Processing the Trees and the Forest during Initial Stages of Face Perception: Electrophysiological Evidence

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Abstract

■ Although configural processing is considered a hallmark of normal face perception in humans, there is ample evidence that processing face components also contributes to face recognition and identification. Indeed, most contemporary models posit a dual-code view in which face identification relies on the analysis of individual face components as well as the spatial relations between them. We explored the interplay between processing face configurations and inner face components by recording the N170, an event-related potential component that manifests early detection of faces. In contrast to a robust N170 effect elicited by line-drawn schematic faces compared to line-drawn schematic objects, no N170 effect was found if a pair of small objects substituted for the eyes in schematic faces. However, if a pair of two miniaturized faces substituted for the eyes, the N170 effect was restored. Additional experiments ruled out an explanation on the basis of miniaturized faces attracting attention independent of their location in a face-like configuration and show that global and local face characteristics compete for processing resources when in conflict. The results are discussed as they relate to normal and abnormal face processing. ■

INTRODUCTION

Configural processing is considered a hallmark of normal face perception in humans (e.g., McKone, Martini, & Nakayama, 2001; Tanaka & Sengco, 1997; Hosie, Ellis, & Haig, 1988; Rhodes, 1988; Haig, 1984; see a review in Farah, Wilson, Drain, & Tanaka, 1998). However, there is ample evidence that face components are processed independently during face recognition and play an important role in face identification (e.g., Cabeza & Kato, 2000; Macho & Leder, 1998). Indeed, most contemporary views posit a dual-code according to which face recognition relies on the extraction of featural codes, that is, local analysis of individual face components, as well as on the extraction of configural codes, that is, the computation of the spatial relations among the face components (e.g., Cabeza & Kato, 2000; Searcy & Bartlett, 1996). In the present study, we analyzed the N170 face-sensitive event-related potential (ERP) component (Bentin, Allison, Puce, Perez, & McCarthy, 1996) to explore how global processing of the face configuration and local processing of the eyes interact during face categorization and whether global or local face-related information takes precedence when they lead to different initial interpretations of the visual input.

The N170 effect is defined as the considerably larger amplitude of the first visual negative potential (measured at posterior lateral sites) elicited after the onset of a human face compared to other stimulus categories, such as human hands, other animal-faces, watches, birds, items of furniture, tools, houses, and so forth (e.g., Itier & Taylor, 2004; Carmel & Bentin, 2002; Bentin et al., 1996). This effect is more robust (although slightly delayed) in response to face components (particularly to eyes) and to inverted faces than to full, upright faces. Bentin and Golland (2002) and Sagiv and Bentin (2001) suggested that it is associated with an early visual mechanism for detecting face-relevant information. According to this interpretation, the N170 effect should appear whenever the visual stimulus is sufficiently suggestive of a face, whether by its individual (local) shape or by its global spatial configuration. Supporting this hypothesis is the fact that the N170 effect is elicited not only by isolated recognizable face components but also by schematically drawn faces whose individual components are simple marks in the locations of the eyes, nose, and mouth. In the latter case, their face-related value is revealed only by their spatial configuration (Sagiv & Bentin, 2001). Furthermore, previous studies showed that scrambling the

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global configuration of natural face components does not reduce the N170 effect (Zion-Golombic & Bentin, 2006; Bentin et al., 1996). However, it is unknown whether the inverse relationship is also true. Are perceptual decisions based on the global configuration influenced by the shape of its local components? To address this question, we contrasted local and configural processing in face perception when each of these processes leads to a different initial interpretation of the stimulus.

In a seminal study using nonface stimuli, Navon (1977) studied local and global processing by building ''global'' letters using sets of repeated ''local'' letters as building blocks. Faster identification of global than local letters suggested a global processing precedence. Using similar procedures with neurological patients, Robertson and Lamb (1991) described a more complex perceptual mechanism in which the right and left hemispheres are biased to process global or local information, respectively, coordinating their actions and providing different levels of hierarchically organized spatial structures; a separate mechanism combines this information to form a coherent percept (see also Hubner & Volberg, 2004). Whereas initial awareness of global aspects of a stimulus could be the default of the perceptual system (cf. Hochstein & Ahissar, 2002), task, perceiver, and stimulus factors can influence the relative emphasis placed on local or global aspects to influence the overt response (Lamb & Robertson, 1988). For instance, even when only the global pattern of a stimulus is relevant, local information could affect global processing, with global information being brought to awareness later, if at all. In Experiment 1, we directly contrast local- and configural-based interpretations of a stimulus in face-like stimuli.

EXPERIMENT 1

In the present experiment, the most interesting stimuli to address the questions outlined in the introduction were schematic faces in which small-size objects substituted for regular eyes in schematic faces (Figure 1, top row). In addition to the faces with object-eyes, line-drawn objects and regular schematic faces (i.e., faces with meaningless shapes or tokens as eyes) were presented in separate blocks of trials to serve as baseline ERPs for nonface and face stimuli, respectively (Figure 1, middle and bottom rows). Participants pressed a button in response to predesignated targets (schematic drawings of flowers) that occurred only occasionally. If configural-based processing preempts local processing of the objects within the face, we should observe an N170 effect—that is, the visual system should respond to such stimuli just as it responds to normal schematic faces. However, if local processing of the component objects prevails, the object-perception mechanism should be activated and no N170 effect should be observed.

Methods

Participants

The participants were 12 undergraduates from Hebrew University with normal or corrected-to-normal vision. They were paid or participated for course credits and gave signed, informed consent as approved by the internal review board at Hebrew University before testing began.

Stimuli

The stimuli were drawn using computer software. Three types of face stimuli were used (Figure 1): 75 schematic

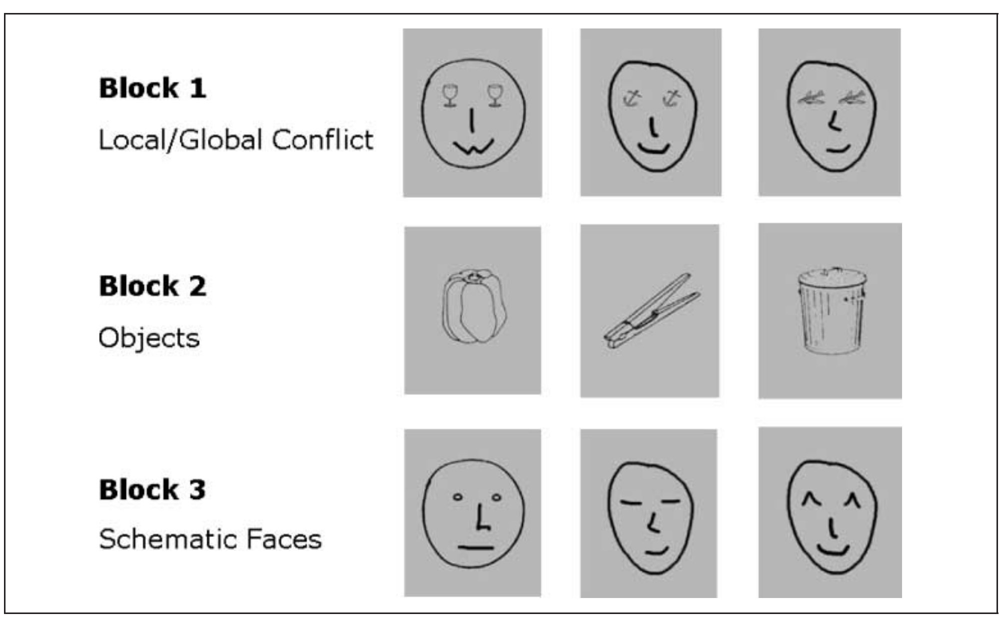


Figure 1. Design of Experiment 1 and examples of stimuli used in all experiments.

faces (faces with meaningless shapes as eyes), 75 line-drawn objects, and 75 faces with object-eyes (configurations of faces in which two identical objects were reduced in size, substituting for the eyes in the schematic faces). In addition, 45 drawn flowers were included as targets in an oddball paradigm (see below). Each stimulus was presented only once in the course of the experiment.

Task and Design

An oddball monitoring procedure was used in which participants were instructed to silently count the number of targets presented in a block of trials and to ignore the other stimuli. Targets were flowers of different kinds, and the different faces and objects were non-targets (distracters) presented in separate blocks of trials. A block contained 9 to 13 targets and 75 distracters, presented in random order.

