Assessment of the State of Activation of the Cortical Zones in Humans during Visual Attention and Selection

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The state of cortical activation during visual symbol shape and position selection tasks was assessed in humans in terms of the magnitude of prestimulus negativity (contingent negative variation, CNV) and the amplitude of the N1–P3 complex in evoked potentials (EP). Evoked potentials in the frontal, parietal, occipital, and temporal leads were recorded in 18 young healthy subjects in two sets of experimental conditions: in a screened chamber and in an "open field" beside the experimenter, who communicated the results to the subjects and guided them towards quicker and more precise responses to the target stimuli. The maximum magnitudes of CNV and evoked potentials during selective attention were seen in the parietal areas, and additional increases of activation indexes were observed in the "open field," where subjects' motivation was enhanced. The state of readiness (CNV) was an informative measure of cortical activation, as it determined the parameters of subsequent evoked potentials; the more marked the readiness, the more marked and stable were EP. Comparison of the situations of passive observation and selective reactions to stimuli revealed a reciprocal relationship between CNV in these conditions: the greater the magnitude of CNV in "passive" conditions, the smaller the difference between CNV in "passive" conditions and during selective attention and vice versa. We termed this "additivity of involuntary and voluntary attention." The fact that activation indexes were greatest in the parietal areas suggests that the occipital-parietal system is dominant in visual selection tasks in humans.

KEY WORDS: visual selection, attention, cortical activation, evoked potentials, CNV.

The major neural structures involved in the visual attention system are the extrastriate associative zones of the parietal and temporal areas of the cortex and the frontal areas [10, 15]. Animal experiments have demonstrated that the parietal cortex is predominantly associated with spatial selection of visual symbols, while the temporal areas are associated with the recognition of the shapes of objects [4, 6, 19, 26]. Data obtained by computer tomography methods in humans are less definitive, as they demonstrate activation of significantly larger numbers of cortical structures in visual attention tasks [8, 14, 20, 22].

Activation of various cortical structures can also be evaluated on the basis of analysis of evoked potentials (EP) and cortical conditional negativity (contingent negative variation). Because of the wide acceptance of this abbreviation and the difficulty of translating prestimulus negativity, this will for the present purposes be designated CNV.

CNV has been shown to consist of two components: an early wave associated with the orienting reaction (the O wave) to the anticipated signal, and a late component (the E wave) associated with the imperative stimulus, independently of whether or not it requires a motor response. The E wave is regarded as reflecting at least two underlying processes: motor readiness and anticipation [5, 11]. The O wave has a frontal distribution, while the E wave, depending on the task and the experimental paradigm, can be located in the precentral or prefrontal areas or in the parietal cortex [5, 16].

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The late wave of CNV probably reflects processes such as motivation, attention, the level of readiness, and cognitive "enhancement," needed for performing psychomotor reactions [18, 23]. However, the connection of these processes with concrete cortical structures thus far remains, according to published data, rather unclear, because CNV recorded from the surface of the head represents the summation of a multitude of cortical potentials of different origins and with different functions [2, 5, 9, 11, 16]. It has been suggested that surface-negative brain potentials reflect increases in the excitability of the underlying cortical structures.

Heilman et al. [10] include the system controlling the level of arousal, selective attention, and preparation for responding (intention) in the general system of attention. The separation of attention into three components is close to this concept, these being: 1) general effort; 2) the state of attention to a task; and 3) selective attention to a "target" stimulus [8]. Processes of the CNV type are a component part of attention related to cortical arousal in one or another part of the brain. The link with attention subsystems (general effort, in terms of CNV parameters, and selective targeted attention, reflected in the parameters of "target" evoked potentials) has received insufficient study, as most investigations have analyzed either EP or CNV [13, 17, 18], as CNV distorts the "pure" components of EP. We have demonstrated that selective attention is accompanied by increases in the magnitude and stability (correlatedness) of EP in repeated averagings as compared with the situation of passive observation [1, 3]. The term extent of EP refers to the maximum negative-positive deviations of EP, i.e., the complex of components N1–P3, which are the most closely associated with attention [11, 13]. However, the effects of CNV on the magnitude of EP and their stability have not yet been studied.

