Effects of static tilt about the roll axis on horizontal and vertical optokinetic nystagmus and optokinetic after-nystagmus in humans

G. Clément and C.E. Lathan

Laboratoire de Physiologie Neurosensorielle du CNRS, 15 Rue de l'Ecole de Médecine, F-75270 Paris Cedex 06, France

Received January 19, 1990 / Accepted October 22, 1990

Summary. Horizontal and vertical OKN and OKAN were recorded in four conditions using the EOG technique. Instructions to subjects were aimed at obtaining a "look" type OKN. Two optokinetic stimulators, a stationary sphere and a binocular portable model, were compared with the subject in the upright condition. Three posture orientations, upright, 90° roll (horizontal), and upside-down, were then compared using the portable stimulator to determine the effect of roll-axis tilt on OKN at three velocities and on OKAN. Vertical OKN asymmetry was found to increase in the 90° roll position and to tend toward a reversal in the upside-down position. The time constant of vertical OKAN with slow phase up increased in both the 90° roll and upside-down positions. And finally, cross-coupled vertical eye movements during and after horizontal OKN were clearly observed. These results confirm the data obtained in monkeys, and are in accordance with the hypothesis of a three-dimensional organization of the velocity storage mechanism.

Key words: Optokinetic nystagmus – Optokinetic after-nystagmus – Head tilt – Otolith organs – Velocity storage – Human

Introduction

Natural head movements about pitch and roll axes cause a reorientation of the otoliths relative to gravity. Numerous studies have recently underlined the effects of this reorientation on the characteristics of vertical vestibulo-ocular reflex (Benson and Guedry 1971; Baloh et al. 1983; Tomko et al. 1987). Also, full-field movement in the sagittal plane that elicits vertical optokinetic nystagmus (VOKN) is usually perceived by the central nervous system as a result of a change in head position with regard to gravity. Therefore, the otolith organs have been expected to have an effect on VOKN and vertical optokinetic after-nystagmus (VOKAN). This hypothesis was first verified in lesion experiments with monkeys which showed that utricular nerve section and bilateral saccular ablation enhance the steady state velocity of VOKN and the duration of VOKAN with slow phase (SP) up (Igarashi et al. 1978). Ninety-degree static lateral tilt also increased VOKN and VOKAN with SP up in monkeys (Matsuo and Cohen 1984).

Although the VOKN and VOKAN have been not extensively studied, a few experiments clearly suggest an otolithic influence in humans as well. For example, the asymmetry of VOKN existing on Earth, i.e. VOKN with SP up is stronger than VOKN with SP down, was reversed during zero-gravity encountered during parabolic and orbital flight (VOKN with SP down stronger than VOKN with SP up) and the time constant of the VOKAN with SP up increased (Clément et al. 1986; Clément and Berthoz 1990). On Earth, a reversal in VOKN asymmetry was observed in one subject with the head declined 30° below horizontal in pitch-back position, but no consistent results were seen concerning VOKAN (Leliever and Correia 1987). Static lateral tilt only implicated an increase in the occurrence of VOKAN with SP up (Calhoun et al. 1983). Furthermore, Young et al. (1975) reported that the sensation of pitching in the sagittal plane during vertical optokinetic stimulation is dependent both on the direction of visual field movement and on head orientation relative to gravity. In particular, the sensation of backward pitch associated with VOKN with SP down was markedly enhanced when subjects were tested in the lateral position. Similar observations were reported by Takahashi et al. (1978).

Otolithic influence is not, however, restricted to the vertical plane. In monkeys, as in humans, off-vertical axis rotation generates a strong horizontal nystagmus (Guedry 1965; Raphan et al. 1981; Darlot et al. 1988) which has been proven to be of otolithic origin (Cohen et al. 1983). Also, a significant modulation of the horizontal OKN (HOKN) slow phase velocity has been demonstrated during dynamic otolithic stimulation provided by a laterally moving linear accelerator (Buizza et al. 1980).
Recently, experiments have shown a vertical component in the OKAN of monkeys in a tilted position with regard to gravity, although the preceding OKN was only in the animal's horizontal plane (Harris 1987; Raphan and Cohen 1988). The nature of this oblique after-nystagmus is such that the axis of rotation of the eyes is brought to alignment with gravity. This "cross-coupling" from the horizontal (yaw axis) to vertical (pitch axis) plane is hypothesized to be due to a three-dimensionality of the velocity storage mechanism responsible for OKAN (Raphan and Cohen 1986). However, this same cross-coupling was not observed in humans (Lafortune et al. 1990).

Effects of gravity on OKN and OKAN in monkeys have been fairly well documented, and despite the fact that several aspects have been looked at in humans, a systematic evaluation is still needed as the results are sparse and often contradictory. The present experiment has the following three objectives: 1) to observe the effect of roll axis tilt on the VOKN asymmetry; 2) to measure the apparent tendency to find an increase in the VOKAN time-constant during roll axis tilt; and 3) to examine the presence of cross-coupling during and after HOKN.

