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Research report

Early processing of the six basic facial emotional expressions

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Abstract

Facial emotions represent an important part of non-verbal communication used in everyday life. Recent studies on emotional processing have implicated differing brain regions for different emotions, but little has been determined on the timing of this processing. Here we presented a large number of unfamiliar faces expressing the six basic emotions, plus neutral faces, to 26 young adults while recording event-related potentials (ERPs). Subjects were naive with respect to the specific questions investigated; it was an implicit emotional task. ERPs showed global effects of emotion from 90 ms (P1), while latency and amplitude differences among emotional expressions were seen from 140 ms (N170 component). Positive emotions evoked N170 significantly earlier than negative emotions and the amplitude of N170 evoked by fearful faces was larger than neutral or surprised faces. At longer latencies (330–420 ms) at fronto-central sites, we also found a different pattern of effects among emotions. Localization analyses confirmed the superior and middle-temporal regions for early processing of facial expressions; the negative emotions elicited later, distinctive activations. The data support a model of automatic, rapid processing of emotional expressions.

Theme: Neural basis of behavior

Topic: Motivation and emotion

Keywords: Event-related potential; Facial expressions; Emotions; Implicit processing

1. Introduction

Facial expressions are a means of communication that are more rapid than language, with which people can quickly infer state of mind of their companions. Facial expressions allow a group to easily understand the opinions and attitudes of the others, thus constituting a powerful tool in social coordination. Basic facial expressions of emotion are universal; Ekman and Friesen [13] reported that six (anger, happiness, fear, surprise, disgust and sadness) are readily recognized across very different cultures.

Converging neuroscience studies have demonstrated that particular brain regions are implicated in the processing of faces [3,43] such as the fusiform gyrus and superior temporal sulcus. Selective impairments in recognizing facial emotions without a deficit in facial identity [26], and conversely [9], have been reported indicating that different aspects of faces are processed in separate neural subsystems. A number of studies using imaging techniques have also investigated these two aspects of face recognition in humans, and suggested a spatial and temporal dissociation in the processing of identity and emotion [37,45]. Further separation of neural networks has been demonstrated for processing specific facial emotions, with the implicated regions including cortical (prefrontal, frontal and orbito-frontal cortices, occipito-temporal junction, cingulate cortex and secondary somatosensory cortex) and subcortical structures (amygdala, basal ganglia and insula) [12,16,24,28,47]. The amygdala has often been linked with processing fearful faces [2,35,51] and sad faces [6,44], while the cingulate sulcus is activated by happy faces [24,39] and the orbital frontal regions by angry faces [6]. Disgust seems to activate preferentially basal ganglia and

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insula [11,40]. Most of the above studies offer evidence of a dissociation as well as an overlapping of the cerebral structures involved in processing different facial emotions.

The important aspect of the speed with which facial emotions are processed has only recently been investigated neurophysiologically (e.g. [47]). Using event-related potentials (ERPs), several studies have found differences between emotional and neutral faces at 250–500 ms in occipital areas, and among different facial affects after 450 ms (e.g. [25,37]). Others have found some differences between positive and negative emotional affect around 110 ms [19,41]. The N170 ERP component has been shown to be particularly sensitive to faces, being a reliable index of early stages of encoding of facial features and configurations [5,20,22,32,42,49].

However, few studies have examined the range of basic emotional expressions or distinguished possible differential spatio-temporal activation as a function of the emotions. ERPs should allow clear indication of any timing differences among the various emotions, as well as aiding in the spatio-temporal localization of the emotions. Although a number of studies have shown activation in specific brain regions that differ depending on the emotion, the timing of this activation has not been shown, although it is included in the elegant model proposed by Adolphs [1]. Furthermore, few have employed a large number of faces to avoid the problem of habituation [7,14], which greatly diminishes recorded effects. Here we investigated the implicit processing of neutral and emotional faces, using all six basic emotions (see Fig. 1), with a large number of unfamiliar faces. We hypothesized that processing emotions starts very early and that the different emotional expressions would be processed with different timing and in different brain regions, consistent with other neuroimaging studies (e.g. [34,36,40,45]). Early ERPs were analyzed in 26 young adults in order to determine the speed of processing emotions; ERP source analyses were conducted to obtain spatial localization of the processing, which could then be linked with extant neuroanatomical models.

