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RESEARCH NOTE

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Alternating optokinetic nystagmus (OKN) induced by intermittent display of stationary gratings

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Abstract In this paper, we report a novel optokinetic nystagmus (OKN), which was evoked by stationary gratings presented intermittently. OKN eye movements were accurately measured by the electromagnetic scleral search-coil technique. For the luminance stimuli, alternating OKN was elicited when the interstimulus interval (ISI) ranged from 33 to 83 ms duration and the ISI luminance approximated to the mean luminance of the stimulus grating; for chromatic (red/green) stimuli, the OKN could be evoked in non-isoluminant condition and vanished in the isoluminant condition. It is a plausible explanation that the present OKN, intermittent display-of-gratings-induced OKN (IDG-OKN), might be related to the temporal impulse response of the luminance channel in vision.

Keywords Optokinetic nystagmus · Stationary grating · Intermittent display · Visual temporal impulse response · Isoluminant chromatic grating

Introduction

Eye movements elicited by large field moving stimuli are called optokinetic nystagmus (OKN), which is a series of involuntary eye movements consisting of slow phases for tracking the moving stimulus and fast phases for resetting the eye position (Collewijn 1981). Besides this conventional OKN, two types of optic nystagmus elicited by stationary stimuli have been reported, and have been assumed to reflect different neural mechanisms in vision. One is flash-induced nystagmus (FIN), which can only be elicited by monocular flashing light and may reflect direction-selective elements in retina (Costin et al. 1965; Pasik et al. 1970; Van Dalen 1977; Verhagen and Huygen 1986). The other is Sigma-OKN, which is elicited when the initial slow-phase angular velocity of the eye matches the “sigma paradigm”, which equates to the product of the pattern’s spatial cycle and flash frequency. Sigma-OKN could result from the interaction between efferent and afferent signals of the visual system (Adler et al. 1981; Behrens and Grüsser et al. 1979; Behrens et al. 1999).

In the present experiments, with the new approach of stationary-grating stimuli, we reported a novel type of OKN that was elicited by the intermittent display of stationary luminance stimuli or non-isoluminant chromatic (red/green) stimuli, and had different oculomotor characteristics from FIN and Sigma-OKN. This new OKN, intermittent display-of-gratings-induced OKN (IDG-OKN), was possibly related to the visual temporal impulse response of the luminance channel, which has been demonstrated to be biphasic characteristic, a positive lobe followed by a negative lobe (Burr and Morrone 1993; Ikeda 1986; Swanson et al. 1987). These results may provide a novel eye-movement approach to detect nervous system defects in the visual pathway.

Materials and methods

Computer-generated stimuli were displayed on a ViewSonic PT813 short-persistence monitor whose luminance was re-calibrated with a Minolta photometer. The frame rate of the monitor was 60 Hz, with spatial resolution of 640×480 pixels and 16×10^6 colors in total. The CIE chromaticity coordinates of the red and green phosphors were 0.625, 0.34, and 0.29, 0.605, respectively. At 57 cm viewing distance, vertical sinusoidal stimulus gratings covered 40°H × 30°V visual angle and had a spatial frequency of 0.5 cycles per degree. Main intermittent display stimuli were presented in each trial in the following sequence: first, a stimulus grating was presented for approximately 17 ms (one video frame at 60 Hz); second, an interstimulus interval (ISI), during which a homogeneous lumi-

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nance field was presented; then, the stimulus grating was presented for 17 ms again, and followed ISI. This alternation of gratings and homogeneous field ISI were presented for 20 s in each trial. In the luminance experiments, the stationary luminance grating, which had contrast of 10% and mean luminance of 16 cd/m^2, was constructed by summing in-phase red and green gratings of identical contrast and mean luminance.

In the first set of luminance stimuli experiments, the ISI duration was randomly selected from approximately 17, 33, 50, 67, 83, or 100 ms (1, 2, 3, 4, 5, or 6 video frames) in each trial, while the ISI luminance (the luminance of homogeneous field during ISI) was fixed at the mean luminance of the grating. In the second set of luminance stimuli experiments, the ISI luminance was randomly selected as –0.3, –0.2, –0.1, –0.05, 0, 0.05, 0.1, 0.2, or 0.3 log relative luminance compared with the mean luminance of the grating, while the ISI duration was fixed at 50 ms. In the chromatic experiments, the red/green chromatic grating was generated by the combination of a red grating with an out-of-phase green grating. The mean luminance of the red grating was constant at 8.0 cd/m^2, while the mean luminance of the green grating was altered between 5.0 and 11.0 cd/m^2. Under the non-isoluminant condition, the chromatic stimuli contained luminance contrast. For chromatic experiments, the stimulus present during the ISI was also a uniform luminance stimulus, with a fixed 50-ms duration and the same luminance as the mean of the chromatic grating. For distinctly showing the effect of ISI on OKN, we employed the continuous display of stationary grating as the control stimuli, prior to and after the main stimulus in each trial. Each trial lasted 30 s and was repeated three times.

