Emotional expression boosts early visual processing of the face: ERP recording and its decomposition by independent component analysis

Wataru Sato,[CA] Takanori Kochiyama,[1] Sakiko Yoshikawa and Michikazu Matsumura[1]

Department of Cognitive Psychology in Education and [1]Department of Human and Environmental Studies, Kyoto University, Yoshida-honmachi, Sakyo-ku, Kyoto, 606-8501, Japan

[CA]Corresponding Author

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To investigate the hypothesis that early visual processing of stimuli might be boosted by signals of emotionality, we analyzed event related potentials (ERPs) of twelve right-handed normal subjects. Gray-scale still images of faces with emotional (fearful and happy) or neutral expressions were presented randomly while the subjects performed gender discrimination of the faces. The results demonstrated that the faces with emotion (both fear and happiness) elicited a larger negative peak at about 270 ms (N270) over the posterior temporal areas, covering a broad range of posterior visual areas. The result of independent component analysis (ICA) on the ERP data suggested that this posterior N270 had a synchronized positive activity at the frontal–midline electrode. These findings confirm that the emotional signal boosts early visual processing of the stimuli. This enhanced activity might be implemented by the amygdalar re-entrant projections. *NeuroReport* 12:709–714

Key words: Emotional expressions; Event related potential (ERP); Face recognition; Independent component analysis (ICA)

INTRODUCTION

Emotion has developed through Darwinian evolution to facilitate the survival of the species and individuals [1,2]. Immediate and appropriate responses to the emotionally salient (e.g. threat-related) cues in the environment obviously confer adaptive values for creatures. For this purpose, the detection of emotionally charged stimuli should be rapid and accurate.

Recent neuroimaging studies have demonstrated that the visual presentation of emotionally charged stimuli activates not only emotion-specific brain areas (e.g. amygdala, orbitofrontal cortex) but also extensive areas in the extrastriate cortex more than that of neutral stimuli [3–12]. For example, an fMRI study has shown that the presentations of fearful and happy faces more highly activate the fusiform gyrus than neutral faces (especially in the case of fearful faces) [3]. Another fMRI study has used a broad class of emotional or neutral pictures to show that presentation of emotional (negative or positive) stimuli produced higher and more sizable activations bilaterally in the occipital and fusiform gyri than did neutral stimuli [6]. A PET study [9] revealed, by using regression analyses of brain activity, that this enhanced activity of the extrastriate areas is functionally interconnected with an activation of the amygdala, which has been confirmed to be crucial in emotional processing by a number of animal studies [2] as well as human lesion and functional imaging studies [13]. These data suggest that visual processing can be modulated by the inherent emotional signals of the stimuli.

What seems lacking are the temporal profiles of this enhancement by emotionality implemented on the visual stimulus, because of the limited temporal resolution of neuroimaging techniques. This activation in the visual area may be realized at the early stage of visual processing [9], because the amygdala sends direct feedback projections to the visual cortices [14]. Although this proposal sounds very plausible from a biological view of emotion, it is still not conclusive because the amygdala might also implement visual activation via some indirect efferent to the visual cortex, such as projections from nucleus reticularis pontis caudalis of the brain stem, the effect of which takes a second or longer.

The event related potential (ERP) is one of the most appropriate measures to determine the temporal organization of the neural activity, with a temporal resolution of milliseconds. Vanderploeg *et al.* [15] reported that the visual presentations of the simple drawings of emotional facial expressions elicited more negative amplitudes during 230–420 ms (with peak at about 340 ms) after the stimulus onset than did neutrally rated stimuli. Similarly, Marinko-

vic and Halgren. [16] reported that the presentations of the photos with emotional facial expressions evoked a significantly larger lateral occipito-temporal negativity during 200–400 ms, with a peak at about 240 ms, than neutral faces. These data suggest that activation in response to the emotional stimuli may be implemented as early as 200 ms after stimulus onset. As these subjects were, however, instructed to evaluate the emotionality of stimuli, these explicit emotional tasks might inform the subjects that the experiment deals with emotionality [17] and may cause them be more attentive to the emotional stimuli than the neutral stimuli. Therefore, the visual area activation of the previous studies could be due to the subjects' overt attention [18] rather than the emotional processing.