2. Material and methods

2.1. Participants

Twenty-six subjects with normal or corrected to normal vision were tested: 13 males (10 right-handed) and 13 females (12 right-handed), 21–32 years of age (M=24.6 years). All subjects provided informed written consent prior to participation in the study, which was approved by the 'Comité Opérationnel pour l'Ethique dans les Sciences de la Vie' of the CNRS.

2.2. Stimuli and task

Black and white photographs of the faces of about 100 adults were taken specifically for this study. They were trained to adopt the six basic emotional expressions described by Ekman and Friesen [13] as well as neutral faces. The resulting set of 1300 photographs was shown in randomized order to a group of 20 subjects (10 males and 10 females, who did not subsequently participate in the ERP experiment), who classified the emotions expressed in each photograph; 210 of the photographs that were categorized as the same expression by at least 18/20 subjects (≥80%) were used in the ERP task. Fig. 1 presents examples of facial stimuli used.

The protocol consisted of three blocks presented twice in a random order. Each block contained 70 different facial stimuli, 10 of each expression, five male and five female, and 15 non-facial stimuli (cars, planes or butterflies, depending the block). All photographs were 11×8 cm; the mean luminance was equal across expressions. Stimuli were presented on a light gray background on a computer

Fig. 1. Examples of the 210 faces used in this study, expressing the seven basic emotional expressions (sadness, fear, disgust, anger, neutral, surprise and happiness). All of the faces used were correctly classified by emotion by at least 80% of 20 observers (who did not serve as subjects in the experiment).

screen 50 cm in front of the subject for 500 ms with a random ISI of 1200–1600 ms.

Subjects were comfortably installed in a chair and were told that they would be shown a series of photographs and to respond with a mouse-click to the target stimuli (cars, planes or butterflies, depending on the block). They were naïve with respect to the specific questions investigated. The task was to ensure that subjects attended to the stimuli.

2.3. Electrophysiological recording and analysis

ERPs were recorded from 32 scalp electrodes in an *EasyCap* according to the international 10–10 system. An average reference montage was used, with Cz used as the reference during recording; the average reference was calculated off-line. Impedances were maintained below 5 kΩ. EEG was sampled by *SynAmps* for 1100 ms, with 100 ms pre-stimulus at 500 Hz with a band-pass of 0.1–30 Hz. Vertical and horizontal EOG were simultaneously recorded with electrodes at the outer canthi and the superior orbital ridge. Trials contaminated with ocular activity greater than ±90 μV were rejected before averaging. Trials were then averaged according to the emotion expressed by the faces.

Early components (P1, N170) were measured at the electrodes where they were most prominent. P1 was measured at O1, O2, PO9, PO10; N170 was measured at P7 and P8. Latencies were taken at the electrode where amplitude was maximal over each hemisphere, and amplitudes were measured at this latency on other electrodes over the hemisphere, as recommended in international ERP guidelines [41]. To assess slower fronto-central activity, mean amplitudes were measured in six 30-ms time windows from 270 to 450 ms at Fz, F3, F4, Cz, C3, C4, Fc5 and Fc6. The data were submitted to repeated measures ANOVAs. Type I errors associated with inhomogeneity of variance were controlled by decreasing the degrees of freedom using the Greenhouse–Geisser epsilon. The probability estimates were based on these reduced degrees of freedom; the corrected degrees of freedom are given in the text. The data were analyzed as a function of emotion and sex, and for P1 and N170 amplitudes also as function of hemisphere, with post-hoc tests using Bonferroni statistics.

For the localization of the intracranial generators of the ERP data, we used LAURA, part of Cartool software (D. Brunet, Functional Brain Mapping Lab., Geneva, Switzerland), which uses a linear inverse solution, capable of dealing with multiple simultaneously active sources. This local autoregressive average solution based on interpolation formulas uses a realistic model of the head constructed based on an average brain of 152 MRIs provided by the MNI [17]. A recent review paper demonstrates the application of LAURA to sensory and cognitive ERP data [33]. We applied the inverse solution to the periods corresponding to the time range measured in the ERPs, to estimate the brain areas activated during the various processing periods.

