

**Asymmetry of automatic change detection as shown by brain
electric activity:
An additional feature is identified faster than missing features**

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Key words: change detection, visual, visual mismatch negativity, search asymmetry

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Abstract

In two experiments, we demonstrated that an asymmetric effect of brain electric activity that is elicited by non-attended visual stimuli is similar to responses observed in the performance of visual search tasks. The automatic detection of violated sequential regularities was investigated by measuring the visual mismatch negativity (vMMN) component of event-related brain potentials (ERPs). In Experiment 1 within a sequence of stimulus displays with O characters, infrequently presented Q characters elicited earlier vMMN compared with infrequent O characters within a sequence of Q characters. In Experiment 2 similar asymmetric results emerged if only 16 per cent of the characters were different within an infrequent display. In both experiments, these stimuli were irrelevant; during the stimulus sequences, participants performed a demanding video game. We suggest that the underlying match/mismatch and decision processes are similar in the vMMN and in the attention-related visual search paradigms, at least in the case of stimuli in the present experiments.

INTRODUCTION

The detection of environmental events that deviate from the regularity of previous and/or expected events is an important task for our perceptual system. However, the possibility of detecting deviant events is not independent of the relationship between the specific regularity and the specific deviant event. In studies of visual search, i.e., on the topic of attention search asymmetry was demonstrated for target stimuli that contained a feature that was absent in the distractor stimuli, i.e., such targets are easier to find than targets without a feature (e.g., Treisman and Souther, 1985; Treisman and Gormican, 1988; for a review see

Wolfe, 2001). In the former case, the number of distractors had only a slight effect on the search efficiency, whereas in the latter case, as a function of the number of distractors, the reaction time steeply increased. As another case of search asymmetry, a search for familiar objects among unfamiliar ones is more effective than a search for unfamiliar objects among familiar ones (e.g., Wang et al., 1994; Malinowski and Hübner, 2001; Shen and Reingold, 2001). In the present study, we demonstrate a similar asymmetry in automatic change detection by using the visual mismatch negativity (vMMN) component of event-related potentials. The vMMN (an analog of the auditory mismatch negativity; for a review, see Näätänen et al., 2007) is usually investigated in 'oddball' sequences. The frequent stimuli (standards) of the sequence acquire the representation of regularity, and the infrequent stimuli (deviants) violate it. The vMMN is the difference between the event-related potentials (ERPs) not the deviant and the standard (for reviews, see Czigler, 2007; Kimura et al., 2011). The emergence of vMMNs does not depend on attentional processing of the standard and deviant events; therefore, the processes that underlie these ERP components are considered to be a type of automatic change detection (for reviews, see Czigler, 2007; Kimura et al., 2011). Usually, vMMN is investigated in the passive visual oddball paradigm. In this paradigm, standard and deviant stimuli are irrelevant; participants perform a demanding task that is unrelated to the stimuli that elicit the vMMN.

In a recent study, in a sequence of standard symmetric patterns, infrequent random patterns (deviants) elicited vMMN, but when the roles of the stimulus categories were reversed, no vMMN emerged (Kecskés-Kovács et al., 2013~~2~~). This result was interpreted as a category-related effect: a sequence of symmetric patterns elicited a perceptual category, and the regular presentation of this category was violated by the random deviant. However, there is no category of 'randomness'; therefore, infrequent symmetric patterns did not violate a categorical rule. Consequently, no vMMN emerged for the symmetric deviants. Accordingly, a standard-deviant arrangement elicited vMMN, but reversing the role of the deviant and standard stimuli did not.

Comment [s1]: Itt nem lett véletlenül kitérőve valami?

Comment [s2]: Nyomtatásban (oldalszámmal) ekkor jelent meg

In the present study, we attempted to demonstrate that a deviant with an additional visual feature elicits a different vMMN effect than a deviant with the absence of a feature. For this goal, we used one of the most frequently used stimuli of search asymmetry tasks, the O-like and Q-like stimuli (we use the term ‘O-like and Q-like’ because in these studies the stimuli were circles without or with a vertical bar at the bottom part of the circle see Figure 1. For brevity, we will use the terms O and Q stimuli). More recent explanations of search asymmetry attribute the effect to a processing difference in low-level features (Carrasco et al., 1998; Rosenholtz, 2001; Spratling, 2012) or a variability difference between the representations of the stimuli (Saiki, 2008). Considering that the vMMN is a consequence of memory comparison processes (Czigler, 2007; Winkler and Czigler, 2007), we expect a more efficient mismatch process in response to deviant Q stimuli, i.e., an effect similar to the more efficient visual search.

