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The influence of defocus on multifocal visual evoked potentials

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Abstract *Background:* In order to assess the influence of optical factors on the multifocal visual evoked potential (mfVEP), we obtained mfVEPs with optimal refraction and compared them to recordings with various degrees of dioptrical defocus. *Methods:* Monocular mfVEPs were recorded from the right eye in eight normal subjects. Dartboard stimuli with 60 sectors arranged in six concentric annuli spanning 60° were generated with a VERIS system and presented on a computer monitor. Two pairs of electrodes were placed 3 cm above and below and 3 cm to the right and left of the inion. Two sets of mfVEP records per subject were obtained, one with best-corrected visual acuity and another when the stimulus was defocused by +1.0, +2.0 or +3.0 D. A signal-to-noise ratio (SNR) measure was calculated for every response from the two channels. *Results:* The effect of defocus depended on eccentricity: when defocus was at +2.0 D and higher, reducing visual acuity to <0.3, the central mfVEP responses were reduced to approximately 60%, while defocus had no marked effect at eccentricities >7°. *Conclusions:* The results suggest that, in contrast to the mfERG, the mfVEP requires optimal refraction to correctly assess the cortical responses.

Introduction

The multifocal visual evoked potential (mfVEP) may become a useful tool for objective perimetry. Its primary shortcoming is its interindividual variability, which is likely due to the variability of the underlying cortical morphology [5, 16] and its relationship to external landmarks, such as the inion [10, 15]. This complex cortical folding furthermore leads to a marked variability of the mfVEP amplitude across the visual field. Another possibly confounding factor for clinical applications, which has not been addressed so far in the mfVEP, is the influence of refraction and/or optical imaging quality on the retina. For the pattern VEP this has been repeatedly studied. It was shown that with intermediate check size amplitudes displayed a linear decrease and diminished down to noise level after a defocus of >+4 D to +5 D [11, 4]. The effect of refractive blur has also been studied for the mfERG [1, 6, 14]. Consequently, the ISCEV mfERG guidelines [13] state—somewhat obliquely—that "some experts deem refraction unnecessary within these (±6 D) limits". The mfVEP stimulus usually invokes rather tiny structures for the central stimulation [9], making it more sensitive to defocus (see also Fig. 5). We tested this hypothesis by defocusing the mfVEP stimulus in normal subjects over a range of +1.0 D to +3.0 D.

Materials and methods

Subjects

Eight subjects aged from 19 to 33 years (mean 24.5) with no known abnormalities of the visual system except for refractive errors participated in the study. Refraction ranged from –4.0 D to +1.0 D spherical equivalent. Informed consent was obtained from all subjects before their participation. The procedures followed the tenets of the declaration of Helsinki.

Stimulation

The stimulus was produced with VERIS software (Version 3.5, Electro-diagnostic Imaging, San Mateo, CA). We employed a VERIS dartboard stimulus consisting of 60 sectors, arranged in six concentric rings, each sector with 4×4 checks, eight white and eight black.(Fig. 4b) At a distance of 28 cm the stimulus spanned 60°. Space-averaged luminance of the dartboard stimulus was 200 cd/m^2. The stimulus array was displayed on a black-and-white monitor driven at a frame rate of 75 Hz. The 16-element checkerboard of each sector had a probability of 0.5 to reverse on any new frame, and the pattern of reversals for each sector followed a pseudorandom m-sequence [17] with a sequence length of 2^{15} steps.

Acuity testing and degradation

Acuity was tested with the Freiburg acuity test [2] at the same distance and under the same illumination as evoked by the multifocal stimulus to insure comparable pupil size. In each subject visual acuity (VA) and mfVEPs were determined for two conditions: first with best-corrected refraction for the observation distance, then with dioptric defocus by a plus lens of either +1.0, +2.0 or +3.0 D. As the stimuli were presented in a viewing distance of 28 cm, +3.0 D to +4.0 D had to be added to best far correction to exclude accommodation. The aim was to cover a wide range of VA; eventually the range of 0.1–0.6 decimal VA was covered with roughly equidistant intervening values.

