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SENSORY-MEMORY-BASED CHANGE DETECTION IN FACE STIMULI

Ana Susac[1,*],
Risto J Ilmoniemi[2,3],
Selma Supek[1]

[1]*Department of Physics, Faculty of Science, University of Zagreb, Zagreb 10000, Croatia*

[2]*Department of Biomedical Engineering and Computational Science, Aalto University, FI-00076 AALTO, Finland*

[3]*BioMag Laboratory, HUSLAB, Helsinki University Central Hospital, P.O. Box 340, FI-00029 HUS, Finland*

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Abstract

Detection of a change in face is a socially important skill. Both event-related potential (ERP) and magnetoencephalographic (MEG) measurements were conducted using face stimuli presented in an oddball paradigm to investigate detection of a change in face identity and facial expression. In condition 1, a non-target deviant neutral face was presented among standard happy faces. In condition 2, the same deviant neutral face was presented with a standard neutral face of another person. The task in both conditions was silent counting of a second deviant (face with glasses). Non-target deviants elicited more negative ERP and corresponding MEG responses than standards in both conditions. This negativity was strongest at lateral posterior channels around 280 ms. Responses to the same deviant neutral face differed in two conditions. Deviance-related negativity resembled auditory mismatch negativity (MMN). Different responses to the same deviant in the two conditions suggest the existence of a sensory-memory trace for the standard to which the deviant was compared.

Keywords

Event-related potential (ERP) • Magnetoencephalography (MEG) • Mismatch negativity (MMN)
Change detection • Face processing • Visual oddball paradigm • Face identity • Facial expression

1. Introduction

Detection of changes in the environment is essential for humans in determining their responses and actions. Halgren and Marinkovic [1] described the N2/P3a complex from ERP oddball studies as the orienting complex that indicates an attention switch to potentially important external events. The mismatch negativity (MMN) is an earlier ERP component which is believed to reflect an automatic detection of stimulus change [2]. It is evoked by an infrequent stimulus (deviant), which differs from the frequently-occurring stimulus (standard) in one or several physical parameters. MMN implies a comparison between the deviant stimulus and a representation held in sensory memory of recently encountered standard stimuli. Although MMN is well-established for the auditory system, it is not completely clear whether there is an analogous phenomenon in the visual modality (for a review, see [3]).

Several ERP studies reported visual change detection based on sensory memory (e.g., [4-6]). Functional magnetic resonance imaging (fMRI) and MEG studies showed that the middle occipital gyrus (MOG) was activated by a change in visual stimulus [7-9]. Recently, it has been found that the MOG has an important role in visual change detection based on sensory memory [10].

Face is an important social stimulus and it is particularly important to detect its changes. It has been reported that successful detection of change in face stimulus is reflected in a posterior N2pc component [11], which appears posterior-contralateral to the attended side of the visual field at a latency of approximately 200-300 ms following a stimulus. Similarly, N2b is related to discrimination of emotional facial expressions in a visual oddball task [12,13]. It is restricted to the posterior areas and associated with simultaneous frontal positivity (P3a). N2b and P3a are evoked by attentively detected deviant stimuli in an oddball paradigm. Visual oddball tasks have also been used to examine recognition of facial expression in various patient groups [14-17]. An fMRI study using faces in an adaptation paradigm found that the occipital face area (OFA) is activated by conscious and non-conscious change detection [18]. This corroborates our finding that early cortical responses around 100 ms after stimulus onset are sensitive to changes in face stimuli [19].

Most of the studies agree that face identity and emotional expression are, at least partially, processed independently (for a review, see [20]). In our previous study, we examined the effects of a change of emotional expression and identity in upright and inverted faces [21]. Face inversion diminished deviance-related negativity at around 280 ms, suggesting an important role of face recognition in the observed effect. In the present study, we wanted to explore if observed deviance-related negativity reflects sensory-memory-based change detection.

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* *E-mail: ana@phy.hr*

In a preliminary behavioral study on the perception of faces, we noted that a neutral face when presented alone or with another neutral face was perceived as neutral. However, the same face appeared emotional (sad, angry, etc., depending on subject) when it was presented among happy faces. Our hypothesis was that detection of a change in face stimuli could involve analogous processes that underlie auditory MMN such as comparison of the stimulus to the memory trace of the previously encountered stimuli. A visual oddball paradigm was used to address these issues.