The current study was designed to exclude this problem, by recording ERPs while viewing emotional (fearful and happy) or neutral faces with a covert emotion task. The task was to specify the gender of the presented faces that prevented the subject's explicit recognition or categorization of the emotion expressed. Based on the previous evidence, we predicted that faces with emotional expressions would modulate the ERP waveforms over posterior temporal sites (T5 and T6) within a time range of 200–400 ms. We also conducted the independent component analysis (ICA), a new approach to linear decomposition [19] which can extract functionally independent components that contributed to the emotional visual processing, their time course and scalp topography, to understand underlying neuro-cognitive mechanisms [20].

SUBJECTS AND METHODS

Subjects: Twelve right-handed normal volunteers (seven females and five males) ranging from 19 to 24 (mean 22.8) years of age with normal or corrected-to-normal visual acuity participated in the experiment after giving informed consent.

Stimuli: The stimuli were grayscale photographs of seven individuals' faces from a standard set [21] depicting fearful, happy, and neutral expressions. There were two levels of intensity (100 and 140%) for the facial expressions of fear and happiness for each individual face, and one level (100%) for the neutral expression, all of which were produced by computer morphing [22]. To gain averaging numbers of the ERP, however, these two condition levels were combined together.

Procedure: Experiments were conducted in a chamber room. The stimuli were presented on a 17-inch PC monitor (Flex scan, T550). The subject was comfortably seated with her/his head supported by a chin-and-forehead rest, 0.57 m from the CRT monitor. The resulting visual angle of the stimulus was $11.1 \pm 7.6°$. There were four presentations of each stimulus for fearful and happy expressions and eight presentations for neutral expressions, making a total of 84 trials (with 28 trials each being fearful, happy, and neutral) for each subject. The stimuli were presented in random order.

Subjects were instructed to specify the gender of the presented faces by pressing one of two buttons with their forefinger. This task ensured the subjects' attention to stimuli and prevented the explicit recognition or categorization of the emotional expressions. *Post-hoc* debriefing confirmed that the subjects were not aware that the investigation of emotional variable was the purpose of the experiment.

In each trial, the stimulus was presented for 100 ms in central vision. A short tone as a warning signal preceded the stimulus presentation for 1000 ms. The response panel was presented with a 1000 ms delay after the stimulus onset until the subject finished the response. The subjects were instructed to wait without giving any response until presentation of the response panel, and also requested not to blink until then. The intertrial intervals were randomly changed from 2000 ms to 5000 ms. To avoid habituation and drowsiness, subjects had a short rest when the trials were half finished. Before data collection, subjects were familiarized with the procedure through a block of 10 training trials.

ERP recording: ERPs were recorded from 14 scalp sites according to the international 10-20 system (Fp1, Fp2, C3, C4, P3, P4, O1, O2, F7, F8, T5, T6, Fz, and Pz) using Ag/AgCl electrodes. All scalp electrodes were referenced to the nose tip. A ground electrode was placed on the forehead. Impedances were balanced and maintained below 15 kΩ. Data were sampled by an amplifier (NEC, Synafit 1000) for 1000 ms at 256 Hz (40 samples for the prestimulus baseline) through a bandpass of 0.01–30 Hz. Vertical and horizontal electro-oculograms (EOGs) were simultaneously recorded from bilateral electrodes (horizontally from the outer canthi of both eyes; vertically above and below the right eye).

Independent component analysis: The ICA was conducted using Psychophysiological Analysis Software (version 3.3) provided by the Computational Neuroscience Laboratory of the Salk Institute, California, implemented in MATLAB version 5.3 (Mathworks). The ICA allows for blind source separation of a linear mixture of source in the electroencephalogram those are spatially fixed and temporally independent [23]. Components were determined using a neural network to train unmixed weighted matrices that maximize the joint entropy between the nonlinearly transformed channel data [23]. In the present study, ICA was conducted twice. First, the single trial data of each subject was analyzed for the purpose of artifact rejection. It has been confirmed that ICA is one of the most effective methods of separating a wide variety of artifacts (e.g. eye movement, eye blinks, and muscle noise) from ERPs [24]. Second, the averaging data of all subjects were analyzed to extract functional components. It has been shown that this analysis can decomposite the ERP data into the activities of functionally distinct brain systems [20].