Electrophysiological recordings

Two pairs of electrodes were placed 3 cm above and below and 3 cm to the right and left of the inion. These were combined into two channels with orthogonally orientated bipolar derivations. The signals were amplified and band-pass filtered (low-frequency and high-frequency cut-offs: 3 Hz and 70 Hz). The chosen m-sequence required approximately 20 min for one run including brief rests between blocks. To improve the subject's ability to maintain fixation, each 20-min session was broken up into 16 segments. The VEP reversal response appeared in the second-order kernel. Two sets of mfVEP records were obtained from the right eye, one with best-corrected VA and another when the stimulus was defocused by a plus lens of either +1.0, +2.0 or +3.0 D. Half of the time, we started the recordings with a defocused stimulus. The left eye was occluded, and the pupils were not dilated. Fixation was observed with a camera.

Analysis and statistics

Data were offline digitally low-pass filtered at 30 Hz. For quantitative analysis we employed the "mean noise-window signal-to-noise ratio" measure (SNR) as described by Zhang [19]. Briefly, the RMS value from a "signal window" (45–150 ms after stimulus onset) is compared to the RMS from a "noise window" (325–430 ms); in a previous study we found this to be a reliable objective measure [8]. Only traces with an SNR $\geqq$0.5 were analysed further. Since optical properties of the dartboard stimulus are equal for constant eccentricity, we aggregated the traces into six rings as follows: 0–1.5°, 1.6–3.2°, 3.3–7.3°, 7.4–12°, 13–19° and 20–30°.

Results

Figure 1 shows the influence of defocus on VA. As would be expected, stronger defocus leads to lower acuity, with a marked scatter between subjects. Figure 2a depicts a raw mfVEP trace array recorded from Oz versus inion from a sample subject with optimal refraction (black traces) and +2.0 D defocus (grey traces). The responses are spatially arranged corresponding to the visual field locus of the evoking stimulus patch. The amplitudes are largest in the centre and decrease towards the periphery. In the outer ring, representing 20–30° of eccentricity, responses can hardly be discriminated from noise. Typical mfVEP peculiarities are seen, such as nearly total absence of responses even in the central visual field (here in the top right of the innermost ring), and polarity reversal near the horizontal meridian (here evident only in the intermediate rings). For quantitative analysis SNRs are calculated as described in "Materials and methods". The SNRs calculated from the traces of Fig. 2a are seen in Fig. 2b, where symbol diameter represents SNR magnitude. An insufficient signal (as defined by SNR<0.5) is indicated by a cross, thus representing a spurious scotoma. Dioptrical defocus of +2.0 D reduced VA in this subject to 0.16 and reduced SNRs especially in the central visual field (see grey symbols). In the outer two rings (beyond 12° eccentricity) spurious scotomas (indicated by crosses) are most probably due to a spectacle rim artefact.

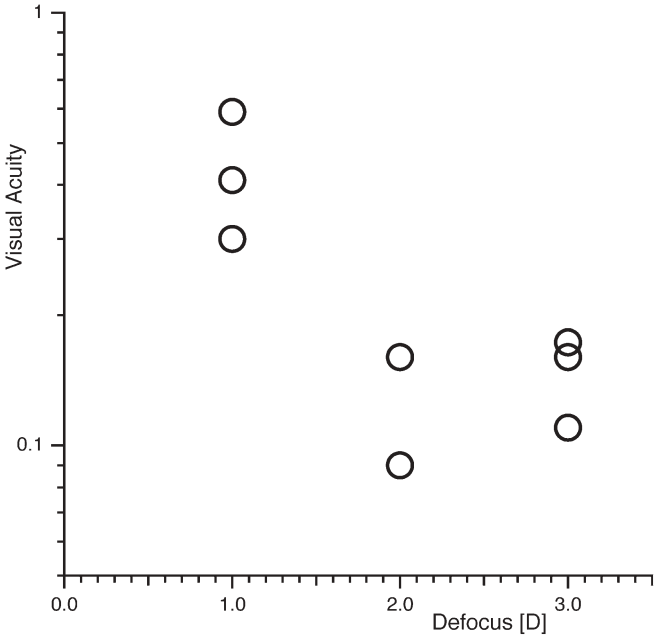

Fig. 1 Visual acuity for three values of defocus from 1 D to 3 D. Unsurprisingly, acuity diminishes with increasing defocus, but note the marked interindividual scatter

Figure 3 depicts the RMS ratio (blurred divided by fully corrected VA) averaged across all subjects and plotted per eccentricity ring. The responses were always selected from the channel that showed the higher SNR. There is a stronger reduction of the responses from ring 1 (0–1.5° eccentricity) than from ring 4 (7.4–12° eccen-