The blocks were presented in a fixed order, as shown in Figure 1. The blocked presentation and the fixed order (presenting the critical faces with object-eyes as the first block) were adopted so that the resolution of the conflict of local versus configural processing could be examined without a bias induced by possible priming effects that have been previously reported in the literature (Bentin & Golland, 2002; Bentin, Sagiv, Mecklinger, Friederici, & von Cramon, 2002).[1] Previous studies (see also Experiment 5) showed that a block of schematic faces presented prior to ambiguous schematic stimuli biases the interpretation of the ambiguous stimuli as faces.

Procedure

The experiment was run in an electrically isolated and sound-attenuated booth. Following electrode montage and instructions, a few stimuli (including one flower) were presented to familiarize participants with the task and stimuli. The experimental blocks were presented in succession with about 1 min rest between blocks. The stimuli were presented at fixation for 350 msec with a stimulus onset asynchrony of 850 msec and subtended a visual angle of $6.5^\circ \times 8.1^\circ$. During the interstimulus interval, a fixation cross was presented at the center of the screen. The run duration of each block was about 2 min, and an entire run lasted about 10 min.

EEG Recording and Analysis

The electroencephalogram (EEG) was recorded from 48 tin electrodes mounted on a custom-made cap (ECI-Ohio). It was continuously sampled at 250 Hz, amplified at 20 K by a set of SAI battery-operated amplifiers with an analog band-pass filter of 0.1 to 70 Hz, and stored on disk for off-line analysis. The electrooculogram (EOG) was recorded by two electrodes, one located on the outer canthus of the right eye and the other at the supraorbital region of the same eye. Both the EEG and EOG were referenced to an electrode placed at the tip of the nose. Throughout the EEG recording, the electrodes' impedance was kept under 5 kΩ.

Event-related potentials resulted from averaging EEG epochs of 1000 msec starting 100 msec prior to stimulus onset. Average waveforms were computed for each subject separately for each stimulus condition and were digitally filtered with a band-pass of 0.8 to 17 Hz (3 dB/octave). Trials contaminated by EOG and/or EEG artifacts were excluded from the average by an automatic rejection algorithm with a threshold amplitude of ±100 mV. No ERP was based on less than 50 trials.

The amplitude and the latency of N170 were the dependent variables for statistical analysis. This ERP component was defined as the most negative peak between 120 and 210 msec from stimulus onset. Based on our previous studies, only six posterior temporal and temporo-occipital electrode sites were selected for statistical analysis where the N170 is most conspicuous. These sites were P8, IM2,[2] and PO10 on the right hemiscalp and the corresponding sites on the left hemiscalp. For factors that had more than two levels, the Greenhouse–Geisser Epsilon was used to adjust the degrees of freedom.

Results and Discussion

As expected, faces elicited a prominent N170 effect; that is, the N170 elicited by schematic faces (in the third block) was considerably larger than that elicited by objects (in the second block). This effect was most conspicuous over the posterior-lateral temporal scalp. Interestingly, although during debriefing participants reported having seen faces even when objects substituted for eyes, the ERPs showed no N170 effect to these stimuli. In fact, the negative components elicited by faces with object-eyes were almost identical to those elicited by single objects (Figure 2).

The statistical reliability of these differences was confirmed by within-subjects analysis of variance (ANOVA). The factors were stimulus type (faces, faces with object-eyes, and objects), hemisphere (right, left), and site (P7/8, P9/10, IM1/2). The main effect of stimulus type was significant, $F(2,22) = 6.65$, $p < .01$. Post hoc univariate contrasts showed that objects and faces with object-eyes elicited similar N170 amplitudes (−1.44 and −1.54 μV, respectively), both significantly smaller than the amplitude of the N170 elicited by schematic faces (−3.56 μV). Although the N170 amplitude was numerically larger over the right hemisphere (−2.9 μV) than over the left hemisphere (−1.7 μV), the main effect of hemisphere was not significant, $F(1,11) = 1.55$, $p = .24$. The main effect of site was significant, $F(2,22) = 6.32$, $p < .05$. Post hoc contrasts revealed that this effect reflected smaller absolute amplitude sizes at the

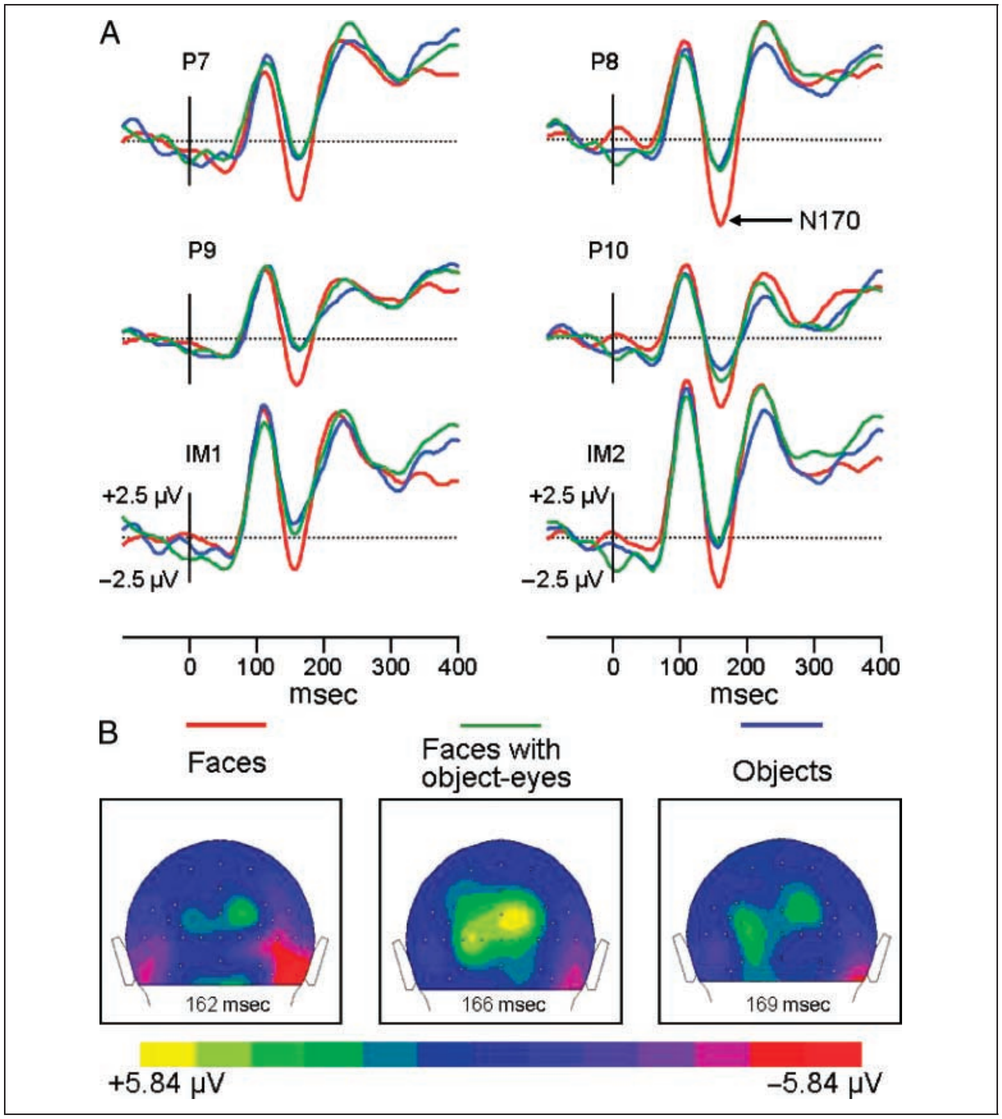


Figure 2. ERPs elicited at posterior-temporal sites by schematic faces, faces with object-eyes and objects (A) and the scalp distribution of the N170 for each stimulus (B). Note the similarity between the N170 elicited by faces with object-eyes and objects.

IM sites (-1.1 µV) than at the P7/8 sites (-3.0 µV). Neither the first-order nor the second-order interactions was significant; all *F* values reflecting these interactions were smaller than or close to 1.00. In order to explore whether similar effects were evident earlier at P1 (mean amplitude between 70 and 130 msec poststimulus onset), we ran an additional ANOVA that included the factor of component (P1, N170) (all other factors and levels were the same as above). A significant Component × Stimulus type interaction, $F(2,22) = 5.2$, $p < .01$, and the absence of stimulus type effects on P1, $F(2,24) < 1.00$, indicated that the effects reported are specific to the N170.

