happiness		Anger		Happiness	
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static
Valence	*M*	3.0	3.0	6.7	6.7	2.5	2.6	7.4	7.5
	(SE)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Arousal	*M*	5.4 *	5.0	5.3	5.4	5.4	5.0	5.6	5.5
	(SE)	(0.2)	(0.2)	(0.1)	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)

Note. Asterisk indicates the significant differences between dynamic and static presentations. *, $P<0.05$.

zygomatic major activity for dynamic than for static presentations, was significant only for happy expressions, $F(1, 56)=5.06$, $P<0.05$.

Significantly higher zygomatic major activity was observed for the dynamic and static happy expressions than for the baseline, $ts(28)>2.53$, $Ps<0\ 05$.

3.2. Psychological ratings

The results of the psychological ratings are shown in Table 1. For the valence of experienced emotion, the ANOVA showed that only the main effect of expression, indicating higher negative valence ratings for angry than for happy expressions, was significant, $F(1, 28)=146.40$, $P<0.001$. For the arousal of experienced emotion, only the interaction was significant, $F(1, 28)=8.36$, $P<0.01$. Follow-up analyses of the interaction indicated that the simple main effect of presentation condition, indicating higher arousal ratings for dynamic than for static expressions, was significant only for angry expressions, $F(1, 56)=6.55$, $P<0.05$.

For the valence of recognized emotion, only the main effect of expression, indicating higher negative valence ratings for angry than for happy expressions, was significant, $F(1, 28)=256.22$, $P<0.001$. For the arousal of recognized emotion, the main effect of presentation condition, indicating higher arousal ratings for dynamic than for static expressions, reached marginal significance, $F(1, 28)=3.24$, $P<0.1$. The main effect of expression, indicating higher arousal ratings for happy than for angry expressions also reached marginal significance, $F(1, 28)=3.05$, $P<0.1$.

4. Discussion

The results of facial EMG activity revealed that for the corrugator supercilii, which are prototypical facial muscles related to angry expressions, dynamic presentations of angry expressions induced stronger EMG activity than static presentations of angry expressions. For the zygomatic major, which are prototypical facial muscles related to happy facial expressions, dynamic presentations of happy expressions induced stronger EMG reactions than static presentations of happy expressions. Because the participants viewed the stimuli passively, these facial actions reflected automatic activity. These results agree with those of previous studies that recorded facial EMG and found that the presentation of static pictures of facial expressions elicited automatic facial muscular activity, interpretable as facial mimicry (e.g., Dimberg and Thunberg, 1998). Extending this idea, our results support our hypothesis and indicate that specific facial EMG reactions, interpretable as facial mimicry, occur more evidently in response to dynamic rather than to static facial expressions of emotion.

A previous EMG study (Weyers et al., 2006) reported partially inconsistent results about facial EMG activity while viewing dynamic and static emotional expressions. The study presented dynamic and static facial expressions of anger and happiness and recorded facial EMG. They found that dynamic facial expressions induced greater facial muscular activity only with happy expressions. This inconsistency can be explained by the differences in the stimuli used in the two studies. Whereas Weyers et al. (2006) utilized avatars, we used stimuli consisting of real people. The high ecological validity and liveliness of real people, compared to artificial animations, could be responsible for inducing more evident facial reactions. Consistent with this speculation, a previous study (Sato and Yoshikawa, 2007a), which behaviorally investigated the facial reactions in response to dynamic facial expressions using video clips, reported that specific facial-action patterns were more frequently elicited in response to dynamic rather than to static facial expressions of both anger and happiness. Note, however, that in addition to differences in the stimuli utilized in the previous studies, differences existed in the methodology of recording facial muscular reactions as well as differences in the cultural background among participants. Hence, to make conclusions regarding the effects of various stimuli on facial muscular reactions, experiments must be conducted to control for these factors. Nevertheless, our data indicate that dynamic facial expressions of emotion from real people induce evident facial muscular activity interpretable as facial mimicry.

