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Pattern Reversal Visual Evoked Potentials (White-Black- and Colour-Black-PVEPs) in the Study of Eye Dominance

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Summary. We investigated the influence of eye dominance scaled by 6 tests on the parameters (N80, P100 latency and N80-P100 amplitude) of the white-black-, green-black-, red-black- and blue-black-pattern visual evoked potentials (PVEPs) of 40 healthy subjects (20 males and 20 females) with normal visual acuity. The P100 latency of the white-black PVEPs was, for both sexes, shorter ($P \leq 0.001$) in the PVEPs of the dominant eyes. This P100 latency shortening could also be verified for both right dominant and left dominant eyes with no significant difference between them. A consistent relationship, however, between the different degrees of eye dominance and the P100 latency shortening could not be established. In contrast to the P100 latency findings the N80 latencies of the white-black-PVEPs and the N80-P100 amplitudes did not show any significant differences with respect to eye dominance. Furthermore, the colour-black PVEPs did not present any differences of latency and amplitude depending on eye dominance. Thus our results give further electrophysiological evidence for eye dominance as a lateralized CNS phenomenon that is not influenced by colour.

Key words: Eye dominance – PVEPs, Colour-Black – PVEPs – Nervous system lateralization

Introduction

Dominance can be defined as the preferential activity of one member of any bilateral pair of structures in the body. Eye dominance was first described by the Neapolitan Porta in his work "de refractione" of 1593 [9]. Crider [3] also found that a majority of subjects with normal visual acuity have a dominant eye. This phenomenon was differentiated by Coren and Kaplan [2] into the following three subtypes: sighting dominance, sensory dominance and acuity dominance. Acuity dominance of one eye is caused by a visual deficiency of the other eye. When two different inputs are presented simultaneously to corresponding areas of both eyes that eye would be called the sensory dominant one whose input was first perceived [1]. In contrast to these kinds of eye dominance, sighting dominance refers to the eye preferred in a sighting task in which both eyes cannot be used simultaneously. We investigated this sighting dominance in the present study to see whether it correlates with electrophysiological parameters. For this purpose we used both the traditional white-black patterned checkerboard stimuli [10, 11], and – to our knowledge for the first time – we used green-black, red-black and blue-black patterned checkerboard stimuli, since colour could theoretically play a role in eye dominance.

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Materials and Methods

In the present study we investigated 40 healthy subjects, 20 males and 20 females, with a mean age of 23.7 ± 3.3 years. The following 6 tests were used to scale and determine their eye dominance: (1) ring test, (2) magnifying glass test, (3) aiming-at test, (4) looking through a slit test, (5) hole in the card test and (6) pointing test. In each test attention was paid to the eye preferentially used for solving the task. If it was the right eye (R), the test score was 2, if it was the left eye (L), the score was 0, and if no eye (A) was preferred, the score was 1. As an example this procedure may be explained for the important "pointing test": that is the shift to the dominant eye for the experimenter if the subject is asked to bring his thumb in line with his nose binocularly.

Thus the criterion for objectively determinating the eye preferred for solving the task was the subject's behaviour, not his experience. Summing the results of the above 6 subtests we obtained a scale extending from 0 to 12. The range between 0 and 5 indicated left eye dominance, the range from 7 to 12 right eye dominance and 6 ambiguity. The 20 males and 20 females tested in this way were sitting in the dark in a Faraday box 1.5 m in front of a colour TV set and had to fixate a red L.E.D. lamp in the centre of the screen. Each eye was stimulated separately twice with 2 Hz reversal of the white-black (luminance = 20.3 cd/m^2), green-black (10.4 cd/m^2), red-black (5.5 cd/m^2) and blue-black (6.6 cd/m^2) patterned checkerboards (16×16 caskets with a check size of 48.6' of visual angle), generated by a Nic-1006a Color Visual Stimulator. The potentials were averaged over 120 artefact-free sweeps of 370 ms duration, derived from Oz to Fz (Cz was ground) by a Mingograf EEG 10 (time constant = 0.3; filter frequency = 30 Hz;) in line with a Philips Analog 714 instrumentation recorder (sensitivity = 25 μV) and then averaged by a Nicolet-Med 80. Since eye dominance was the major subject of this study, we chose the midline scalp derivation to avoid a contamination of the pattern visual evoked potentials (PVEPs) by possible hemispheric asymmetries. Latency and peak to peak amplitude measurements were performed with the help of electronic cursors. The latencies of the first recognizable negative peak (= N80) and the main positive peak (= P100) as well as the N80-P100 amplitudes obtained in this way were statistically evaluated by means of t-difference tests according to Immich [4].

