Repeated optokinetic stimulation in conditions of active standing facilitates the recovery from vestibular deficits

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SUMMARY

Successful results obtained with training sessions using optokinetic (OK) stimulations in order to rehabilitate patients with balance disorders have triggered this study.

The aim of the study was to measure eye movement parameters and postural sway during OK stimulation before and after the rehabilitation program. Two populations of patients were studied : bilateral and unilateral labyrinthine-defective patients.

Before training the OK nystagmus (OKN) showed slow phase velocity irregularities and a low frequency when compared to a control group of age-matched volunteers. After training the slow phase velocities (SPV) of the OKN were regular and the frequency was similar to the control group (3 Hz). Body stabilization was measured by dynamic posturography (EQUITEST) before and after sessions. The improvement of OKN was correlated with the improvement of body stabilization at the end of the sessions.

INTRODUCTION

Complex repeated optokinetic (OK) stimulation in standing humans has been used successfully for the treatment of unsteadyness in presbyastasic elderlies (Sémont et al 1992). The same training procedure has been used with encouraging results to suppress motion sickness encountered by airflight pilots and commercial airflight attendants (Vitte et al 1992).

The aim of this study was to understand the mechanisms underlying this surprising beneficial effects. We have made the hypothesis that the improvements in postural control were mediated by a decrease of retinal slip due to a recovery of a good OK nystagmus (OKN) control.

It is well known that moving visual field induces in humans an OKN (Ter Braak, 1936 ; Dubois, Collewijn, 1979 ; Collewijn, 1985 ; Van Den Berg, Collewijn, 1988) composed of a slow component in the direction of the movement of the visual field (due to a combination of pursuit and of true optokinetic reflex action) and a fast phase in the opposite direction. The quantitative parameters of OKN and the effect of visual scene characteristics are well documented (Tjissen et al. 1989 ; Zee et al. 1976). In addition to these two dynamic eye movements, two slow processes have been described : a shift of the beating field towards the direction of the fast phase which is probably an anticipatory mechanism, and a slow build up of slow phase velocity which is acompagnied by a storage of this velocity leading to an optokinetic after nystagmus (OKAN) (Cohen et al. 1977 ; Jell et al. 1984), which can be measured in darkness after the exposure to the OK stimulus for a certain time. The influence of vestibular stimulation on OKN demonstrates the close link between these two oculomotor subsystems (Cohen et al. 1981 ; Koenig et al.1991).

The effect of unilateral vestibular lesions on optokinetic nystagmus have been studied previously in human patients (Blakely et al. 1993 ; Zee et al. 1976). Also the disappearance of OKAN after labyrinthine lesions is a general and well documented effect (Zee et al 1976). OKAN has not been studied in the present work.

In addition to eye movements, the movement of large visual scenes has been shown to induce postural reactions during both circular (Lee, Aronson, 1974; Dichgans, Brandt, 1978; Van Asten et al. 1988) and linear (Lestienne et al. 1977; Nashner, Berthoz, 1978) motion. Generally the postural sway is observed in the direction of the slow phase of nystagmus. This postural sway has been attributed to at least three mechanisms: firstly a direct action of the visual input on the structures controlling posture, for instance visual input to the vestibular nuclei, secondly an indirect action through the central representation of body orientation to the vertical, thirdly a consequence of the coupling between eye movement and neck muscles.

In the present work we have explored two main series of parameters in either unilateral or bilateral labyrinthine-defective patients. Firstly we have measured the modifications of slow phase velocity (SPV), beating frequency and have observed beating field shifts during the course of successive training sessions of optokinetic stimulation. Secondly we have measured the postural sway of the same patients. We shall describe the parallel evolution of the improvement in balance and in OKN.

METHODS

Optokinetic device :

The optokinetic device was a planetarium (Simpson et al 1981) mounted on a three axis sytem in order to project different stimulation patterns. Walls, ceiling and floor (i.e the whole room) were used as screens. On the extreme left and right of the frontward "screen" were two black horizontal bars (with a diedral angle of 160°) which gave a stable reference to enhance "vection". The three axes of rotation (X, Y, Z) could be used separately or together in order to induce complex patterns and go from pattern to pattern in a smooth continuous change in direction without stopping the stimulation. The rotation of the sphere with respect to the Z axis induced an horizontal drumlike pattern of white dots ; the Y axis a vertical upward or downward moving pattern ; the X axis a torsional pattern.

In this study, the Z axis of the sphere was tilted 45° backwards. The subject was at a distance of 2 m from the frontal "nearest wall" with the OK device on his right side at the head level. The angular velocity of the sphere was 40°/s and the temporal frequency of dot presentation was 5.55 Hz .The angle between each projected white dot was 7°55'.