The aims of the present work were 1) to analyze the topography of late CNV during performance of tasks associated with visual selection and attention and 2) to assess the relationship between CNV and EP parameters during visual selection.

METHODS

In the first series of experiments, recordings were made in eight young healthy subjects of monopolar evoked potentials in six leads (O1, O2, P3, P4, F3, F4) with lateral (right or left) presentation of two easily distinguished visual symbols (the letter A and a cat's snout), one of which was the target for the session and required a rapid response. Fp2 was always recorded for eye movements (electrooculogram, EOG). Subjects had to look at a cross in the center of the display and they were told not to move the eyes in response to eccentric symbols (6°) at a distance of 70 cm from the display. Since subjects had been told not to make saccades in response to the target stimuli, the task selected here was one of the cryptic orientation or cryptic attention type [25]. At the start of the experiments, subjects observed symbols without having any task to perform (passive observation). This situation was regarded as a reference situation, with which changes in EP parameters during selective attention (four sessions, in which four stimuli were randomly defined as targets) were compared. Each experiment involved presentation of 800 stimuli, i.e., 160 stimuli in each of five experimental sessions.

The experimental apparatus consisted of a Telepat 102 20-channel encephalograph and a eight-bit analog-to-digital converter with a frequency of 250 Hz connected to an IBM PC (computer 1). Stimulus images were presented on a monitor screen serving another IBM PC (computer 2), connected to computer 1 via a serial cable. Computer 1, the main computer in the recording system, was controlled by the Evoked Potentials 1.0 program, developed at the Institute of the Brain, Russian Academy of Sciences. Computer 2, controlled by signals from the main computer, computer 1, was used for presentation of visual stimuli and recording of subjects' responses. Test stimuli consisted of images of a cat's snout and the letter A. The EEG analysis epoch was 1000 msec, including a prestimulus period of 150 msec. The program provided automatic rejection of fragments with EOG movements. After averaging, data were imported into Statgraphic for subsequent processing by dispersion and correlation analysis. In this series of experiments, subjects were located in a screened chamber; after being instructed, subjects received no information on their results.

The following EP parameters were recorded: prestimulus negativity (CNV), the negative component N1 in the period 130–170 msec after the stimulus, the late positive component P3, more precisely defined as P3b, at 330–500 msec, and our own evaluation of the stability of EP based on the correlatedness of repeated averaged EP in "masses" of 1000 msec [1, 3]. Only statistically significant results will be discussed, as identified using parametric and nonparametric methods of comparing sets in terms of the Wilcoxon test [7].