2. Experimental Procedures

2.1 Subjects

Five right-handed volunteers, with normal or corrected vision, participated in the experiment. The mean age was 24 years (range 22–28 years). As behavioral and neuroimaging studies have reported gender differences in responses to emotional facial stimuli (e.g., [22]), only males participated in the study. All subjects were young to avoid age-related differences (e.g., [23]). The study was approved by an Ethical Committee of Helsinki University Central Hospital (HUCH).

2.2 Stimuli and procedure

The subject sat in a dimly lit room and viewed images delivered by the Presentation software (Neurobehavioral Systems Inc., Albany, CA). The "egg-shaped" stimuli consisted of gray-scale face photographs (169 pixels high by 127 pixels wide) processed to have the same size and luminance. A mid-gray background with the same average luminance was chosen to avoid flickering. The size and luminosity of the stimuli were chosen to correspond approximately to face images from everyday experience. Between stimuli, the subjects fixated on a dark gray cross at the center of the screen. Each image subtended a 2.7° × 2° visual angle and was presented at the center of the visual field for a duration of 150 ms. The onset-to-onset interstimulus interval was 600 ms. An increase in interstimulus interval might cause a decay of the neural representation of the standard stimulus (Näätänen, 1992). In this study, the rate of facial stimuli was set high to establish a strong memory trace for standards and to collect a large number of responses for the averages.

The experiment consisted of two conditions. In condition 1, a happy face (Figure 1a, HS) was the standard (probability of occurrence, P = 0.75) and a neutral face (Figure 1b, ND1) of the same person was the deviant (P = 0.13). In condition 2, the deviant was the same (Figure 1b, ND2) and the standard was a neutral face of another person (Figure 1c, NS). In order to focus attention on the visual stimuli in both conditions, the subjects silently counted the occurrences of a second deviant (face with glasses, Figure 1d, P = 0.12).

The short blocks lasted until 50 neutral face deviants were presented; a one-minute break followed. The two conditions were alternated in short blocks. After four blocks, a longer break was made and the data were saved. In each condition, the total number of trials per long block was approximately 770 (100 deviants, approximately 578 standards and 92 targets). Everything was performed three times (Figure 1e). Overall, 600 neutral face deviants were presented, 300 in each condition. The stimulus sequences were pseudorandom so that each deviant was preceded by at least three standards.

2.3 Data acquisition and analysis

Brain activity was recorded with a 60-channel MEG-compatible EEG electrode cap in parallel with a 306-channel whole-scalp magnetometer (Elekta Neuromag Oy, Helsinki, Finland) in a magnetically shielded room (Euroshield Ltd., Finland) at the BioMag Laboratory, HUCH. Electrode impedances were kept below 20 kΩ. Horizontal and vertical eye movements were monitored with electrooculogram (EOG) electrodes placed above and below the left eye and lateral to each eye. A nose electrode was used as a reference. Epochs with EOG or MEG values exceeding 150 µV or 3000 fT/cm, respectively, were excluded from averaging.

The ERP and MEG data were recorded with a bandwidth of 0.1–200 Hz, sampled at 600 Hz, and averaged on-line separately for standard and deviant stimuli with subaveraging categories (even- and odd-numbered stimuli were averaged separately). The average signal value between 50 ms before and 50 ms after the stimulus onset served as the baseline. The data were digitally filtered off-line with 30-Hz lowpass and 1-Hz highpass frequencies. Data display and analysis were carried out with Neuromag software.

First, we wanted to compare responses to standard and deviant faces in both ERP and MEG data to confirm the emergence of the deviance-related negativity from our previous study [19]. We further explored the topography of the deviance-related negativity, its reliability by comparing responses in different experimental blocks, and dependence of the response on face emotion and identity

