Early Dissociation of Face and Object Processing: A Magnetoencephalographic Study

Ana Susac,^{1*} Risto J. Ilmoniemi,^{2,3,4} Elina Pihko,^{3,4}
Jussi Nurminen,^{3,4} and Selma Supek¹

¹Department of Physics, Faculty of Science, University of Zagreb, Zagreb, Croatia

²Department of Biomedical Engineering and Computational Science, Helsinki University of Technology, Espoo, Finland

³BioMag Laboratory, HUSLAB, Helsinki University Central Hospital, Helsinki, Finland

⁴Helsinki Brain Research Centre, Helsinki, Finland

Abstract: The early dissociation in cortical responses to faces and objects was explored with magnetoencephalographic (MEG) recordings and source localization. To control for differences in the low-level stimulus features, which are known to modulate early brain responses, we created a novel set of stimuli so that their combinations did not have any differences in the visual-field location, spatial frequency, or luminance contrast. Differing responses to face and object (flower) stimuli were found at about 100 ms after stimulus onset in the occipital cortex. Our data also confirm that the brain response to a complex visual stimulus is not merely a sum of the responses to its constituent parts; the nonlinearity in the response was largest for meaningful stimuli. *Hum Brain Mapp* 30:917–927, 2009. © 2008 Wiley-Liss, Inc.

Key words: magnetoencephalography (MEG); face processing; object recognition; human; visual; occipital cortex; M100; nonlinearity

INTRODUCTION

Well-established markers of face processing are the N170/M170 component of the event-related potential (ERP) or evoked magnetic field measured by magnetoencephalography (MEG) [e.g., Bentin et al., 1996; Lu et al.,

1991; Sams et al., 1997] and an increased hemodynamic response in the fusiform face area [e.g., Kanwisher et al., 1997; Puce et al., 1995; Sergent et al., 1992]. These responses are larger to faces than to nonface stimuli (objects, scrambled faces, etc.). Many studies have suggested that a face-related response appears even before the N170/M170 [Halit et al., 2000; Herrmann et al., 2005a,b; Itier and Taylor, 2002, 2004a,b; Itier et al., 2006; Kato et al., 2004; Linkenkaer-Hansen et al., 1998; Liu et al., 2002; Pegna et al., 2004; Thierry et al., 2007a].

Intracranial and scalp EEG recordings have provided evidence for differential responses to novel and repeated faces as early as 50 ms after stimulus onset [Seeck et al., 1997]. Similar results were obtained by Braeutigam et al. [2001], who reported very early (30–60 ms) MEG responses that were strongest for the first image in pairs of faces. However, a similar effect was found for stimuli not perceived as faces [George et al., 1997], suggesting that this early effect was caused by stimulus repetition rather than categorization per se [Debruille et al., 1998].

Contract grant sponsor: Croatian Ministry of Science, Education, and Sport; Contract grant number: 199-1081870-1252; Contract grant sponsors: National Foundation for Science, Higher Education and Technological Development of the Republic of Croatia; Centre for International Mobility, Finland.

*Correspondence to: Ana Susac, Department of Physics, Faculty of Science, University of Zagreb, Bijenicka 32, 10 000 Zagreb, Croatia. E-mail: ana@phy.hr

Received for publication 7 June 2007; Revised 19 January 2008; Accepted 24 January 2008

DOI: 10.1002/hbm.20557

Published online 14 March 2008 in Wiley InterScience (www.interscience.wiley.com).

TABLE I. Combinations of stimuli giving identical superpositions that were used for the comparisons of MEG responses

Face comparisons	Flower comparisons	Control comparisons
1 + 4 + 7 vs. 3 + 6 + 9	2 + 5 + 8 vs. 3 + 6 + 9	4 + 5 + 6 vs. 7 + 8 + 9
1 + 3 vs. 5 + 8	2 + 3 vs. 4 + 7	3 + 6 vs. 7 + 8
1 + 4 vs. 8 + 9	2 + 5 vs. 7 + 9	3 + 9 vs. 4 + 5
1 + 7 vs. 5 + 6	2 + 8 vs. 4 + 6	

The early evoked visual EEG/MEG component, P1/M100, emerging around 90–120 ms, has longer latency and sometimes larger amplitude for inverted than upright faces [Itier and Taylor, 2002, 2004a,b; Itier et al., 2006; Linkenkaer-Hansen et al., 1998; Susac et al., 2004], implying that some aspects of face-sensitive processing could take place already at these latencies. However, some studies did not reveal any effect of inversion at these early latencies [e.g., Rossion et al., 1999b]. It has been observed that the P1 component can be modulated by facial configuration [Halit et al., 2000], face familiarity [Debruille et al., 1998], task [Rossion et al., 1999a; Streit et al., 1999], affective information conveyed by faces [Pizzagalli et al., 1999, 2002], and emotional facial expression [Batty and Taylor, 2003; Eger et al., 2003; Eimer and Holmes 2002; Holmes et al., 2003; Pourtois et al., 2004, 2005]. Mouchetant-Rostaing et al. [2000, 2003] found an effect of age and gender discrimination tasks on ERPs over the central region already at 45–90 ms poststimulus. Liu et al. [2002] reported a face-selective MEG response 100 ms after the stimulus onset that was larger to faces than houses. Similar early differences between responses to faces and houses were found with ERPs [Herrmann et al., 2005a,b]. Thierry et al. [2007a] observed larger P1 amplitudes for faces than cars; this difference was not affected by interstimulus perceptual variability (ISPV).

