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The Neurophysiologic Significance of Frontal Negativity in Pattern-Reversal Visual-Evoked Potentials

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To demonstrate that the frontal negative potential (N100) does exist in response to pattern-reversal visual stimulation and its independence of the dipole source from the major occipital positive potential (P100), modifications of P100 and N100 with changes in the check size, contrast, and luminance of the stimulus pattern were studied in healthy subjects. Eight different check sizes (10–90 min of arc), eight different contrast levels (10–85%), and six different luminance levels (11–180 cd/m^2) were used. Changing the stimulus conditions modified the latencies and amplitudes of P100 and N100 in different ways. P100 latency had a band pass spatial tuning function against check size; N100 latency did not. P100 was sensitive to changes in contrast and luminance; N100 was less dependent on these parameters. These findings suggest the existence of different physiologic properties for N100. Consequently, frontal negativity is considered to be independent of P100. Invest Ophthalmol Vis Sci 33:2423–2428, 1992

Recently, it was shown that there is a negative potential (N100) of similar latency to the major occipital positivity (P100) in the frontal region.[1-4] However, its nature has not been elucidated fully, and its existence is still controversial. There are three hypotheses of the generator source of N100 as follows: (1) expression of an inverted polarity of the positive potential at a reference electrode caused by an extension of the electrical field of the P100,[5,6] (2) expression of the opposite end of a single dipole generating the P100,[7-9] or (3) expression of an independent generator localized in the frontal region.[2-4]

To solve this problem, we recently investigated the nature of the negative potential in the frontal region by using different reference electrodes and experimental manipulations of the stimulating visual field ("central scotomata" and "peripheral constriction").[10] Although the ear lobe was found to be activated by components of pattern-reversal visual-evoked potential, P100 and N105, it was found that the amplitude of frontal negativity, which was not affected by ear lobe activation, was much greater than those produced by activated potentials. Moreover, it was concluded that frontal negativity was not an electrographic expression of dipolar sources that generated P100 and N105 because the physiologic properties of frontal negativity detected using visual field manipulations were shown to be different from those of occipital components.

The latency and amplitude of P100 can be modified by various stimulus parameters (eg, check size of the stimulus pattern,[9,11-21] stimulus contrast levels,[22-31] and stimulus luminance levels).[32-34] However, to our knowledge, there have been no reports showing how N100 is modified by these parameters. If the hypothesis that N100 is related to reference activation or an expression of the opposite end of a single dipole of P100 is true, the effects of check sizes, contrast, and luminance changes on the latencies and amplitudes of P100 and N100 could be similar. However, if N100 is independent of P100, these effects on the latencies and amplitudes of P100 and N100 could be different and confirm the results of our previous study.[10] Therefore, we investigated the effects of check sizes, contrast, and luminance on P100 and N100 to determine whether N100 was independent of P100.

Materials and Methods

Subjects and Stimuli

Experiment 1: The study was done on 11 healthy volunteers (5 men and 6 women; age range, 20–33 yr;

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mean age, 26 yr). The corrected visual acuity was 20/20 or better in all subjects.

The visual stimulation consisted of a black-and-white checkerboard pattern, which was back projected onto a translucent screen and reversed at a rate of 1 Hz. The pattern was set to subtend 8° in radius of the visual field, with eight different check sizes (10, 15, 18, 22.5, 30, 50, 60, and 90 min of arc). The mean luminance of the bright and dark checks was maintained at 180 cd/m^2. The contrast between dark and light checks was 90%. Stimulation was done monocularly. The subject gazed at a red point in the center of the screen during the recording session.

Experiment 2: The study was done on ten healthy women (age range, 20–26 yr; mean age, 21 yr). The corrected visual acuity was 20/20 or better in all subjects.

A black-and-white checkerboard pattern was generated on a video monitor by means of a minicomputer (88VA; NEC, Japan) and was reversed at a rate of 1 Hz.[35] The display field subtended 17 × 11° with a check size of 30 min of arc. The checkerboard pattern was presented at eight different contrast levels: 85%, 64%, 48%, 35%, 28%, 21%, 16%, and 10%. The contrast presentation was randomized. The mean luminance was maintained at 57 cd/m^2.

Experiment 3: This experiment involved the same subjects tested in Experiment 2. The stimuli were generated and displayed in the same fashion as in Experiment 1 except for the luminance level and check size. With a check size of 30 min of arc, the checkerboard pattern was presented at six different luminance levels: 180, 90, 57, 36, 22, and 11 cd/m^2. The method for changing luminance was described in detail previously.[36] The luminance presentation was randomized.