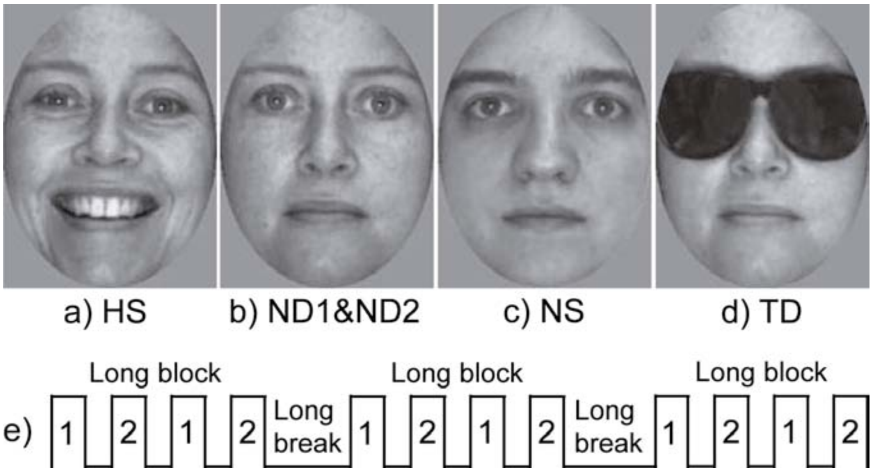

Figure 1. Facial stimuli: a) happy standard (HS); b) neutral deviant (ND1&ND2); c) neutral standard (NS); d) target deviant (TD). e) Time course of the measurements. The short blocks (conditions 1 and 2, respectively) lasted about five minutes.

by comparing conditions 1 and 2. The sensory-memory-based explanation of the observed response was examined by comparison of the response to the same neutral deviant in the two conditions. Finally, attention effects were evaluated by comparing responses to target and non-target deviants.

The peak latencies and amplitudes of the observed negativity were measured from deviant-standard difference waves. The peak amplitudes were calculated as the mean of a 25-ms time window centered around the individual ERP peaks at the right occipito-temporal ERP electrode PO8. Significance levels were computed with a two-tailed paired t-test.

The statistical significance of the observed effects shown in Figures 5 and 6 was evaluated by comparing the ERPs for time windows of 25 ms within the interval 200–350 ms. The averages of 25-ms interval in individual ERP responses to A and B (e.g., HS and ND1) were calculated and submitted to the paired t-test. Responses to A and B were considered significantly different if $p < 0.05$.

3. Results

Deviant-related negativity was found in ERP and MEG responses of all five subjects (Figure 2). The ERPs had similar characteristics across the subjects, so grand-averages were calculated. The corresponding MEG responses were much more localized and had different topography across the subjects. Consequently, MEG grand-averages were not justified.

Deviant-related negativity in ERP grand-averaged data started in lateral posterior channels and then spread medially and anteriorly, reaching maximum around 280 ms in most channels in condition 1 (Figure 3). The strongest negativity was found at the right occipito-temporal ERP electrode PO8. The peak latencies and amplitudes of this negativity were not statistically different for condition 1 and 2 (Table 1).

Negativity in response to the deviants was observed in individual ERPs of all subjects in both conditions. The persistence of the observed effect was verified during the time course of the experiment. ERP averages for the

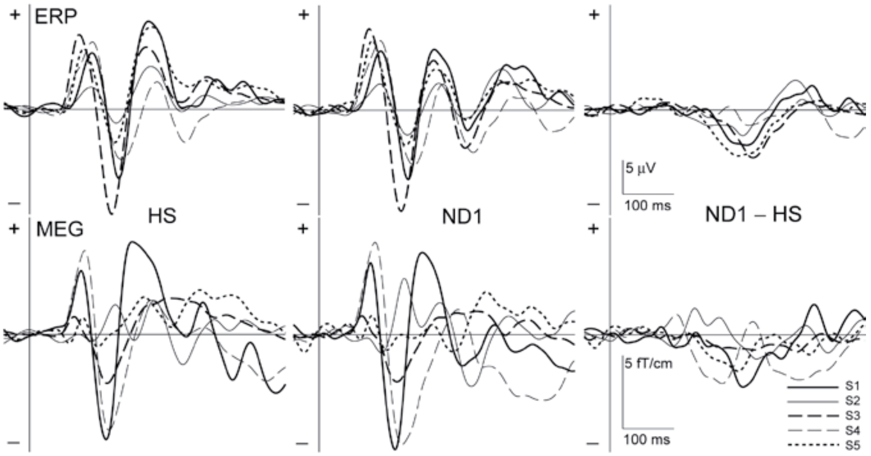

Figure 2. Evoked responses of five subjects to standard happy face (HS) and deviant neutral face (ND1) and the difference waveforms (ND1 – HS) at the ERP electrode PO8 and corresponding MEG channel above the right occipito-temporal region.