Our static presentations of angry facial expressions did not clearly induce corrugator supercilii muscle activity. This is inconsistent with the results of previous studies (e.g., Dimberg, 1982). We speculate that some methodological differences may account for this inconsistency. Whereas most of the previous studies used the cover story that facial electrodermal activity would be recorded, we used the cover story that the physiological recording would be made after the first passive viewing. This method was adopted to compare the results with a previous behavioral study (Sato and Yoshikawa, 2007a) and to reduce the participants' intentional interference of their facial reactions. Our less-controlled instruction induced a relatively high rate of artifacts, so the sensitivity may have been lowered. Alternatively, whereas many previous studies presented stimuli for several seconds (e.g., 10 s), we presented the stimuli for only 1500 ms. This methodology was adopted because it has been shown that dynamic presentations of facial expressions become unnatural during presentations lasting more than 2 s (Sato and Yoshikawa, 2004). It may be possible that our rapid presentations of stimuli had less impact than previous studies. Regardless of these possible methodological limitations, we clearly showed differences between dynamic and static presentations of facial expressions.

Our results showing the expression of facial mimicry while participants viewed dynamic facial expressions agree with those of previous developmental studies that reported facial mimicry in newborn infants (e.g., Field et al., 1982; Meltzoff and Moore, 1977; Vinter, 1986). Specifically, Vinter (1986) tested the effect of dynamic versus static stimulus presentations and found that infants show facial mimicry only when presented with dynamic stimuli. Based on the infant data, Meltzoff and Moore (1995) proposed that an innate psychological mechanism exists for facial mimicry in which motor outputs are linked to visual inputs of others' facial motion. Taken together, these data suggest that such a psychological mechanism of visual-motor matching may continue throughout life to implement facial mimicry.

It is interesting to speculate on the neural mechanisms for the enhanced facial mimicry to dynamic facial expressions. A previous neuroimaging study indicated that the inferior frontal gyrus was more active in response to dynamic facial expressions than in response to static facial expressions (Sato et al., 2004). The homologous ventral premotor cortex of monkeys has been shown to contain mirror neurons that discharge while performing specific actions and while observing another performing similar actions (Rizzolatti and Arbib, 1998). We speculate that the mirror-neuron system may play an important role in facial mimicry by matching motor outputs of facial motions with the visual inputs of facial motions.

The results of our psychological ratings revealed that experienced and recognized emotional arousal is higher for dynamic than for static facial expressions. This agrees with previous studies that investigated emotion elicitation (Sato and Yoshikawa, 2007b) and emotion recognition (Biele and Grabowska, 2006). In the studies, participants viewed dynamic and static facial expressions and reported enhanced emotional arousal for dynamic facial expressions. However, our results were not clear-cut compared to those of previous studies. This inconsistency may have occurred because the stimuli were repeatedly presented in our study. The effect of dynamic presentations may be reduced relative to the effects of the initial presentations.

In summary, we found that dynamic facial expressions of emotion induced specific facial EMG activity, interpretable as facial mimicry, more evidently than static expressions. These results suggest that in the dynamic facial communication of real-life, facial mimicry plays more important roles than previous experiments using static stimuli have suggested.

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References

Berry, D.S., 1990. What can a moving face tell us? J. Pers. Soc. Psychol. 58, 1004–1014.

Biele, C., Grabowska, A., 2006. Sex differences in perception of emotion intensity in dynamic and static facial expressions. Exp. Brain Res. 171, 1–6.

Bruce, V., Valentine, T., 1988. When a nod's as good as a wink: The role of dynamic information in facial recognition. In: Gruneberg, M.M., Morris, P.E., Sykes, R.N. (Eds.), Practical Aspects of Memory. Current Research and Issues, vol. 1. John Wiley & Sons, New York, pp. 169–174.

Dimberg, U., 1982. Facial reactions to facial expressions. Psychophysiology 19, 643–647.

Dimberg, U., Thunberg, M., 1998. Rapid facial reactions to emotional facial expressions. Scand. J. Psychol. 39, 39–45.

Dimberg, U., Thunberg, M., Elmehed, K., 2000. Unconscious facial reactions to emotional facial expressions. Psychol. Sci. 11, 86–89.