The primary visual cortex and extrastriate visual areas are sensitive to the location of the stimuli in the visual field, as well as to the spatial frequency and luminance contrast of the visual input [e.g., Aine et al., 1996; Boynton et al., 1999; Haynes et al., 2004; Johannes et al., 1995; Portin et al., 1999; Singh et al., 2000; Supek et al., 1999; Tzelepi et al., 2001]. Some MEG studies have suggested that early visual responses to complex images, such as faces, depend on the low-level physical features of the stimuli [Halgren et al., 2000; Tanskanen et al., 2005; Tarkiainen et al., 2002]. For example, spatiotemporal analysis of MEG responses to faces and control stimuli has revealed that a near-midline occipital source can distinguish between face and nonface stimuli as early as 110 ms [Halgren et al., 2000]. This early activity is sensitive to the sensory characteristics of the stimuli (e.g., photographs vs. sketches). It has also been reported that this early MEG midline occipital response to faces is sensitive to the noise level and its spatial frequency [Tanskanen et al., 2005; Tarkiainen et al., 2002]. One ERP study reported that the P1 component was not modulated by the gradually increased amount of noise in the face

stimuli [Jemel et al., 2003]. However, most MEG and EEG studies on face processing have not addressed differences in the low-level physical features of face and object stimuli, although some investigators have tried to reduce them [e.g. Rousselet et al., 2005]. In the recent study by Thierry et al. [2007a], ISPV was minimized by normalizing location, orientation, and size of the stimuli. In their comment on this study, Bentin et al. [2007] have shown that ISPV was controlled in many studies on the N170. However in both cases, ISPV was controlled only within the category, and not between categories, e.g., faces and cars.

Our aim was to determine the earliest dissociation of MEG responses to faces and objects avoiding the differences in the low-level physical features of the stimuli. Our stimuli, when superposed in certain groups (Table I), will produce identical images (see Fig. 1). Comparison of the summed responses to these superposition groups, containing face, object (flower), or just meaningless stimuli, and source localization gives information about the timing and location of the dissociation of face and object processing.

MATERIALS AND METHODS

Subjects

Eleven subjects (age range 23–34 years, one left-handed, five females), with normal or corrected-to-normal vision, participated in the MEG experiment. Structural magnetic resonance images (MRIs) were available for all subjects. Each participant gave an informed consent before taking part in the experiment. The study was approved by the Ethical Committee of the Helsinki University Central Hospital (HUCH). Twenty-two subjects (age range 23–44 years, three left-handed, 11 females) who did not participate in the MEG experiment took part in the behavioral experiment.

Stimuli

The stimulus set consisted of nine different images: a face, a flower, and seven meaningless figures (Fig. 1a). The stimuli were created so that the superposition of particular stimuli (Table I) would produce the same image (Fig. 1b). For example, superpositions 1 + 4 + 7 and 3 + 6 + 9 are identical, enabling a face-specific comparison, because the former group contains the face and the latter only mean-

Figure 1.

(a) The stimuli used in the study. (b) Superpositions of different groups of stimuli give the same resulting image; e.g., $1 + 4 + 7 = 2 + 5 + 8 = 3 + 6 + 9 = 4 + 5 + 6 = 7 + 8 + 9$. For all possible combinations, see Table I.

ingless stimuli. Each image subtended $9.3^\circ \times 9.3^\circ$ of visual angle.

Procedure

The subject sat in a dimly lit room and viewed nine gray-scale images (Fig. 1a) delivered by the Presentation software (Neurobehavioral Systems, Albany, CA) in a pseudorandom order, so that each stimulus was presented 100 times without consecutive repetition of the same image. The stimuli were projected on a screen in front of the subject for a duration of 200 ms, with a red fixation cross at the center of the visual field. The same gray background was displayed during the interstimulus interval that lasted 1,300 ms. The stimuli were delivered in five 4.5-min blocks separated by 1-min rest periods. The task was silent recognition of stimuli 1, 2, and 3 (face, flower, meaningless target). The subjects were instructed to pay attention to all three target stimuli during all blocks. To avoid motor-related cortical activity, we did not require behavioral responses in the MEG experiment.

Evoked magnetic fields were measured in a magnetically shielded room (Euroshield, Finland) at the BioMag Laboratory, HUCH, with a 306-channel whole-head magnetometer (Elekta Neuromag Oy, Helsinki, Finland) containing two planar gradiometers and one magnetometer at each of the 102 sensor locations. Horizontal and vertical eye movements were monitored with electro-oculogram electrodes placed above and below the left eye and lateral to each eye. The data were recorded with a bandwidth of 0.1–200 Hz and sampled at 600 Hz.

The Presentation software provides a submillisecond accuracy in timing of stimulus delivery on the computer screen and in sending triggers to the MEG system, taking into account scanning and screen refresh rates. However, the LCD projector introduces a fixed delay between the trigger and the appearance of the visual stimulus on the screen in the magnetically shielded room. To determine the delay of the projection system, we measured the time course of light intensity at the projector lens with a phototransistor (Siemens SFH 350V) after delivering a black stimulus on the previously gray screen. The time required for the complete transition from gray to totally black was about 20 ms. Because the visual system is likely to react quickly to any detectable change in the stimulus, it is probably able to react before the transition is fully complete. We characterized the delay of the LCD projector by half of the intensity transition time to minimize the possible error. In conclusion, all latencies reported in the present study are computed with an estimation that the delay of the projection system was 10 ms.

In the behavioral experiment, stimuli and task settings were the same as in the MEG experiment. The only difference was that the subjects were instructed to press the left mouse button when they recognized any of the three targets (face, flower, meaningless target). The measurements were conducted at the Laboratory for Psycholinguistic Research, University of Zagreb.

Figure 2.

Illustration of MEG responses in one occipital channel for one subject (S9). Responses were clearly different for various stimuli. We compared the sums of responses 1 + 4 + 7 and 2 + 5 + 8, with responses to stimuli that would give the same superposed image.