Results

Among the 40 subjects 26 were right eye dominant (= 65%), 11 left eye dominant (= 27.5%) and 3 were ambiguous (= 7.5%); the latter were excluded from further evaluation. Concerning the influence of eye dominance on the parameters of the White-Black-PVEPs, 81% of the eyes classified as "dominant" showed shorter P100 latencies as shown in Fig. 1.

In contrast to this we did not find a similar dominance effect on the N80 latencies and the N80-P100 amplitudes, whose entries in Fig. 1 are irregularly distributed above and below the 45° line. These findings are illustrated by the PVEPs of both the Grand Average that was made of 15 male and 15 female potentials being available for this operation and 4 single cases shown in Fig. 2. The main positive peak (= P100) was slightly, but noticeably shorter in the PVEPs of the dominant eyes, whereas the N80-P100 amplitudes obviously did not show such differences. Considering all subjects, this P100 latency shortening was significant ($P \leq 0.001$) in the PVEPs of the dominant eyes with a mean value (± 1SD) of -1.22 ± 1.80 ms (Table 1).

Dividing our study group ($n = 37$) into male ($n = 19$) and female ($n = 18$) subgroups we found that the P100 latencies of the White-Black-PVEPs were significantly ($P \leq 0.02$ and 0.01)

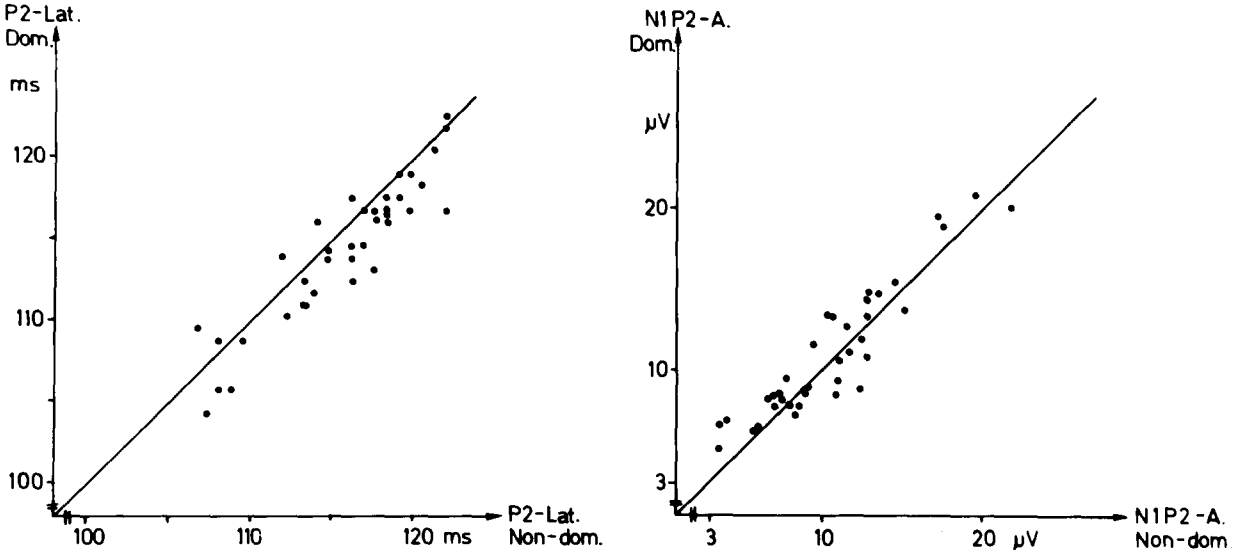

Fig. 1. The relationship between the P2 (= P100) latencies and the N1P2 (= N80-P100) amplitudes of dominant and non-dominant eyes. It shows the P100 latencies *(left)* and the N80-P100 amplitudes *(right)* of the white-black pattern visual evoked potentials (PVEPs) of the non-dominant eyes *(abscissa)* and the dominant ones *(ordinate)*. Of the 37 P100 latency entries, 30 are located below the 45° line, indicating P100 latency shortening in the PVEPs of the dominant eyes. In contrast to this, the N80-P100 amplitude entries are evenly distributed above and below the 45° line