A similar analysis was performed on the peak latency of the N170. The only factor that showed a significant influence on latency was stimulus type, $F(2,22) = 5.99$, $p < .025$. Post hoc contrasts showed that the latency of the N170 elicited by schematic faces (162.5 msec) was shorter than that elicited by objects (169.7 msec), whereas the latency of the N170 elicited by faces with object-eyes (166.3 msec) was not significantly different from that elicited by objects and only barely different from that elicited by schematic faces, $F(1,11) = 3.94$, $p = .073$.

When asked, ''What did you see?'' at the end of the first block, a typical participant's answer was ''I saw faces with eyes that were different objects.'' Apparently, at a higher perceptual level, participants not only were aware of the global configuration of the stimulus, but also that the stimulus could be a face. Yet, the results of Experiment 1 reveal that, despite awareness of the face configuration, the perceptual system at the level of the N170 responded to the faces with object-eyes as it did to isolated objects. This result may reflect interference from processing local objects on the initial global analysis of the face configuration. Had configural processing preempted local processing, the N170 should have been similar to that for regular schematic faces. A possible account for this pattern of results is that the meaningful objects presented in the eyes' position captured visual attention (either because of their oddity or because of their relative complexity) and prevented the immediate processing of the configural organization of the global stimulus. To test this hypothesis, in Experiment 2 we presented global face configurations in which two small faces substituted for the eyes. Given their face shape, local analysis of the global face's eyes' position should be sufficient to elicit an N170 effect, even if the perception of the global face was delayed as may have been the case for faces with object-eyes in Experiment 1.

EXPERIMENT 2

In the present experiment, we created stimuli in which local analysis of the global eyes' position should direct the visual input to face perception channels. To accomplish this, we changed the faces with object-eyes from the previous experiment to faces with two little schematic faces in the eyes' position (Figure 3). Thus, as in Experiment 1, the local, complex, meaningful patterns placed in the global faces' eyes location should capture attention. If the absence of an N170 effect to faces with object-eyes in Experiment 1 reflected the dominance of information processed at the ''local'' eyes' position, we should find an N170 effect in response to the face-eyes in the present experiment. On the other hand, the reason for the absence of the N170 effect in Experiment 1 might have been the substitution of meaningful stimuli instead of meaningless schematic eyes' shapes rendering a complex and strange stimulus that could not be streamed into the characteristic face-perception system. If this hypothesis is correct, the faces with face-eyes stimuli in the present experiment should replicate the pattern observed in Experiment 1 for face with object-eyes (i.e., the face with face-eyes stimuli should elicit no N170 effects).

Methods

Participants

The participants were 12 undergraduates from Hebrew University who did not participate in Experiment 1. They were paid or participated for course credits. All gave signed, informed consent before testing began.

Stimuli

All the stimuli used in Experiment 1 were also used in the present experiment. In addition, 75 faces with face-eyes were included. These stimuli were configurations of schematic faces with two identical, smaller schematic faces in the eyes' position (Figure 3). Thus, the faces with face-eyes were similarly complex and bizarre as the faces with object-eyes, but the local eyes preserved a face quality in the new stimuli in the present experiment. None of the stimuli were repeated.

Task and Design

The oddball monitoring task used in Experiment 1 was also used here. As in Experiment 1, the different types of faces and objects were distracters in different blocks. As before, the order of the blocks was fixed: faces with object-eyes, faces with face-eyes, objects, and regular schematic faces. The fixed order in which faces with object-eyes were presented prior to faces with face-eyes again ensured that processing of these ambiguous stimuli would not be biased by a prior block of schematic faces. On the other hand, faces with object-eyes could have biased subsequent processing of faces with face-eyes, but, if anything, this would discourage processing faces with face-eyes as faces and no N170 effect would emerge.

Procedure

The procedure was the same as in Experiment 1.

EEG Recording and Analysis

Recording and analyses were the same as in Experiment 1.

Results and Discussion

Replicating the results of Experiment 1, faces with object-eyes elicited no significant N170 effects. Again, the ERPs elicited by these stimuli were very similar to those elicited by objects. In contrast, faces with face-eyes elicited reliable N170 effects that were very similar to those elicited by regular schematic faces (Figure 4A). As with regular schematic faces, the N170 discriminated

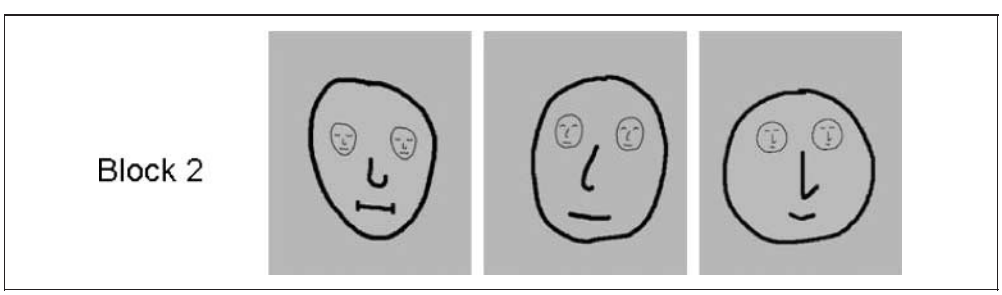
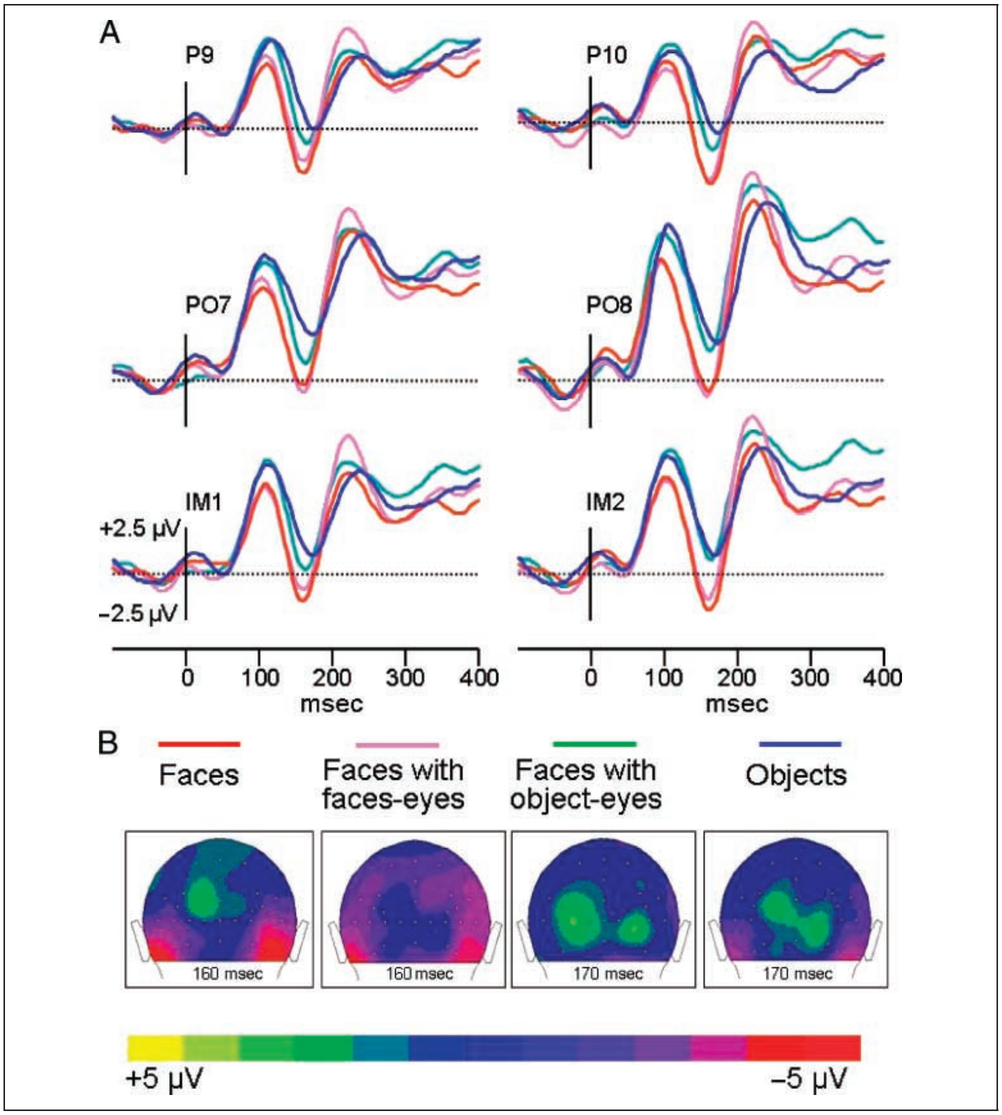


Figure 3. Examples of faces with face-eyes used in Experiment 2, Block 2.