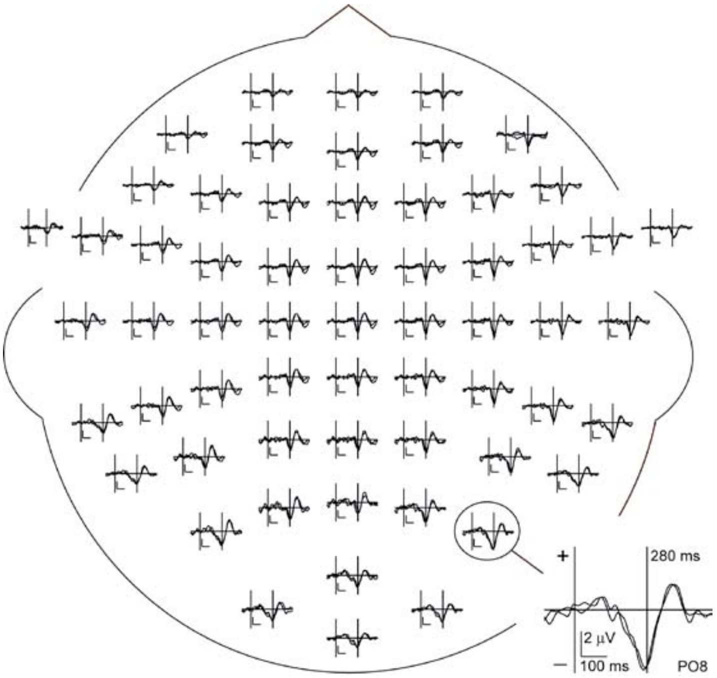

Figure 3. ERP grand-averaged difference waveforms obtained by subtracting HS (happy standard) from ND1 (neutral deviant). The responses were strongest in the enlarged right occipito-temporal electrode PO8. Deviant-related negativity appeared at the latencies 180–330 ms in lateral posterior channels and at 240–330 ms in medial posterior and anterior channels. Late positivity was evident in most of the channels. Even- and odd-numbered subaverages are given to show the reliability of the observed effect.

Table 1. Mean peak latencies and amplitudes of deviant-related negativity at the electrode PO8 for conditions 1 and 2.

	Latency / ms	Amlitude / µV
Condition 1	269 ± 21	−3.0 ± 1.0
Condition 2	280 ± 17	−2.7 ± 1.3

three long blocks (Figure 1e) were compared: negativity did not disappear due to habituation (Figure 4). Furthermore, the subaveraging categories confirmed the reliability of the effect (Figures 3 and 4).

Figure 5 shows grand-averaged ERP responses to standard and deviant stimuli for both conditions from approximate electrode position PO8, where amplitudes were largest. Responses to standards and deviants were statistically different ($p < 0.05$) for all five subjects at time window 225 – 300 ms in condition 1 and at 250 – 300 ms in condition 2.

ERP responses to physically the same neutral face deviant in condition 1 were larger and their latencies were shorter than in condition 2 (Figure 6). The difference in amplitude was most pronounced in parietal channels and reached statistical significance ($p < 0.05$) at the ERP electrode FCz in the time window 250–275 ms and at the electrode Pz at 275–300 ms. Differences between ND1 and ND2 were also evident in MEG data.

ERP responses to standard, target and non-target deviant in condition 1 are shown in Figure 7. Differences between the non-target deviant and the standard were more obvious than the differences between the target deviant and the standard and they appeared already at earlier latencies (120–170 ms). All three stimuli elicited the N170 component. This component was found at an earlier latency and with a larger amplitude for the target than for the standard and non-target deviant.

At later latencies, ERP data showed a more positive response to the deviants than to the standards (Figures 3 and 5). The P3 ERP component was rather small for non-target deviant, especially in condition 2 (Figure 5) and not clearly evident in all subjects (Figure 4). This late inverted polarity was not very distinctive in MEG data (Figure 2). P3 in ERP responses was larger for the target deviant than for the non-target deviant (Figure 7).