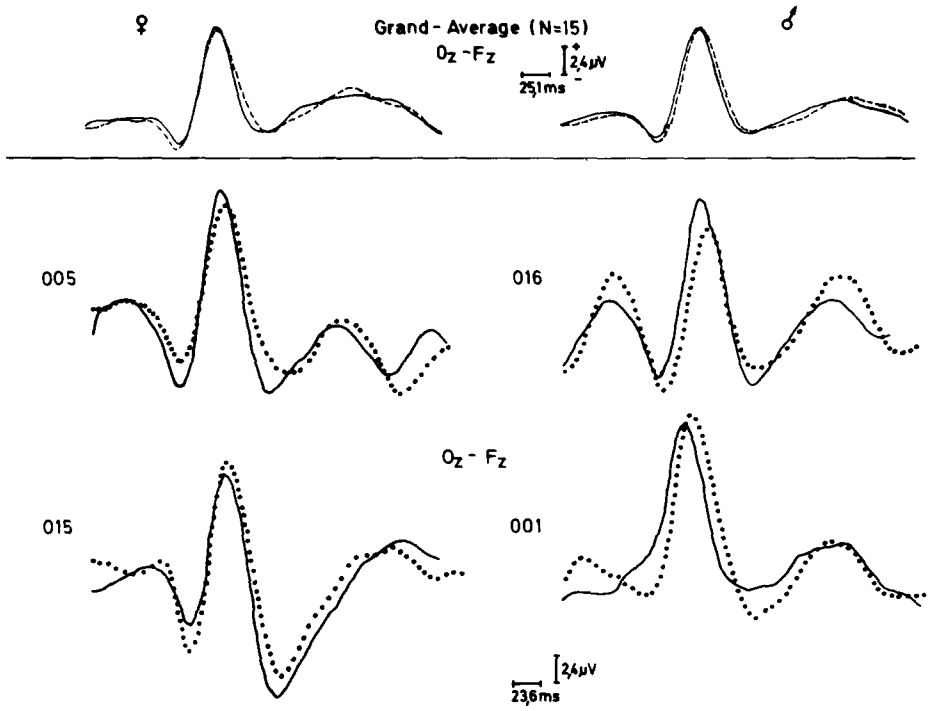

Fig. 2. The influence of eye dominance on black-white PVEPs. Grand Average of 15 female PVEPs *(left)* and 15 male PVEPs *(right)* for dominant (———) and the corresponding non-dominant (·····)eyes on the top. Below, the PVEPs of 4 single cases are shown for both dominant and non-dominant eyes (positivity upward, the main positive deflection (=P100) is clearly visible). There is no dominance-dependent difference in the amplitudes, a slight P100 latency difference is visible in the Grand Average, but more clearly in the single cases (the numbers refer to individual subjects)

Table 1. The influence of eye dominance on the P2 (= P100) latency of the White-Black-PVEPs. The P100 latency of the dominant eyes was significantly shorter than that of the corresponding non-dominant eyes. This was true for the whole group and for female and male subjects with no differences between the sexes

	n	$\bar{x}$	SD	P
♂	19	−1.04	1.58	≤0.01
				NS
♀	18	−1.40	2.03	<0.01
	37	−1.22	1.80	≤0.001