In the second series of experiments, EP were measured in ten subjects in the parietal and temporal leads (P3, P4, T3, T4, T5, T6) with lateral but different stimuli: circles and squares. Subjects were located in an experimental room along with the investigator. The apparatus and instructions were as in the first series, but after each session subjects were told of their response times and errors and they were constantly encouraged to work quickly and accurately. The following visual targets were used: 1) a square on the right-hand side; 2) a square on the left-hand side; 3) a circle on the right-hand side; 4) a circle on the left-hand side; 5) squares (on the right- and left-hand sides); 6) circles (on the right- and left-hand sides); 7) symbols on the right-hand side; and 8) symbols on the left-hand side. The first series of experiments is designated the "chamber" series, and the second the "open field" series.
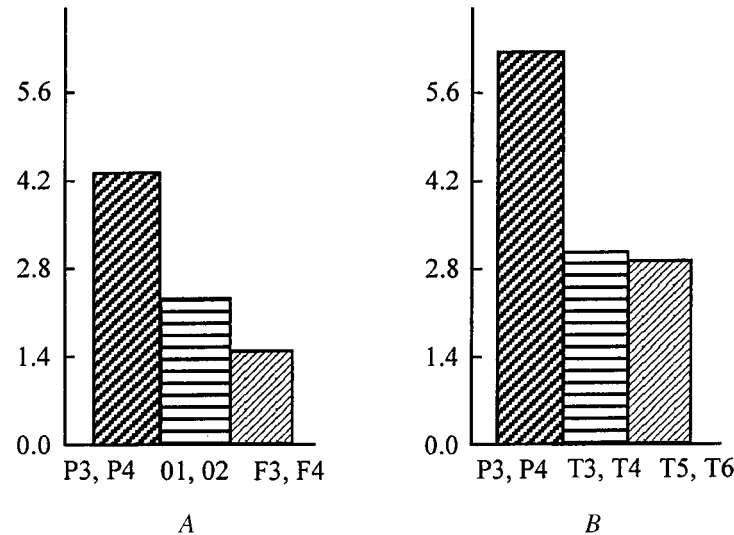
Fig. 1. CNV during visual selection. CNV amplitude in cortical leads. *A*) Leads F3, F4, P3, P4, O1, O2; *B*) leads P3, P4, T3, T4, T5, T6. Vertical axes show negativity amplitude, μV.
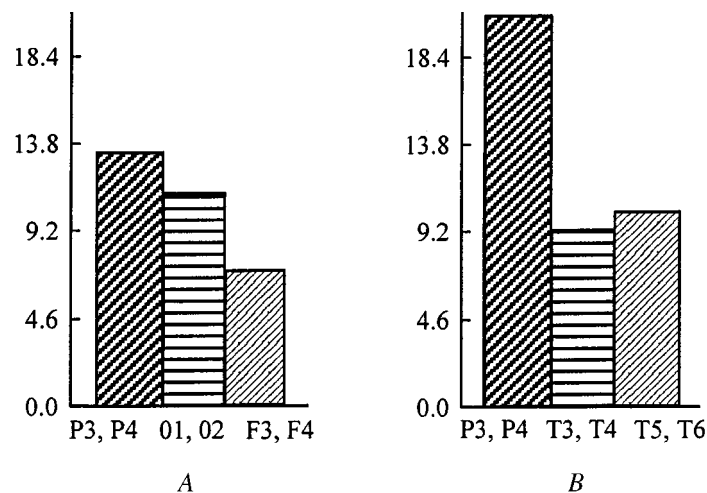

Fig. 2. The N1–P3 complex of evoked potentials during selective of visual signals. The amplitude of the N1–P3 complex of evoked potentials in the frontal, parietal, and occipital leads (*A*) and in the parietal, upper and lower infratemporal leads (*B*). Vertical axes show the amplitude of the complex, μV.

RESULTS

Topography of CNV and the N1–P3 Complex of EP during Visual Selection. Figure 1 shows mean CNV amplitudes for cortical leads in the first and second series of experiments (*A*, *B*) for "target" symbols using lateralized signals. Mean values were determined for 150 msec of the prestimulus epoch. This shows that the maximum value for prestimulus activation was seen in the parietal areas. The parietal dominance of CNV relative to other areas was significant. Thus, in the first series (*A* – using cat and letter

symbols), differences according to the non-parametric Wilcoxon test were: (P3, P4) vs (O1, O2) vs (F3, F4) $n = 16$; $Z = 3.75$; $p(Z) = 1.8E–4$. For the second series (*B*, circle and square symbols), differences were: (P3, P4) vs (T3, T4) vs (T5, T6) $n = 20$; $Z = 4.36$; $p(Z) = 1.2E–5$.

High levels of correlation were found between CNV amplitudes in the parietal and other cortical areas: r(P3, P4/F3, F4) = = 0.71, $n = 8$, $p = 0.04$; r(P3, P4/O1, O2) = 0.88, $n = 8$, $p = 0.004$. r(P3, P4/T3, T4, T5, T6) = 0.86, $n = 20$, $p = 0$.