Data Analysis

The data were analyzed with the Elekta Neuromag software. To reduce magnetic disturbances and measurement artifacts including eye blinks, we used the spatiotemporal signal space separation method (tSSS) [Taulu and Simola, 2006]. tSSS is able to remove external interference from the data more efficiently than the basic SSS method [Taulu and Kajola, 2005]. Visual inspection of data before and after tSSS did not reveal any change in the latencies of the observed responses. Signals were averaged offline over a time interval starting 100 ms before and ending 1,000 ms after stimulus onset. The averaged data were digitally low-pass-filtered at 40 Hz; the mean signal value from 100 to 0 ms before stimulus onset served as the baseline.

Sums of the MEG responses to stimuli in the comparison groups (Table I) were evaluated (e.g., Fig. 2). Differences in the low-level stimulus features were eliminated in these sums of responses, because superposition of the particular groups (Table I) would produce the same image (Fig. 1b), and consequently, the same parts of the visual field were stimulated with the same luminance and spatial frequency. To compare two summed MEG responses, e.g., face-containing and meaningless object-containing sums, the difference between 1 + 4 + 7 vs. 3 + 6 + 9 was calculated (sum of 3 + 6 + 9 was subtracted from 1 + 4 + 7). Other face-related comparisons, based on the equivalent superpositions of figures (e.g., Fig. 1b), are given in the first column of Table I. If only one or two face comparisons had shown the difference, it might have been an incidental, nonface-related effect. However, as all four face comparisons showed a similar pattern, we considered these responses as face-related (Figs. 4a and 5a). Analogous flower-related comparisons are listed in the second column of Table I. In the control comparisons, we evaluated MEG responses to the pairs of stimulus groups that contained only meaningless images (third column of Table I). Finally, to determine the dissociation of responses to the face (image 1) and the flower (image 2), the difference between

MEG responses to 1 + 4 + 7 and 2 + 5 + 8 was evaluated (see Fig. 2). Again, comparing the sums, differences in the low-level physical features of the stimuli (different locations in the visual field) were avoided.

The early response was considered reliably face- or flower-related if all four face or flower comparisons, respectively, peaked above the noise level around the same latency before 150 ms, in at least four sensor locations. The noise level was defined as two standard deviations of signal during the baseline period. For each pair of planar gradiometers, the amplitude of the gradient vector, $[(\partial B_z / \partial x)^2 + (\partial B_z / \partial y)^2]^{1/2}$, was computed, the local radial direction defining the z-axis. The amplitude of this vector is largest just above a source [Hämäläinen et al., 1993]. To determine the face and flower latencies, we used the first reliable peak (all comparisons above the noise level) in the vector amplitude of the channel pair with the maximal amplitude for the comparisons 1 + 4 + 7 vs. 3 + 6 + 9 and 2 + 5 + 8 vs. 3 + 6 + 9, respectively. We chose these comparisons because 3 + 6 + 9 contained the meaningless target 3, and consequently, the same attentional load required by the task could be assumed in the compared groups.

Magnetic source localization methods for equivalent current dipoles (ECDs) in a sphere were used to identify cortical activity related to the difference in response to face and flower (i.e., difference between 1 + 4 + 7 and 2 + 5 + 8). As we had MRIs of all subjects, the sphere model was fitted to the local curvature of the occipital area.

To evaluate nonlinearity in the MEG responses, we used the vector amplitudes for all gradiometer pairs in each comparison (e.g., 1 + 4 + 7 vs. 2 + 5 + 8). Because of individual variability in the location of early visual MEG responses [e.g., Aine et al., 1996], a set of sensors with a significant difference in the response is usually identified individually and used for the analysis [e.g., Furey et al., 2006; Liu et al., 2002]. To avoid arbitrariness in the selection criterion for significant sensors, we summed differences in the responses across all sensor locations. Total differences obtained in this way were used for the comparisons across all 11 subjects. The average responses in the time window 80–150 ms were compared using a two-tailed paired *t*-test. To illustrate these total differences, we averaged them across all subjects (Fig. 7). Analogously, to compare early responses to face and flower, and face-containing and flower-containing sums across all subjects, we summed the vector amplitudes of MEG signal in all gradiometer channels and submitted these total responses averaged in the time interval 70–120 ms to a two-tailed paired *t*-test.

RESULTS

The total MEG responses to face and flower summed across all gradiometer channels and averaged across all subjects are shown in Figure 3. Early responses (70–120

Figure 3.

Vector amplitudes of MEG responses to face, flower, face-containing sum (1 + 4 + 7), and flower-containing sum (2 + 5 + 8) calculated for each gradiometer pair, summed across all sensor locations and averaged across all subjects. The rectangle indicates the time window 70–120 ms.

ms) to flower were larger than to face ($P = 0.027$), but responses to other stimuli did not differ from each other. Similarly, the flower-containing sums of the responses 2 + 5 + 8 were larger than the face-containing sums 1 + 4 + 7 in the same time window ($P = 0.014$) while the control sums, not containing any targets, 4 + 5 + 6 and 7 + 8 + 9 did not differ ($P = 0.244$). Analogous results were obtained for MEG signals in a different selection of the channels over the occipital cortex where the early responses were most prominent.

Eight out of the 11 subjects showed reliable early face- and flower-related MEG responses that were over the noise level in at least four sensor locations for all four comparisons (Table I). Indications for similar responses were found in the data of two additional subjects, but they were not reliable probably because of strong alpha activity. Figure 4a shows the MEG responses of one subject for all comparisons (Table I) at all gradiometer channels. A com-

Figure 4.

(a) The difference in the sums of the MEG responses of subject S9 to stimuli with identical superpositions. The figure shows the responses from the pairs of orthogonal planar gradiometers at 102 sensor locations and two enlarged channels I and II. The horizontal lines indicate the largest noise level (two standard deviations during baseline). (b) Isofield contour maps for the sums of responses containing face and flower response (1 + 4 + 7 and 2 + 5 + 8, respectively) and their subtraction with fitted ECD at 110 ms. The contour lines are separated by 80 fT/cm. (c) The ECD is superimposed on the individual MRI: coronal, sagittal, and horizontal views.