Recording Methods

Recording electrodes were placed at O_z (5 cm above the inion) in Experiment 1, O_z' (2.5 cm above the inion) in Experiments 2 and 3, and at F_z (12 cm above the nasion). All electrodes were referred to linked ear lobes (A1A2). Electrode impedance was kept below 5000 Ohms. Recordings were made with a band pass between 0.5 and 120 Hz, averaging 64 responses with an analysis time of 300 msec. At least two traces were obtained, which confirmed the reproducibility of the responses.

Measurements

The definition of each visual-evoked potential component and its amplitudes was as follows (Fig. 1). We determined P100 as the first major positivity at O_z or O_z', and amplitude was measured between the peaks of P100 and the preceding negativity (or the baseline). We detected N100 as the first major negativity at F_z, and amplitude was measured between the peaks of N100 and a preceding positivity (or the baseline).

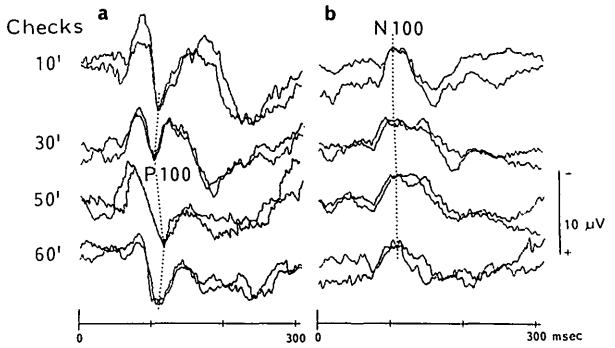

Fig. 1. An example of representative VEPs evoked by four different check sizes (10, 30, 50, and 90 min of arc) in a subject (AF). The latencies and amplitudes of P100 (**a**) and N100 (**b**) are modified in a different manner by changes in the check size.

Statistical Analysis

Using one-way analysis of variance, first, we tested the relationships between: (1) the latencies or the amplitudes of each component and the check size; (2) the latencies or the amplitudes of each component and the contrast; and (3) the latencies or the amplitudes of each component and the luminance. When analysis of variance revealed a statistically significant level ($P < 0.05$), least-squares polynomial regression analysis was used to determine the equations.

Results

Experiment 1

The effect of check size on the latencies and amplitudes of P100 and N100 is shown in Figures 1 and 2.

Check size–latency function of P100 and N100: The check size had a significant effect on the P100 latency ($F = 4.74$; df = 7, 72; $P < 0.05$). There was no statistically significant effect observed on N100 latency ($F = 2.05$; df = 7, 56; $P > 0.05$). The mean latency of P100 showed a second-order polynomial regression with the shortest one for 38.9 min of arc ($F = 32.2$; df = 1, 3; $P < 0.01$) and increased progressively with both smaller and larger checks, indicating that P100 latency had a spatial tuning function (Fig. 2A).

Check size–amplitude function of P100 and N100: The amplitudes of P100 and N100 were not affected by changes in check sizes (for P100 amplitudes versus check size: $F = 0.82$; df = 7, 72; $P > 0.5$; for N100 amplitudes versus check size: $F = 0.62$; df = 7, 56; $P > 0.5$).

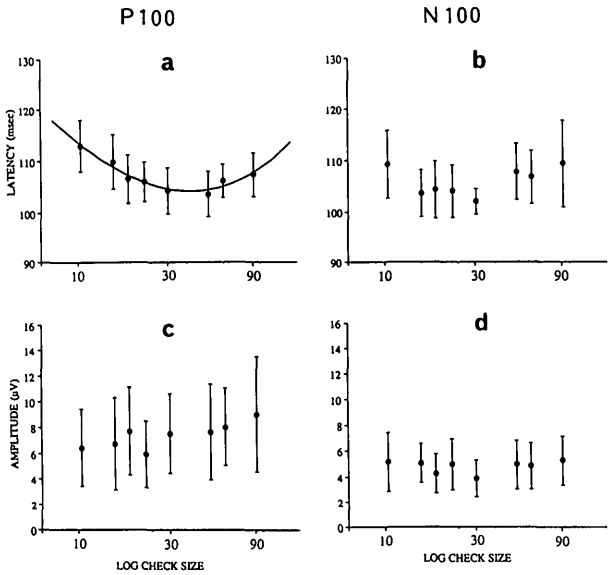

Fig. 2. Modifications of the latencies (**a** and **b**) and amplitudes (**c** and **d**) caused by changes in the check size (min of arc). The data indicate the mean of all subjects (closed circles) and one standard deviation (vertical bars) in this figure and in Figures 3 and 4. The check sizes are plotted in a logarithmic scale. Regression line is drawn when applicable. Note the curvilinear regression of the latency of P100 against the logarithm of the check size. P100 latency (msec) = $169.7 - 83.3X + 26.2X^2$, where X = log check size.

