THE EYE MOVEMENT CAPACITY TO PURSUE OPTOKINETIC STIMULI OF INCREASING FREQUENCY AND VELOCITY

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Abstract. Changes in the mean frequency, amplitude and angular velocity of the slow phases of optokinetic nystagmus (OKN) were examined in 72 subjects when the frequency and velocity of optokinetic stimuli were step-wise increased from 1 Hz (17°s\(^{-1}\)) up to 12 Hz (204°s\(^{-1}\)). The gradual failure of the oculomotor component of visual motion perception was characterized by progressive lagging of the OKN parameters behind the increasing frequency and velocity of moving stimuli and by episodic cessation and reappearance of the OKN pattern at higher frequencies and velocities of stimuli. The frequency and velocity of stimuli at which OKN completely ceased was related to the degree of lagging of the OKN pursuit phases behind the stimuli already at low velocities of their motion.

INTRODUCTION

The relationship between the frequency and velocity of optokinetic stimuli and the parameters of optokinetic nystagmus (OKN) was investigated by several authors. It has been concluded that the OKN parameters may follow the above parameters of stimuli to a certain degree only (3, 5, 6, 8). In some studies the critical frequency and/or velocity was ascertained, at which optokinetic stimuli fused and OKN ceased (1, 2, 5). Blomberg (1) termed this velocity “the optokinetic fusion limit” and compared it to the critical flicker-fusion frequency, at which, however, no objective indicator was found and the evaluation was based on a subjective report. In studies of the optokinetic fusion limit, continuous changes of the opto-
kinetic stimuli velocity were used and the process of gradual failure of the oculo-
motor component of visual motion perception was not analyzed in more detail.

The aim of the present work was to study the changes in frequency, amplitude, angular velocity of the pursuit phase and OKN duration when frequency and velocity of optokinetic stimuli were step-wise increased from low values up to the limit of the cessation of OKN.

METHODS

As optokinetic stimuli, black and white vertical stripes (1:2 ratio) were used, which were projected on a 150 × 135 cm panoramic screen in a darkened room at a distance of 110 cm from the subject’s eyes. The frequency and velocity of stimuli were increased step by step from 1 Hz (17°s⁻¹) up to 12 Hz (204°s⁻¹) with each particular frequency and/or velocity of motion lasting 1 min. Both horizontal directions of motion were used with each subject in an alternating order. Horizontal eye movements were continuously recorded using the Zwönitz EEG apparatus (t. c. 1.5 s). Two silver-silver chloride disc electrodes were placed near the outer canthi of the eyes. The mean frequency, amplitude and angular velocity of the slow OKN phases were evaluated during the first 10 s and 30–40 s of particular recordings. In some of the subjects EOGs were tape-recorded and intervals between the consecutive fast eye movement components were evaluated by means of interval histograms made from the whole 1-min periods using the PDP11E10 minicomputer.

Experiments were performed on 72 subjects with normal vision (64 males, 8 females, mean age 18 years). Most of them were students of a railway technical school and the experiment was part of an examination which was carried out in order to determine the aptitude for the profession of engine-driver. The subjects sat in comfortable chairs with shaped headrest. They were instructed to look straight ahead, to attentively follow the stripes while these crossed the middle of the screen, and to try to avoid their fusion as long as possible. The whole examination lasted about 40 min.

RESULTS

Certain variations were observed in the interval histograms of the consecutive fast eye movement components, depending on the frequency and velocity of optokinetic stimuli. As illustrated in Fig. 1, the histograms were mostly bimodal and polymodal at both very low (1 Hz and 17°s⁻¹) and very high frequencies and/or velocities of stimuli (from about 8 Hz and 136°s⁻¹); when ranging from 2 Hz up to 6 Hz (34°s⁻¹–112°s⁻¹) they were mostly unimodal.

When the frequency and velocity of the optokinetic stimuli were increased, the system of OKN generation and/or the oculomotor mechanism of visual motion
perception was failing gradually rather than abruptly. The EOG recordings in Fig.
2 show that the basic OKN pattern does not undergo any conspicuous changes at
higher frequencies and velocities of optokinetic stimuli. When the frequency and

Fig. 1. Histograms of intervals between consecutive fast OKN components when the frequency
of optokinetic stimuli was increased at 1-min lasting steps from 1 Hz to 12 Hz in 24 years old man.
Optokinetic nystagmus to the left; N, total of intervals; abscissa, intervals in 100 ms; ordinate,
% of intervals.

Fig. 2. EOG recordings at the optokinetic stimuli (OKS) frequencies 8 Hz, 10 Hz and 12 Hz in
two subjects.

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velocity of stimuli approaches the limit of complete OKN cessation, the OKN incidence acquires a cyclic character: it appears for increasingly shorter and disappears for increasingly longer periods, alternating either with saccadic eye movements or with periods without any marked oculomotor activity. This is accompanied by a gradual loss of ability to perceive clearly particular moving stripes and a prolongation of the periods of fusion of the optokinetic pattern.

Regular OKN lasting at least 2 s was recorded in 98% of the subjects, up to 8 Hz optokinetic stimuli frequency. When the frequency of stimuli increased to 12 Hz, the OKN incidence decreased to 54%. Differences in the above proportion were found to depend upon the direction of the stimuli motion: the OKN pattern was still recorded in 62% of the subjects when the stimuli moved at 12 Hz to the right, and only in 46% when they moved to the left.

As shown in the left part of Fig. 3, the mean OKN frequency increased with the optokinetic stimuli frequency up to 3 Hz only and then it slightly decreased.