Figure 4. ERPs elicited at posterior-temporal sites by schematic faces, faces with face-eyes, faces with object-eyes and objects (A), and the scalp distribution of the N170 for each stimulus (B). Note the clustering of schematic faces and faces with face-eyes on the one hand and object and face with object-eyes on the other.



faces with face-eyes from objects and was most conspicuous at P7/8, P9/10, and PO7/PO8 sites (Figure 4B).

The statistical reliability of these differences was confirmed by a within-subjects three-way ANOVA. The factors were Stimulus type (faces, faces with face-eyes, faces with object-eyes, and objects) × Hemisphere (right, left), and Site (P7/8, P9/10, PO7/8). The main effect of stimulus type was significant, $F(3,33) = 6.2$, $p < .01$. Post hoc univariate contrasts showed the existence of two clusters across sites: Objects and faces with object-eyes elicited similar N170 amplitudes (−0.05 and −0.64 µV, respectively), both significantly smaller than the amplitude of the N170 elicited by schematic faces (−2.8 µV) and faces with face-eyes (−2.2 µV). No other main effects and none of the higher order interactions were significant; all F values were smaller than or close to 1.00. As shown in Figure 4, the difference between the two clusters of stimuli appeared at P1 and N170. As in Experiment 1, we explored the relationship between these two effects by adding the factor of component (P1, N170) to the ANOVA. This analysis revealed a significant Component × Stimulus type interaction, $F(3,33) = 3.1$, $p < .05$, explained by the considerably reduced stimulus type effect at P1 where it only approached significance, $F(3,33) = 2.1$, $p = .06$.

Analysis of the N170 peak latencies showed a significant effect of stimulus type, $F(3,33) = 12.36$, $p < .001$. Post hoc contrasts showed that the N170 elicited by objects peaked later (170 msec) than those elicited by schematic faces (163 msec), faces with object-eyes (162 msec), and faces with face-eyes (159 msec), $F(1,11) = 20.4$, $p < .001$. No reliable differences were found between the latter three conditions.

The results of this experiment support our conclusion that, at least for the present ''hierarchical face-like'' stimuli, local information processed at the global eyes' position influences the N170 more than the configuration of the global stimulus. The face-eyes stimuli were at least as visually complex as the object-eyes stimuli. Therefore, if the absence of the N170 effect in response to faces with object-eyes had been caused by the difficulty in globally integrating complex and/or odd stimuli into a face configuration, no N170 effects should have been elicited by faces with face-eyes. It appears that the reliable N170 effect observed in this condition was induced by local analysis of the stimuli in the ''eyes'' position that in this case detected faces despite the global face complexity and unusual nature of the stimuli.

An alternative account for this pattern of results, however, is that the N170 elicited by the two small faces in Experiment 2 is not evidence for either global or local processing. Rather, it is additional evidence that faces attract attention (e.g., Hershler & Hochstein, 2005).[3] According to this account, faces with face-eyes would elicit an N170 effect not because the eyes (local information) were processed first, but because faces received priority and would do so regardless of their position in the global configuration. The next experiment tested this hypothesis.

EXPERIMENT 3

In the present experiment, we investigated whether small faces in a global face configuration would attract attention and generate an N170 effect independent of their spatial position. For one group of participants, we recorded ERPs elicited by faces with object-eyes that also included two small faces within the global face circumference. These ERPs were compared with those elicited in another group by faces with face-eyes that also included two little objects within the global face circumference. These two stimulus sets were identical in all respects except for the location of the small faces and objects (Figure 5). If the small faces attract attention and elicit an N170 effect independent of their location within the global configuration, we should observe robust N170 effects in both groups. However, if the N170 effect elicited by faces with face-eyes (Experiment 2), but not by faces with object-eyes (Experiment 1), reflects sensitivity of the face-processing mechanism to the eyes' region, we should observe similar N170 effects to stimuli with small faces in the eyes' position but not to the stimuli with small faces outside the eyes' position.

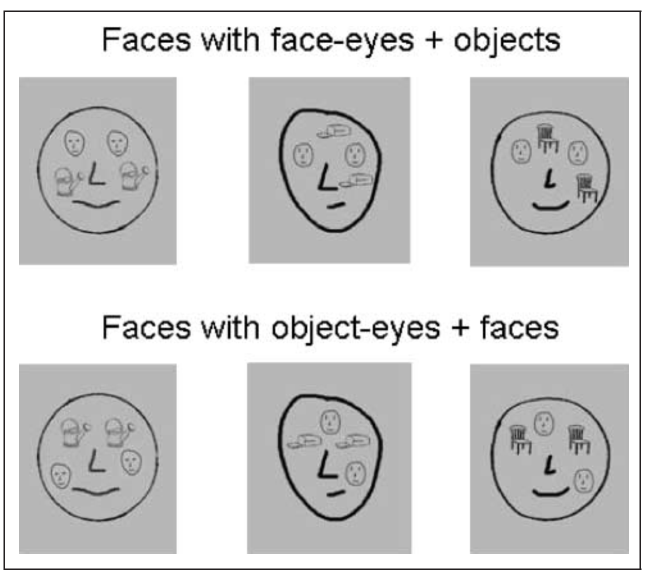


Figure 5. Examples of faces with face-eyes + objects and of faces with object-eyes + faces presented in Block 1 for each group of participants in Experiment 3.

Methods

Participants

The participants were 32 undergraduates from Hebrew University with normal or corrected-to-normal vision who did not participate in the previous experiments. Sixteen participants were tested with faces with object-eyes + faces and the other 16 with faces with face-eyes + objects. They were paid or participated for course credits. All gave signed informed consent before testing began.

Stimuli

In addition to the 75 schematic faces and 75 objects presented in Experiment 1, we prepared two additional sets of 75 stimuli each. One set was based on the faces with object-eyes presented in Experiment 1; to each of these faces we added two little faces that were the ''eyes'' of the faces with face-eyes in Experiment 2. The other set was based on the faces with face-eyes presented in Experiment 2; to each of these faces we added two little objects that were the ''eyes'' of the faces with object-eyes in Experiment 1 (Figure 5).

Task and Design

As in the previous two experiments, participants counted the number of flowers in each block. The block order was fixed as before. The first block presented faces with face-eyes + objects to one group and faces with object-eyes + faces to the other group. For both groups objects were presented in Block 2 and regular schematic faces in Block 3.

Procedure

The procedures were the same as in Experiments 1 and 2.

EEG Recording and Analysis

The EEG was recorded continuously by 64 Ag–AgCl pin-type active electrode (BioSemi Instrumentation, Munich) mounted on an elastic cap (ECI) according to the extended 10–20 system (American EEG Society guidelines, 1994), and referenced to the tip of the nose. Two additional flat-type active electrodes were used to record brain activity from the mastoids. Eye movements and blinks were monitored using bipolar horizontal and vertical EOG derivations via two pairs of flat-type electrodes, one pair attached to the exterior canthi and the other to the infraorbital and supraorbital regions of the right eye. The analog signals were sampled at 250 Hz using BioSemi Active II digital 24 bits amplification system with an active input range of −262 to +262 mV per bit without any filter at input. The digitized EEG was saved and processed off-line.

The ERPs were analyzed using commercially available software (Analyze; Brain Products). Artifacts were removed from the data by monitoring the bipolar EOG derivations as well as the right posterior lateral EEG recording sites P8, P10, PO8, right mastoid, and the homologous sites over the left hemisphere. A change in voltage of more than 50 μV during an epoch of 100 msec at any of the monitored channels was considered artifact, and the EEG recorded during the 200 msec surrounding the artifact was marked as bad. EEG segmentation, baseline subtraction, and averaging followed this procedure. Segments with bad intervals were excluded from the average. Finally, data were digitally filtered with a band-path of 0.8 to 17 Hz (24 dB/octave). No ERP was based on less than 50 single trials. Because the IM2 and IM1 sites were not represented in this montage, we analyzed P10 and P9 sites instead.

