

VISUAL ORIENTATION DISCRIMINATION
IN SENSORY-MENTAL TASK

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Abstract

The effect of orientation difference on the visual event-related potential components (VERP) was studied in “coarse” and “fine” identification counting task. The basic result was the fact that much greater changes in the VERP waves were observed within the range of 5–15° than within the range of 15–90°. The amplitude of the second sensory component-P2, the latencies of both sensory components (N1 and P2) and of the second cognitive one (P3) increased with the orientation difference increase while the amplitudes of both cognitive components N2 and P3 decreased. These VERP changes might be interpreted as an electrophysiological correlate of the hypothesis that at orientation difference of more than 15°, activation of a single orientation-selective channel is sufficient for the stimulus orientation identification due to the specificity (“label”) of the activated channel, whereas at small orientation differences, identification is based on some kind of interaction among activated channels.

Key words: sinusoidal gratings, orientation identification, VERP, sensory-mental task

Introduction. It is well known that at initial stage of visual information processing orientation, selective channels exist, which operate in parallel and automatically [1, 2]. It is proposed that activation of a single channel is sufficient for the stimulus orientation identification due to the specificity (“label”) of the activated channel. There is psychophysical evidence in support of this “detector” model. It has been shown [3, 4] that at orientation differences of more than 15°, threshold contrasts for both stimulus detection and orientation identification coincide. It has also been shown [5–7] that human observers and animals are able to

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distinguish orientation differences much less than the tuning width of orientation selective channels. This suggests that orientation identification in this case should be based on some kind of interaction among activated channels, for instance on comparison among channel responses [8]. In previous work of ours [9], we obtained electrophysiological evidence in support of these two types of orientation identification (“coarse” and “fine”). It was found that some parameters of VERP components (the amplitudes of N1, P2, N2 and the latency of P2, N2, P3) change more substantially with orientation difference variation within the range of 5–15° rather than 15–90°. It is known, however, that the type of the observer task influences substantially the behaviour of VERP waves. The task type-detection or discrimination, as well as its difficulty are factors affecting the N1 parameters [10, 11]. The P2 component of VERP is also differentially affected by the task demands [10]. Two stages as early selection in high-load tasks and late selection in low-load tasks decide which stimulus is included in or excluded from the attentional focus [12]. The next VERP wave, N2, and particularly its subcomponent N2pc typically observed at posterior scalp sites is influenced by the attention to the stimulus features while ignoring distracters [10]. The P3 wave is affected by appearance of unexpected task-irrelevant stimuli within an attended stimulus train, the target probability [13], as well as the degree of the efforts which the subject devotes to a task [3]. The fact that too many factors, including the task type, influence the VERP parameters is the reason to study again the effect of orientation difference on the VERP-waves employing not motor, but mental task (counting), which would cause a substantial cognitive load and different effect on the VERP waves respectively.

Method. Stimuli. Stimuli were sinusoidal gratings with spatial frequency of 2.9 c/deg, presented in a circular Gaussian window with spatial constant of 0.483° and contrast of 0.05. They were presented for 100 ms in the centre of the visual field. Stimulus orientation was 90°, 85°, 75° or 0°.

Apparatus. The stimuli were generated by a computer as 12-bit signals and were displayed on the screen of a monochrome monitor (640 × 480 pixels and a frame rate of 60 Hz). The viewing distance was 1.14 m and the mean luminance was 50 cd/m² and it was not changed by stimulus onset and offset.

Procedure. In each trial, the stimulus orientation varied randomly between two possible values – 90° and 0°, 90° and 75° as well as 90° and 85°. Therefore, the difference between orientations was 90°, 15° and 5°. The subjects performed sensory-mental task. They had to count the number of stimuli with orientation different from vertical (90°) orientation. The interval between trials also varied randomly within the range of 2.5–3.5 s. Each block contained 100 trials. The electroencephalography (EEG) was recorded from 12 positions Fz, Cz, Pz, Oz, C3, C4, T3, T4, P3, P4, O1, O2 (10/20 system) with a reference to both processi mastoidei and a ground electrode placed on the forehead. An oculogram (EOG) was recorded from electrodes placed above and below the lateral cantus of the

left eye for a detection of eye movements and blink artifacts. EEG and EOG data were recorded using a Nihon Kohden EEG-4314F (cut-off frequencies of 0.3–70 Hz) together with markers of the stimulus onset. The signals were digitized at a rate of 500 Hz and written to hard disk for off-line analysis. The length of the EEG segment was chosen to cover 500 ms pre-stimulus and 1000 ms post-stimulus interval. Only artifact-free EEG records respectively VERP were processed. The processing of extraction VERPs and wave parameters was the same as those described in our previous work [9]. The statistical differences between the corresponding VERP components at orientation differences of 90°/15°, 90°/5° and 15°/5° were performed by means of Kruskal–Wallis test for pair comparison of the scalp leads between stimulus datasets.