P = level of significance, NS = non-significant

shorter for the dominant eyes of both sexes with no significant difference between male and female subjects. We also investigated whether there were differences between right and left eye dominance with respect to the P100 latency. The P100 latencies of the right and left dominant eyes were compared to those of the corresponding non-dominant eyes using t-difference tests. We found the P100 latency to be significantly ($P \leq 0.05$ and 0.01) shorter for both the right dominant eyes ($n_1 = 26$: $\bar{x}_1 = -1.08 \pm 1.70$ ms) and the left dominant eyes ($n_2 = 11$: $\bar{x}_2 = -1.55 \pm 2.05$ ms), with no differences between them. These right and left eye dominance effects on the P100 latency of the white-black PVEPs determined the mean value of the traditional interocular latency differences obtained by subtracting the P100 latencies of one eye (e.g. the right = R) from the other (e.g. the left = L) regardless of their eye dominance. In our population ($n = 37$) the mean value of the interocular latency difference (R–L) of P100 was 0.26 ± 2.16 ms. This mean value was the result of the distribution of right- ($n_1 = 26$) and left-($n_2 = 11$) eyed subjects in this group ($n = 37$) as the following calculation demonstrates:

$$(n_1 \cdot \bar{x}_1 - n_2 \cdot \bar{x}_2) : N =$$
$$[26 \cdot (-1.08) - 11 \cdot (+1.55)] : 37 = 0.29 \text{ ms!}$$

We also investigated the possible relationship between our scaled degrees of eye dominance and the electrophysiological P100 latency shortening (Fig. 3). A clear relationship such as the higher the degree of eye dominance, the shorter the P100 latency of the dominant eye was not found. This may be due – at least in part – to our eye dominance scaling being only semiquantitative. Interestingly, however, right eye dominance was stronger determined than left eye dominance: 72% of the right-eyed subjects preferred the right eye in all subtests, whereas in the left-eyed group only 40% did so.

Further, we investigated the influence of eye dominance on the N80, P100 latencies and on the N80-P100 amplitudes of the Green-Black, Red-Black and Blue-Black-PVEPs according to the method described elsewhere [12]. Surprisingly, neither the N80, P100 latencies nor the N80-P100 amplitudes showed any differences between dominant and non-dominant eyes in the t-difference tests. This was true for the whole group as well as for the male and female subgroups.

Discussion

Many papers have been concerned with eye dominance as one phenomenon of lateralization from the point of view of experimental psychology [2, 7, 8]. However, only one study has approached this phenomenon electrophysiologically [10]. Because of this paucity of data and certain methodological shortcommings of the Seyal et al. study we undertook the present study applying 6 tests for scaling and classifying eye dominance. We found 26 (= 65%) right-eyed, 11 (= 27.5%) left-eyed and 3 (= 7.5%) ambiguous subjects in our experimental group of 40. Seyal et al. who used only one behavioural test for classifying eye dominance also found two ambiguous cases in their group of 25 subjects, but they did not report either on the right versus left eye dominance or on the age and sex distribution of their experimental group.

Comparing the dominant with the non-dominant eyes we found the P100 latencies of the White-Black-PVEPs to be significantly shorter for the dominant eyes supporting Seyal et al., with an average shortening of −1.2 ms (Seyal et al. about −0.69 ms).

Differentiating eye dominance into right and left eye dominance we found the same P100 latency shortening for both right dominant eyes and left dominant eyes with no difference