In Experiment 1, the displays were homogeneous (32 O or 32 Q characters); in Experiment 2, the infrequent display contained only 16 per cent deviant characters. In both tasks, irrelevant vMMN-related stimuli were presented in the lower half of the visual field, while participants paid attention to the center and upper half of the field.

EXPERIMENT 1

METHOD

Participants

Participants were 14 paid students (4 female, 10 male; mean age=21.9 years; range=19-24 years) from Budapest. All had normal or corrected-to-normal vision. They gave written informed consent to participate in the study. The study was accepted by the local committee on professional ethics.

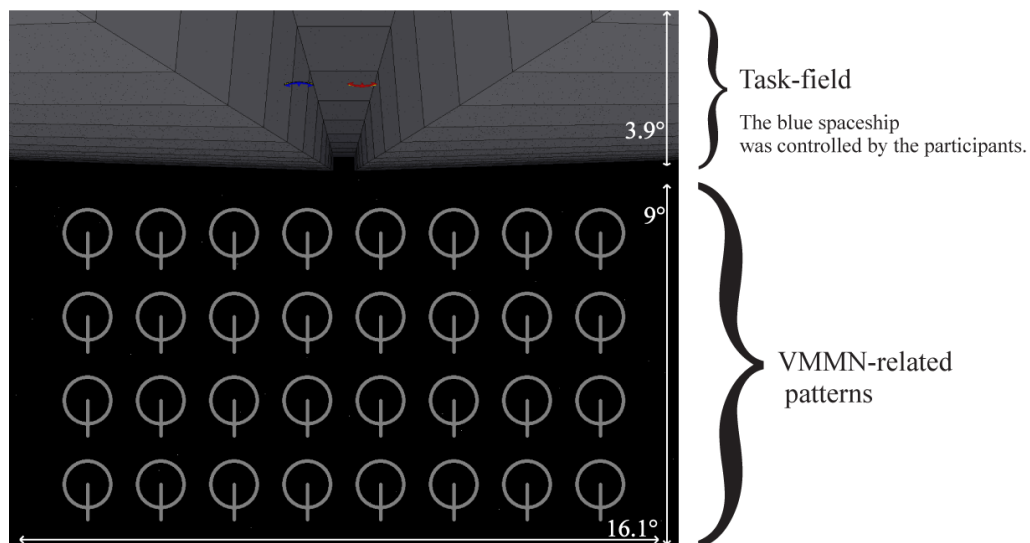
Stimuli and procedure

The vMMN-related stimuli were matrices of O or Q characters (Figure 1). A matrix was composed of 8 columns and 4 rows, i.e., 32 characters, and subtended a 16.1×3.9 degree visual angle from 120 cm. These stimuli were presented for 300 ms with 417-617 ms (mean = 517 ms) ISI. Within a stimulus sequence, there were 350 stimuli. In the 'Q-deviant' sequence, 59 stimuli were Q matrices, and 291 stimuli were O matrices; in the O-deviant sequences, the numbers were reversed. Within a session, there were 2 Q deviant and 2 O deviant sequences, in random order.

The participants performed a video game that was displayed on the upper half of the screen (Figure 1). The task was to maneuver a spaceship across a canyon, and catch objects with green color and avoid objects with red color. To perform properly, a continuous central fixation was needed (for more details, see Kecskés-Kovács et al., 2013³²).

Figure 1.

A



B

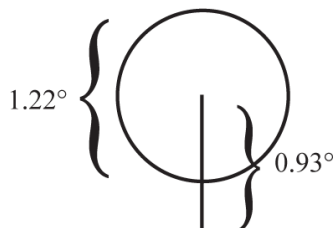


Figure 1. A: Stimulus display. Visual mismatch negativity (vMMN) was investigated by the stimuli at the $9.0^{\circ} \times 16.1^{\circ}$ part of the visual field. Above this part of the field the stimuli of the video-game were presented. Participants maneuvered a spaceship (blue color) across a canyon, and catch objects with green color (not seen in the figure) and avoid objects with red color. B: The size of vMMN-related stimulus elements.