Observers. The observers (11 females, 9 males, 31 ± 7 years old) were with a normal or corrected-to-normal visual acuity. They had no known ophthalmological or neurological diseases. The subjects were introduced to the nature of the study and their informed written consent was obtained according to the declaration of Helsinki. The subjects were instructed to fixate the centre of the screen. Handedness was assessed by a questionnaire adapted from the Edinburgh Handedness Inventory (Oldfield 1971).

Results. Performance accuracy. The performance accuracy of the counting at smallest orientation difference of 5° was slightly worse (mean \pm s.e., 91.12% \pm 2.03) in comparison with the accuracy observed at the medium of 15° (96.97% \pm 0.76) and the highest of 90° (95.76% \pm 2.10) orientation difference. Pair comparison of the performance accuracy observed at different orientation differences has shown the following results: $F_{(5^\circ,15^\circ)}(1,39) = 5.09$, $p_{(5^\circ,15^\circ)} = 0.024$; $F_{(5^\circ,90^\circ)}(1,39) = 6.72$, $p_{(5^\circ,90^\circ)} = 0.0095$, $F_{(15^\circ,90^\circ)}(1,39) = 0.35$, $p_{(15^\circ,90^\circ)} = 0.55$.

Orientation difference effect on VERP-waves. The first negative VERP wave N1 showed an amplitude scalp distribution with a maximal value at the temporal lobe and a minimal value at the occipital lobe. This was observed at orientation difference of 90° and 5° (Fig. 1A, first row), as at the medium orientation difference (15°) the maximal values of N1 were observed over the central scalp positions (Fig. 1A, first row).

The amplitude of N1 component first increased with orientation difference decrease from 90° to 15° and then decreased with further orientation difference decrease being approximately the same as at 90° orientation difference. This was not in the case at two scalp positions – T3 and T4, whereas the amplitude of N1 component did not depend on the orientation difference. The latency of N1 component (Fig. 1B, first row) did not demonstrate clear extremes at any scalp positions as it prolonged with orientation difference decrease. The prolongation of N1 latency was statistically significant only within the orientation difference range of 5–15° at most electrode positions without O1 and Oz, whereas the orientation difference influenced the N1 latency within all the range studied (5–90°).