Figure 5.

(a) The face, flower, and control comparisons of MEG responses in one gradiometer channel over the occipital cortex for seven subjects with reliable early face- and flower-related responses. The channel was chosen individually for each subject. (b) Magnetic field pattern of the difference $1 + 4 + 7$ vs. $2 + 5 + 8$ and fitted ECDs. ECDs are superimposed on individual MRIs.

Figure 6.

Locations of sensors with the reliable responses for face and flower comparisons.

plex pattern of responses can be seen over the occipital, temporal, and parietal areas. The enlarged channel I, over the occipital cortex, had maximal amplitudes for the differences, which started at about 75 ms and peaked at about 110 ms in this channel. These early differences were reliable for all face and flower comparisons, and they peaked in the opposite directions for face and flower. On the other hand, the response pattern of the three control comparisons was inconsistent and variable, with amplitudes being often below the noise level. The enlarged channel II illustrates larger responses for face than flower comparisons around 160 ms over the occipitotemporal cortex.

Figure 5a shows face, flower, and control comparisons in one individually chosen channel for the seven additional subjects with reliable face and flower responses. They show a response pattern similar to that of the subject from Figure 4, except for the two subjects who had responses with reversed polarity. Two additional subjects (not shown) had similar responses, but they were not reliable in the required four sensor locations because of the high noise level. The 11th subject showed a face-related response around 125 ms, but no reliable flower-related response. Locations of sensors with the reliable face and flower responses for eight subjects are illustrated in Figure 6.

Table II shows latencies for eight subjects with reliable face and flower responses. The latencies of the early face- and flower-related responses, 106 ± 14 and 102 ± 11 ms, respectively, were not significantly different. Face vs. flower latency ($1 + 4 + 7$ vs. $2 + 5 + 8$) was 102 ± 15 ms. The peak latency of these difference responses varied across the subjects from 75 to 124 ms.

The magnetic field patterns for the sums of the responses (and also for the original responses) were very complex (Fig. 4b) and difficult to model with ECDs. However, the difference between the face- and flower-summed responses had a dipolar field pattern for eight subjects and was modeled adequately with a single current dipole. Goodness-of-fit values were larger than 75% (calculated

TABLE II. Peak latencies of face (1 + 4 + 7 vs. 3 + 6 + 9) and flower (2 + 5 + 8 vs. 3 + 6 + 9) comparisons for subjects with reliable differences

Subject	Face latency (ms)	Flower latency (ms)
S1	101	106
S3	102	120
S6	121	100
S7	79	81
S8	123	105
S9	109	108
S10	100	97
S11	112	95
Mean $\pm$ SD	106 $\pm$ 14	102 $\pm$ 11

with respect to all channels). Estimated source locations were superimposed on individual MRIs (Figs. 4c and 5b) and were located in the occipital lobe, close to the midline for most of the subjects. The estimated ECDs were in the right hemisphere for five subjects and in the left hemisphere for three subjects.

Figure 7 illustrates the total differences of the MEG responses to four pairs of stimulus groups that were averaged across all 11 subjects. Superpositions of the stimuli from all compared stimulus groups produced an identical image (see Fig. 1b). However, superpositions of their MEG responses were different, indicating nonlinearity in brain response. Moreover, the differences varied across the comparisons; the face vs. flower (1 + 4 + 7 vs. 2 + 5 + 8) difference was largest. The differences face vs. flower, face vs. control, and flower vs. control were significantly larger than the difference 4 + 5 + 6 vs. 7 + 8 + 9 between two groups of meaningless stimuli ($P = 0.0002$, $P = 0.003$, and $P = 0.029$, respectively). Stimulus groups in each compared pair had equivalent attentional loads, e.g., in face comparisons (1 + 4 + 7 vs. 3 + 6 + 9), images 1 and 3 were targets.

In the behavioral experiment, task performance (mean $\pm$ SD) was very high, ($99.8 \pm 0.5\%$), ($99.4 \pm 0.8\%$), and ($99.5 \pm 0.7\%$) for the face, the flower, and the meaningless target, respectively. The false alarm rate was ($2.6 \pm 2.0\%$). The reaction time (RT) for the face (425 ± 48) ms was shorter than the RT for the flower (450 ± 36) ms ($P < 0.0001$), which was shorter than the RT for the meaningless target (469 ± 48) ms ($P < 0.002$).

DISCUSSION

This study demonstrates an early dissociation of face and object processing that takes place in the occipital cortex around 100 ms and cannot be attributed to the low-level physical features of the stimuli. Early MEG responses to face and flower were different (as illustrated in Figs. 2 and 3), but we could not draw any conclusions because different locations of the stimulus parts in the visual field could induce differences in evoked responses [e.g., Aine et al., 1996; Portin et al., 1999; Supek et al., 1999; Tzelepi

et al., 2001]. Our experimental paradigm allowed us comparison between MEG responses to face, object (flower), and meaningless stimuli, avoiding differences in the low-level stimulus characteristics by comparing sums of the responses to superposition groups that would produce the same resulting image.

Early face-related MEG responses that are in line with our results have been reported in several previous studies, but it was not possible to exclude the effect of low-level differences between stimuli on these early responses [Halit et al., 2000; Herrmann et al., 2005a,b; Itier and Taylor, 2002, 2004a,b; Itier et al., 2006; Linkenkaer-Hansen et al., 1998; Liu et al., 2002; Thierry et al., 2007a]. An MEG study on stages in face processing [Liu et al., 2002] found an M100 component over the occipitotemporal cortex that was significantly larger for face than nonface stimuli. The amplitude of the M100 response was larger when the identical face stimulus was perceived as a face than when it was incorrectly categorized as a nonface. The authors concluded that M100 reflects an initial stage of face categorization, and cannot be explained merely by differences in the low-level properties of the stimuli. Nevertheless, this result was obtained indirectly, using behavioral responses in a rather small number of trials (20–30).