OK stimulation sessions (rehabilitation) :

Sessions of rehabilitation using OK stimulations were performed as follows:
- The subject was standing in an upright orthostatic position. He or she was instructed to look at the passing dots and let the eyes move freely (Stare OKN) without moving the head, and try to keep balance. The stimulation sessions lasted 10 to 15 mn and began using a torsional stimulus at an angular velocity of 40°/s. The stimulus was kept until the subject began to sway and stopped before the off-limit of stability was reached. The direction was then changed for a few seconds and set back to the disabling direction until the subject was once more out of balance and so forth.
- Pure vertical stimulus (with the Z axis of the sphere horizontal) was then used with the same protocol. Upward or downward direction was chosen in accordance to the most disabling vection and body sway.

During OK sessions, body sway was visually observed and the global results on balance were quantified using the EQUITEST system before and after rehabilitation sessions. Six conditions were tested during the sensory organization test. During conditions 4, 5 and 6 inaccurate foot somatosensory cues were given with accurate visual cue for condition 4, absent visual cue in condition 5 and stabilized visual input in condition 6. During conditions 5 and 6 the subject was maintening his balance using vestibular input only. The global score of the sensory organization test was the composite score.

Recordings :

Binocular eye movements were recorded using surface electrodes (Meditrace) and/or the I.R.I.S (Infra-Red light Eye-Movement Measurement) system. The horizontal component of eye movement was processed on line through a micro computer. Slow phase velocity (SPV), frequency and amplitude of OKN (Z axis of the sphere tilted 45° backward) were calculated using an interactive software. Vertical OKN was not recorded in the present work.

Patients :

Two groups of patients underwent OK sessions. These patients have been tested at the ENT Department of Hôpital Lariboisière in Paris with the following methodology : audiometry, impedance-audiometry, caloric test, EOG and eye-head movements recordings in order to test gaze stabilization in the horizontal plane (Freyss et al 1988). These patients were also submitted to high velocity stimulations(> 400°/s) on a rotatory chair (Sémont, Sterkers 1980). Cerebral Imaging (CT-Scan and MRI) were also performed in order to rule out brain and/or hind brain lesions.

The first group of 5 bilateral labyrinthine-defective patients (3 females, 2 males) was ranging in age from 38 to 68 years (average 42 years). These patients had no responses on both sides at the caloric test and also no post rotatory nystagmus. All these patients have been treated with aminoglycoside (gentamycine) for severe infections.

The second group of 5 unilateral labyrinthine-defective patients (2 females, 3 males) was ranging in age from 33 to 57 years (average 44 years). These patients were seen 1 to 3 months after surgery for acoustic neuroma (3 subjects) or after vestibular neurectomy (2 subjects).

Control responses were given by recording of 5 age-matched normal healthy volunteers (2 females, 3 males) ranging in age from 35 to 58 years (average 45 years).

RESULTS

Control Subjects :

For an OK stimulation session at 40°/s with the Z axis of the sphere tilted 45° backward, the per stimulation SPV of the OKN was regular (average : 28.67 +/- 4.33 °/s) and the frequency of the OKN was

: 2.88 +/- 0.50 Hz. Observed beating field was shifted in order to anticipate the stimulus. No body sway was visually observed. Vection was reported whatever was the direction of the stimulus. EQUITEST results before and after training were normal. Composite score was : 78 +/- 2.

Patients :

Bilateral areflexic patients :

At the beginning of the rehabilitation program (Z axis of the sphere tilted 45° backwards), the patients showed an important irregularity of the SPV of the OKN with an average of 32.14 °/s +/- 12.16 and a frequency of 1.91 Hz +/- 0.45.
Body sway occured in accordance with the direction of the stimulus and would have led to falls if not prevented by the observer. Using pure vertical upward OK stimulus, the whole group was unable to remain stable when the stimulus induced backward body sway with the OK beating field shifted in the direction of the stimulus. EQUITEST composite scores were ranging from 40 to 55 (average : 48) with falls on tests 5 and 6.

By repeating these OK stimuli and after a variable number (from 6 to 7) of sessions the frequency of OKN was : 2.81 Hz +/- 0.46 (Fig 2 B). The mean value of the OKN frequency was statistically different ($p < 0.05$ with Student's t test). There was also a slight improvement of the regularity of the OKN : 29.56 +/- 9.02 °/s.
Patients still fall during tests 5 and 6 but, test 4 was significally improved ($p < 0.01$ with Student's t test).