Results and Discussion

The ERPs elicited by global/local face configurations in the test conditions were compared in each group with those elicited by regular schematic faces and by objects. As clearly seen in Figure 6A, despite the pair of little objects included within the global face, faces with face-eyes elicited N170 effects that were similar to those elicited by regular schematic faces. In contrast, faces

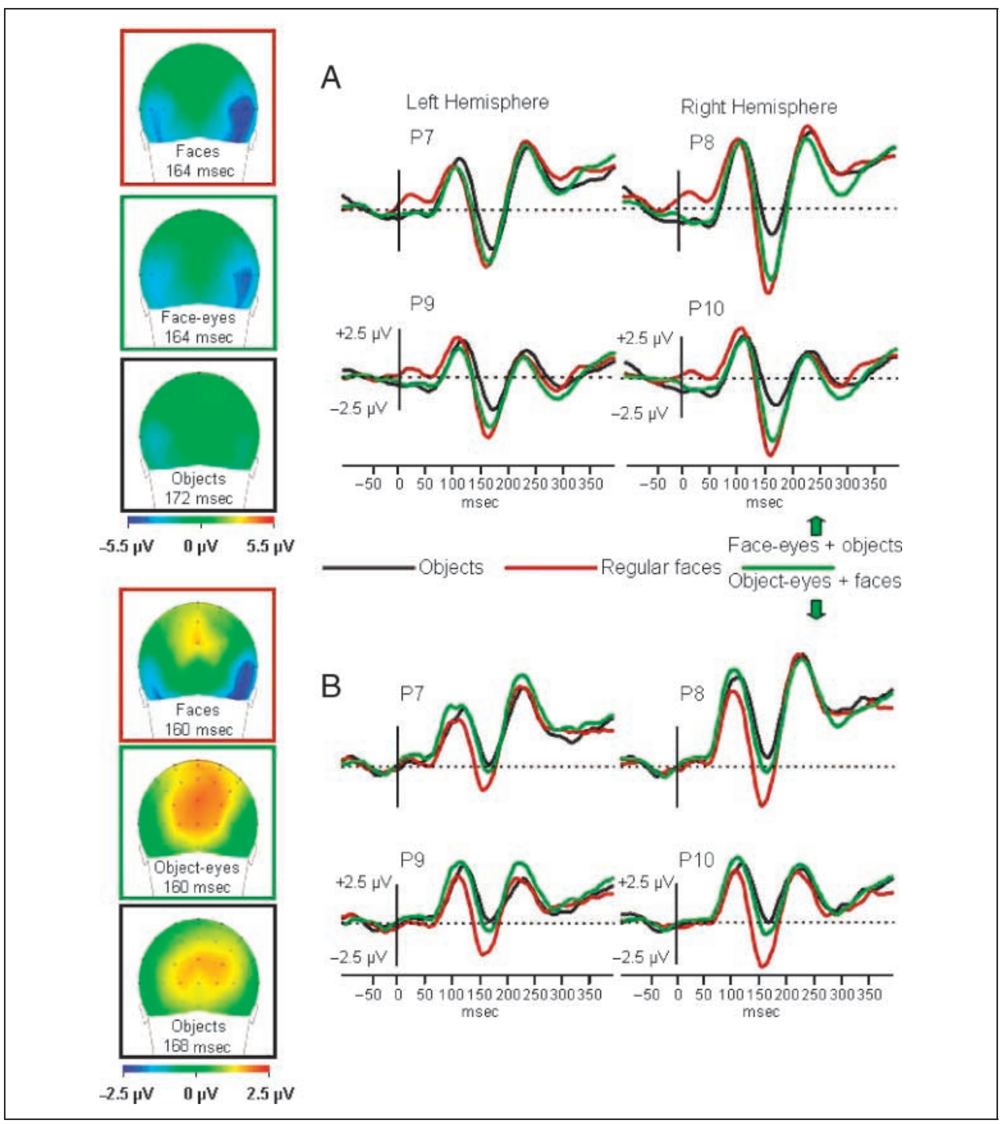


Figure 6. ERPs elicited at posterior-temporal sites by regular schematic faces, objects, and faces with face-eyes + objects and their scalp distributions (A) and by regular schematic faces, objects, and faces with object-eyes + faces and their scalp distributions (B). Note that when faces are in the eyes' position the stimuli elicit a clear N170 effect despite the additional objects within the face, whereas when objects are in the eyes' position there is no N170 effect despite the existence of faces in the display.

with object-eyes did not elicit a conspicuous N170 effect despite the fact that a pair of small faces was clearly visible in the display. The negative-going component elicited by these stimuli in the N170 time range was very similar to that elicited by objects (Figure 6B).

The above observations were confirmed for each group by within-subjects ANOVAs using the same design as in the previous two experiments. These analyses were followed by planned contrasts between the three stimulus types. In the face-eyes + objects group, the significant main effect of stimulus type, $F(2,30) = 10.1$, $p < .001$, was explained by a significant difference between the N1 elicited by objects (−2.6 μV) and the N170 elicited by faces with face-eyes + objects (−4.6 μV) and the N170 elicited by regular schematic faces (−5.2 μV). Univariate tests showed that the difference between the two types of faces was not significant, $F(1,15) = 1.4$, $p = .25$, but both were significantly larger than objects, $F(1,15) = 11.0$, $p < .005$. There were no additional significant main effects, $F(1,15) = 2.6$, $p = .13$ and $F(2,30) < 1.00$, for hemisphere or site, respectively. A significant Stimulus type × Hemisphere interaction, $F(2,30) = 14.3$, $p < .001$, showed that although the stimulus type effect was significant at both hemisphere sites, it was larger over the right, $F(2,30) = 14.8$, $p < .001$, than over the left hemisphere, $F(2,30) = 3.6$, $p < .05$. No other interactions were significant.

As in the previous experiments, the possible stimulus type effect on P1 was explored by adding the factor of component (P1, N170) to the ANOVA. This analysis revealed a significant Component × Stimulus type interaction, $F(2,30) = 11.3$, $p < .001$. ANOVA for the P1 component showed that the stimulus type had no effect on P1, $F(2,30) < 1.00$.

ANOVA for the faces with object-eyes + faces group showed that the main effect of stimulus type was significant, $F(2,30) = 13.8$ $p < .001$. However, univariate tests showed that this effect was caused by a significant difference between the N170 elicited by faces (−2.5 μV) and the N1 elicited by faces with object-eyes + faces (−0.86 μV) and objects (−0.10 μV), which did not differ among themselves, $F(1,15) = 2.3$, $p = .15$. In contrast to the faces with face-eyes +objects, the N1 elicited by faces with object-eyes + faces was significantly smaller than the N170 elicited by regular schematic faces, $F(1,15) = 18.7$, $p < .001$.

As in the previous experiments, adding the component (P1, N170) factor revealed a Component × Stimulus type interaction, $F(2,30) = 6.1$, $p < .01$. A separate ANOVA of the P1 amplitude showed a significant main effect of stimulus type, $F(2,30) = 4.6$, $p < .05$. Post hoc contrast showed that the P1 elicited by objects (5.8 μV) was slightly smaller than the P1 elicited by faces with object-eyes + faces (6.5 μV), $F(1,15) = 4.7$, $p < .05$, but both were significantly more positive than the P1 elicited by schematic faces, $F(1,15) = 8.6$ $p < .01$.

Analysis of the latency of the N170 showed that in the first group the N1 elicited by objects peaked later (170 msec) than for either faces with face-eyes + objects (164 msec) or schematic faces (161 msec), $F(1,15) = 13.2$, $p < .001$. In the second group, the N1 elicited by objects (167 msec) peaked later than that elicited by schematic faces (161 msec), $F(1,15) = 12.6$, $p < .001$, but not from that elicited by faces with object-eyes + faces (165 msec).

Experiment 3 confirmed our hypothesis that two local faces in a global face configuration would elicit an N170 effect, but only if they were placed in the global face's eyes' position. The face configuration appears to draw attention to the eyes' location, and the processing of the information at this location determines whether the stimulus is channeled via the face processing mechanism or not.

On the surface it may appear that these data contradict other findings showing that faces in multiobject displays do attract attention (Hershler & Hochstein, 2005; Ro, Russel, & Lavie, 2001). This apparent contradiction was investigated and resolved in the next experiment in this series.