Methods

Optokinetic test

Two types of stimulators were used to provide OKN and OKAN. Firstly, a stationary stimulator, with a horizontal and vertical viewing range of 180°, displayed a random dot pattern by means of a projection device. Secondly, a head stabilized portable binocular viewing range of 180° displayed a random dot pattern by means of a projection device. Secondly, a head stabilized portable binocular viewing range of 180° displayed a random dot pattern by means of a projection device. Secondly, a head stabilized portable binocular viewing range dimensions were approximately 115° - 336° horizontal and 110° vertical. Both devices provided optokinetic stimulation at constant velocities of 27°/s, 39°/s, and 51°/s.

During optokinetic tests, prior to recording the subject was presented with the illuminated stationary pattern and instructed to look at the center. At this time the EOG signals were offset and recording started. After 5 s, the pattern velocity was 27°/s for 15 s, followed by 39°/s for 15 s, and 51°/s for 15 s. The following instructions were given to each subject: "don't blink", "don't follow just one dot/square across the screen", "count as many dots/squares as possible". These directions clarified the data (Jell et al. 1984) and favoured "look OKN" which is mediated through cortical pathways, as opposed to "stare OKN" which is subcortical in nature (Honrubia et al. 1986; Cohen et al. 1977). Also, since we did not instruct our subjects to look straight ahead during the optokinetic stimulation, we were able to study the change in beating field through conditions. The 3-velocity stimulus profile was immediately followed by 15 s to 30 s of darkness for OKAN recording, where the subject was instructed to look at the center. Each trial ended with the light on and the subject continuing looking center for EOGs drift evaluation.

Procedure

The subjects were first tested in the upright position, and their responses induced by the portable stimulator were compared to those induced by a full-field stimulator. Then, the subjects, with the portable stimulator, were lying on their left side on a tilt table so that their longitudinal body axis made an angle of 90° relative to gravity. Finally, the tilt table was further rotated so that the subjects were freely hanging upside-down by hooked shoes. For each posture orientation, horizontal and vertical optokinetic stimulation was presented in both directions.

Calibration was performed both at the beginning and at the end of the experiment. Data collection started after a 15-minute adaptation in red-light to insure that the corneo-retinal potential being recorded by the EOG electrodes was not altered by a change in the level of ambient illumination. Total duration of the experiment was about one hour.

Complete data on HOKN and VOKN in all four conditions were recorded and analyzed in six subjects. In four of these subjects we analyzed the OKAN and examined the data for cross-coupling. Two of the four subjects were run again two weeks later, but lying on the right side, to obtain complementary data for 90° roll position, and to check for reproducibility in the upright and upside-down positions for both OKN and OKAN. After analysis of these data, the OKAN in upright and 90° roll positions was examined with four more subjects during subsequent experiments.

Eye movement recording and analysis

Horizontal and vertical electro-oculograms (EOG) were recorded using amplifiers with a pass band of DC to 100 Hz. Electrodes were placed at the outer canthus of each eye, and above and below the orbital ridge of the right eye, in line with the pupil during straight-ahead gaze. EOG calibration was performed using a display of 5 horizontal and 5 vertical dots spaced 10° apart. During the calibration procedure, any artifactual cross-talk between horizontal and vertical EOG signals resulted in a re-placement of the electrodes.

Digitalized (200 samples per second) data were stored on a laboratory microcomputer and subsequently analyzed using SAMO software (by EMPHASE, Paris). In each trial raw data were linearly corrected for EOG drift and calibrated. Then, slow phases (SPs) were manually marked during OKN and OKAN from the velocity traces calculated by software using the method of least squares. Each SP was marked at the beginning and at the end. The computer analysis took each point within a marked SP and calculated the mean SP velocity. These values for each slow phase were then averaged to give a final mean SP velocity and standard deviation. OKN gain was computed as the ratio between the final mean SP velocity and the pattern velocity. OKAN gain asymmetry was quantified using the index I = 10 × Log (gain SP right/gain SP left) for VOKN and I = 10 × Log (gain SP right/gain SP left) for HOKN. This index gives a normalized representation of asymmetry. For example, if the gain of OKN with SP up is 0.8 and the gain of OKN with SP down is 0.7, then I = 10 × Log (0.8/0.7) or I = 0.58. Now, if the gain of OKN with SP up is 0.7 and the gain of OKN with SP down is 0.8, then I = 10 × Log (0.7/0.8) or I = −0.58; the asymmetry index is just reversed.

Also, during OKN the ends of the quick phases were averaged to give an eye deviation relative to center, referred to as the center of interest (CI) (Chun and Robinson 1978). The OKAN peak SP velocity was approximated by extending the best fitting exponential curve back from the last OKAN SP through the preceding OKAN SPs. The time constant of decline of OKAN was then separately calculated using a variation of the technique of Cohen et al. (1977) where the area under the SP velocity curve that corresponds to the Time Constant equals 63% of the total area. This variation on Cohen's original time constant calculation has the advantage of not being reliant on the initial SP velocity.

In the figures, upward trace deflections indicate rightward or upward eye movement. Also, the quantitative data are presented according to the direction of the nystagmus slow phases (Right/Up and Left/Down, abbreviated R/U and L/D, respectively).