Six subjects with normal or corrected-to-normal visual acuity, normal color vision and normal oculomotor responses participated in the study. Ages of the subjects ranged from 20 to 38 years. The "isoluminant point" of each subject was obtained by the "minimum motion technique" (Cavanagh et al. 1987). Experiments were performed in a dark room. The subject sat on a stable chair with a chin rest to stabilize the head and binocularly stared at the center of the screen . Eye movements were measured using the magnetic scleral search coil technique (Robinson 1963; Collewijn et al. 1975; Wei and Sun 1998). An annulus of silicone rubber with an induction coil (Skalar Medical BV, Delft, Netherlands) was attached to the subject's eye. The data were sampled at 100 Hz and recorded on a computer for offline analysis. To quantify the occurrence of OKN for each experimental condition, the percentage time of OKN was defined as the cumulative duration of the OKN divided by the stimulus duration, during which the intermittent display of stationary grating was presented. The final results were the average of all trials under each condition. The experimental protocol was approved by the local ethical committee and followed the tenets of the Declaration of Helsinki. Each subject provided signed written consent before the experiments.

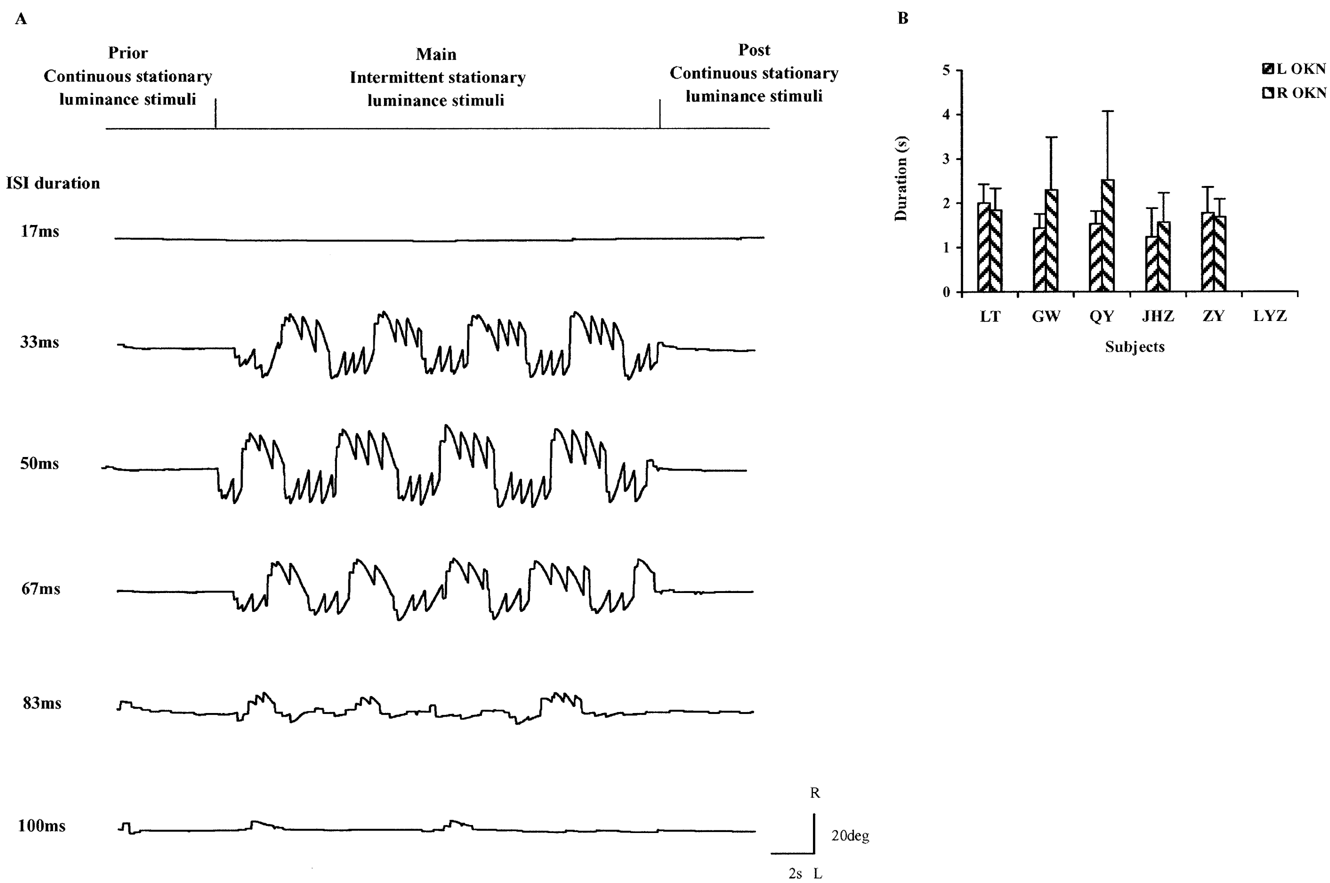

Fig. 1A,B Eye movement recordings for the intermittent display of stationary luminance gratings with variant interstimulus intervals (ISI) duration. Each trial consisted of intermittent stimuli for 20 s, and the continuous display of stationary stimuli (zero ISI duration) for 5 s immediately prior to and after the main stimuli as the reference stimuli to demonstrate that the generation of optokinetic nystagmus (OKN) needs proper ISI conditions. **A** Samples of horizontal eye movement of OKN. **B** The directional duration of alternating OKN for all subjects (no alternating OKN was evoked from subject LYZ). ISI duration 50 ms; *L OKN* OKN slow phases moving from right to left, *R OKN* OKN slow phases moving from left to right; *error bars* indicate SD

Results

Experiments with luminance stationary stimuli