Recording and measuring brain electric activity

Electroencephalographic activity was recorded (DC, 70 Hz; 500 Hz sampling rate; Synamps2 amplifier, NeuroScan recording system) with Ag/AgCl electrodes that were placed at 61 locations according to the extended 10–20 system, using an elastic electrode cap (Easy-Cap). The reference electrode was placed on the nose tip, and offline was re-referenced to the average activity. Horizontal electrooculographic activity was recorded with a bipolar configuration between the electrodes that were positioned lateral to the outer canthi of the eyes. Vertical eye movement was monitored with a bipolar montage between the electrodes that were placed above and below the right eye. The EEG signal was bandpass-filtered offline, with cutoff frequencies of 0.1 and 30 Hz (24-dB slope). Epochs of 600 ms, including a 100 ms prestimulus interval, were extracted for each event and were averaged separately for the standard and deviant stimuli. The mean voltage during the 100 ms prestimulus interval was used as the baseline for amplitude measurements, and epochs with an amplitude change exceeding $\pm 50\text{--}100\text{ }\mu\text{V}$ on any channel were excluded from further analysis. Event-related potentials (ERPs) were averaged separately for the standard and deviant stimuli in the two conditions. ERPs were included in the averaging only if these stimuli were preceded by at least 3 standards. To identify change-related activities, the ERPs elicited by standard stimuli were subtracted from the ERPs elicited by deviant stimuli in the opposite sequences (Kujala et al., 2007). The vMMN amplitudes and latencies were measured in a typical latency range of this component (150–250 ms in the present study. Within these ranges the amplitudes and latencies were measured separately for and earlier (150–200 ms-) and later (200–250 ms) epoch. Within these epochs the ~~main-mean~~ amplitude, and the latency of the largest negativity was calculated.

RESULTS AND DISCUSSION

The participants avoided 82.5 per cent of the red ships and hit 88.5 of the green ships, i.e., they performed the task successfully. In the two types of sequences there were no performance differences. Figure 2 shows the ERPs (A), the deviant minus standard difference potentials for the O and Q deviant sequences stimuli (B), and the surface distributions of the differences in a ± 10 ms range around the largest negative value (measured at Oz).