The present study offers a direct measure of an early dissociation of MEG responses to faces and objects. Physical properties of the stimuli were carefully controlled: we compared sums of the responses to groups of stimuli. If stimuli in these groups were superposed, they would give the same resulting image. However, the sums of the responses to the stimulus groups were not the same. The amplitude of the difference was larger if one of the stimuli in the group was a face or an object (flower), and it was largest for the face vs. flower comparison.

Figures 4 and 5 show that the responses to the face and the flower comparisons (Table I) are mirror-symmetric. For the face comparisons, responses to stimuli 4 and 7 were typically added to the responses to faces, and responses to stimuli 5 and 8 were subtracted. For the flower comparisons, the opposite was true: responses to stimuli 5 and 8 were added, and responses to stimuli 4 and 7 subtracted.

Figure 7.

The vector amplitudes of MEG signal in the gradiometer channels summed across all sensor locations and averaged across all subjects calculated for the face, flower, face vs. flower, and control comparisons.

This opposite summing and subtracting of the meaningless stimuli might have caused the observed difference between face/flower and control sums at 100 ms. As shown in Figure 7, nonlinearity was present in the control sums and certainly contributed to the observed difference at 100 ms. However, it was not the only nor the main source of the early differences in face and flower comparisons, because it was shown that early responses to the face and the flower (stimuli 1 and 2) were different. Comparison of the responses to the face and the flower in Figure 3 resembles the comparison of the responses to the face- and flower-containing sums. Furthermore, visual inspection of the responses to all nine stimuli revealed the largest early response to flower and smallest response to face in many occipital channels. Probably this was the main origin of the observed mirror symmetry. However, our finding that the early response to the flower was larger than to the face is not in agreement with previous studies that reported larger MEG and EEG response to faces than houses [Herrmann et al., 2005a,b; Liu et al., 2002]. Differing responses to faces and houses in these previous studies were found over the occipitotemporal cortex unlike differences in the responses to face and flower stimulus in our study that were most prominent in the medial occipital channels. Further studies with additional meaningful and control stimuli are needed to address this issue.

Kato et al. [2004] used identical stimuli containing ovals and rectangles across two conditions. In one condition, the subjects were instructed to look only at rectangles that formed an abstract image; in the other condition, they were told that the ovals form a face pattern that should be observed. Subtraction between the two conditions showed a response occurring 120 ms after the stimulus onset predominantly in the right occipital region, but the authors did not perform source localization at these early latencies. Our results are consistent with these findings, although the location of the ECD that modeled the difference response in our study was in the left occipital regions for three subjects. Although the visual inputs were identical in the two conditions in Kato's study, the face condition required a higher attentional load and reconstruction of the face representation from fragmentary evidence. In a similar paradigm, Pegna et al. [2004] used degraded images, first perceived as meaningless and then identified as faces, objects, and words. After identification, additional activity started at 100 ms for faces and at about 200 ms for objects and words.

Several studies have shown nonspatial attentional modulation of the P1 component [e.g., Rossion et al., 1999a; Taylor, 2002]. In our study, the task-related attentional demands were the same for face, flower, and one meaningless stimulus; this paradigm allowed comparisons between conditions with the same attentional load. Furthermore, our results suggest that early differences look quite similar for face and flower comparisons with different attentional loads (Figs. 4a and 5a), and therefore cannot be explained by attentional effects. For example, both stimulus groups in the face com-

parison 1 + 4 + 7 vs. 3 + 6 + 9 contained one target, while in the comparison 1 + 3 vs. 5 + 8, the first group contained two targets and the second had no targets. Further evidence that attention has no major effect on early dissociation of responses to faces and objects comes from a study by Furey et al. [2006]. They used superposed pictures of faces and houses with the task of attending either to the faces or to the houses. The face vs. house difference started around 190 ms, which was much later than the difference between responses when faces and houses were presented separately. Similarly, overlaid pictures of faces and cars were used by Thierry et al. [2007a]; a difference between attended faces and cars was evident only after 300 ms.

In our study, earliest dissociation of responses to faces and objects appeared already around 100 ms. However, seven subjects showed a later face-related response that was larger than a corresponding flower-related response (e.g., subject S9 around 160 ms; Fig. 4a), and it is in agreement with many observations of the N170/M170 component of the evoked EEG/MEG response classically associated with face processing [e.g., Bentin et al., 1996; Itier and Taylor, 2002, 2004a,b; Itier et al., 2006; Linkenkaer-Hansen et al., 1998; Liu et al., 2002; Lu et al., 1991; Sams et al., 1997]. This later dissociation of MEG responses to faces and objects was found in more lateral channels (not shown in Fig. 5), indicating activation of the occipitotemporal cortex, including fusiform face area reported in the previous MEG studies on face processing [Halgren et al., 2000; Itier et al., 2006; Linkenkaer-Hansen et al., 1998; Sams et al., 1997; Tanskanen et al., 2005; Tarkiainen et al., 2002; Watanabe et al., 1999, 2003]. In this study, we focused on the first dissociation of responses to faces and objects that appeared in the occipital cortex around 100 ms.

A recent study on controlling interstimulus perceptual variance [Thierry et al., 2007a] raised many controversies [Bentin et al., 2007; Thierry et al., 2007b]. Thierry et al. [2007a] controlled ISPV (at least within the category) for faces, cars, and butterflies and found that the N170 was sensitive to ISPV but not to the stimulus category, while P1 was modulated by category, but not by ISPV. In this study, we focused on controlling physical stimulus features. Our data corroborate early modulation of the brain response around 100 ms by stimulus category. However, later dissociation of the face- and flower-containing sums of MEG responses, corresponding to the N170, does not support the results of Thierry et al.