Differences in CNV amplitude were seen in the parietal leads for the first and second series – CNV amplitudes
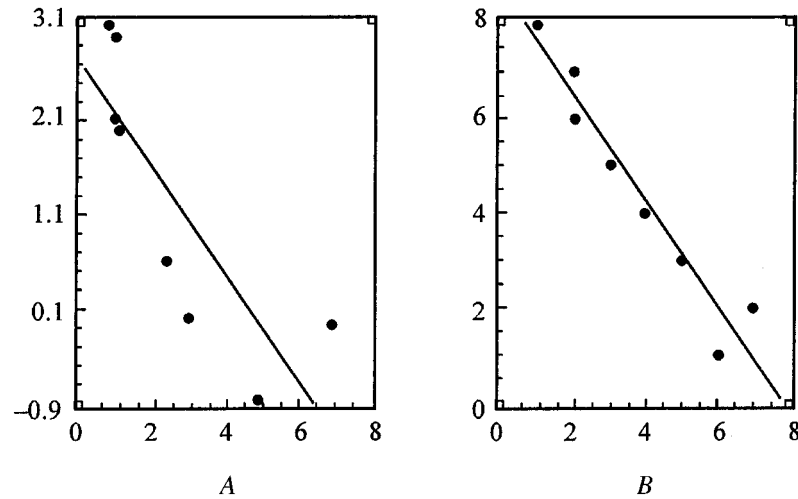
Fig. 3. Relationship between CNV magnitude in the passive situation and the difference in CNV magnitudes in selective attention and passive perception of symbols. *A*) Magnitudes, μV; the abscissa shows CNV in passive conditions and the ordinate shows differences in values; *B*) ranked CNV magnitudes in passive conditions (abscissa) and CNV differences in attention and passive conditions. Data from eight subjects, parietal leads. Small initial readiness values correspond to larger transitions from passive conditions to attention and vice versa. The reciprocal nature of these values is more marked for ranked CNV amplitudes. The correlation in Fig. 3, *A* was $r = -0.83$, $p = 0.1$, while in Fig. 3, *B*, $r = -0.96$, $p = 0.001$.
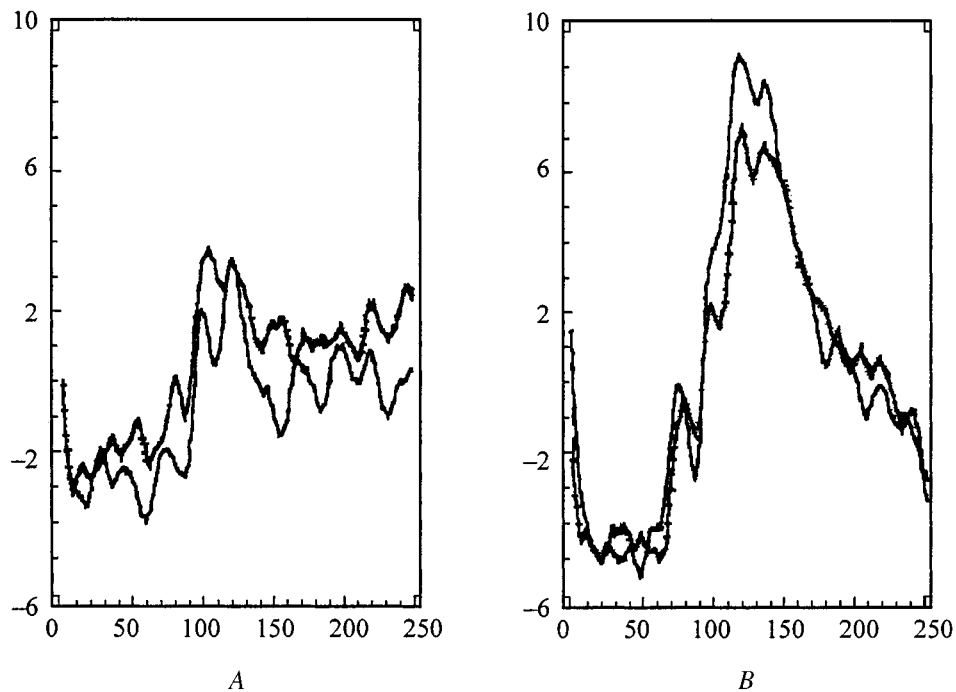