RESULTS

Behavioral performance: Performance of the gender classification task was close to perfect (correct identification rate 98.2%). ANOVA using repeated-measures revealed that there was no difference between facial expressions either on the accuracy or the reaction time ($F(2,20) = 0.75$, n.s.; $F(2,20) = 1.78$, n.s.), respectively.

ERP structure: Figure 1 shows grand averaged ERP waveforms elicited by faces with each expression arranged in relative locations on the scalp. Viewing the posterior temporal sites T5 and T6, there were prominent peaks at about 230 ms (P230), 270 ms (N270), 330 ms (P330), 400 ms (N400), and 500 ms (P500) after the stimulus onset. As our time zone of interest and region of interest, in the earlier time range of 200–400 ms, and in the posterior temporal sites T5 and T6, differences of peak amplitudes between emotional (fearful and happy) and neutral were found to be evident at N270 in these posterior–temporal sites. For these components, the peak amplitudes were analyzed by ANOVA with repeated-measures for Emotions (fear, happiness, and neutral) and Locations (T5 and T6). The results showed that N270 (identified in the 240–300 ms range) had a significant main effect on emotions ($F(2,22) = 4.97$, $p < 0.05$). Follow-up analyses using Dunnet methods indicated that the N270 amplitudes in response to both fearful and happy faces were significantly larger than those in response to neutral faces (Fig. 2). For the N400 (identified in the 350–430 ms range), the main effects of emotion and location were only marginal ($F(2,22) = 2.87$, $p < 0.10$; $F(1,11) = 4.41$, $p < 0.10$), and follow-up analysis did not show any significance (all $p > 0.10$). For the other three components, the P230 (identified in the 200–260 ms range), the P330 (identified in the 290–360 ms range) and the P500 (identified in the 450–510 ms range) did not show any significant effects (all $p > 0.10$).

The 3D topographic scalp distributions of N270 (at 274 ms latency) for each emotional expression are shown in Fig. 3. The negative shifts for emotional faces covered a broader range at posterior visual areas than did those for neutral faces.

ICA component: The first eight components extracted by the ICA accounted for 83.6% of the ERP variance, and there was a component that showed clear corresponding time activation with the N270 (the fifth independent component, which explained 7.7% of the variance). Figure 4 shows the topographic distribution (top left) and projected time envelopes of some representative electrodes (right; realized by multiplying the corresponding time activation by the inverse matrix) of this component. When viewing the time envelopes, it was shown that this component had large triphasic activation within 200–400 ms after stimulus onset and the differentiation between emotions was realized at about 270 ms. Statistical analysis for the time activation of this component confirmed the correspondence with the