Early face-related responses found in this study seem consistent with single-neuron studies in monkeys [Afriz et al., 2006; Ó Scalaidhe et al., 1999; Sugase et al., 1999], although they cannot be directly compared. Sugase et al. [1999] used information theory to analyze single-neuron responses from inferiotemporal cortex. They showed that an early response, about 90 ms after stimulus onset, contains global information on categorization of the face as a face, whereas 50 ms later, fine information about identity or expression was reflected in the response. Similar results were obtained by microstimulation of neurons in inferio-

temporal cortex [Afraz et al., 2006]. Microstimulation during the 50- to 100-ms interval biased monkeys' decision toward face category in categorization task. Ó Scalaidhe et al. [1999] reported a face-selective response 70 ms after stimulus onset in the prefrontal cortex neurons of the macaque monkeys.

Previous MEG studies in humans with simple visual stimuli have identified multiple simultaneously active brain regions during early-evoked activity [Aine et al., 1996; Supek et al., 1999]. MEG studies on face processing have modeled the M100 component by one or two occipital ECDs [Halgren et al., 2000; Tanskanen et al., 2005; Watanabe et al., 1999, 2003]. Our data suggests early activation of multiple regions by complex visual stimuli (complex field pattern in Fig. 4b). Because of the complexity of the evoked fields and pronounced interindividual differences, it was not possible to make a consistent estimate of the cortical areas activated by our stimuli. However, dissociation of face- and flower-related response was localized to one region—the occipital cortex close to the midline (Figs. 4 and 5). High goodness-of-fit values and dipolar field patterns for all subjects indicated that the single-dipole model was adequate to model this activity. The reversed dipole polarity for two subjects was probably caused by individual differences in cortical geometry [Aine et al., 1996; Supek et al., 1999]. We did not find any indications of an early differential activity for faces and objects in the fusiform gyrus bilaterally as reported in the previous ERP study [Herrmann et al., 2005b].

The present paradigm also provided unambiguous information on the nonlinearity of brain responses. Our data indicates that an MEG response to a complex visual stimulus is not simply a sum of the responses to the elements constituting the stimulus. If our stimuli were superposed, they would give identical images (Fig. 1b). However, when corresponding summed MEG responses were compared, they revealed differences (Figure 2–5). The question here is how nonlinearity, i.e., interaction between constitutive elements of the stimuli, is reflected in the response. Our data suggest that the meaningful patterns (face and flower) produce stronger nonlinearity in the response than the meaningless stimuli (Fig. 7). More specifically, this nonlinearity allowed us to determine early dissociation of responses to faces and objects. Low-level configurational features are inherent to meaningful stimuli, especially faces; we perceive four ovals as a face if they have a typical configuration (e.g., stimulus 1 in Fig. 1). Strictly speaking, it is not possible to completely separate the low-level stimulus features and stimulus “faceness.” Even presentation of face parts (eyes, mouth) affects face-related task performance and correlates with the N170 and P300 component of ERPs [e.g. Schyns et al., 2003; Smith et al., 2004].

The task in our MEG experiment was silent recognition of the three target stimuli, i.e., our subjects did not have to press a response button, because we wanted to avoid motor-related cortical activity. In the supplementary behavioral experiment, we checked the target identification rate and RTs. The identification rate was very high for all

three targets (face, flower, and meaningless target), showing that recognition was easy. However, the RT was shortest for the face target, indicating that faces are a special group of visual stimuli. Without entering into discussion on whether the origin of the face specificity is a perceptual expertise network or a face-specific domain [e.g., Gauthier et al., 2003; Xu et al., 2005], we note that this is in agreement with the findings from most of the face studies. The shorter RT for the flower than for the meaningless target suggests that it is easier to recognize meaningful stimuli. These findings are in agreement with our MEG data.

CONCLUSION

This study provides evidence that early dissociation of face and object processing takes place around 100 ms after stimulus onset in the occipital cortex and cannot be attributed to the differences in the low-level physical features of the stimuli or attention demands. Our data suggest that nonlinearity in the brain response is larger for face and object than for meaningless control stimuli.

ACKNOWLEDGMENTS

We thank Marijan Palmovic for his technical assistance. The work was carried out at the BioMag Laboratory, Helsinki University Central Hospital, Helsinki, Finland; Department of Biomedical Engineering and Computational Science, Helsinki University of Technology, Espoo, Finland; Department of Physics, Faculty of Science, University of Zagreb, Zagreb, Croatia; and Laboratory for Psycholinguistic Research, University of Zagreb, Zagreb, Croatia.

REFERENCES

- Afraz SR, Kiani R, Esteky H (2006): Microstimulation of inferotemporal cortex influences face categorization. *Nature* 442:692–695.
- Aine CJ, Supek S, George JS, Ranken D, Lewine J, Sanders J, Best E, Tiee W, Flynn ER, Wood CC (1996): Retinotopic organization of human visual cortex: Departures from the classical model. *Cereb Cortex* 6:354–361.
- Batty M, Taylor MJ (2003): Early processing of the six basic facial emotional expressions. *Brain Res Cogn Brain Res* 17:613–620.
- Bentin S, Allison T, Puce A, Perez E, McCarthy G (1996): Electrophysiological studies of face perception in humans. *J Cogn Neurosci* 8:551–565.
- Bentin S, Taylor MJ, Rousselet GA, Itier RJ, Caldara R, Schyns PG, Jacques C, Rossion B (2007): Controlling interstimulus perceptual variance does not abolish N170 face sensitivity. *Nat Neurosci* 10:801–802.
- Braeutigam S, Bailey AJ, Swithenby SJ (2001): Task-dependent early latency (30–60 ms) visual processing of human faces and other objects. *Neuroreport* 12:1531–1536.
- Boynton GM, Demb JB, Glover GH, Heeger DJ (1999): Neuronal basis of contrast discrimination. *Vision Res* 39:257–269.
- Debruille JB, Guillem F, Renault B (1998): ERPs and chronometry of face recognition: following-up Seeck et al. and George et al. *Neuroreport* 9:3349–3353.
- Eger E, Jedynak A, Iwaki T, Skrandies W (2003): Rapid extraction of emotional expression: Evidence from evoked potential fields