Fig. 4. Repeated average evoked potentials in eight subjects, lead P3, in the passive situation (*A*) and during selective attention, i.e., reactions to target stimuli (*B*). The abscissa shows time, msec ×4; the ordinate shows amplitude, μV. The correlation between repeated evoked potentials in Fig. 4, *A* was $r = 0.49$, while that in Fig. 4, *B* was $r = 0.86$.
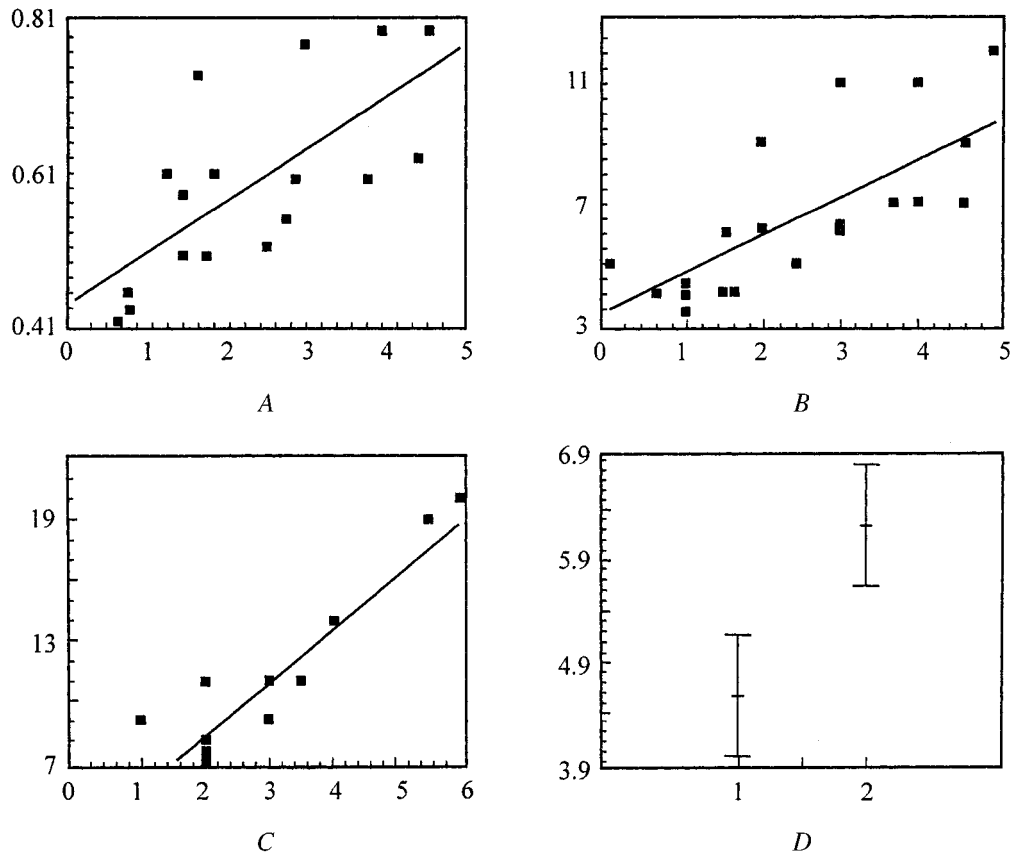
Fig. 5. CNV and evoked potential parameters during visual selection. *A*) Relationship between CNV amplitude (abscissa) and correlations of repeated evoked potentials (stability) using an epoch of 800 msec; *B*) relationship between CNV amplitude (abscissa) and the N1–P3 complex in the first series ("chamber"); *C*) relationship between CNV amplitude (abscissa) and evoked potential N1–P3 complex amplitude with an epoch of 800 msec in the second series, "open field;" *D*) N1–P3 during selection of targets from two and four possibilities. Data from second series.

were significantly greater for the "open field" series than in the "chamber": CNV (*A/B*) (P3, P4) = 4.3 (2.0) μV, $n = 64$; 6.2 (2.2) μV, $n = 23$, $t = 3.8$, $p < 0.001$. Figures in brackets are mean square deviations.