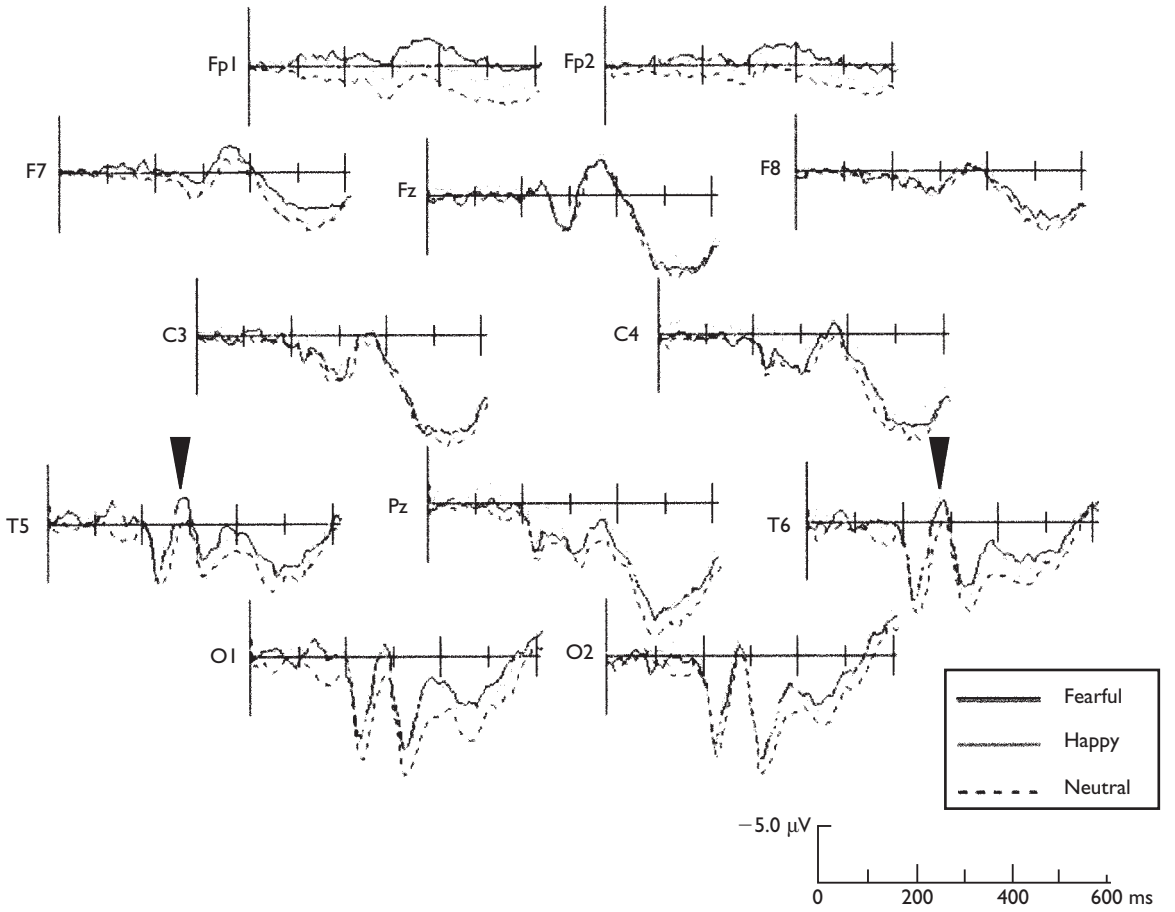

Fig. 1. Grand averaged ERP waveforms after the first pass of the ICA elicited by the faces with fearful (solid line), happy (dotted line) and neutral (dashed line) expressions. Note that there are differences in the amplitude of the negative peak between emotional (both fearful and happy) and neutral faces around 270 ms at posterior temporal sites T5 and T6 (arrowheads).

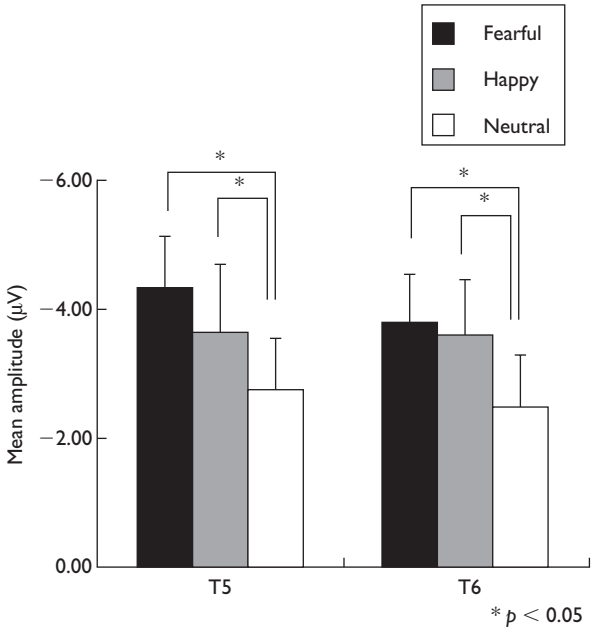

Fig. 2. Mean (with SEM) amplitudes of posterior temporal N270 in response to each expressions (fearful; happy; neutral). Multiple comparisons showed significance between emotional expressions and neutral expression.

proto N270: the multiple comparisons using Dunnet's method (one-tailed, $p < 0.05$) revealed that the amplitudes of this N270 corresponding peak (identified within the 240–300 ms range) for both fearful and happy faces were significantly larger than those for neutral faces. Additionally, the topographic scalp distribution and the time courses of some electrodes show that the corresponding posterior N270 activity showed synchronized positive activity at the frontal–midline electrode.