At first, the ISI duration was randomly selected from 17, 33, 50, 67, 83 and 100 ms, while the ISI luminance was fixed at the mean luminance of the stimulus grating. OKN was clearly evoked from five of six subjects when the ISI duration ranged from 33 to 83 ms; the exception was subject LYZ. Samples of these alternating OKN are shown in Fig. 1A. The directional durations of alternating OKN for each subject are plotted in Fig. 1B. The highest percentage time of OKN occurred when the ISI duration ranged from 50 to 67 ms, and the percentage decreased when the ISI duration deviated from this range (Fig. 2A).

Secondly, the ISI luminance was randomly selected from –0.3, –0.2, –0.1, –0.05, 0, 0.05, 0.1, 0.2, or 0.3 log, compared with that of the stimulus grating, while the ISI duration was fixed (50 ms). The percentage OKN time as a function of ISI relative luminance showed an "inverted-V" shape, the maximum value occurring when the ISI luminance approximated to the mean luminance of stimulus grating, whereas the percentage value decreased with deviation of ISI luminance from the mean level (Fig. 2B).

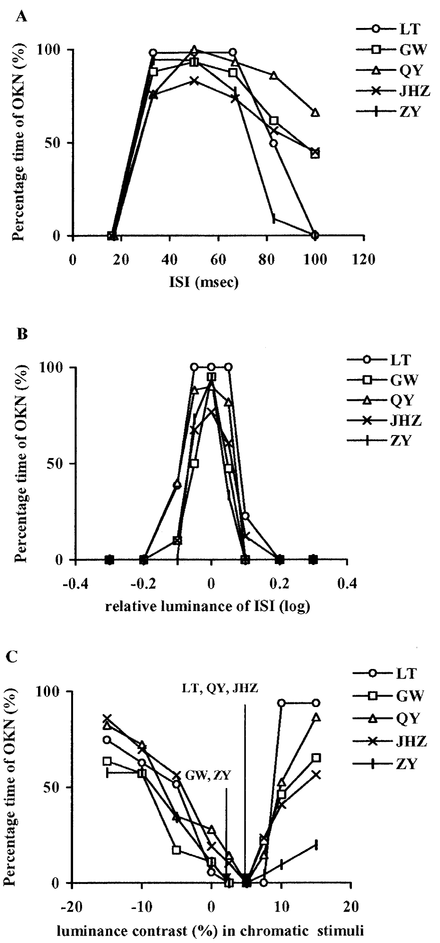

Fig. 2A–C Percentage time of optokinetic nystagmus (OKN) under different experiment conditions for five subjects (LT, GW, QY, JHZ, and ZY). **A** Data for different interstimulus interval (ISI) duration. **B** Data for different ISI relative luminance. The relative luminance of ISI was equal to $\lg\left(L_{ISI}/L_{\overline{sti}}\right)$, where L_{ISI} was the ISI luminance and $L_{\overline{sti}}$ was the mean luminance of the grating. ISI duration was fixed at 50 ms. **C** Data for the chromatic red/green stimuli. The mean luminance of the red grating $(\overline{L_r})$ was fixed and that of the green grating $(\overline{L_g})$ was adjusted. The luminance contrast was calculated by $\left(\overline{L_r}-\overline{L_g}\right)/\left(\overline{L_r}+\overline{L_g}\right)\times 100\%$. ISI duration was fixed at 50 ms. The *abscissa* represents the luminance contrast measured by the photometer, where *arrows* indicate isoluminant points determined by the "minimum motion technique"