The mean OKN amplitude increased up to stimuli frequency of about 8 Hz (the middle part of the figure), similarly as the mean angular velocity of the slow OKN phases (the right part); the latter parameter lagged behind the velocity of the stimuli since the very beginning and reached maximum of about 32°s⁻¹ at the stimuli frequency and/or velocity of 6 Hz (102°s⁻¹). As seen in the same figure, no marked differences were found in the above OKN parameters up to the frequency of about
8 Hz when comparing the first 10 s and 30–40 s intervals of recordings. At higher frequencies and velocities of the stimuli motion a slight decrease of amplitude and of the velocity of slow OKN phases was observed in the second part. Results presented in this figure also point to a certain right-left asymmetry in the OKN parameters.

Subsequently, the OKN recordings were classified according to the limit of complete OKN cessation. The first group comprised recordings with a distinct OKN pattern up to the frequency of the optokinetic stimuli motion of 12 Hz (Fig. 4, full lines); in the second group there were recordings with OKN up to 11 Hz (dashed lines) and in the third group recordings with a distinct OKN pattern up to 9 Hz only (dotted lines). OKN recordings to the right and to the left were included in different groups in some subjects. As may be seen, certain differences exist among the above groups in a general course of the mean values of OKN parameters with an increase of frequency and velocity of the optokinetic stimuli. These differences are most marked when the angular velocities of the slow OKN phases of the first and the second group and of the first and the third group are compared. The OKN recordings to the right and to the left were combined within each group and for

![Fig. 4. Changes in OKN frequency (left part), amplitude (middle part) and angular velocity of the slow OKN phases (right part) in groups of subjects with OKN up to 12 Hz of stimuli motion (full lines), up to 11 Hz (dashed lines) and up to 9 Hz (dotted lines). Thicker lines, movement of stimuli to the right; thinner lines, movement of stimuli to the left; solid straight line, the actual frequency or angular velocity of optokinetic stimuli.](image)
the statistical evaluation of the above differences the \( t \)-test method was used at each particular frequency and velocity of the optokinetic stimuli motion.

Significant differences were found between the first and the second group: from 2 Hz up to 5 Hz (\( P < 0.05 \) at each particular frequency), and between the first and the third group from 1 Hz up to 9 Hz (\( P < 0.05 \) at 1 Hz and 9 Hz, \( P < 0.01 \) at 3 Hz, 4 Hz, 6 Hz and 8 Hz, and \( P < 0.001 \) at 2 Hz and 5 Hz). The right-left differences did not reach the level of statistical significance, with the exception of the velocity of slow OKN phases at 6 Hz within the first and the third group (\( P < 0.05 \)). It may be concluded from this part of the study that there exists certain relationship between the ability to pursue the moving stimuli with the eyes already at low frequencies and/or velocities of motion and the limit at which the oculomotor component of visual motion perception fails.

DISCUSSION

The mechanisms of the OKN generation have not been sufficiently explained. It has been repeatedly stressed that there exist two different kinds of OKN; namely the so called active and/or look-OKN, and the passive and/or stare-OKN (3, 4, 7). In the first a selective foveal pursuit of moving targets is engaged, the essence of the second is to reduce the velocity of gaze displacement between the saccades to an acceptable level, when the eyes try to stabilize in the global visual surrounding that moves in a certain direction (4). The slow OKN phases represent, at least in the look-OKN, visually guided reactions, while the fast OKN phases do not have any direct visual function. On the one hand, they may serve a visual capture of certain objects, similarly as saccadic eye movements, and on the other, they may have merely a mechanical reset function which appears to be generated by a clock-like activity in some brainstem structures (see 9).

The interval histogram analysis of the fast eye movements during the perception of optokinetic stimuli makes it possible to determine the range of frequencies and velocities of the stimuli motion within which the OKN timing system works in an optimal way and/or outside which it gradually fails. However, to study the OKN rhythm in more detail, several other steps of the computerized analysis are necessary (10, 12).

At higher frequencies and velocities of optokinetic stimuli, the substitution of the retinal mechanism of visual motion perception for the oculomotor mechanism is gradual rather than abrupt. Both the OKN frequency and the velocity of the OKN pursuit phase lag progressively behind the stimuli motion and the OKN pattern acquires a cyclic character; it appears for increasingly shorter and disappears for increasingly longer periods, up to a complete cessation of OKN. This periodicity might be related to the oscillations of the visual attention level, and to the
alt. erne failure and recovery of the visuomotor mechanism of visual motion perception respectively.

The finding of a certain relationship between the limit of complete OKN cessation and the degree of lagging of the OKN pursuit phase behind the velocity of stimuli might be related to two factors: (i) the mental set and the visual attention level which may affect both the ocular pursuit and the OKN cessation limit. This factor probably did not influence the presented results in any substantial manner. The subjects were motivated to cooperate in the examination as best as possible and pursuing the stimuli with the eyes did not require any extraordinary effort, at least at lower frequencies and/or velocities of motion. (ii) it may be supposed that there exists another factor that might account for the above differences, namely certain interindividual differences concerning a general capability to process the moving visual stimuli with a visuomotor mechanism of motion perception.

Some right-left differences which were found in this work require further analysis from the point of view of certain OKN asymmetry which has been related to the functional asymmetry of cerebral hemispheres (10, 11) as well as in the aspect of cultural habits.

The optokinetic fusion limit appears to be a suitable tool in the study of visual attention, central fatigue and some other factors which may affect the oculomotor component and/or mechanism of visual motion perception, as already demonstrated by Blomberg and Wassen (2). In order to determine exactly the OKN cessation limit, however, a step-wise increase of the frequency and velocity of optokinetic stimuli seems to be more advantageous.

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