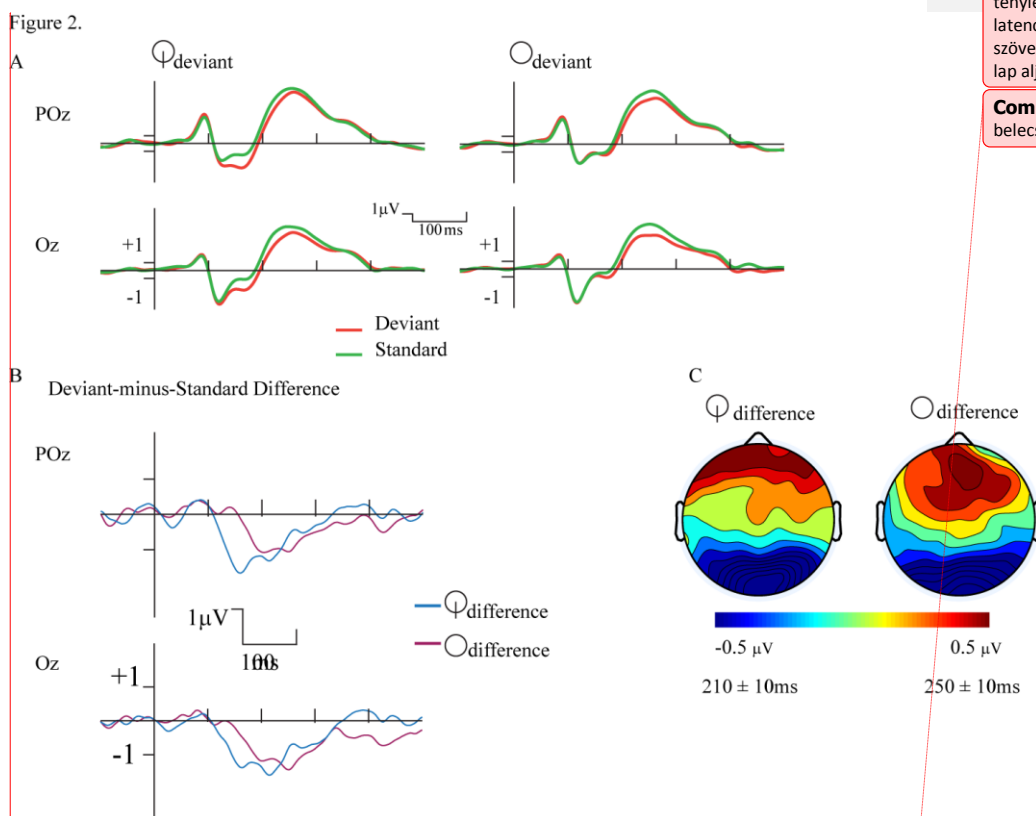


Figure 2. A: Event-related potentials in Experiment 1 in the Q-deviant and O deviant sequences. B: Deviant minus Standard difference potentials for the Q and O stimuli. C: Surface distribution of the deviant *minus* standard difference potential at the latency range of maximal negativity.

Comment [s3]: Nem igaz (bár ez tényleg nem látszik az ábrán). Az átlagos latencia körüli. (ezek az értékek a szövegtestbe is le vannak írva a köv oldal lap alján)

Comment [s4]: A skálánál a 100-ba beleszűzött a ms

The stimuli elicited P1, N1 and P2 exogenous components. There was no significant difference between the standard stimuli and the O and Q patterns. However, as the figure shows, in the ~150-350 ms range, over the posterior locations, the ERPs to the deviant stimuli were more negative/less positive than the ERPs to the standards. Furthermore, for the Q stimuli, the negative difference potentials emerged earlier than the difference potentials to the O deviants. The latency range of negativity corresponds to the expected latencies and the scalp distribution of the vMMN component. These observations were supported by the results of ANOVAs calculated for the main amplitudes of the 150-200 and 200-250 ms ranges and for the latency of the largest negative values within the ranges above. Activities were measured with a 2 x 3 grid of electrodes (PO3, POz, PO4, O1, Oz, and O2). According to a three-way ANOVA (stimulus type: Q vs. O difference, anteriority: parieto-occipital vs. occipital locations; laterality: left vs. midline vs. right locations), for the main amplitude of the 150-200 ms range, the main effects of stimulus type [$F(1,13)=4.99$, $\eta^2=0.28$, $p<0.05$] and laterality [$F(2,26)=5.43$, $\epsilon=0.77$, $\eta^2=0.29$, $p<0.05$] were significant. The stimulus type main effect was due to the larger negativity from the Q deviants. According to post hoc Tukey HSD tests, the negativity was smaller on the left side than in the midline ($p<0.01$). In a similar ANOVA for the 200-250 ms range, the main effect of the stimulus type was significant [$F(1,13)=6.21$, $\eta^2=0.32$, $p<0.05$]. However, in this range, the O deviant elicited larger negativity. An ANOVA on the latency values of the posterior negativity supported the amplitude results; the main effect of the stimulus type was significant again [$F(1,13)=31.78$, $\eta^2=0.71$, $p<0.0001$]. The main latency of the vMMN for the Q and O deviants was 210.3 ms and 249.8 ms, respectively.

Both Q and O deviants elicited vMMN. However, in the earlier latency range Q deviants, while and in the later latency range O deviants elicited larger vMMN. In other words, latency of the vMMN to Q deviant was shorter. Accordingly, irregular irrelevant stimuli with an additional feature were detected faster than irregular stimuli characterized by the absence of a feature.

EXPERIMENT 2

Comment [s5]: check

Comment [s6]: check

Comment [s7]: Az elemzés szerint nincsen szignifikáns különbség a két inger között (egy latencia főhatás van egyedül). Viszont a másik kísérletben pont ez jött ki ugyanezzel a sávra. Tényleg nagy szégyellem, hogy csak most tűnt fel.

The participants were 14 paid students (5 female, 9 male (three of them participated in Experiment 1); mean age=22.5 years; range= 19-26 years) from Budapest. All had normal or corrected-to-normal vision. They gave written informed consent to participate in the study. The study was accepted by the local committee on professional ethics.