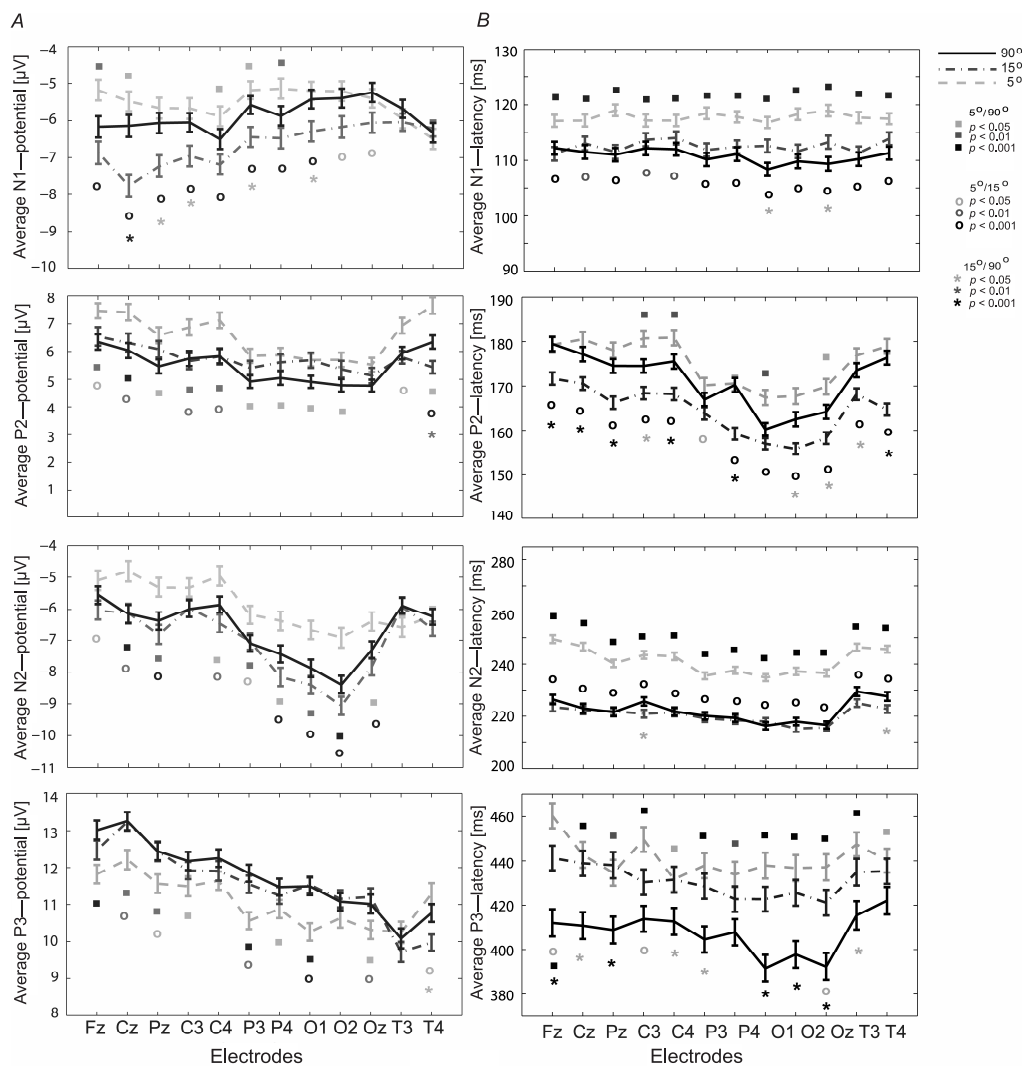


Fig. 1. Scalp distributions and statistical comparisons of the amplitudes of: (A) VERP waves (N1, P2, N2, P3); (B) the latencies of these waves recorded at three orientation differences (90° – black, 15° – gray and 5° – light gray). All VERP component parameters presented in this figure are in response to the vertical gratings only. The vertical bars represent 95% confidence intervals. The symbols correspond to different pair comparisons: circles – 5° difference with 15° difference; squares – 5° difference with 90° difference and stars – 15° difference with 90° difference. The colours of these symbols correspond to different critical values of significance: black – $p < 0.001$, gray – $p < 0.01$, light gray – $p < 0.05$

P2 wave demonstrated maximal amplitude over the fronto-central as well as the sensorimotor areas at all orientation differences. The maximal amplitude of P2 was also observed over the temporal area at the highest (90°) and the smallest (5°) orientation differences. The minimal values of the P2 amplitude were

observed over the occipital and parietal areas, as well as over the temporal area – at the medium orientation difference, 15° (Fig. 1A, second row, black and gray). The amplitude of P2 component increased with orientation difference decrease as this effect was statistically significant at the frontal areas within the range of $5\text{--}15^\circ$ only (there are no “stars” in Fig. 1B, second row, with an exception at T4, where symbols indicate statistically significant changes caused by orientation difference variation within the range of $90\text{--}15^\circ$). Similarly to the amplitude distribution, the P2 latency also demonstrated maximal values over the fronto-central, sensorimotor and temporal areas, and minimal values over the occipital lobe (Fig. 1B, second row). The P2 latency first decreased with orientation difference decrease from 90° to 15° and then increased with further orientation difference decrease. The changes in P2 latency were statistically significant within all the range of orientation differences studied ($5\text{--}90^\circ$) at most scalp positions with exceptions at P3 and O1 leads, whereas the changes of P2 latency were observed within the range of $5\text{--}15^\circ$.

N2 wave showed a maximal amplitude over occipital lobe and a minimal amplitude over the central fronto-parietal, sensorimotor and temporal areas. This was better expressed at the highest (90°) and the medium (15°) orientation differences, and to a lesser extent – at the smallest (5°) orientation difference (Fig. 1A, third row). The amplitude of N2 decreased with an orientation difference decrease, mainly within the range of $5\text{--}15^\circ$. This effect, however, was not observed in the temporal lobe where the N2 amplitude was not influenced by the orientation difference. The latency of N2 component demonstrated maximal values over the fronto-central, sensorimotor and temporal areas, and minimal value over the occipital lobe. The N2 latency increased with orientation difference decrease as this effect was statistically significant within the range of $5\text{--}15^\circ$ only, with two exceptions – C3 and T4, whereas the effect of the orientation difference was statistically significant within the whole studied range of $5\text{--}90^\circ$ (Fig. 1B, third row).