4. Discussion

The present study confirmed that the deviant face stimuli presented in an oddball paradigm elicited a negative shift in both ERP and MEG responses. This deviant-related negativity started in lateral posterior channels, reaching maximum value around 280 ms. A comparison between responses to the same neutral face deviant in conditions 1 and 2 (Figure 6) demonstrated that the response to deviant depended on the relationship between deviant and standard, suggesting sensory-memory explanation of the observed effect. This might be related to the behaviorally different perception of the physically identical neutral deviant stimulus in the two conditions

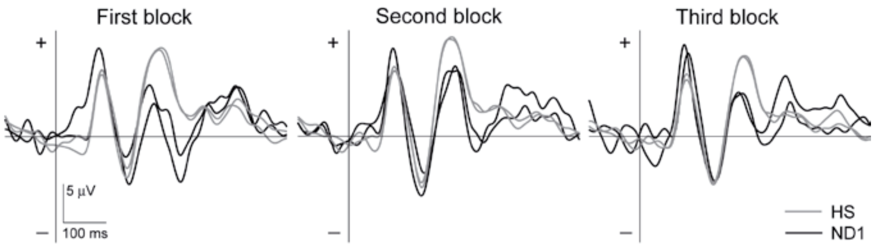

Figure 4. Even- and odd-numbered subaveraged ERP responses of subject S5 to the happy standard (HS, gray lines) and the neutral deviant (ND1, black lines) at the right occipito-temporal electrode PO8 during the time course of the experiment. ERP data are subaveraged for three long blocks of presentation of the stimuli (Figure 1). The number of evoked responses was 288 ± 26 in standard subaverages and 49 ± 2 in deviant subaverages.

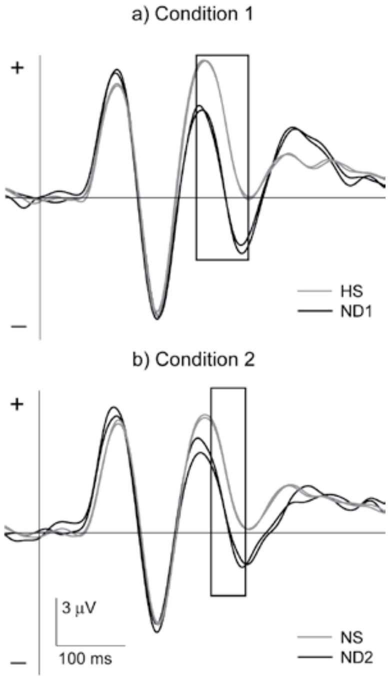

Figure 5. ERP grand-averaged responses to: a) happy standard (HS) and neutral deviant (ND1) in condition 1, b) neutral standard (NS) and neutral deviant (ND2) in condition 2 at the electrode PO8. Responses to standards are shown in gray color and deviants in black. Even- and odd-numbered subaverages are presented as well. The rectangles show statistically significant ($p < 0.05$) differences between ERPs based on averages of consecutive sample points at 25-ms time windows.

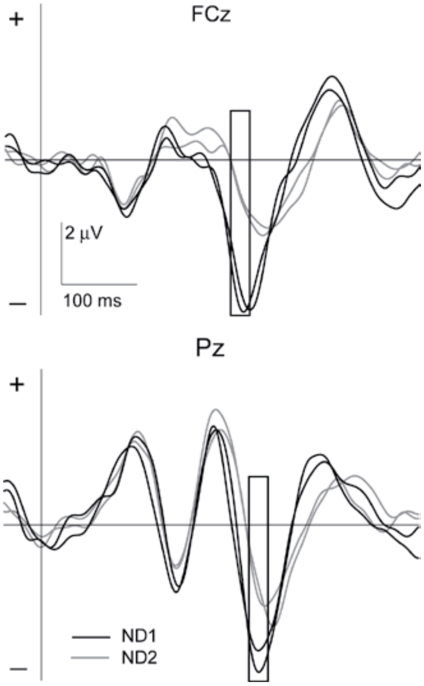

Figure 6. ERP grand-averaged responses to ND1 (black lines) and ND2 (gray lines) at the electrodes FCz and Pz. Even- and odd-numbered subaverages are shown. The rectangles show statistically significant ($p < 0.05$) differences between ERPs based on averages of consecutive sample points at 25-ms time windows.