DISCUSSION

In the present study, we could clarify the temporal organization of the high activation of the extrastriate areas to emotionally charged stimuli by recording ERPs and analyzing them by the ICA technique. The results showed that emotional faces elicited greater negativity than neutral faces over the posterior temporal sites with a latency of about 270 ms after stimulus onset. Because the current task was implicit to emotionality and did not require the subjects to focus on the emotional content of stimuli, we could exclude the possibility that the results were attributable to a voluntary attentional effect to the emotional stimuli. These results were in overall agreement with the previous ERP studies [15,16]. The highly consistent results, also obtained from other experiments using different tasks and subjects, suggests that this activation of visual areas to the emotionally charged stimuli share a common neural substrate, excluding a possibility of inadvertent artifacts of the stimuli.

The current results provide convergent evidence with previous neuroimaging studies. First, like the current N270 potentials, previous neuroimaging studies have found that both negative and positive stimuli elicited the higher activation of the visual areas relative to the neutral stimuli [3]. Second, and again like the current N270 topographic distributions, previous neuroimaging studies have found that emotional visual area activation covered a broad range of the occipito temporal cortices [5]. Taken together, the present results confirmed the temporal organization of enhanced visual area activity in response to emotional stimuli. This activity has been reported by many previous imaging studies, and its influence is realized during the early stage of visual processing at about 270 ms after stimulus onset.

Using the ICA, we could extract the functional component corresponding to proto N270 activity. This component showed intense activity between 200 and 400 ms after stimulus onset and the differentiation between emotions was realized at about 270 ms. It is interesting to note that this component not only had posterior negative peaks but also had front–midline positive peaks. Midline specific topography and positive polarity suggest that the generator of this component was located in the limbic systems. The emotion-specific activity in the limbic system that synchronized with the enhanced activity of the posterior visual areas concurs with the previously proposed mechanism that this enhanced neural activity would be implemented by the amygdalar re-entrant projections [9]. Taken together, the present result using the ICA may indicate that the dynamic linkage between the visual areas and amygdala occurs about 200–400 ms after stimulus onset and the visual area activation as a result of the amygdalar emotional analysis is implemented at about 270 ms, through direct projection to the visual areas.

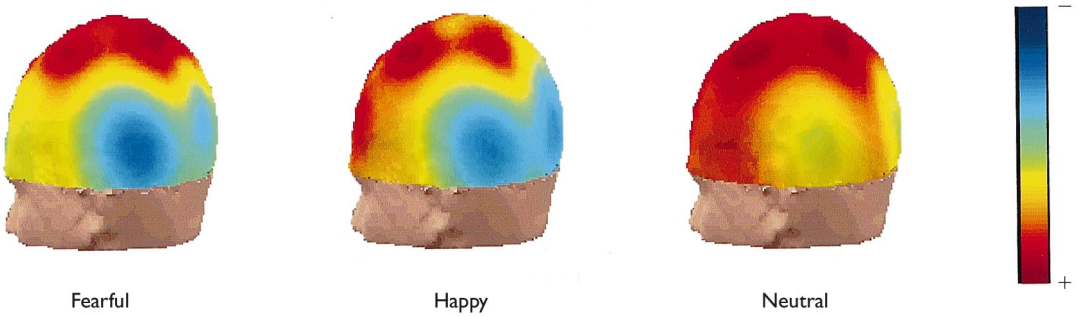

Fig. 3. The 3D topographic scalp map for facial stimuli with fearful, happy and neutral expressions at 274 ms post-stimulus. All scalp maps are shown with the same relative scales as indicated in the color bar on the right. Note that the negative shifts for the faces with emotional expressions cover broad range at posterior visual areas in comparison with those for the neutral faces.