Experiment 2

Latencies and amplitudes of P100 and N100 for contrast changes are shown graphically in Figure 3.

Contrast-latency function of P100 and N100: Changes in contrast had a significant effect on the latencies of both P100 and N100 (for contrast versus P100 latency: F = 16.2; df = 7, 72; $P < 0.01$; for contrast versus N100 latency: F = 7.99; df = 7, 72; $P < 0.01$). Both P100 and N100 latencies showed an inverse linear relationship to the logarithm of the contrast (up to 35%) and tended to show saturation above 35%. The slopes of the fitted regression lines over a range of 10–35% for mean P100 latency and mean N100 latency were −35.6 and −32.1, respectively (Figs. 3A–B).

Contrast-amplitude function of P100 and N100: The amplitude of P100 was affected significantly by contrast changes (F = 3.74; df = 7, 72; $P < 0.01$). There was no statistically significant effect on the amplitude of N100 (F = 0.84; df = 7, 72; $P > 0.5$). The mean amplitude of P100 had a significant linear relationship with the logarithm of the contrast (F = 87.6; df = 1, 4; $P < 0.01$; Fig. 3C).

Experiment 3

Latencies and amplitudes of P100 and N100 for luminance changes are displayed graphically in Figure 4.

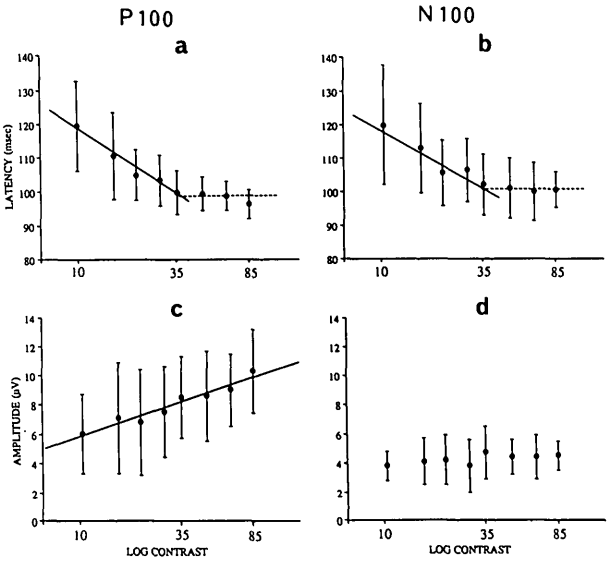

Fig. 3. Modifications of the latencies (**a** and **b**) and amplitudes (**c** and **d**) caused by changes in the contrast (%) with a check size of 30 min of arc at a luminance level of 57 cd/m^2. (**a** and **c**), P100; (**b** and **d**), N100. There were two distinct changes between P100 latency and log contrast—linear relation (up to 35%) and saturation above 35%. N100 latency also shows the same tendency. The slope of P100 latency is not different from that of N100 latency. The regression equation (contrast up to 35%) is: P100 latency (msec) = 154.0 − 35.6X; N100 latency (msec) = 150.2 − 32.1X, where X = log contrast. There is a linear relationship between the amplitude of P100 and the log contrast (**c**), whereas there is no linear relationship between N100 and log contrast (**d**). The regression equation is: P100 amplitude (μV) = 1.39 + 4.28X, where X = log contrast.

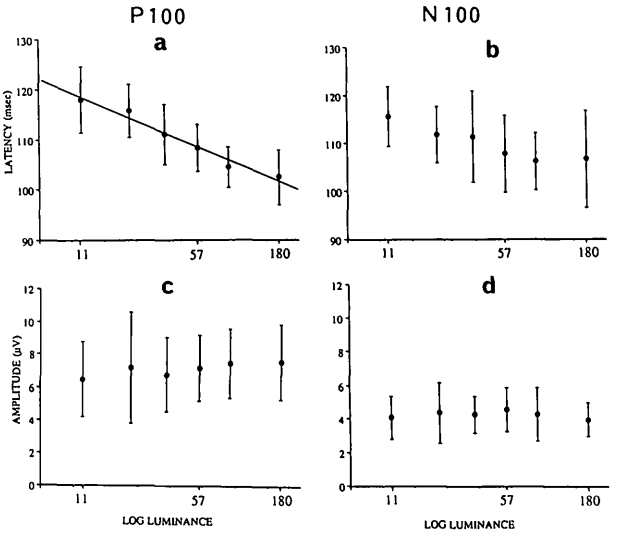

Fig. 4. Modifications of the latencies (**a** and **b**) and amplitudes (**c** and **d**) caused by changes in the luminance (cd/m^2; note logarithmic scale) with a check size of 30 min of arc at a constant contrast level (90%). (**a** and **c**), P100; (**b** and **d**), N100. Note the linear relationship between P100 latency and the logarithm of the luminance (**a**), whereas there is no relationship between N100 latency and log luminance. The regression equation is: P100 latency (msec) = 132.5 − 14.0X, where X = log luminance. Changes in luminance do not have a significant effect on the amplitudes of P100 and N100.