EXPERIMENT 4

A major difference between the presentation of faces in the "faces with object-eyes + faces" condition in Experiment 3 and displays of faces in studies where faces pop out is that in the present study the local faces were constrained by a global face configuration. In order to directly examine the implications of this constraint, in the present experiment we replicated the design of Experiment 3, except that the local faces were presented within global frames but all the inner components were misplaced. Thus, each of these stimuli was a "scrambled global face" that also contained a pair of small faces (Figure 7). In a previous study, Bentin and Golland (2002) reported that scrambled schematic faces do not elicit the N170 effect, consistent with these types of stimuli not being processed as faces. It follows that in the absence of a global face configuration, the two small faces might attract attention

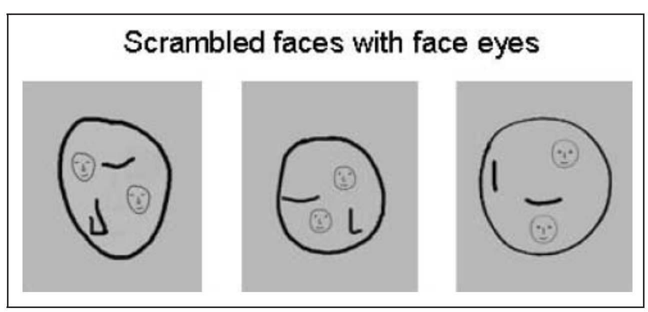


Figure 7. Examples of faces with face-eyes in which the inner components do not preserve the face configuration.

and elicit an N170 effect regardless of their location. Such an outcome would support the hypothesis that the overall pattern of results in the previous experiments reflected an interaction between the perception of the global face configuration and processing the local elements in the position of the eyes.

Methods

Participants

The participants were 16 undergraduates from the University of California, Berkeley with normal or corrected-to-normal vision. They were paid for participation. All gave signed informed consent approved by the internal review board of the University of California, Berkeley, before testing began.

Stimuli

The 75 faces and 75 objects presented in Experiment 1 were also presented in the present experiment. In addition, we presented 75 faces with face-eyes with the configuration of the inner components distorted (Figure 7).

Task and Design

The task and design were the same as that of Experiment 1, except that scrambled faces with face-eyes rather than faces with object-eyes were presented in Block 1.

Procedure

The procedures were the same as in Experiment 1.

EEG Recording and Analysis

Recording and analyses were the same as in Experiment 3.

Results and Discussion

The two local faces presented within a global scrambled-face configuration elicited N170 effects similar to those elicited by regular schematic faces (Figure 8).

This observation was confirmed by a Stimulus type × Hemisphere × Site ANOVA and planned contrasts. The main effect of stimulus type was significant, $F(2,30) = 15.6$, $p < .001$, reflecting a difference between the amplitude of the N1 elicited by objects (−0.52 μV) and the N170 elicited by the small faces placed in scrambled global faces (−2.82 μV), $F(1,15) = 16.4$, $p < .001$. The difference between the N170 elicited by these small faces and those elicited by regular schematic faces (−3.6 μV) was not significant, $F(1,15) = 3.2$, $p = .09$.

The addition of the P1 in a four-way repeated-measure ANOVA demonstrated that the Component × Stimulus type interaction was significant, $F(2,30) = 7.4$, $p < .025$, as in the previous experiments, supporting differential effects of P1 and N170. A three-way ANOVA of P1 amplitudes resulted in a significant stimulus type main effect, $F(2,30) = 3.6$, $p < .05$, but unlike the N170, the P1 response to small faces and to objects was similar, $F(1,15) < 1.00$.

Analysis of the N170 latency revealed a significant main effect of stimulus type. Post hoc contrasts showed that latency of the N170 elicited by the small faces in scrambled stimuli (164 msec) was similar to that elicited by regular schematic faces (164 msec), and both were shorter than that elicited by objects (172 msec), $F(1,15) = 11.1$, $p < .005$.

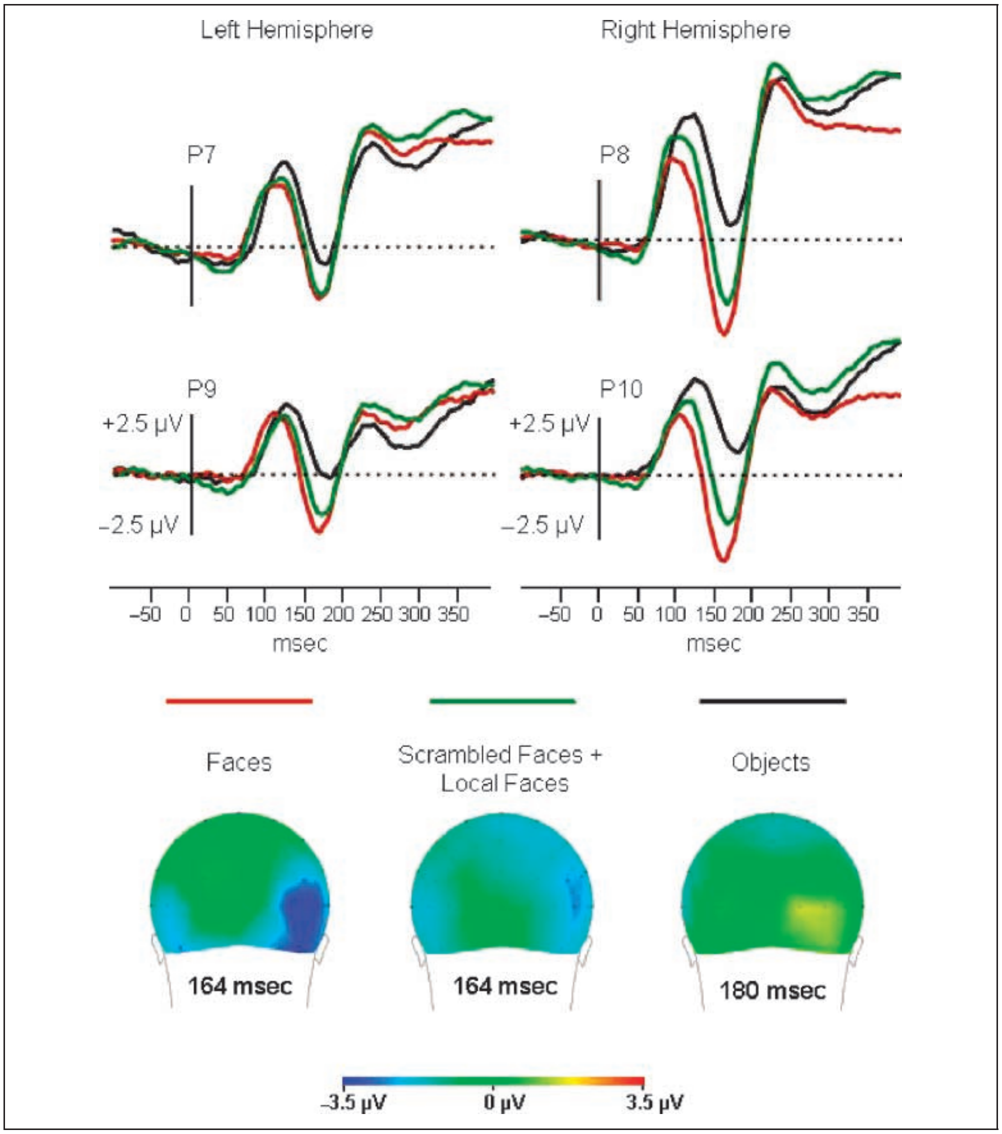
The N170 effect elicited by the pair of small faces in the present experiment is consistent with other evidence that faces attract attention, but contrasts with the absence of such effects when the small faces are presented in well-configured schematic faces but outside the eyes' position. This outcome was predicted by our hypothesis that a global face configuration focuses attention on the eyes' region. In concert with the results of Experiment 3, these data shed light on the interaction between perceptual processes that lead to the categorization of a visual stimulus as face-like, channeling such stimuli to downstream face identification mechanisms. We will elaborate more on this interaction in the General Discussion.

EXPERIMENT 5

The robust N170 effect elicited by schematic faces indicates that a stereotypical face configuration (two "eyes" symmetrically placed above a "nose," above a "mouth") is sufficient to detect a face-like structure even if the inner components are only symbols, none of which could have been identified in isolation as a face component. However, this raises the question of why faces with object-eyes, which preserve the face configuration, do not elicit an N170 effect? It is possible that the recognition of these objects activates an object-perception process that competes with a face-perception process with the local objects in the eyes' position taking precedence over the global configuration. If this is the case, then it should be possible to bias the outcome of this competition by priming face perception. The goal of Experiment 5 is to test this hypothesis by introducing a face context prior to the presentation of the face with object-eyes stimuli.