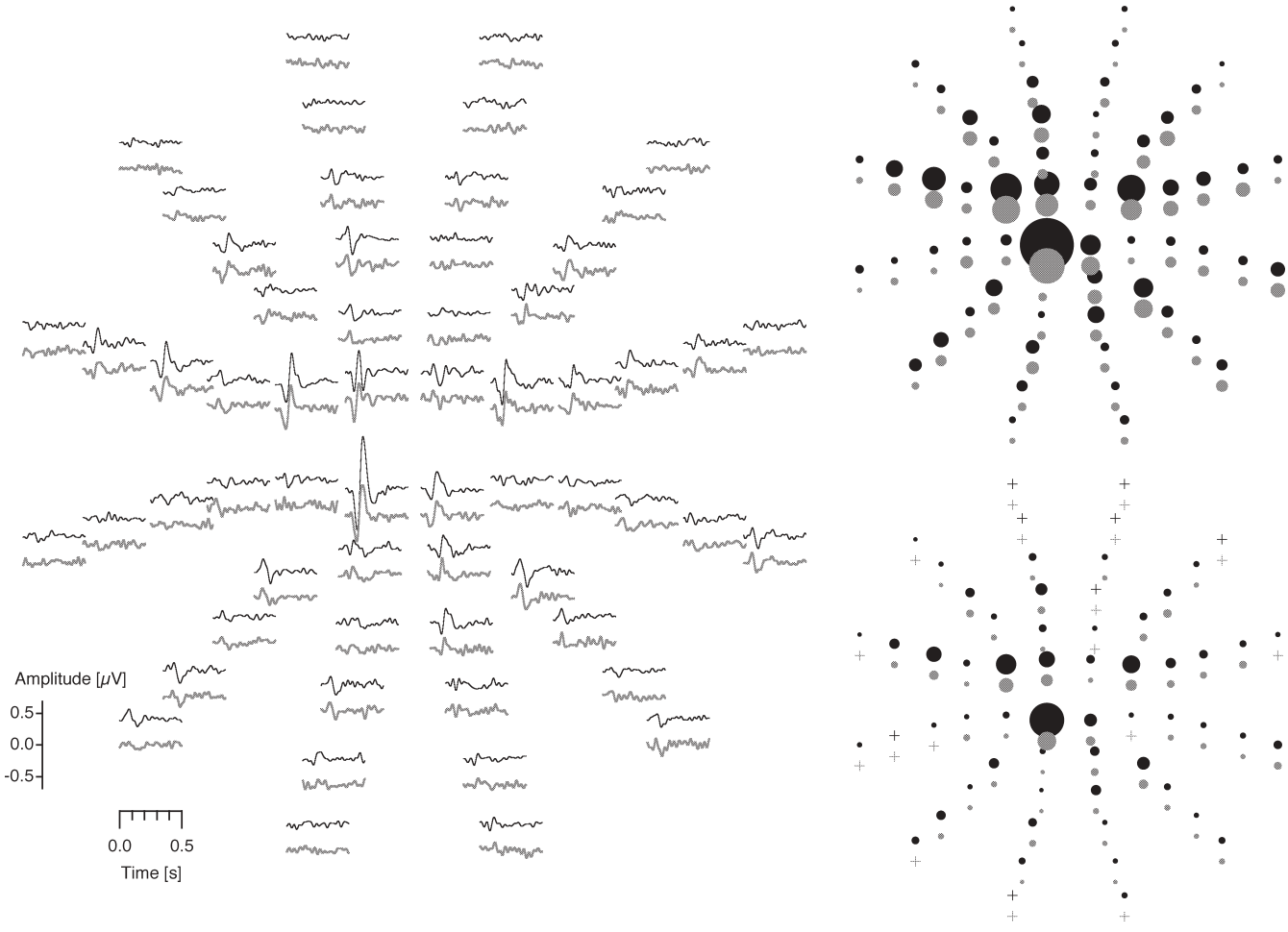

Fig. 2 MfVEP responses recorded in a subject at full VA (*black*) and at VA=0.16 due to +2.0 D blur (*grey*). Note that traces from different eccentricities are arranged in an equidistant manner, while the actual stimulus layout is approximately m-scaled. **a** Raw mfVEP traces. Typical mfVEP peculiarities such as almost total absence of central responses at the *top right* of the innermost ring and polarity reversal near the horizontal meridian in the intermediate rings are seen. **b** SNRs of the mfVEP traces. The symbol diameter represents SNR magnitude, switching to a *cross symbol* to indicate that SNR is below 0.5 (i.e. a spurious scotoma). Central mfVEP-responses are particularly reduced for blurred compared with fully corrected VA