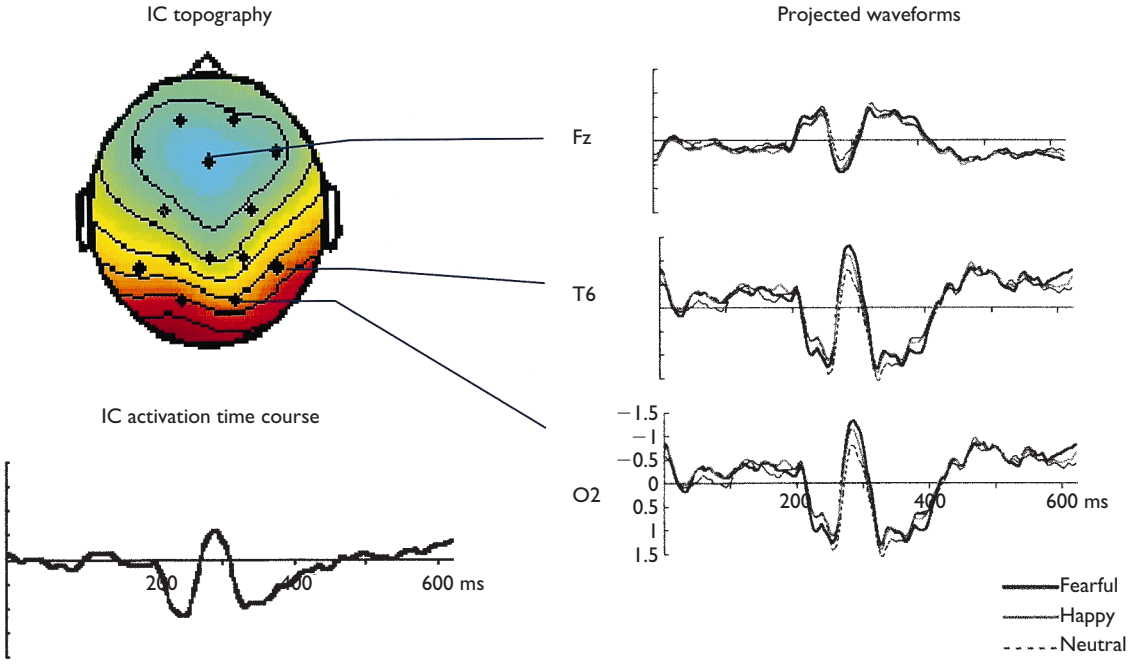

Fig. 4. Scalp topography (top left), activation time course (bottom left), and the projected waveforms of some electrodes (right) of the N270 correspondent component decomposited by the ICA algorithm. The color saturations of the topography encode the strength of this component and the color hues represent the relative directions of voltage polarity (i.e. dose not always correspond to the signs of actual voltage). Note that there was a temporally synchronized activity at the frontal-midline electrode with the posterior visual area activity. Multiple comparisons showed that the amplitudes of the N270-corresponding peaks of this component for both fearful and happy faces were significantly larger than those for neutral faces.

Given that the enhanced activity in the visual areas is implemented by the amygdalar re-entrant projections, the latency of about 270 ms is thought to be plausible. First, regarding the initial face recognition processing in the extrastriate cortex, recent scalp and intracranial recordings in humans have shown that a face-specific activity with a latency of about 170–200 ms (the ambiguous negative peak at around 190 ms in the present study would correspond to this face processing potential) performs the configuration analysis of the face [25]. Second, as for the amygdala activity, human intracranial recording has indicated that the simple auditory stimuli elicit the amygdala activity with a peak latency of 200 ms [26]. Therefore, it would be plausible that the amygdala implements emotional analysis of the complex visually presented objects with the current latency of about 270 ms.

What might psychological correspondence with the current physiological phenomena be? The current results indicated that emotional facial expressions induced relatively greater activation of the posterior temporal areas, with a latency of about 270 ms from stimulus onset. As for the scalp topography, human lesion studies have shown that lesions of specialized cortical areas impair the phenomenal perception [27]. Regarding the time latency, single unit recordings in monkeys revealed that the 200–300 ms activity of face selective neurons in the temporal cortex are decreased by backward masking, which interferes with conscious perception of the faces in human subjects [28]. Taken together, the extrastriate activation in response to emotional stimuli reported here with a latency of about 270 ms may enhance perceptual awareness of the stimuli. Natural selection may have implemented for the human being this survival-appropriate system that facilitates detection of emotionally charged stimuli.

CONCLUSION

We investigated ERPs while subjects were viewing static grayscale images of faces with emotional (fearful and happy) or neutral expressions. The result demonstrated that the faces with emotional expressions (both fear and happiness) boosted an earlier negative component at about 270 ms (N270) over posterior temporal sites. The topographic distribution of the N270 for the emotional faces covered a broad range of posterior visual areas. ICA of ERP data suggested that this posterior N270 showed synchronized positive activity at the frontal–midline electrode. These findings prove that an emotional signal boosts early visual processing of the stimuli. This enhanced activity might be implemented by the amygdalar re-entrant projections.

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