We used the same blocks of stimuli as in Experiment 1, but reversed their order of presentation so that the schematic faces were presented first. Previous studies have shown that this procedure can change the interpretation of meaningless face components as reflected in the appearance of an N170 effect (Bentin & Golland, 2002; Bentin et al., 2002). If the face context established in Block 1 facilitates configural processing in Block 2 and biases the system in favor of processing the global

Figure 8. ERPs elicited at posterior-temporal sites by regular schematic faces, objects, and scrambled faces with face-eyes and their scalp distributions. Note that when the global configuration does not guide attention to the eyes' position the miniaturized faces attract attention and elicit an N170.



configuration, we should find that faces with object-eyes now elicit an N170 effect.

However, a bias in favor in processing the global face is not the only possible account for the hypothesized emergence of an N170 effect to faces with object-eyes. An alternative possibility is that after seeing several stimuli processed within a face context, the interpretation of the objects in the eyes' position changes, assigning them the value of schematic eyes. In other words, the N170 effect in response to faces with object-eyes would not stem from processing of the global face configuration per se but from changing local processing of items in the eyes' position. To explore this possibility, pairs of objects without the global configuration were presented in a third block of trials, immediately following the faces with object-eyes. If the pair of objects was now assigned face-related value, it should elicit an N170 effect even outside the face configuration. The absence of such an effect with the pair of objects alone in Block 3 combined with its presence in Block 2 with faces with object-eyes would indicate that the face context induced by regular schematic faces in Block 1 biased processing to the global configuration.

Methods

Participants

The participants were 12 undergraduates from Hebrew University with normal or corrected-to-normal vision who did not participate in any of the other experiments. They were paid or participated for course credits and gave signed informed consent before testing began.

Stimuli

The stimuli were the 75 schematic faces, 75 faces with object-eyes, and 75 single objects presented in Experiment 1. In addition, we presented 75 pairs of isolated object-pairs that were the same size as in the faces with object-eyes stimuli. None of the stimuli were repeated within one experiment, and the object pairs used to simulate eyes were different than those presented in isolation.

Task and Design

The task and design were the same as Experiment 1, except that the object-pairs block was added and the blocks were presented in a different fixed order: schematic faces, faces with object-eyes, isolated object-pairs, and objects. Again, note that the fixed order was part of this experiment's rationale.

Procedure

The procedures were the same as in Experiment 1.

EEG Recording and Analysis

Recording and analyses were the same as in Experiment 1.

Results and Discussion

In the present experiment, faces with object-eyes elicited an N170 effect as large as that elicited by regular schematic faces (Figure 9). In contrast, object-pairs presented outside a global face configuration did not elicit an N170 effect. Object processing per se was not affected by the addition of a face context, whereas the interpretation of the objects in the face with object-eyes was. Indeed, at some locations, the N1 elicited by object-pairs was less pronounced than that elicited by single objects.

The reliability of these findings was confirmed by ANOVA that included three factors: stimulus type (faces, faces with object-eyes, object-pairs, and objects), hemisphere (right, left), and site (P7/8, P9/10, IM1/2).[4] Anal-

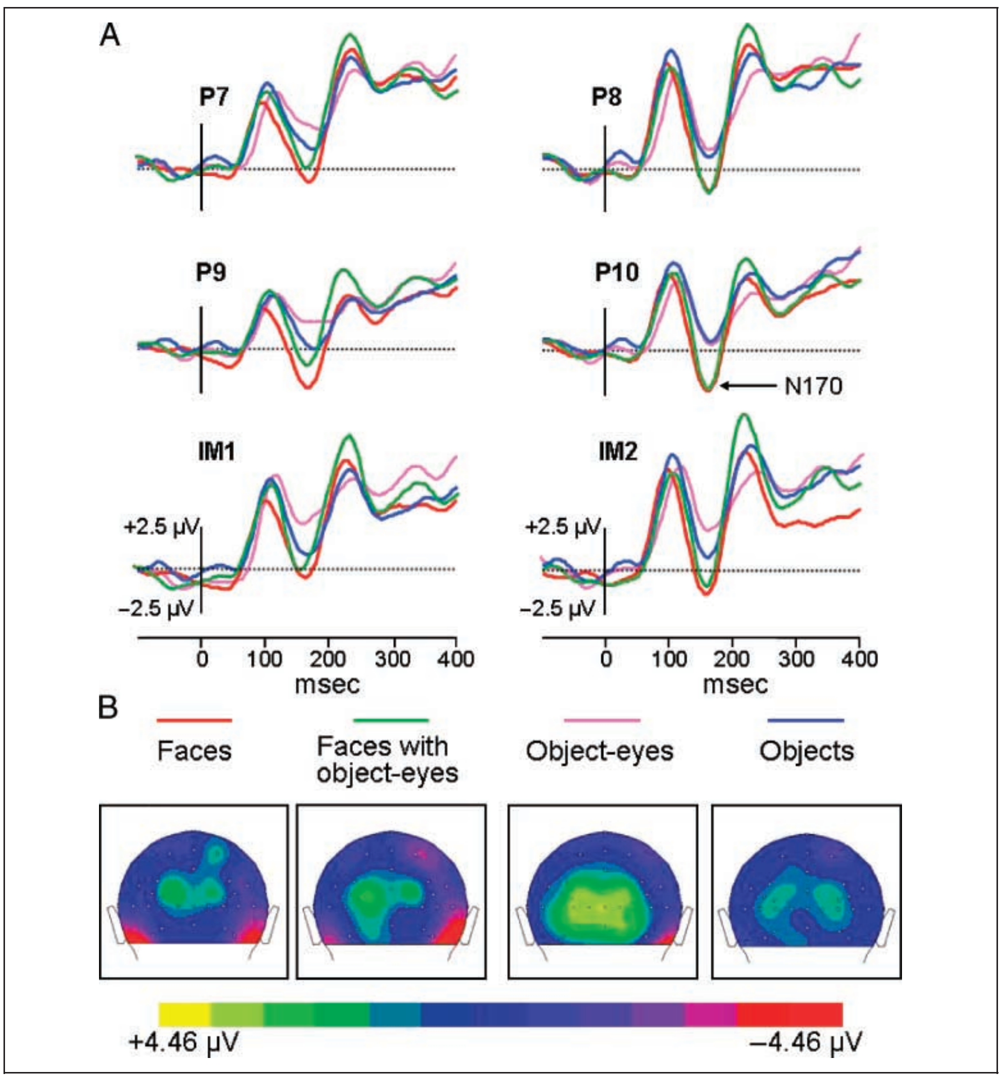


Figure 9. ERPs elicited at posterior-temporal sites by regular schematic faces, faces with object-eyes, isolated "objects eyes" pairs, objects, and their scalp distributions. Note the influence of the established face context demonstrated by the N170 effect elicited by faces with object-eyes.

ysis of the N170 amplitude showed a significant main effect of stimulus type, $F(3,33) = 8.6$, $p < .01$, and no other significant main effects or interactions. There was a trend between stimulus type and site, $F(6,66) = 2.2$, $p = .10$, the difference between stimulus types appeared slightly bigger at P7 and P8 than at the IM1 and IM2 sites. Post hoc contrasts showed that the N170 amplitude elicited by schematic faces and by faces with object-eyes was larger than that elicited by objects and object-pairs. No other effect approached significant levels. A similar analysis with the amplitude of P1 as a dependent variable showed no effect of stimulus type, $F(3,33) < 1.0$.

The analysis of latencies revealed no significant effects, although the stimulus type main effect approached significance, $F(3,33) = 3.0$, $p < .07$. This tendency was related to a relatively longer latency to the peak of the N170 elicited by isolated object-pairs (170.6 msec) than by faces (164.2 msec), faces with object-eyes (163.3 msec), or objects (162.4 msec).

The most important outcome of the present experiment was that, in contrast to Experiment 1, faces with object-eyes elicited N170 effects as large as those obtained with schematic faces. Because the only relevant difference between the current experiment and the previous studies was the order of blocks, it is reasonable to conclude that the emergence of the N170 effect to faces with object-eyes resulted from the face context induced by seeing regular schematic faces in Block 1.