The amplitude scalp distribution of the P3 wave showed a maximum at central frontal areas (Fz and Cz) for all three orientation differences (Fig. 1A, fourth row). The P3 amplitude increased as the orientation difference increased and this increase was statistically significant within the range of $5\text{--}15^\circ$ for scalp positions Cz, Pz, P3, O1, Oz and T4, and within the range of $15\text{--}90^\circ$ for position T4. The P3 latency demonstrated a small maximum at frontal and temporal positions at the highest orientation difference and a maximum at frontal positions only at smaller orientation differences. The latency of the P3 component prolonged at the orientation difference decrease within the whole range of orientation difference variation of $5\text{--}90^\circ$ (Fig. 1B, fourth row).

Discussion. The basic result obtained in this study is the fact that much greater changes in the VERP wave parameters are observed when the orientation difference varies within the range of $5\text{--}15^\circ$ than within the range of $15\text{--}90^\circ$. This

applies to the amplitudes of P2, N2 and P3 waves as well as to the latency of N1 and N2. Our previous VERPs data [9] recorded when binary motor task was employed also showed greater changes in the VERP wave parameters within the orientation difference range of 5–15° than within the range of 15–90°. This is valid for amplitudes of N1, N2, P2 and to a lesser extent of P3, as well as for the N1, P2 and N2 latency. It might be suggested that the changes in the VERPs parameters observed with orientation difference variation might reflect the transition of the identification mechanisms from one mode of operation to another mode. This is in accordance with the hypothesis that two different types of orientation identification processes are effectuated in the visual system: 1) detector type or “coarse” identification (at orientation difference of more than 15°); 2) “fine” (computational) orientation identification (at differences smaller than 15°). The data obtained in this study have shown that the type of the observer task is also a factor which influences the behaviour of the VERP waves. When mental task was used, the amplitude of N1 first increased with orientation difference decrease from 90° to 15° and then decreased with further orientation difference decrease. In a motor task experiment, the amplitude of N1 decreased only with orientation difference decrease, as this effect was more substantial for orientation difference of 5–15° than for 15–90°. When mental task was used, the latency of N1 prolonged with orientation difference decrease, as this effect was more significant within the range of 5–15°. In a motor task experiment, the latency of N1 shortened more substantially within the same range. The amplitudes of P2 and N2 increased with orientation difference decrease when both mental and motor tasks were employed, as this effect was more significant within the range of 5–15°. However, the latencies of P2 and N2 depended in a different way on orientation difference when different tasks were used. With mental task, the latency of P2 first decreased with orientation difference decrease from 90° to 15° and then increased with further orientation difference decrease. In a motor task experiment, the latency of P2 decreased with orientation difference decrease, predominantly within the range of 5–15°. With mental task, the latency of N2 increased, whereas with motor task the latency of N2 decreased with orientation difference decrease, again predominantly within the range of 5–15°. The behaviour of the P3 wave was also different with different observer tasks. In a mental task experiment, the amplitude of P3 decreased and its latency increased, whereas in a motor task experiment both the P3 amplitude and the latency increased with orientation difference decrease. It might be suggested that the motor response, on the one hand, and counting – on the other hand, are processes generating very different type of brain activity, interfering with the activity concerned with the discrimination process. The type of the observer task along with the orientation difference is a factor determining the task difficulty. The effect of the task difficulty could be considered as a result of attentional effort modulation [15, 16], which influences the N1 parameters in two ways – as “N1 discrimination effect” and “N1 reorienting effect” [17]. The

“N1 discrimination effect” could be influenced by the mental fatigue on attention [18]. The N1 “reorienting effect” represents an enhanced negativity reflecting the attentional switch from one orientation to another [19]. Regarding the next VERP wave, P2, it might be suggested that the changes in the task difficulty influence the P2 parameters as a result of an attentional effort modulation [15, 16]. The majority of observed N2 effects could be related to processes such as response inhibition, response conflict and error monitoring [20]. The N2 component could also be influenced by activity generated in unsuccessful trials. The error-related negativity could reflect adjustment of short- and long-term response strategies after a mistake, a compensatory response and a slower response to the subsequent trial [20]. The correlation between orientation difference decrease and P3 amplitude in a mental task experiment was consistent with the view that more difficult tasks were associated with less attention to the targets [17, 21]. The P3 latency was associated with the task difficulty and regarded as a measure of the duration of stimulus-evaluation processes (encoding, recognition and classification), independent of response selection and execution [22].

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