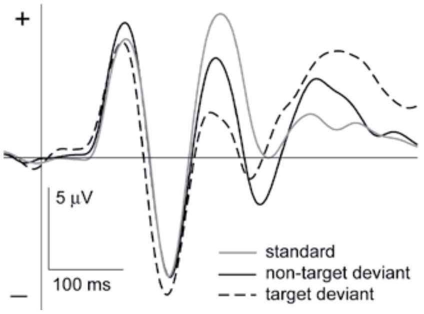

Figure 7. ERP grand-averaged responses to standard (gray line), non-target deviant (black solid line) and target deviant (black dashed line) in condition 1 at the electrode PO8.

that some subjects reported. In spite of the small number of subjects (n = 5), our data reliably showed negativity related to non-target deviants in the oddball paradigm that is confirmed by subaveraging. Deviant-related negativity was present during the whole time course of the experiment (Figure 4).

In our paradigm, the subjects had to look at the visual stimuli in order to count the appearance of the target face. Figure 7 shows distinct ERP responses to target and non-target stimuli already at 120–170 ms, which is in agreement with a number of studies on attentional modulation of early visual responses (e.g., [24]). Black glasses of the target face were very salient and easy to discern. Subjects did not need to discriminate between standard and non-target deviant stimuli. One subject reported that he saw more than two faces besides target face in a short block. Even if subjects did consciously discriminate between standard and non-target deviant stimulus in the beginning of the measurement, it is not likely that they paid attention to task-irrelevant stimuli after many repetitions of the same short blocks. However, the observed effect did not disappear in ERP responses (Figure 4), suggesting that its main cause was not a conscious discrimination process.

Four out of five subjects were naïve (two participated for the first time in an electrophysiological measurement) and their only concern was correct counting of the target faces. The small P3 component also indicated minor involvement of attention. However, it is difficult to assess involvement of attention with the present paradigm. Further research with a stringent control of attention, such as in Heslenfeld's study [4], is needed to evaluate the automaticity of the observed effect.

It remains an open question which process underlies visual change detection: stimulus-specific refractoriness or comparison to the memory trace of the standard [5,25]. In the present study, different responses to the same deviant faces in two conditions argue for the explanation based on a sensory-memory trace for standards to which deviants were compared. However, this should be confirmed by using equiprobable condition to avoid differential stimulus-specific refractoriness [5]. In equiprobable condition several different stimuli are presented with the same probability. The difference in the responses to the same stimulus presented in an oddball condition and in an equiprobable condition, argue for the sensory-memory-based explanation.

Visual-modality-specific EEG and MEG distributions suggest that deviance detection mechanisms (and its underlying mismatch mechanism) are located at early, sensory-specific levels of processing. This could imply that comparison between deviants and standards first takes place in the visual areas where the sensory-memory trace of standards is held [2], and when mismatch is found, the activity expands to a distributed fronto-parietal circuit subserving attention [1].

MEG responses showed the same deviant-related negativity as ERPs but they were much more localized. As we did not have MRIs of our subjects, we could not determine locations of underlying sources. However, as the planar gradiometers measure the maximum signal above the source [26], our data suggest that the lateral extrastriate cortex is involved in detection of change in face stimuli. This is in agreement with the previous reports on the important role of MOG in visual change detection [7-10]. Further studies are needed to explore spatio-temporal dynamics of the observed memory-based change detection in face stimuli.

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References

[1] Halgren E., Marinkovic K., Neurophysiological networks integrating human emotions, In: Gazzaniga M.S. (Ed.), The Cognitive Neuroscience, MIT Press, Cambridge, 1995

[2] Näätänen R., Attention and Brain Function, Erlbaum, Hillsdale, N.J., 1992

[3] Pazo-Alvarez P., Cadaveira F., Amenedo E., MMN in the visual modality: a review, Biol. Psychol., 2003, 63, 199-236

[4] Heslenfeld D.J., Visual mismatch negativity, In: Polich J. (Ed.), Detection of change: event-related potential and fMRI findings, Kluver Academic Publishers, Boston, 2003

[5] Czigler I., Balazs L., Winkler I., Memory-based detection of task-irrelevant visual changes, Psychophysiology, 2002, 39, 869-873.