The dominance of parietal activation during visual selection was seen not only in terms of measures of the state of readiness, but also in terms of the magnitude of EP (N1–P3 complex). Figure 2 shows values of this complex for the parietal, frontal, and occipital leads (*A*, first series) and the parietal and temporal leads (*B*, second series). The greater magnitude of the complex in the parietal leads was significant. Differences in terms of the non-parametric Wilcoxon criterion in the first series were: $Z(P/F) = 4.12$, $n = 16$, $p(Z) = 3.7E-5$; $Z = (P/O) = 2.12$, $n = 16$, $p(Z) = 0.03$. For the second series: $Z(P/T) = 3.75$, $n = 20$, $p(Z) = 1.7E-4$. P is the magnitude of N1–P3 in the parietal leads P3, P4; F is the magnitude in leads F3, F4; O is the magnitude in frontal leads F3, F4; and T is the magnitude in parietal leads T3, T4, T5, T6. Thus, during selection of very different lat-

eralized symbols, the greatest level of activation was seen in the parietal areas of the cortex.

In the "open field," the amplitude of EP in subjects in the parietal leads, like CNV, was significantly greater than in the "chamber": the magnitude of the N1–P3 component (Fig. 2, *A*) was 13.2 (2.0), $n = 8$; N1–P3 was 20.5 (3.8), $n = 10$ (Fig. 2, *B*), $t = 4.86$, $p = 1.7E-4$. Figures in brackets are mean square deviations.

Characteristics of CNV and Its Relationship with EP Parameters. Analysis of CNV amplitude in passive observation and during selective attention – the search for the target symbol – showed the following characteristic: the greater the initial CNV in passive observation, the smaller the magnitude of the transition from passive observation to selective attention and vice versa. Figure 3, *A* shows individual values for CNV in the parietal leads in passive observation in eight subjects (abscissa) and the corresponding differences in CNV between passive observation and selective attention (ordinate). The correlation between these val-

ues was $r = -0.83$, $p = 0.1$, $n = 8$. The relationship was more marked for CNV amplitudes ranked in increasing order (Fig. 3, *B*), where $r = -0.96$, $p = 0.001$, $n = 8$. The relationship between these CNV parameters was seen in all leads although, given that values were different in different leads, the relationship was clearest for rankings of CNV amplitudes: $r = -0.83$, $n = 24$, $p < 0.01$.

Figure 4 shows repeated average CNV (first 40 points on the abscissa) and EP in lead P3 in eight subjects during passive observation (*A*) and selective attention (reactions to "target" stimuli). This shows that maximum CNV values corresponded to the greatest correlations for repeated EP ($r_{1/2}$ in passive observation was 0.49, and $r_{1/2} = 0.86$ in selective attention) and N1–P3 EP magnitudes.

Statistical analysis supported the relationship between CNV magnitude and EP parameters. Figure 5, *A* shows the regression relationship between CNV amplitude and EP stability (correlatedness of repeated EP): $r = 0.73$, $n = 17$, $p = 0.005$. A significant regression relationship between CNV and the EP N1–P3 complex was seen in the first (Fig. 5, *B*) and second (Fig. 5, *C*) series: $r(1) = 0.74$, $n(1) = 23$, $p(1) = 0.003$; $r(2) = 0.9$, $n(2) = 14$, $p(2) = 0.001$.

Comparison of CNV amplitude in the second series for selection from two possibilities (target stimuli were only circles or only squares, all on the right or all on the left) and selection of the target from four possibilities (circle on the right, etc.) showed that CNV amplitude in the first case was significantly less than that in the second (Fig. 5, *D*). The differences were significant by ANOVA: $n = 46$, df $= 1$, $F = 7.98$, $p = 0.007$.