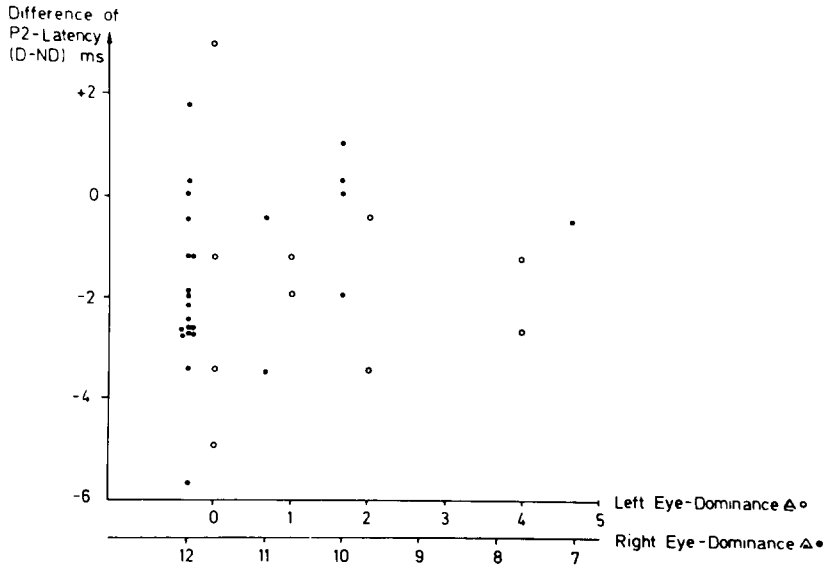

Fig. 3. The relationship between the grade of eye dominance and the P2 (= P100) latency shortening of the white-black PVEPs. It shows the degree of right and left eye dominance obtained with our dominance scaling *(abscissa)* and the P100 latency difference between dominant and non-dominant eyes *(ordinate)*. A functional relationship between the degree of eye dominance and the P100 latency shortening cannot be recognized. Furthermore, 18 of the 26 right-eyed subjects were dominant in all subtests (sum of the 6 subtests = 12), whereas in the left-eyed group only 4 of 11 cases showed this consistency. D = dominant eyes, ND = non-dominant eyes

between them. In contrast to this, Seyal et al. did not find this P100 latency shortening in the right and left eye dominant subgroups, probably due to their small subgroup size. Since Seyal et al. could not rule out possible sex differences, we separated our group into male and female subgroups because of the well-known sex differences in VEPs and PVEPs [13]. We found that sex did not influence the effect of eye dominance on the P100 latency of the White-Black-PVEPs.

In contrast to Seyal et al. we did not find any N80-P100 amplitude differences in the White-Black-PVEPs of the dominant and non-dominant eyes. Since amplitudes are very sensitive to stimulus parameters, this may be in part due to differences in the experimental procedure (Seyal et al. used a 1 Hz reversal and 75 sweeps for each potential). The fragmentation of the 120 sweeps we averaged for each potential could explain this discrepancy because of the late ones being subject to adaptation.

Have these effects of eye dominance on the White-Black-PVEPs any practical or diagnostic relevance? The effect of eye dominance on the P100 latency is very small (-1.2 ± 1.8 ms). This small effect was further diminished in the interocular latency differences according to the distribution of right- and left-eyed subjects in the norm group. Nevertheless, we think that eye dominance effects could be helpful in the diagnosis of brain disorders, namely in such cases in which the traditional interocular latency differences are not unequivocal. In such cases the determination of eye dominance and the assessment of the P100 latency difference (between dominant and non-dominant eyes) in the context of the above norm values for right and left eye dominance would be an additional diagnostic help.

We also investigated – to our knowledge for the first time – the influence of eye dominance on parameters (N80, P100 latencies, N80-P100 amplitudes) of Colour-Black-PVEPs. In contrast to the results with White-Black-PVEPs we did not find any significant differences in the N80, P100 latencies or the N80-P100 amplitudes of the Green-Black, Red-Black and Blue-Black-PVEPs caused by eye dominance.

So far it is not clear what mechanisms underly the complex phenomenon of eye dominance, whether it is caused by differential outputs from the two eyes or primarily by cortical meachanisms. The electrophysiological differences between dominant and non-dominant eyes cannot be due to the length of the optic nerve as Lang and Reiter [5] did not find a significant difference between the right ($\bar{x} = 23.14$ mm) and the left ($\bar{x} = 22.74$ mm) human optic nerve. Of greater importance, however, was the work of Narang [6], who found right-left asymmetries of myelin development in the epiretinal portion of rabbit optic nerve. In about 75% of rabbits which first opened their right eye on the 10th day after birth he found that the epiretinal portion of the right optic nerve showed a greater number of myelinated nerve fibres developing at a faster rate than in the corresponding left eye. The same was true for the left optic nerves in about 25% of rabbits which opened their left eye first.

These results were underscored by the findings that in the same 3 : 1 ratio in which the rabbits open their right versus left eye on the 10th day after birth the right or left optic nerve developed faster in 1 to 3-day-old rabbits with their eyes still closed. This 3 : 1 ratio between the right and left dominant development of optic nerve myelination suggested that the underlying mechanisms are genetically controlled.

As far as one can transfer these results from rabbits to man one might assume a genetically controlled mechanism for the preferential faster myelination of optic nerve fibres as one possible model for the explanation of the known right-left eye asymmetries. Since these processes take place at very early stages of the development of the visual system, one can suggest that colour does not play a role in determining eye dominance, and this would be in good agreement with our negative findings with Colour-Black-PVEPs.

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