Ekman, P., Friesen, W.V., 1978. Facial Action Coding System. Consulting Psychologist, Palo Alto.

Ekman, P., Hager, J., Irwin, W., Rosenberg, E., 1998. Facial Action Coding System Affect Information Database (FACSAID). http://www.face-and-emotion.com/dataface/facsaid/description.jsp.

Field, T., Woodson, R., Greenberg, R., Cohen, D., 1982. Discrimination and imitalion of facial expressions by neonates. Science 218, 179–181.

Fridlund, A.J., Cacioppo, J.T., 1986. Guidelines for human electromyographic research. Psychophysiology 23, 567–589.

Frijda, N.H., 1953. The understanding of facial expression of emotion. Acta Psychol. 9, 294–362.

Gerleman, D.G., 1992. Instrumentation. In: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, (ed.), Selected Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives, National Institute for Occupational Safety and Health, Atlanta, pp. 43–68.

Harwood, N.K., Hall, L.J., Shinkfield, A.J., 1999. Recognition of facial emotional expressions from moving and static displays by individuals with mental retardation. Am. J. Ment. Retard. 104, 270–278.

Hess, U., Philippot, P., Blairy, S., 1999. Mimicry: facts and fiction. In: Philippot, P., Feldman, R., Coats, E. (Eds.), The Social Context of Nonverbal Behavior. Cambridge University Press, New York, pp. 213–241.

Keltner, D., Kring, A., 1998. Emotion, social function, and psychopathology. Rev. Gen. Psychol. 2, 320–342.

Lander, K., Christie, F., Bruce, V., 1999. The role of movement in the recognition of famous faces. Mem. Cogn. 27, 974–985.

Meltzoff, A.N., Moore, M.K., 1977. Imitation of facial and manual gestures by human neonates. Science 198, 75–78.

Meltzoff, A.N., Moore, M.K., 1995. Infants' understanding of people and things: From body imitation to folk psychology. In: Bermudez, J.L., Marcel, A., Eilan, N. (Eds.), The Body and the Self. The MIT Press, Cambridge, pp. 43–70.

Moser, E., Derntl, B., Robinson, S., Fink, B., Gur, R.C., Grammer, K., 2007. Amygdala activation at 3T in response to human and avatar facial expressions of emotions. J. Neurosci. Methods 161, 126–133.

Rizzolatti, G., Arbib, M.A., 1998. Language within our grasp. Trends Neurosci. 21, 188–194.

Russell, J.A., Weiss, A., Mendelsohn, G.A., 1989. Affect grid: a single-item scale of pleasure and arousal. J. Pers. Soc. Psychol. 57, 493–502.

Sato, W., Yoshikawa, S., 2004. The dynamic aspects of emotional facial expressions. Cogn. Emot. 18, 701–710.

Sato, W., Yoshikawa, S., 2007a. Spontaneous facial mimicry in response to dynamic facial expressions. Cognition 104, 1–18.

Sato, W., Yoshikawa, S., 2007b. Enhanced experience of emotional arousal in response to dynamic facial expressions. J. Nonverbal Behav. 31, 119–135.

Sato, W., Kochiyama, T., Yoshikawa, S., Naito, E., Matsumura, M., 2004. Enhanced neural activity in response to dynamic facial expressions of emotion: an fMRI study. Brain Res. Cogn. Brain Res. 20, 81–91.

Soderberg, G.L., 1992. Recording techniques. In: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, (ed.), Selected Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives, National Institute for Occupational Safety and Health, Atlanta, pp. 23–41.

Vinter, A., 1986. The role of movement in eliciting early imitations. Child Dev. 57, 66–71.

Wehrle, T., Kaiser, S., Schmidt, S., Scherer, K.R., 2000. Studying the dynamics of emotional expression using synthesized facial muscle movements. J. Pers. Soc. Psychol. 78, 105–119.

Weyers, P., Muhlberger, A., Hefele, C., Pauli, P., 2006. Electromyographic responses to static and dynamic avatar emotional facial expressions. Psychophysiology 43, 450–453.