Unilateral vestibular patients :

At the beginning of the rehabilitation program, the patients did not exhibit spontaneous nystagmus anymore but an important asymmetry of the OKN (Z axis of the sphere tilted 45° backwards) with an irregularity of SPV . The average of SPV was 22.70 +/- 8.44 °/s when OKN was beating ipsilaterally to the lesion (quick phase directed towards the lesion) and 32.27 +/- 6.91 °/s when beating contralaterally. There was also a decrease of OKN frequency especially when the OKN was beating ipsilaterally to the lesion. The values of the OKN frequency were respectively 1.64 Hz +/- 0.76 (ipsi) and 2.3 Hz +/- 0.68 (contra).
Body sway and falls occurred when the direction of the OK stimulus was opposite to the side of the lesion. EQUITEST scores were : for composite : 60 +/- 10, for tests 5 and 6 : 20 +/- 20 (normal : 68),and for test 4: 65 +/- 15 (normal : 80).
After training, the asymmetry of the OKN frequency (Z axis of the sphere tilted 45° backwards) between the two sides was strongly reduced. The frequencies of the of OKN were: 2.94 Hz +/- 0.44 when beating ipsilaterally to the lesion and 3.12 Hz +/- 0.52 when beating contralaterally. A statistically significant improvement of the frequency of the OKN was noticed for the whole group and especially for the OKN beating ipsilaterally to the the lesion ($p < 0.05$ with Student's t test). Also, there was a slight improvement of the regularity of the OKN with an average of 28.70 +/- 7.48 °/s (ipsi) and 26.68 +/- 6.42 °/s (contra).
The scores of the EQUITEST were for the composite : 75 +/- 5, for tests 5 and 6 : 65 +/- 5 and for test 4 : 80 +/- 5.

For the two groups of patients :

After training, patients did not sway anymore whatever the direction and velocity of the stimulus was and most of the patients still had the feeling that they did not know what was moving: the room or themselves, but without any body sway. EQUITEST showed improvement of the scores of the test 4 for the two groups of patients.

DISCUSSION

The first striking result of this study is the remarkable improvement in optokinetic nystagmus parameters following only 6 sessions of training. This finding seems to be robust and indicates that complex optokinetic stimulation in a standing human subject induces some adaptive process which restores OKN asymmetry, slow phase velocity and beating field normal value.

It has been suggested by Igarashi et Al (1975) in primates and by Lacour (1981) in the cat that activity is fundamental in the recovery of vestibular deficits and, more generally it is known that adaptive mechanisms are more efficient when the subject is dealing actively with sensory conflicts and when sensory inputs are as natural and complex as possible. Although we have not explored the effects of OKN training on seated subjects we would like to propose the hypothesis that the rapid improvement of both OKN parameters and postural control were due to the fact that our subjects were standing and therefore actively counteracting the effects of OKN on posture. In addition the complex visual pattern motion induced by the planetarium projected on the walls of the room, may have required an additional impetus for active adaptation.

Unilateral vestibular patients :

We have observed that OK stimulations induced body sway towards the direction of the stimulus. Unilateral patients demonstrated body sway only when the stimulus was opposite to the lesioned side. This means that the patient has a perception of vection and body sway when OKN is opposite to vestibular spontaneous nystagmus. A possible interpretation of the decrease in postural sway which is observed in unilateral vestibular deficits after OKN training is the following :

- Before training the amplitude of OKN is greater when the visual scene is moving towards the side of the lesion because the slow phase of latent spontaneous vestibular nystagmus is driving the eye in this direction and facilitates the OKN slow phase. Therefore retinal slip is small and consequently the visually induced postural effect are smaller in this direction. This observation is similar to what can be seen on central diseased patients with spontaneous down beat nystagmus. When the OK stimulus provokes an upbeat nystagmus the patient strongly sways frontward. This has to be related to the visual stimulation of the pavement shifting under the feet of somebody walking straight ahead: in that condition the OK stimulation induces an upbeat nystagmus.
- By contrast when the visual scene moves towards the intact side three factors contribute to a large postural sway in this direction :

a) The slow phase of OKN is small and very irregular and therefore retinal slip is increased.
b) This increase of retinal slip induces a larger body sway by the visual projections to the neck and postural muscles.
c) The beating field of OKN seems shifted towards the side of the visual field motion. The well known oculo-nucal coupling may induce an eye movement related postural effect towards the side of the moving visual scene.

The effect of training can then be seen as inducing the following changes :
a) Probably a general increase of OKN amplitude and a recovery of symmetry between the two sides whose effect is to reduce retinal slip. Also a decrease of the OKN irregularities has been observed.
b) The consequence of this decreased retinal slip is that there is less visually induced postural sway.
c) In addition it could be suggested that the recovery of a well balanced OKN allows also a recovery of a normal beating field which tends to drive the eye in the direction opposite to the movement of the visual scene and therefore inducing a counter effect to the postural sway.

Bilateral vestibular patients :

We have demonstrated the role of OK stimulations in rehabilitation of presbyastasic elderly patients

(Sémont et Al 1992). These patients with normal vestibular fonction behaved like bilateral vestibular deficient patients (free falls in conditions 5 and 6 of the EQUITEST). After training, the scores of these patients on tests 5 and 6 were normalized, demonstrating the back to normal equilibrium sensory organization with full use of the vestibular imput.

On the other hand, bilateral vestibular deficient patients cannot obviously use their vestibular informations and the equilibrium sensory organization modification stands in the increase of the score of condition 4. This could be due to a more appropriate use of somatosensory input helped by the visual input. This is correlated with the improvement of the regularity of the OKN associated with a normalization of OKN frequency.