3. Results

3.1. Electrophysiological data

Early stages of processing were assessed by measures of the P1 and N170 ERP components, previously shown to be differentially sensitive to faces [5,20,22,29,49], maximal over posterior temporal–occipital regions. P1 had a mean latency of 94 ms (Fig. 2a), which did not vary with facial expression. For P1 amplitude there were main effects of electrode ($F_{1,24}$=22.3, P<0.0001) and hemisphere ($F_{1,24}$=4.8, P<0.04), as P1 was larger medially, and larger over the right hemisphere. An effect of emotion was seen ($F_{3.6,85.7}$=3.001, P<0.03), as neutral and surprised faces had the smallest P1 amplitudes, although post-hoc analyses did not reveal differences between any two emotions (Fig. 2b).

The N170 latency, here seen around 140 ms (Fig. 2c), varied with emotion ($F_{3.5,82.8}$=5.3, P<0.001) as N170s to faces expressing fear, disgust and sadness were longer than N170s evoked by neutral (P<0.05), happy (P<0.006) and surprised faces (P<0.02; Fig. 2e). There was also an overall effect of emotion on N170 amplitude ($F_{4.1,97.7}$=4.4, P<0.003), driven by a larger N170 to fearful faces than to neutral (P<0.001), happy (P<0.006), disgusted (P<0.005), surprised (P<0.004), sad (P<0.002), and angry faces (P<0.04); Fig. 2d). There were no sex or hemisphere effects on N170.

As several previous studies have seen effects of emotional expressions only centrally and at longer latencies, we also measured fronto-central mean amplitudes from 270 to 420 ms. An effect of emotion was found, largest from 360 to 390 ms ($F_{4.7,116.7}$=4.97, P<0.001); the preceding and following 30-ms windows had the same pattern of results, but less marked (P values of 0.02 for each). Mean amplitude was largest for neutral faces; angry faces were significantly smaller (P<0.016) with a trend for smaller responses for disgusted and fearful faces (P<0.058 and 0.073, respectively) (Fig. 3).

3.2. Source analyses

Source analyses (using LAURA [33]) were conducted across the time range where the ERP components were measured (80–450 ms). We found the most prominent and persistent activation bilaterally in the superior temporal and the middle temporal gyri (Fig. 4), having the highest values at the P1 and N170 latencies across emotional expressions. From 220 to 350 ms, this activity was larger on the right for all emotions except for anger, while from 350 to 400 ms the activity was larger in left than right