tricity). These responses were reduced by 38% and 12%, respectively (paired *t*-test: $p<0.05$). Beyond ring 4, i.e. at 13–30° eccentricity, response reduction became more pronounced again, which was probably due to a spectacle rim artefact and therefore indicated as a colour change of the graph (from black to grey).

Figure 4 shows the quantitative relation between the degree of VA reduction by defocus and RMS ratio for the centre (0–1.5°), and the fourth ring (7.4–12°). While defocus progressively reduced the RMS for the centre (discs), the RMS values in the fourth ring (circles) were hardly altered.

Discussion

Defocus reduces acuity, but to different degrees in different subjects. This could be explained as follows: (1) The defocus effect of a constant plus addition depends on vertex distance and/or ocular length. (2) The optical contrast transfer function depends not only on defocus, but also on pupil size; the latter differs slightly among subjects [7, 18].

The traces we obtained (Fig. 2a) display the typical features of the mfVEP, such as polarity reversal near the horizontal meridian [3, 10]. This, and the well-known inter-subject variability in the mfVEP responses due to different cortical anatomy and possible correlation to sex [12], do not interfere with the current results since each recording was repeated in the same subject, just under differing dioptric conditions.

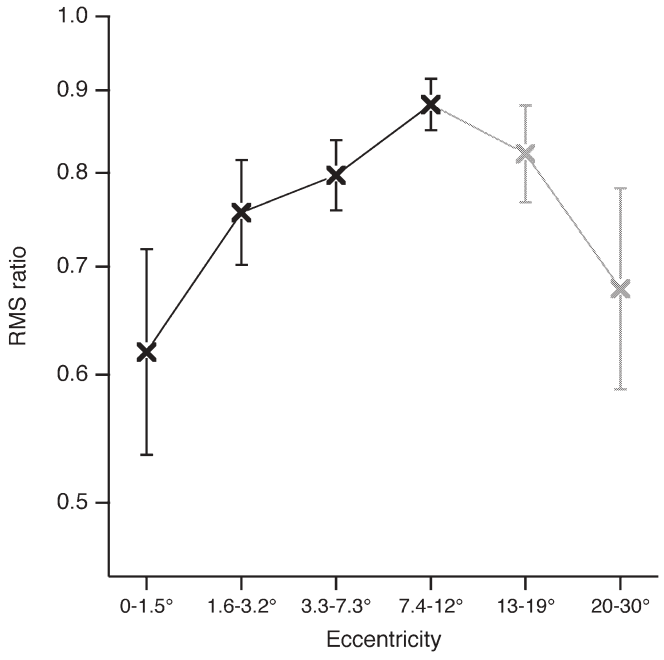

Fig. 3 Log RMS ratio (RMS in the blurred condition divided by RMS at fully corrected VA), averaged across all subjects and plotted versus eccentricity ring. Only traces with SNR ≧0.5 were included. The effect of defocus in the centre is evident, the peripheral reduction (above 12° eccentricity) is probably caused by spectacle rim scotomata and therefore drawn in *grey*