DISCUSSION

The frontal, parietal, and occipital associative systems are involved in the visual attention system. The separation of the two supraprojectional systems is well known: these are the parietal-occipital and temporal-occipital systems, which have different anatomical substrates: the magno and parvo systems, the dorsal and ventral systems [14, 19, 24]. Monkey experiments with removal of these two areas and recording of neuron activity suggested that the parietal system is associated predominantly with spatial visual analysis (spatial attention), while the temporal system is associated with analysis of stimulus shape [4, 6, 19, 22, 26].

Concepts relating to the interaction of the parietal and temporal systems in the visual attention systems in humans show great differences. Concepts include: 1) that these systems have clearly different functional directions [22, 26]; 2) that there is a general parietal-temporal visual attention system [8, 14]; 3) that the temporal areas are dominant [6, 4]; and 4) that the parietal areas are dominant [24] in the visual attention system.

The data obtained here, showing maximal values for activation indexes (CNV, N1–P3) in the parietal areas dur-

ing visual selection (Figs. 1, 2) and increases in the activation of the parietal areas of the cortex in response to increases in the subjects' motivation in the "open field," suggest that the parietal cortex is dominant in the visual attention system, perhaps because the magnocellular pathway forms the most important visual input to the dorsal, parietal pathway of the neocortex [24]. The suggestion of parietal dominance in visual attention is also supported by data obtained by Kanunikov, showing maximal CNV amplitudes in the parietal areas in visual signal observation tasks [2].

The maximal expression of CNV in the parietal areas and the high levels of correlation between CNV in the parietal and other areas may be evidence that the CNV focus in visual selection is in fact in the parietal areas.

The complexity of the problem of attention is to some extent due to the different components included in this term. Thus, if attention is understood as only an enhancement in the sensory response, as shown in monkey experiments [6], and the analogous increase in the sensory component of EP (P1, N1) [11, 17], then attention is activated only after a stimulus, and entire processes of the pre-attention, automatic stimulus detection, etc., types operate before this point [12, 13]. If the term attention is assigned a wider meaning, to include the system controlling the level of arousal and the response preparation (intention) system [10], then preparative processes of the CNV type are component parts of attention and, as shown here, determine the parameters of post-stimulus activation: the magnitude and stability of EP. In this sense, CNV can be regarded as a very effective index for assessing visual attention, since our studies have demonstrated that prestimulus activation determines the parameters of post-stimulus EP (Fig. 5, *A–C*). The reciprocal relationship between CNV in passive observation (involuntary attention) and the magnitude of the transition in CNV to voluntary selective attention identified here (Fig. 3) suggests "additivity" in the visual attention system: the greater the involuntary attention, the smaller the "addition" to the total level of attention (involuntary and voluntary).

According to Seltzer and Mesulam [21], attention has two operational components: a matrix and a vector; the matrix describes the level of arousal and the vector is its direction. The most marked preparative activation and amplitude of the negative-positive component of monopolar EP (the reference channel was a combined ear electrode) in visual selective attention in the parietal leads suggest the formation of a vertical parietal vector during visual selection and attention. This suggestion appears to be valid on the basis that CNV and the N1 and P3 components are modulated by influences from subcortical structures, particularly the reticular formation, a critical structure in the attention system [18, 23].

Thus, these considerations lead to the following conclusions:

1. The greatest level of activation of CNV and the EP N1–P3 complex during visual searches for lateralized target

symbols requiring selection in terms of position and shape is seen in the parietal areas of the cortex. Artificial enhancement of the subjects' motivation leads to additional increases in parietal activity.

2. Assessment of preparative activation (CNV) is an important factor for determining cortical activation during visual attention, since CNV magnitude determines the parameters of EP, i.e., the stability and amplitude of the negative-positive N1–P3 complex.

3. Involuntary attention, assessed in terms of CNV during passive observation, and selective voluntary attention have the property of "additivity": the greater the magnitude of the former, the smaller the "transition" to voluntary attention and vice versa.

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