Comment [s8]: 5 egyezett

STIMULI, PROCEDURE AND MEASUREMENT OF BRAIN ELECTRIC ACTIVITY

All but the deviant stimuli were identical to Experiment 1. In this experiment, the stimulus matrix of the standard stimuli was homogeneous, i.e., it comprised either O or Q characters. Within the deviant matrices, 16 percent of the characters were the alternative type. The position of these characters varied randomly within the deviant stimuli. In this experiment the within-sequence standard and deviant were physically more similar than the between-sequence standard and deviant, therefore in the difference potentials the within sequence deviant minus standard subtractions were used. In this experiment vMMN emerged later than in Experiment 1, therefore amplitude and latency values were calculated for the 200-250 ms and 250-300 ms epochs.

RESULTS AND DISCUSSION

The participants avoided 83.4 percent of the red ships and hit 88.2 of the green ships, i.e., they performed the task successfully. The performance was similar in the two experiments.

Figure 3 shows the ERPs (A), the deviant-standard difference potentials for the O and Q deviants (B), and the surface distributions of the differences in a ± 10 ms range around the largest negativity (measured at Oz).

Comment [s9]: Átlagos latencia

Figure 3.

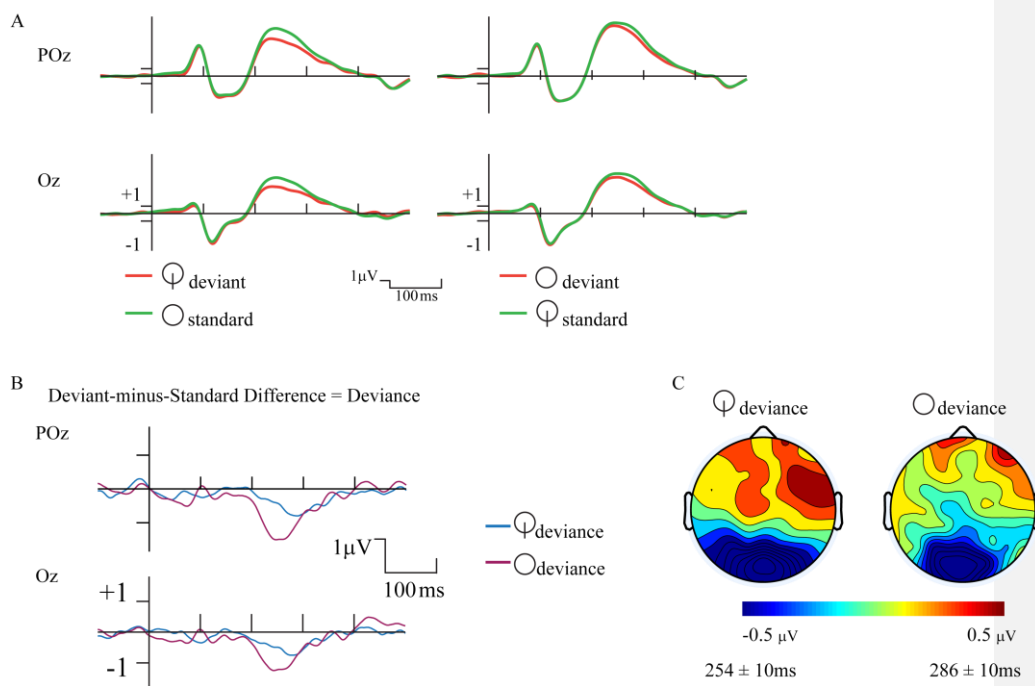


Figure 3. A: Event-related potentials in Experiment 2 in the Q-deviant and O deviant sequences. B: Deviant minus Standard difference potentials for the Q and O stimuli. C: Surface distribution of the deviant *minus* standard difference potential at the latency range of maximal negativity.

The P1, N1 and P2 components were similar to those of Experiment 1. Deviant displays with 16 per cent Q characters elicited larger vMMN, and the latency of this negativity peaked earlier than the deviants with 16 per cent O characters. However, in this experiment, vMMN emerged later, even for the stimuli with Q deviants, compared with Experiment 1. Accordingly, vMMN was measured in the 200-250 and 250-300 ms ranges.

In ANOVAs similar to Experiment 1, in the 200-250 ms range, the main effect of the stimulus type was significant [$F(1,13)=6.21$, $\eta^2=0.2732$, $p<0.05$], which indicates that there was a larger vMMN for the deviants with Q stimuli. In the 250-300 ms range, there was no significant amplitude difference. The vMMN latency to the deviants with Q characters was shorter (254 *versus* 286 ms), as indicated by the significant main effect of the stimulus type [$F(1,13)=83.11$, $\eta^2=0.86$, $p<0.00001$].