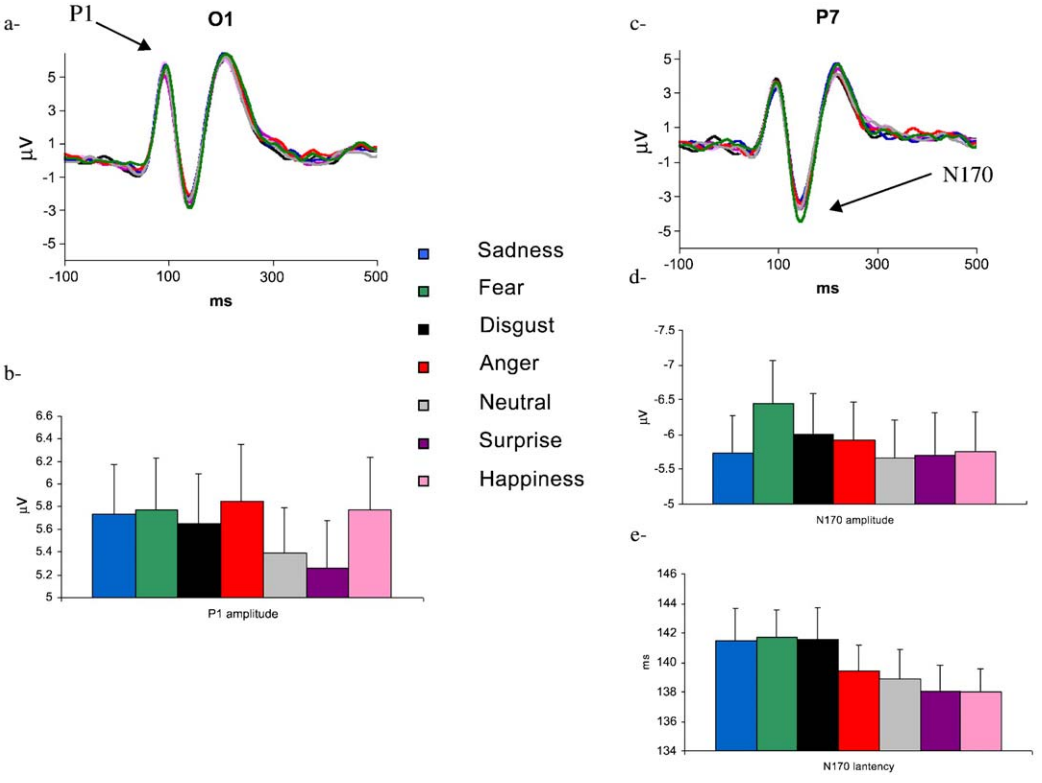

Fig. 2. Grand averaged ERPs for all emotional expressions from an occipital site where the P1 component was maximal; (b) mean amplitudes of the P1 component to the different facial expressions, showing the smaller amplitude to neutral and surprised faces; (c) grand averaged ERPs from a posterior–temporal electrode (P7) showing the N170 overplotted for all the emotions; (d) mean N170 amplitudes with the largest responses seen for fearful faces; and (e) mean N170 latencies showing the longest latencies for sad, fearful and disgusted faces.

temporal regions except for angry and sad faces. After 400 ms, temporal activity diminished, while anterior activity increased.

The source analyses showed other brain regions activated differently for the basic emotional expressions. Around 350 ms, disgusted and sad faces activated the left lingual gyrus. For disgust, this activity persisted until 400 ms, at which latency fearful faces also activated the lingual gyrus. The right lentiform nucleus in the basal ganglia was activated for angry, neutral and sad faces around 350 ms. At 450 ms source analyses showed frontal activity in the superior and middle frontal gyri and to a lesser extent in the inferior frontal gyrus, essentially in the right hemisphere that was largest for disgusted, fearful and neutral faces.

4. Discussion

The presentation of faces expressing the six different emotions produced significant effects starting at the P1 component (94 ms). Fifty milliseconds later (at a mean latency of 140 ms) the N170 showed both amplitude and latency modulation differentially with emotional expressions. Both of these components were at shorter latencies than seen traditionally [5,19,29] including our own previous studies [22,49], although the variability of the N170, for instance, is considerable, ranging from 140 to 220 ms in the literature. Whether this is due presently to low-level stimulus factors or to the use of emotional faces is still to be determined. A number of studies have shown early effects with configural changes to face stimuli [20,22,29,30,49], reflecting encoding processes starting at the P1 latency, and have suggested that P1 reflects global processing of face stimuli. The present data expand this to include early processing of the emotional expression of the faces. These effects were not due to stimulus factors, which did not vary across emotional categories, nor due to configuration, as surprised and fearful faces have a similar configuration (open mouthed, wide-eyed) yet the ERPs to these two types of faces presented differences in latency and amplitude. As the task did not require the subjects to focus on particular emotional expressions, the possibility that these results are attributable to directed attention is unlikely. Thus, these data suggest an early automatic encoding of emotional facial expressions. The differences in impact of the emotional expressions on the P1 and N170 are consistent with these components indexing separate stages of face processing [22,29,30,49]. The timing lag between the P1 and the N170 is the same as seen in the impressive study of Sugase et al. [48], where they found temporal lobe neurons in monkeys responding first to