However, when pairs of objects that formed the ''eyes'' of the global faces with object-eyes in Block 2 were presented in isolation in Block 3, they did not elicit an N170 effect, even though they were previously seen in the eyes' position of a schematic face. This pattern differs from the significant priming effects exerted by faces on meaningless shapes reported by Bentin et al. (2002). Apparently, the face context in the present experiment did not cause the object-pairs to be processed as eyes but rather as objects. It appears that the face context established in Block 1 biased the competition between the global configuration of a face-like structure and the local information in the eyes' position.

GENERAL DISCUSSION

Faces with object-eyes were consciously reported as ''faces,'' but did not elicit the face-characteristic N170 effect in absence of any contextual bias. A major difference between faces with object-eyes and the regular schematic faces that elicited normal N170 effects in previous studies (e.g., Sagiv & Bentin, 2001) was that here the eyes were drawings of objects rather than meaningless shapes. In contrast, when the eyes in the global configuration were small schematic faces, a normal N170 effect was found. This effect did not reflect attention captured by faces per se because the same pair of face-eyes did not elicit an N170 effect when placed in a random location within the global face frame while objects occupied the eyes' position. The eyes' region seemed to be crucial. When objects were placed in a random location within the global face frame while local faces occupied the eyes' position, a normal N170 effect was found. Apparently, in the absence of a processing bias, the information provided by local objects in the eyes' position ''won'' the competition for object or face processing mechanisms, at least as reflected by the N170. This is not to say that the global configuration was ignored. Indeed, the eyes' position must be defined by the global frame, and focus on the eyes' region was not random. It was imposed by a global configuration with items in the locations of a face. In the absence of a global face-like configuration, small faces elicited N170 effects regardless of where they were located within the global frame as revealed in Experiment 4. The information in the eyes' region was consequential only if the stimulus had a face configuration.

These results are consistent with the conclusions of Lamb and Robertson (1988) that global precedence depends on several factors, including context and attentional bias as well as their arguments that global and local processing occur in parallel. We have shown here that if global and local levels of a face-like structure provide conflicting information, they compete with one another and global processing does not always prevail.

In order to appreciate the relevance of these findings for face processing, we should briefly recapitulate the essential aspects of face processing mechanisms. The speed and expertise at which humans are able to identify familiar faces suggest that this process is very fast and efficient. Given the distance and various conditions under which faces can be identified accurately and the relative global similarity among different faces and the local similarity among face components, this is not a trivial achievement. Therefore, it is not surprising that the most distinctive differences between faces may be the spatial relations among the component parts, that is, the ''second-order'' configuration of the face (Maurer, LeGrand, & Mondloch, 2002). Indeed, face identification requires the computation of these relations (e.g., Leder & Bruce, 2000; Goldstone, Medin, & Gentner, 1991; Rhodes, 1988). However, note that in order for these computations to be performed, the relevant components must first be located in regions that do not violate the structural description of a face. Furthermore, evidence that spatial relationships are less important for identifying many nonface stimuli at the individual exemplar level (e.g., Tanaka, 2001; Tanaka & Sengco, 1997) suggests that configural processing is not applied to all stimulus types.[5] Thus, early, fast, and efficient categorization of faces would be a reasonable prerequisite for efficient face identification. We suggest that the N170 effect is an electrophysiological manifestation of this early categorization process and precedes (and perhaps triggers) the face-characteristic computation of second-order configurations. If so, modulation of the N170 by different factors could illustrate how faces are categorized in early vision.

As reviewed in the Introduction, the N170 is sensitive to inner components of natural faces as well as to the stereotypical first-order (global) configuration of a face. To reiterate, the sensitivity to inner face components is demonstrated by the robust N170 effect elicited by recognizable components (e.g., eyes, nose, mouth) presented in isolation and even when their spatial configuration is scrambled. The sensitivity to global, face-like configurations is demonstrated by the robust N170 effect elicited by schematic faces.

The difference between the consequences of global and local face processing mechanisms is evident, for example, in the face inversion effect on N170. The N170 elicited by photographs of natural faces presented upside-down (in which the canonical face configuration is not retained) is actually larger than that elicited by upright faces, albeit its peak is delayed (Rossion et al., 2000; Bentin et al., 1996). However, the inverse is found for schematic faces (stimuli whose face value depends only on the configuration of parts). Inversion of schematic faces actually reduces the N170 (Sagiv & Bentin, 2001). This pattern suggests that the neural mechanisms involved in early categorization of faces are naturally sensitive for face features. Such a mechanism was modeled by Ullman, Vidal-Naquet, and Sali (2002), who also suggested that face categorization is based on face parts of intermediate complexity rather than whole face configurations.[6]

If this system is tuned to face-defining parts when face configurations are present, the inner components will be immediately detected and will elicit the N170 effect as long as the parts do not compete for other processing mechanisms. The present data suggest that the global face configuration directs attention to the eyes' region, perhaps because the eyes are the first elements to be integrated in the second-order configuration. If a typical schematic face is presented, the visual system has no relevant local information to compete with face processing, and the configural information is sufficient to categorize the stimulus as a face, eliciting the N170 effect. However, when the information in the eyes' location is meaningful (as is the case with faces with object-eyes or faces with face-eyes), local processing captures the processing resources. Consequently, when the local parts are objects, the stimulus is not processed prima facie as a face (thus, no N170 effect), but instead via a general object processing mechanism. Within this model, the N170 effect elicited by face with face-eyes would reflect processing of the faces in the eyes' position by face processing mechanisms.

Why would the competition between local and global processing be biased in favor of the local process in a face configuration? The context effects observed in Experiment 5 provide a possible answer to this intriguing question. Apparently, the competition between the two types of processing can be easily biased by having just seen stimuli in which global processing of face-like structures was performed (i.e., elicited an N170 effect). Replicating previous studies published by Bentin and Golland (2002) and Bentin et al. (2002), this experiment demonstrated that a face context established by the presentation of one block of schematic faces is enough to bias perception to process meaningless stimuli as pertaining to faces. However, the absence of the N170 effect in response to isolated object pairs (Block 3 in Experiment 5) indicates that perception of objects was not altered. Thus, the bias likely reflects prioritizing processing of the global configuration and delaying processing of the local parts.

Finally, it is interesting that postexperiment questioning indicated that participants recognized the face with object-eyes stimuli as faces even when there was no N170 effect. Apparently, these stimuli were recognized as faces by some perceptual process without activating the early vision mechanisms responsible for the N170 effect. This observation is consistent with those of face recognition in a person with visual object agnosia but normal recognition of upright faces (CK) (Moscovitch et al., 1997; Behrmann et al., 1992). When shown faces constructed from objects such as paintings by Arcimboldo or even schematic drawings of the type of faces we used here, CK did not notice the objects that formed the internal features and saw only the face configuration. When his attention was directed to the objects, he then noticed them and could transfer that type of processing to subsequent pictures (unpublished observations). In CK's case, the absence of a properly functioning object recognition system allowed configural face processes to assume such powerful control over perception that the objects that were in the place of the local parts did not reach awareness unless CK's attention to them was deliberately manipulated.

In conclusion, based on the outcome of the studies presented here and on previous work with natural faces, we propose that efficient face perception and identification involves a network of highly selective but flexible and mutually interacting neural mechanisms. It is reasonable to suppose that the process is initiated by bottom-up activation of a face detection mechanism biased toward face features. This detection mechanism could be guided by local processing of the features and its activation is manifested at the scalp by an N170 effect. However, the robust N170 effect elicited by schematic faces suggests that this mechanism may also be activated by global analysis of a typical face configuration, which in turn directs attention to the eyes' region of the face. The competition between local feature and global configural information will determine whether face-characteristic structural encoding is engaged under conflicting conditions. Under normal conditions, when both levels signify a face, face encoding mechanisms will be rapidly employed and will send information to higher-level face mechanisms, resulting in fast and efficient face identification.

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Notes

1. The order of the objects' and the schematic faces blocks was also the same across subjects. Note, however, that if the responses to schematic faces were influenced by a preceding block of objects, the N170 effect should have been reduced.
2. The IM1 and IM2 locations are halfway between the inion and the left and right mastoids, respectively.
3. We are grateful to an anonymous reviewer of a previous version of this article for suggesting this alternative account.
4. These sites were used in Experiment 1.
5. Indeed, it is reasonable that if the same perceptual processes were applied to all stimuli, humans would probably be equally expert in within-category identification of all kinds of objects (cf. Ullman, 1996).
6. This conclusion does not imply that a similar (or the same) mechanism cannot detect and categorize other stimuli of expertise. However, this discussion is beyond the scope of the present article.

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