Comparison of luminance–latency function of P100 and N100: The latency of P100 was affected significantly by luminance changes ($F = 11.65$; $df = 5, 54$; $P < 0.01$). There was no significant effect on the latency of N100 ($F = 1.61$; $df = 5, 54$; $P > 0.2$). The P100 latency increased as the luminance level decreased. The mean latency of P100 showed an inverse linear relationship with the logarithm of the luminance ($F = 142.4$; $df = 1, 4$; $P < 0.01$; Fig. 4A).

Comparison of luminance–amplitude function of P100 and N100: Changes in contrast did not have a significant effect on either the amplitudes of P100 or N100 (for P100 amplitude versus luminance: $F = 0.24$; $df = 5, 54$; $P > 0.5$; for N100 amplitude versus luminance: $F = 0.10$; $df = 5, 54$; $P > 0.5$).

Discussion

Our study showed that stimulus parameters (check size, contrast, and luminance) had different influences on P100 and N100 components of visual-evoked potentials (Table 1).

Effect of Check Size

Several authors have reported that the latency and/or amplitude of P100 have a band pass spatial tuning function against check size,[16,17,19,21] although others found no such function.[9,18,20] Our results showed that P100 latency also exhibited spatial selectivity and band pass tuning in the spatial domain; N100 latency did not show any band pass effect. By contrast, neither P100 nor N100 amplitude provided evidence of such a tuning function. The interpretation of these findings may be that P100 arises from cells that respond to a limited subset of the stimulus size and N100 from the cells that do not have the selectivity or specificity for the size of the stimulus. Therefore, N100 may reflect the function of the cells with broad receptive fields, and P100 may result from narrowly tuned cells.

Table 1. Modifications of P100 and N100 caused by stimulus parameters

	Stimulus parameters		
	Check size	*Contrast*	*Luminance*
P100 latency	S*	S†	S†
N100 latency	NS	S†	NS
P100 amplitude	NS	S†	NS
N100 amplitude	NS	NS	NS

* Significant ($P < 0.05$).
† Significant ($P < 0.01$).
NS, not significant.

Effect of Contrast

With respect to the response of peak time against contrast change, the P100 latency shortened steadily up to the contrast of 16–20% but not markedly at higher contrast levels.[26,28,31] The P100 amplitude also increased linearly up to the contrast of 16–30% and tended toward saturation at higher levels.[24,28] In our results, P100 amplitude was sensitive to contrast changes, and a linear relationship between P100 amplitude and logarithmic contrast was observed. However, N100 amplitude was independent of contrast. These findings suggest that the P100 response depends more on the contrast of the pattern than the N100 response. It is likely that P100 may represent contrast-specific information, but N100 does not.

Effect of Luminance

Previous studies found that P100 latency varied as an inverse linear logarithmic function of luminance, over a range of 180 to 10 cd/m^2.[32,34,36] The P100 amplitudes were saturated above 3.6 cd/m^2.[33] These findings agree with our results. We found that P100 latency was modulated linearly by logarithmic changes of the luminance; there was no significant relationship to N100 latency. The amplitudes of both P100 and N100 were not affected by luminance. Our results agree with the findings of previous investigations. Others[32] also found that the early positive potential (P60) showed a different attitude from P100 in response to luminance changes, suggesting functional subdivisions in the visual pathways. Therefore, we believe that N100 may be generated in different neuronal populations somewhere in the visual system, based on the differential luminance effects on P100 and N100.

Possible Generator Source of the Frontal Negativity

In the prefrontal cortex in monkeys, electrical activities occur in response to visual stimulation, gazing at a spot,[37,38] or doing a visually guided movement task[39–42] with latencies ranging from 60–440 msec. Although recording visual-evoked potentials in humans does not involve a task paradigm in the practical sense, the subjects are asked to gaze at a target located at the center of the screen. The process of gazing and the attending visual stimulation, along with other unidentified neuropsychologic activities, therefore, may produce frontal negativity during recording in humans.

As mentioned, the neurophysiologic properties of N100 are different from those of P100. We conclude, therefore, that the frontal negativity of the visual-evoked potential cannot be ascribed to a "reference contamination" or a single horizontal dipole of P100. Therefore, N100 does exist in response to pattern-reversal visual stimulation. These results are consistent with our previous study.[10] We found N100 is independent of P100, and we believe it is mediated by different neuronal populations in the visual system related to prefrontal electrical events.

Key words: frontal negativity, P100, check size, contrast, luminance

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