Experiments with chromatic stationary stimuli

When the chromatic grating was at isoluminance, the intermittent display of chromatic stimuli was unable to evoke OKN, so that the percentage time reached zero. Under non-isoluminant conditions, the chromatic stimuli evoked OKN responses due to the luminance contrast contained in the chromatic grating (Fig. 2C).

Discussion

Previous investigations have reported that two different types of optic nystagmus, FIN and Sigma-OKN, could be evoked under different stationary stimuli conditions (Costin et al. 1965; Behrens and Grüsser et al. 1979). FIN can only be evoked by monocular repetitive flashes of homogeneous light within proper ranges of flash frequency and intensity, and its slow phase direction is toward the side opposite that of the stimulated eye (Costin et al. 1965; Pasik et al. 1970; Van Dalen 1977). FIN might result from the stimulation of direction-selective retinal elements (Verhagen and Huygen 1986). On the other hand, Sigma-OKN can only be evoked when the initial eye velocity, which could be achieved by smooth pursuit, post-rotatory or optokinetic after-nystagmus (OKAN), matched the product of stimulus spatial cycle and flash frequency (sigma paradigm). The slow phase of Sigma-OKN evoked by the stationary gratings would always follow the direction of initiation eye movement (Adler et al. 1981; Behrens and Grüsser et al. 1979; Behrens et al. 1999). Sigma-OKN might be caused by the interaction of efference copy signals and the afferent signals within the visual system (Adler et al. 1981; Behrens and Grüsser et al. 1979).

Because the present OKN was evoked by the intermittent display of gratings, it can be called as intermittent display-of-gratings-induced OKN (IDG-OKN). Significant differences exist between the present IDG-OKN and FIN or Sigma-OKN. Firstly, the present OKN could be elicited under binocular presentation conditions, and secondly, could only be elicited when the ISI luminance was approximately equal to the mean luminance of the stimulus grating. In addition, the elicitation of the present OKN did not need any initiation eye velocity (see

Fig. 1A). More importantly, the present OKN exhibited dual-directional alternation characteristics compared with the unidirectional characteristic of FIN or Sigma-OKN. These differences indicate that the present IDG-OKN and the two previous nystagmus, FIN and Sigma-OKN, are based on different origins of oculomotor behavior.

How could the IDG-OKN be evoked? Due to the fact that a flash presentation of a grating pattern was equivalent to a temporal pulse stimulus, whose luminance amplitude was sinusoidally modulated in space, one plausible explanation is that since the visual temporal impulse response to the luminance pulse stimulus has been reported to be biphasic (Burr and Morrone 1993; Ikeda 1986; Swanson et al. 1987), the positive phase of the impulse response resulted in the in-phase representation, and the negative phase of the impulse response could reverse the modulation of grating into its counter-phase representation under suitable ISI conditions. Consequently, to the repetitive flash presentation of stationary grating, the combination of the in-phase representation and the counter-phase representation could elicit the alternation of motion perception as well as the corresponding OKN. This possible explanation was also supported by the result of our chromatic experiments. The temporal impulse response to isoluminant chromatic stimuli has been suggested to be monophasic (Burr and Morrone 1993; Swanson et al. 1987), so that no counter-phase representation can be generated at the isoluminant point. Thus, OKN could only be evoked by chromatic stimuli containing luminance contrast.

It should be noted that one exception among the subjects (LYZ) did not have evoked alternating OKN by this intermittent display stimuli, although his conventional OKN to moving gratings was quite normal. Further systematic examinations should be required to find its causes.

The biphasic characteristics of the temporal impulse response to luminance stimuli have been suggested by previous psychophysical findings using different methods, such as flicker or double-pulse summation (Burr and Morrone 1993; Ikeda 1986; Swanson et al. 1987). Correspondingly, electrophysiological recordings from ganglion cells of the macaque retina suggested that magnocellular (M) ganglion cells are credible neural candidates for the generation of biphasic impulse response (Lee et al. 1990, 1994). It would be a reasonable assumption that the damage of M-pathway in the visual nervous system could cause abnormal IDG-OKN responses. This means that the IDG-OKN measurement might provide an objective approach to examine pathological defects of M-pathway in vision.

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