- during brief presentation of face stimuli. *Neuropsychologia* 41:808–817.
- Eimer M, Holmes A (2002): An ERP study on the time course of emotional face processing. *Neuroreport* 13:427–431.
- Furey ML, Tanskanen T, Beauchamp MS, Avikainen S, Uutela K, Hari R, Haxby JV (2006): Dissociation of face-selective cortical responses by attention. *Proc Natl Acad Sci USA* 103:1065–1070.
- Gauthier I, Curran T, Curby KM, Collins D (2003): Perceptual interference supports a non-modular account of face processing. *Nat Neurosci* 6:428–432.
- George N, Jemel B, Fiori N, Renault B (1997): Face and shape repetition effects in humans: A spatio-temporal ERP study. *Neuroreport* 8:1417–1423.
- Halgren E, Raji T, Marinkovic K, Jousmäki V, Hari R (2000): Cognitive response profile of the human fusiform face area as determined by MEG. *Cereb Cortex* 10:69–81.
- Halit H, de Haan M, Johnson MH (2000): Modulation of event-related potentials by prototypical and atypical faces. *Neuroreport* 11:1871–1875.
- Hämäläinen M, Hari R, Ilmoniemi RJ, Knuutila J, Lounasmaa OV (1993): Magnetoencephalography—Theory, instrumentation, and applications to noninvasive studies of the working human brain. *Rev Mod Phys* 65:413–497.
- Haynes JD, Lotto RB, Rees G (2004): Responses of human visual cortex to uniform surfaces. *Proc Natl Acad Sci USA* 101:4286–4291.
- Herrmann MJ, Ehlis AC, Ellgring H, Fallgatter AJ (2005a): Early stages (P100) of face perception in humans as measured with event-related potentials (ERPs). *Neural Transm* 112:1073–1081.
- Herrmann MJ, Ehlis AC, Muehlberger A, Fallgatter AJ (2005b): Source localization of early stages of face processing. *Brain Topogr* 18:77–85.
- Holmes A, Vuilleumier P, Eimer M (2003): The processing of emotional facial expression is gated by spatial attention: Evidence from event-related brain potentials. *Brain Res Cogn Brain Res* 16:174–184.
- Itier RJ, Taylor MJ (2002): Inversion and contrast polarity reversal affect both encoding and recognition processes of unfamiliar faces: A repetition study using ERPs. *Neuroimage* 15:353–372.
- Itier RJ, Taylor MJ (2004a): N170 or N1? Spatiotemporal differences between object and face processing using ERPs. *Cereb Cortex* 14:132–142.
- Itier RJ, Taylor MJ (2004b): Effects of repetition learning on upright, inverted and contrast-reversed face processing using ERPs. *Neuroimage* 21:1518–1532.
- Itier RJ, Herdman AT, George N, Cheyne D, Taylor MJ (2006): Inversion and contrast-reversal effects on face processing assessed by MEG. *Brain Res* 1115:108–120.
- Jemel B, Schuller AM, Cheref-Khan Y, Goffaux V, Crommelinck M, Bruyer R (2003): Stepwise emergence of the face-sensitive N170 event-related potential component. *Neuroreport* 14:2035–2039.
- Johannes S, Münte TF, Heinze HJ, Mangun GR (1995): Luminance and spatial attention effects on early visual processing. *Brain Res Cogn Brain Res* 2:189–205.
- Kanwisher N, McDermott J, Chun MM (1997): The fusiform face area: A module in human extrastriate cortex specialized for face perception. *J Neurosci* 17:4302–4311.
- Kato Y, Muramatsu T, Kato M, Shintani M, Yoshino F, Shimono M, Ishikawa T (2004): An earlier component of face perception detected by seeing-as-face task. *Neuroreport* 15:225–229.
- Linkenkaer-Hansen K, Palva JM, Sams M, Hietanen JK, Aronen HJ, Ilmoniemi RJ (1998): Face-selective processing in human extrastriate cortex around 120 ms after stimulus onset revealed by magneto- and electroencephalography. *Neurosci Lett* 253:147–150.
- Liu J, Harris A, Kanwisher N (2002): Stages of processing in face perception: An MEG study. *Nat Neurosci* 5:910–916.
- Lu ST, Hämäläinen MS, Hari R, Ilmoniemi RJ, Lounasmaa OV, Sams M, Vilkmann V (1991): Seeing faces activates three separate areas outside the occipital visual cortex in man. *Neuroscience* 43:287–290.
- Mouchetant-Rostaing Y, Giard MH (2003): Electrophysiological correlates of age and gender perception on human faces. *J Cogn Neurosci* 15:900–910.
- Mouchetant-Rostaing Y, Giard MH, Bentin S, Aguera PE, Pernier J (2000): Neurophysiological correlates of face gender processing in humans. *Eur J Neurosci* 12:303–310.
- Ó Scalaidhe SP, Wilson FAW, Goldman-Rakic PS (1999): Face-selective neurons during passive viewing and working memory performance of rhesus monkeys: Evidence for in trinsic specialization of neuronal coding. *Cereb Cortex* 9:459–475.
- Pegna AJ, Khatib A, Michel CM, Landis T (2004): Visual recognition of faces, objects, and words using degraded stimuli: Where and when it occurs. *Hum Brain Mapp* 22:300–311.
- Pizzagalli D, Regard M, Lehmann D (1999): Rapid emotional face processing in the human right and left brain hemispheres: An ERP study. *Neuroreport* 10:2691–2698.
- Pizzagalli DA, Lehmann D, Hendrick AM, Regard M, Pascual-Marqui RD, Davidson RJ (2002): Affective judgments of faces modulate early activity (approximately 160 ms) within the fusiform gyri. *Neuroimage* 16:663–677.
- Portin K, Vanni S, Virsu V, Hari R (1999): Stronger occipital cortical activation to lower than upper visual field stimuli. *Neuro-magnetic recordings*. *Exp Brain Res* 124:287–294.
- Pourtois G, Grandjean D, Sander D, Vuilleumier P (2004): Electrophysiological correlates of rapid spatial orienting towards fearful faces. *Cereb Cortex* 14:619–633.
- Pourtois G, Thut G, Grave de Peralta R, Michel C, Vuilleumier P (2005): Two electrophysiological stages of spatial orienting towards fearful faces: Early temporo-parietal activation preceding gain control in extrastriate visual cortex. *Neuroimage* 15:149–163.
- Puce A, Allison T, Gore JC, McCarthy G (1995): Face-sensitive regions in human extrastriate cortex studied by functional MRI. *J Neurophysiol* 74:1192–1199.
- Rossion B, Campanella S, Gomez CM, Delinte A, Debatisse D, Liard L, Dubois S, Bruyer R, Crommelinck M, Guerit JM (1999a): Task modulation of brain activity related to familiar and unfamiliar face processing: An ERP study. *Clin Neurophysiol* 110:449–462.
- Rossion B, Delvenne JF, Debatisse D, Goffaux V, Bruyer R, Crommelinck M, Guerit JM (1999b): Spatio-temporal localization of the face inversion effect: An event-related potentials study. *Biol Psychol* 50:173–189.
- Rousset GA, Husk JS, Bennett PJ, Sekuler AB (2005): Spatial scaling factors explain eccentricity effects on face ERPs. *J Vis* 5: 755–763.
- Sams M, Hietanen JK, Hari R, Ilmoniemi RJ, Lounasmaa OV (1997): Face-specific responses from the human inferior occipito-temporal cortex. *Neuroscience* 77:49–55.
- Seeck M, Michel CM, Mainwaring N, Cosgrove R, Blume H, Ives J, Landis T, Schomer DL (1997): Evidence for rapid face recognition from human scalp and intracranial electrodes. *Neuroreport* 8:2749–2754.
- Schyns PG, Jentzsch I, Johnson M, Schweinberger SR, Gosselin F (2003): A principled method for determining the functionality of brain responses. *Neuroreport* 14:1665–1669.
- Sergent J, Ohta S, MacDonald B (1992): Functional neuroanatomy of face and object processing. A positron emission tomography study. *Brain* 115:15–36.