Comment [s10]: check

Comment [s11]: check

As the results of this experiment show, the latency of the vMMN was generally longer than in Experiment 1. However, a small number of deviant characters was sufficient to elicit the vMMN, and the asymmetry was similar: deviants with Q characters elicited vMMN with shorter latencies than deviants with O characters.

GENERAL DISCUSSION

The results of the present study provide clear evidence of vMMN asymmetry; in both experiments, the vMMN latency was shorter for deviant stimuli that were composed of (Experiment 1) or contained (Experiment 2) Q characters. The main point to be discussed is the relationship of this asymmetry to the search asymmetry, using O versus Q target stimuli. In other words: Is it only a superficial analogy, or is there a significant overlap between the underlying mechanisms?¹

First some obvious difference between the paradigms is listed. The two paradigms are characterized by different ERP components. A posterior ERP component, contralateral to the target stimuli of visual search tasks, N2pc (Luck and Hillyard, 1994) is sensitive to search asymmetry. Although the latency of this component is shorter if a 'popout' C target is presented within O deviants than in the reverse 'non-popout' condition (Dowdall et al., 2012), the processes underlying the emergence of N2pc are fairly complex. The task set of the visual search has considerable effect on N2pc. Ansorge et al. (2011) investigated N2pc to informative and non-informative spatial cues in a search task. Non-informative cues elicited large and early N2pc if the color of the cue was identical to the expected target stimulus. In other words, a stimulus matching to the representation of a feature of the task-set elicits the N2pc component. Accordingly, the results of these studies show that visual search involves matching processes (match to the memory representation of the task set) and a mismatch process, discrimination of the target and distractors (reflected by the shorter latency at popout displays). In contrast, in the vMMN paradigm there is no task set, this component is elicited by the mismatch between the modality specific representation of regularity and the

incoming event. The two paradigms are obviously different at later, response-related stages. Visual search involves response selection and response organization processes, and these stages are absent in the vMMN paradigm. Accordingly, if there is a fundamental connection between the processes of the two paradigms, and these connections contributes the asymmetric results, one have to look for the similarities within the earlier processing stages.

Traditional accounts attribute search asymmetry to the dichotomy of parallel/automatic *versus* serial/attentional processes (e.g., Treisman and Souther, 1985), while all of the processes that underlie vMMN are *per definitionem* automatic. This difference appears to be obvious, but some models of search asymmetry do not hypothesize a stage of serial search and instead attribute efficiency differences to dissimilar speeds of distractor processing (e.g. Saki et al., 2005). Efficient distractor processing is facilitated by familiarity (Malinowsky and Hübner, 2001; Shen and Reingold, 2001; Wang et al., 1994), processing differences of low-level features (Carrasco et al., 1998; Rosenholtz, 2001), a variable difference between the representations of stimulus elements (Saiki, 2008), or the asymmetric internal uncertainty level of the two stimuli (Vincent, 2011). In principle, any of these factors could also contribute to asymmetric vMMN responses. Moreover, as our vMMN results show, no attentional processes such as serial processing are necessary for asymmetric information processing.

According to recent theories, the (auditory) MMN and vMMN are considered to be error signals that are generated by the discrepancy between the bottom-up flow of information and predictions represented within subsequent processing structures (e.g., Garrido et al., 2009; Kimura et al., 2011, Stefanics et al., 2011; Wacongne et al., 2012; Winkler and Czigler, 2012; Winkler et al., 2012). According to the predictive coding approach, bottom-up evidence is combined with prior knowledge, and at each level of the hierarchical system, there is a search for a correspondence between bottom-up information and top-down predictions (e.g., Friston, 2005). Lee and Mumfold (2003) proposed a predictive coding mechanism in the visual system, and Spratling (2012) developed a predictive model that is capable of explaining search asymmetry results. According to this model, in the case of the

deviant compared to the case of the standard, the larger the discrepancy between the input predicted by the cells of the primary visual cortex (specifically, the larger the discrepancy from a Gábor function, i.e., from the receptive field characteristics of the V1 cells), the larger the saliency of the target. As the model shows, in this respect, Q targets are more salient than O targets. Comparing the putative predictive mechanisms that operate both in the search and vMMN paradigms, the saliency-based approach appears to be similar in the search paradigms and in Experiment 2 of the present study. This observation arises because, in the O-standard sequences, an almost homogeneous map was compared to a map with some salient locations, but in the reverse condition, there was no such saliency difference. The situation in Experiment 1 is slightly different, but the explanation is similar. In the O-standard condition, the vertical bars of the deviants do not fit a primed set of Gábor-filters, but in the reverse condition (the Q standard), the deviants stimulate primed receptive fields.