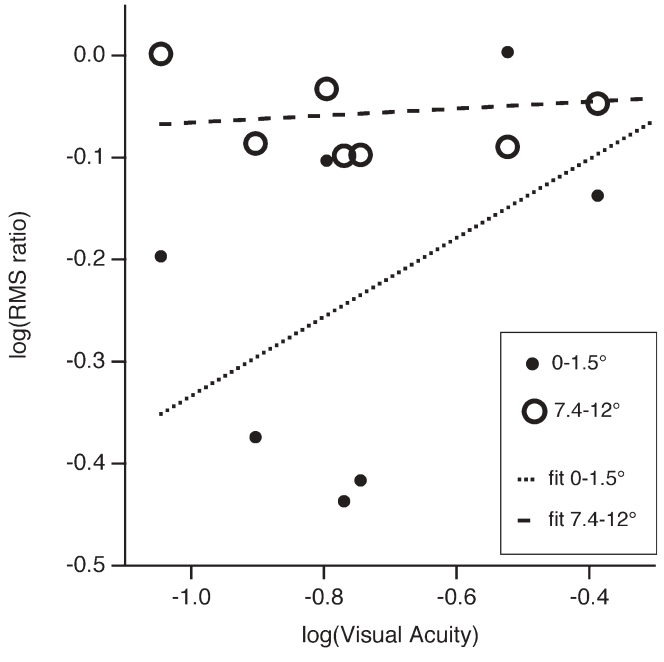

Fig. 4 Log RMS ratio versus log(visual acuity), grouped by eccentricity. Only traces with SNR ≧0.5 were included. Defocus progressively reduces RMS for the centre, whereas RMS values in the fourth ring are not affected

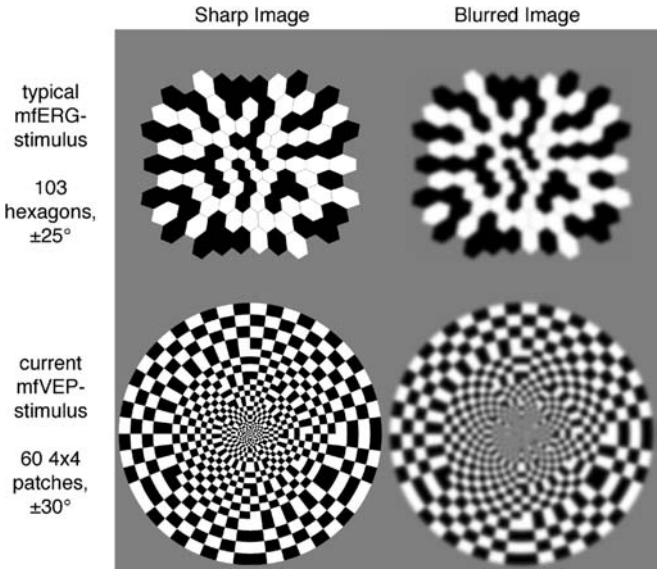

Fig. 5 Effect of defocus on **a** mfVEP and **b** mfERG stimuli. A Gaussian blur was chosen to mimic the subjective effect of a +3 D defocus. Since the mfVEP dartboard stimulus has much finer structures (corresponding to higher spatial frequency) than a 103-hexagon mfERG stimulus (drawn to scale), defocus affects the central mfVEP responses to a much higher extent than the mfERG

While it is easy to understand the central amplitude reduction induced by defocus (see below), the reduction in the outermost rings (Fig. 3, 13–30°) was unexpected. We view this as an artefact caused by spectacle scotomata due to our suboptimal choice of lenses with a broad rim. To circumvent this artefact we confined the statistical analysis to the four innermost rings covering 0–13° of eccentricity.

The main finding of the present study is the marked effect of even moderate defocus (≤3.0 D) on the central responses (Fig. 3). We verified fixation with a camera; however, instability due to refractive blur cannot be totally excluded. This would cause a minor shift of the amplitude from the centre to the periphery, but alone would not explain the marked decrease of the central responses.

The present findings are in striking contrast to those obtained with the mfERG, where optical defocus of −3.0 D to +6.0 D [14] showed no influence on latencies nor amplitudes. Since the studies published on mfERG used corneal electrodes, one might argue that the "Burian-Allen" effect on refraction of the electrode itself is so high that additional refractive blur does not significantly alter the responses. Although contact lenses certainly influence the mfERG recordings, a major difference between the mfERG and mfVEP stimulus is the size of the central stimulus elements. The mfVEP dartboard stimulus (Fig. 5) has much finer structures (corresponding to higher spatial frequency) than a 103-hexagon mfERG stimulus (Fig. 5, drawn to scale). For a given defocus and pupil size, the

optical contrast reduction depends on spatial frequency [7, 18]; small element size corresponds to high spatial frequencies. This probably explains how defocus of 3 D nearly abolishes the central mfVEP responses, while it may have little effect on the mfERG.

In conclusion, the present results suggest that a defocus of 2 D and more leads to sizeable deterioration of the central mfVEP responses. Therefore, in contrast to the mfERG, recording the mfVEP requires optimal refraction to correctly assess cortical function.

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