- Singh KD, Smith AT, Greenlee MW (2000): Spatiotemporal frequency and direction sensitivities of human visual areas measured using fMRI. *Neuroimage* 12:550–564.
- Smith ML, Gosselin F, Schyns PG (2004): Receptive fields for flexible face categorizations. *Psychol Sci* 15:753–761.
- Streit M, Ioannides AA, Liu L, Wölwer W, Dammers J, Gross J, Gaebel W, Müller-Gärtner HW (1999): Neurophysiological correlates of the recognition of facial expressions of emotion as revealed by magnetoencephalography. *Brain Res Cogn Brain Res* 7:481–491.
- Sugase Y, Yamane S, Ueno S, Kawano K (1999): Global and fine information coded by single neurons in the temporal visual cortex. *Nature* 400:869–873.
- Supek S, Aine CJ, Ranken D, Best E, Flynn ER, Wood CC (1999): Single vs. paired visual stimulation: Superposition of early neuromagnetic responses and retinotopy in extrastriate cortex in humans. *Brain Res* 830:43–55.
- Susac A, Ilmoniemi RJ, Pihko E, Supek S (2004): Neurodynamic studies on emotional and inverted faces in an oddball paradigm. *Brain Topogr* 16:265–268.
- Tanskanen T, Näsänen R, Montez T, Päälyssaho J, Hari R (2005): Face recognition and cortical responses show similar sensitivity to noise spatial frequency. *Cereb Cortex* 15:526–534.
- Tarkiainen A, Cornelissen PL, Salmelin R (2002): Dynamics of visual feature analysis and object-level processing in face versus letter-string perception. *Brain* 125:1125–1136.
- Taulu S, Kajola M (2005): Presentation of electromagnetic multichannel data: The signal space separation method. *J Appl Phys* 97:124905.
- Taulu S, Simola J (2006): Spatiotemporal signal space separation method for rejecting nearby interference in MEG measurements. *Phys Med Biol* 51:1759–1768.
- Taylor MJ (2002): Non-spatial attentional effects on P1. *Clin Neurophysiol* 113:1903–1908.
- Thierry G, Martin CD, Downing P, Pegna AJ (2007a): Controlling for interstimulus perceptual variance abolishes N170 face selectivity. *Nat Neurosci* 10:505–511.
- Thierry G, Martin CD, Downing PE, Pegna AJ (2007b): Is the N170 sensitive to the human face or to several intertwined perceptual and conceptual factors? *Nat Neurosci* 10:802–803.
- Tzelepi A, Ioannides AA, Poghosyan V (2001): Early (N70m) neuromagnetic signal topography and striate and extrastriate generators following pattern onset quadrant stimulation. *Neuroimage* 13:702–718.
- Watanabe S, Kakigi R, Koyama S, Kirino E (1999): Human face perception traced by magneto- and electro-encephalography. *Brain Res Cogn Brain Res* 8:125–142.
- Watanabe S, Kakigi R, Puce A (2003): The spatiotemporal dynamics of the face inversion effect: A magneto- and electro-encephalographic study. *Neuroscience* 116:879–895.
- Xu Y, Liu J, Kanwisher N (2005): The M170 is selective for faces, not for expertise. *Neuropsychologia* 43:588–597.