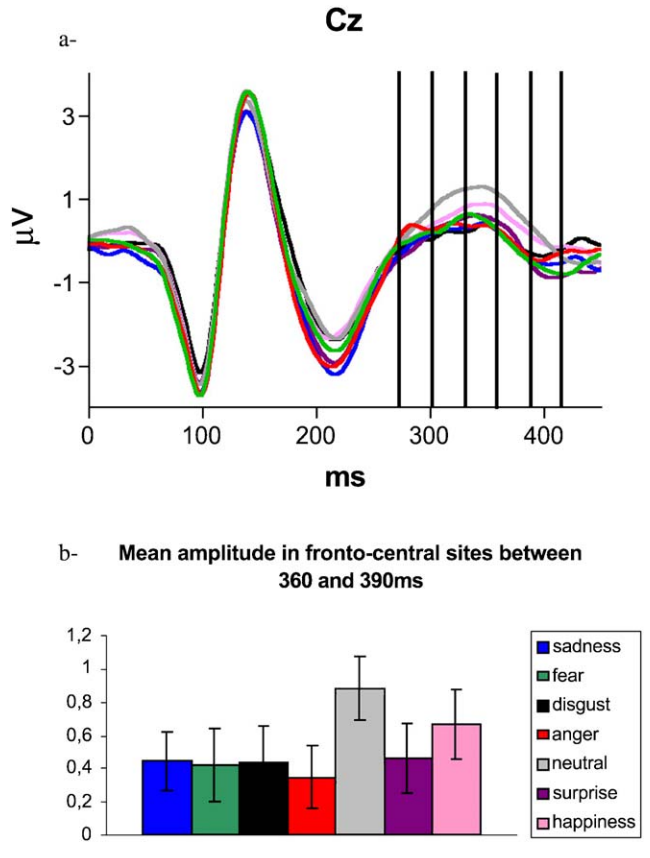

Fig. 3. Grand averaged ERPs by emotion at Cz with the time windows in which the mean amplitudes were measured at fronto-central sites indicated by the vertical lines; (b) mean fronto-central amplitudes showing the discrimination of neutral versus emotional faces.

global characteristics of faces and 50 ms later showing effects of identity or expression. This rapid processing with feedback fits well with recent models of visual processing [10], and visual evoked potential studies in humans [15].

An early ERP differentiation between neutral and emotional faces (or faces judged to have a positive vs. negative affect) has been reported between 110 and 250 ms, depending on the study [25,31,42]. For example, Pizzagalli et al. [42] found the earliest difference between liked and disliked faces as punctate effects at two electrode sites around 112 ms, while Marinkovic and Halgren [31] found

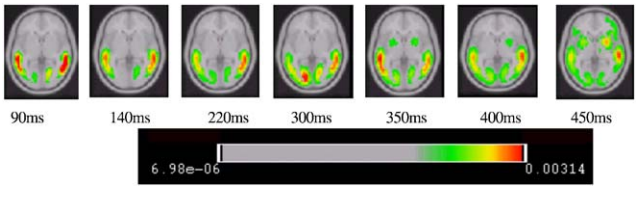

Fig. 4. Results of the LAURA localization analyses, over-plotted on an averaged MRI scan for the faces expressing anger. Note the persistent activation of the lateral temporal brain, localized to the superior and medial temporal regions. Only by 350 ms was there anterior activation, generally larger for the negative emotions and larger on the right.

an effect of neutral versus emotional faces on the frontal P170. These studies did not find early effects dependent on separable, individual emotions.

Effects specific to particular emotional expressions have been seen, however, at longer latencies, from 400 to 750 ms [25,31,37]; it was argued that this was consistent with modularity in face processing, wherein faces were encoded and identified, prior to processing of facial emotion [37]. However, the model of Bruce and Young [8] shows processing of facial expression occurring coincidentally with other encoding stages, consistent with the present data. These differences among studies could be due to task differences, which could mask individual emotion effects, or due to habituation, as most studies have used only a few faces, shown repeatedly to subjects, without considering the effects of habituation [7,14]. In contrast to the above studies, we found the slower frontal activity was not as sensitive to emotional expressions as was the N170. The late frontal activity differentiated primarily neutral from other faces, suggesting an underlying frontal processing negativity for emotional expressions, particularly the negative emotions anger, disgust, and fear.

There are several models as to how the early visual processing can be modulated by the emotional signal of the stimuli. Morris et al. [34] suggested two parallel visual pathways, associated with different levels of conscious awareness: a cortical and a subcortical pathway. The latter, a colliculo-pulvinar–amygdala pathway, would be faster and could facilitate the cortical pathway with the precise identification of the stimulus. They demonstrated enhanced activity in the extrastriate cortex for emotional stimuli that correlated with activation in the amygdala [36]. Similar models propose that the amygdala sends re-entrant projections to all levels of the visual processing stream, thus modulating visual cortices as a function of the emotional content of the stimuli [4] or that rapid activation of the basal forebrain regions would tune subsequent activity in the visual cortices subserving face processing [42].