[6] Astikainen P., Lillstrang E., Ruusuvirta T., Visual mismatch negativity for changes in orientation – a sensory memory-dependent response, Eur. J. Neurosci., 2008, 28, 2319–2324

[7] Downar J., Crawley A.P., Mikulis D.J., Davis K.D., A multimodal cortical network for the detection of changes in the sensory environment, Nat. Neurosci., 2000, 3, 277-283

[8] Tanaka E., Kida T., Inui K., Kakigi R., Change-driven cortical activation in multisensory environments: an MEG study, Neuroimage, 2009, 48, 464-474

[9] Tanaka E., Inui K., Kida T., Kakigi R., Common cortical responses evoked by appearance, disappearance and change of the human face, BMC Neurosci., 2009, 10, 38

[10] Urakawa T., Inui K., Yamashiro K., Tanaka E., Kakigi R., Cortical dynamics of visual change detection based on sensory memory, Neuroimage, 2010, 52, 302-308

[11] Eimer M., Mazza V., Electrophysiological correlates of change detection, Psychophysiology, 2005, 42, 328-342

[12] Campanella S., Gaspard C., Debatisse D., Bruyer R., Crommelinck M., Guerit J.M., Discrimination of emotional facial expressions in a visual oddball task: an ERP study, Biol. Psychol., 2002, 59, 171-186

[13] Campanella S., Rossignol M., Mejias S., Joassin F., Maurage P., Debatisse D., et al., Human gender differences in an emotional visual oddball task: an event-related potentials study, Neurosci. Lett., 2004, 367, 14-18

[14] Maurage P., Philippot P., Verbanck P., Noel X., Kornreich C., Hanak C., et al., Is the P300 deficit in alcoholism associated with early visual impairments (P100, N170)? An oddball paradigm, Clin. Neurophysiol., 2007, 118, 633–644

[15] Mejias S., Rossignol M., Debatisse D., Streel E., Servais L., Guerit J.M., et al., Event-related potentials (ERPs) in ecstasy (MDMA) users during a visual oddball task, Biol. Psychol., 2005, 69, 333–352

[16] Ueno T., Morita K., Shoji Y., Yamamoto M., Yamamoto H., Maeda H., Recognition of facial expression and visual P300 in schizophrenic patients: differences between paranoid type patients and non-paranoid patients, Psychiatry Clin. Neurosci., 2004, 58, 585–592

[17] Valkonen-Korhonen, M., Tarkka, I.M., Pääkkönen, A., Kremlacek, J., Lehtonen, J., Partanen, J., et al., Electrical brain responses evoked by human faces in acute psychosis, Brain Res. Cogn. Brain Res., 2005, 23, 277–286

[18] Large M.E., Cavina-Pratesi C., Vilis T., Culham J.C., The neural correlates of change detection in the face perception network, Neuropsychologia, 2008, 46, 2169-2176

[19] Susac A., Ilmoniemi R.J., Pihko E., Supek S., Neurodynamic studies on emotional and inverted faces in an oddball paradigm, Brain Topogr., 2004, 16, 265-268

[20] Posamentier M.T., Abdi, H., Processing faces and facial expressions, Neuropsychol. Rev., 2003, 13, 113-143

[21] Susac A., Ilmoniemi R.J., Pihko E., Ranken D., Supek S., Early cortical responses are sensitive to changes in face stimuli, Brain Res., 2010, 1346, 155-164

[22] Orozco S., Ehlers C.L., Gender differences in electrophysiological responses to facial stimuli, Biol. Psychiatry, 1998, 44, 281-289

[23] Tales A., Troscianko T., Wilcock G.K., Newton P., Butler S.R., Age-related changes in the preattentional detection of visual change, Neuroreport, 2002, 13, 969-972

[24] Aine C.J., Supek S., George J.S., Temporal dynamics of visual-evoked neuromagnetic sources: effects of stimulus parameters and selective attention. Int. J. Neurosci., 1995, 80, 79-104

[25] Kenemans J.L., Jong T.G., Verbaten M.N., Detection of visual change: mismatch or rareness? Neuroreport, 2003, 14, 1239-1242.

[26] Hämäläinen M., Hari R., Ilmoniemi R.J., Knuutila J., Lounasmaa O.V., Magnetoencephalography - theory, instrumentation, and applications to noninvasive studies of the working human brain, Rev. Mod. Phys., 1993, 65, 413-497