Concerning this explanation, two comments are needed. First, this account retains an important point of the original explanation as proposed by Treisman and Souther (1985). Search asymmetry, at least in the case of O and Q characters, is the result of the additional element of the more efficient target (visual search). Similarly, earlier vMMN arises from the additional element of the deviant stimuli. However, there is an important difference between the traditional explanation and the predictive model explanation. Unlike the traditional explanation, the predictive model does not hypothesize attentional processes. Second, in the predictive model, as developed by Spratling (2012), the corpus geniculatum laterale (CGL) and primary visual cortex (V1) receptive field characteristics are specified. However, as localization attempts of the vMMN show, this ERP component emerges in structures that are outside of the striate cortex (e.g., Stefanics et al., 2011; Sulykos and Czigler, 2011; Urakawa et al., 2010). It is important to emphasize that the essential feature of the predictive models is a hierarchical structure. Therefore, an error signal with an ERP manifestation on the scalp could originate in visual structures that are above the primary visual areas, such as within the prestriate cortex or parieto-occipital structures.

In conclusion, our visual system is more sensitive to the violation of regular stimulation if the deviant event contains additional stimulus elements. This asymmetry is similar to the asymmetric result of many visual search studies. Predictive coding models explain both asymmetries without referring to attentional processes.

Footnote

¹Frequently, the effect of repeated identical stimulation is a state of neural refractoriness. Accordingly, in the oddball sequence on the average the standard stimuli are supposed to elicit smaller exogenous ERP components than the deviant. (Exogenous (or obligatory) components are elicited even if the stimuli are unrelated to the ongoing task, and their appearance depends on physical stimulus parameters.) In the O standard condition, in comparison to the refractory state of the structures specific to O characters, the additional feature of the Q deviant (the vertical line) may stimulate a 'fresh' neural population, whereas in the Q standard condition the deviant (O) stimulates a neuronal population in refractory state. Therefore, in the O standard condition larger deviant minus standard difference is expected than in the Q standard condition. In fact, as the results of some vMMN studies show (e.g. Kimura et al., 2009) an early phase of the deviant-related negativity can be attributed to the refractoriness of an exogenous component (N1). Refractoriness of this component seems to be a possible explanation of the vMMN latency differences of this study. (This possibility was suggested by an anonymous reviewer.) However, such account of the present results is not without problem. As Figure 2 shows, at the peak region of the N1 component there was no ERP difference between the deviant and the standard. One may say that the early part of the difference potential is connected to the refractoriness of a subsequent small negativity. However, this is an unlikely explanation. As the results of Experiment 2 shows (Figure 3), in the range of the negative difference potentials the ERPs were *positive*. Accordingly, refractoriness effect would have been manifested as 'deviant-related positivity', with shorter latency for the Q-deviants. On a more general level, there is no *a priori* reason to assume that N1 has a specific refractoriness status. This component is preceded by a positivity (P1) and as Figures 2 and 3 show, deviant and standard stimuli elicited identical P1 in both experiments, instead of an 'early deviant-related' positivity.

Authorship

I.C. developed the study concept, contributed to the interpretations and drafted the paper; I.S. designed the study, analyzed the data, contributed to the interpretations; K.K-K contributed to data collection and data analysis. All authors approved the final version of the paper for submission.

Comment [s12]: A képeket Kriszti rajzolta, nem tudom, ez mennyire contributed to the interpretation, de azt hiszem inkább az, mint nem.

Acknowledgement

We thank Zsuzsa d'Albini for her assistance in gathering data in this experiments.

This research was supported by the National Research Found, Hungary (OTKA), Grant No. 104462

Comment [s13]: Endre figyelmeztette erre még 2 hónapja, hogy az összes eddigi közös cikkben found van

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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