Previous studies showed early effects of positive versus negative affect, information that may be extracted rapidly from presented stimuli. We found that the six basic facial emotional expressions are also processed very quickly suggesting that facial details, reflecting emotional content, are included in this rapid processing. N170 evoked by negative emotions (fear, disgust and sadness) was later than the N170 to neutral and positive emotions (happy, ‘good’ surprise). This seems counter-intuitive—that the negative expressions that may signal danger have slower N170 latencies. However, if a subcortical pathway is activated for negative emotions, sending information rapidly to different levels of the ventral pathway [1], then N170 latency may be later for these emotions due to including information arriving from the subcortical processing. As N170 evoked by fear was also larger than N170 evoked by other emotions, this implies that the subcortical feedback loop may also activate a larger underlying neuronal

network. Alternatively, this could be a result of unconscious mobilisation of attention (e.g. [52]), which can also produce larger amplitudes or an enhancement of perceptual processes [50,51]. There is recent discussion in the literature as to whether emotional expressions capture attention automatically or require allocated attention to be processed [38,51,52]. The present data do not deal explicitly with this question, but certainly show that without intentionally directing subjects' attention to the emotional expressions of the facial stimuli, these basic expressions were nevertheless processed differentially.

There were no subcortical sources shown to be active in the early processing periods (before 140 ms), perhaps due to the insensitivity of ERPs to deep, transient sources. Thus, of the proposed fast forward sweep of information from the visual and temporal regions through to the amygdala and orbital frontal regions [1], only a posterior aspect was measured over the occipito-temporal regions as P1. The reason we found inferior and subcortical sources later (after 320 ms) could be due to a more extensive activation, spatially as well as temporally, at those time periods.

The activation of the middle and superior temporal regions from 140 to 400 ms is in accordance with social perception, face-processing models, which show these brain areas to be involved in several different aspects of social face processing [1,3]. As this area is particularly sensitive to human and facial movement [3], it is a prime candidate for processing facial expression. The extended duration of the activity in the STS region suggests repeated activation (as shown by others [1,47]) likely due to encoding as well as recognition and/or retrieval processes [27].

Despite having an implicit emotional perception task [34] our data suggested right lentiform nucleus activation for angry, neutral and sad faces, consistent with others who have found the basal ganglia implicated in emotional tasks [16,28,34] and in clinical series [11,46]. For disgusted, sad and fearful faces, activation was located in the left lingual gyrus, similar to results from PET studies [27,45,50], particularly for negative emotions [50]. This latter study further suggested that the lingual gyrus was involved in the recognition of salient negative images; this implies that faces are automatically salient, as we found sources localized to this region with an implicit task. In contrast, the localization analyses did not reveal any activity of the amygdala even for fearful faces, although the amygdala is traditionally linked with processing fearful expressions or emotions [2,35]. Recent reports have found that the amygdala is not necessarily engaged whenever emotional stimuli are processed [12,18,21]. Thus, either the amygdala was not activated in this implicit task, or because of its deep location, amygdala activation was not visible using these source analysis, ERP methods. As seen in other neuroimaging studies positive (happy and surprised) or neutral faces did not show localized activity; perhaps the positive emotions are less salient or critical from an evolutionary point of view.

Studies of patients with brain injuries proposed the ventral and inferior frontal area as a main candidate in expression recognition processes in human [23], which is activated with an expression recognition task [47]. Sprengelmeyer et al. [46] have shown that separate neural systems are used for the recognition of disgust, fear and anger, and the output of these systems converge on the frontal areas for further processing. Here, we found very little frontal activation, although its late appearance is consistent with other studies (reviewed by [1]); this frontal activity apparently reflects cognitive processes such as explicit retrieval and recognition, not necessary in our task.

In conclusion, these data, in light of the extant literature, would suggest that the earliest P1 effects were due to rapid global processing of the facial stimuli, which nevertheless started to differentiate among the different emotional expressions. The second stage of early processing may be influenced by rapid feedback projections to cortical areas, yielding slightly slower but more detailed cortical processing that allows differentiation of the basic emotions. What is remarkable is that this is occurring by 140 ms. The source analyses showed continued activity for 300 ms in the superior and medial temporal regions, underlining the importance of these brain areas in processing facial expressions. The later activity showed more specific localization for the different emotions, supporting separate neural networks for processing the negative emotional expressions. Subcortical activity may be more evident in an explicit recognition task [16]; its presence in the present study suggests the automatic recruitment by emotional stimuli.

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