Original papers

Strabismus 0927-3972/97/US$ 12.00

Strabismus – 1997, Vol. 5, No. 1, pp. 13-20

Accepted 6 January 1997

Dissociated vertical deviation and eye torsion: Relation to disparity-induced vertical vergence

L.J. van Rijn
H.J. Simonsz
M.P.M. ten Tusscher

Department of Ophthalmology, University Hospital Maastricht;
Department of Neuro-Ophthalmology, University Hospital Rotterdam;
The Netherlands

Abstract We studied the relation between vertical eye movements and binocular torsion in five subjects with dissociated vertical deviation (DVD). During trials, subject viewed a well illuminated Snellen letter chart, with both eyes uncovered during 4 seconds, Subsequently, DVD was induced by covering one eye during 4 seconds. Finally, both eyes were uncovered during 4 seconds. Several trials were recorded for each subject and covered eye. Eye movements were measured with scleral coils.

We found that in all subjects, the vertical divergence followed an exponential course with a time constant of 0.67 ± 0.14 seconds on average. In three of the five subjects this vertical divergence was associated with binocular torsion (cycloversion), partly, in the form of a cycloversional nystagmus. The time course of the vertical divergence as well as the direction and nystagmic nature of the cycloversion was similar to the behaviour that was previously observed in disparity induced vertical vergence in normal subjects. In two of the subjects, the torsion that was associated with the vertical divergence was monocular.

Our results indicate that DVD and disparity induced vertical vergence share the same characteristics. In addition, they demonstrate that extorsion associated with the elevation in DVD possibly but not necessarily points at a dissociated torsional deviation.

Correspondence to: L.J. van Rijn, M.D., Department of Ophthalmology, University Hospital Maastricht, P.O. Box 5800, 6202 AZ Maastricht, The Netherlands

Key words Dissociated vertical deviation; vertical vergence; torsion; scleral coils; strabismus; strabismus, pathophysiology

Introduction Dissociated vertical deviation (DVD) is the elevation of one eye in response to a relatively decreased illumination in that eye and/or in response to fixation with the other eye[1,2]. It may also occur spontaneously. In most cases it is associated with loss of binocular vision, although sometimes it occurs as an isolated finding[3]. Often, the elevation in DVD is accompanied by extorsion of the elevating eye[4], although torsional movements may also occur (almost) in isolation[5]. The fellow (fixating) eye may also exert a torsional movement, resulting in cycloversion rather than monocular torsion[6].

It has been reported, as a rather unanticipated finding, that vertical vergence, induced by vertical disparities, in subjects without ocular abnormalities is also associated with binocular torsion[7,8]. This association may find its origin in the close relation between torsional and vertical oculomotor commands in the brain stem[9].

The purpose of this study was to compare the characteristics of the vertical divergence in DVD with those in disparity induced vertical vergence. We measured the vertical and associated torsional eye movements in subjects with DVD, using a protocol that allowed comparison of the results with those of a previous study involving disparity induced vertical vergence[8].

Methods

SUBJECTS Five human subjects participated in this study after giving their informed consent. All had DVD that could be elicited by the occlusion of one eye. In addition, all subjects had varying degrees of horizontal and/or vertical tropias. These subjects were recruited from the outpatient department of the University Hospital, Rotterdam, They visited this department for orthoptic evaluation and/or possible cosmetic squint surgery. Subject data are summarized in the table.

RECORDING OF EYE POSITIONS Eye positions were measured with scleral coils of the combination type, suited for measuring in three movement dimensions[10]. Eye positions were expressed in Fick coordinates[11]. Measurement technique and calibration procedures were identical to those used in an earlier experiment[8].

PROTOCOL AND VISUAL STIMULUS Subjects were seated with their eyes near the centre of the eye position measurement system. Their heads were supported by chin and forehead rests. Just in front of the subject's face was a grey plastic plate which contained a gap for each eye so as to allow unrestrained vision. This gap could be occluded by a grey shutter device.

At 143 cm distance in front of the subjects there was a Snellen letter chart that was mounted on a white screen. The chart and surroundings were brightly illuminated (1000 cd/m^2). Subjects were asked to fixate the one particular optotype that was located straight ahead. The elements of this opto-

TABLE 1. Subject data.

Subject	*Sex*	*Age*	*Diagnosis*
1	F	27	surgery for esotropia in early childhood, mild amblyopia OD, latent nystagmus, A pattern, strabismus deorsoadductorius ODS, consecutive exotropia 8 deg.
2	F	40	strabismus, formerly convergent, from early childhood, mild amblyopia OD, latent nystagmus consecutive exotropia 6 deg.
3	M	20	strabismus, age of onset unknown, mild amblyopia OS, latent nystagmus, exotropia 5 deg., strabismus deorsoadductorius OD
4	F	17	infantile esotropia, congenital nystagmus, alternate suppression, latent nystagmus, V pattern, exotropia 22 deg., left hypertropia 10 deg.
5	M	32	infantile esotropia, mild amblyopia OS, exotropia 3 deg., left hypertropia 11 deg.

type subtended 5 arc min of visual angle.

An experiment consisted of 8 measurements of 12 seconds each. During a measurement, subjects looked with both eyes open for 4 seconds. Subsequently, either the left or the right eye was occluded during 4 seconds. During the last 4 seconds both eyes were unoccluded again.

DATA ANALYSIS All data were corrected for coil misalignment[10]. Vertical vergence, cycloversion and cyclovergence were calculated for each data sample. Data were plotted for inspection and analysis.

The time constant of the vertical vergence was measured from the plots, as the time at which 63 % of the total deflection had occurred. Time constants were tested for differences using the Manova routine and the paired t-test from the SPSS-PC statistical package. For each subject and condition, three trials were included in the analysis.

Results

VERTICAL EYE MOVEMENTS All 5 subjects showed a dissociated vertical deviation after the occlusion of one eye. In case of occlusion of the non-fixating eye, this DVD response comprised a vertical deflection of the occluded eye. Examples are shown in Figs 1, 2 and 3, upper panels. When the fixating eye was occluded, the relative upward deflection of this eye was accompanied by a binocular refixation saccade which directed the previously non-fixating eye towards the fixation point (Figs. 1, 2 and 3, lower panels). In subjects no's 1 through 3, these refixation saccades were small (less than 8 deg). In subject no. 4, refixation comprised a large (larger than 20 deg.) horizontal saccade, accompanied by a vertical saccade that was almost exclusively monocular. Data of this subject have been reported earlier[14]. In subject no. 5, the refixation saccade had a vertical component of about 10 deg.

In all cases (occlusion of either eye), the vertical vergence followed an approximately exponentially shaped course (Figs. 1,2 and 3) The overall time constant was 0.67 ± 0.14 seconds (mean ± SD across 5 subjects). The time constant of the vertical vergence after occlusion of the fixating eye (resulting in refixation) was slightly shorter (0.61 ± 0.16 deg.) as compared to occlusion of the non-fixating eye (0.73 ± 0.10 deg). The difference was statistically significant (Manova, P = 0.007). After removal of the cover, the time constant of the return vergence movement was 0.70 ± 0.24 sec. The difference in time constant between occlusion and removal of occlusion was not statistically significant (Paired t-test, P = 0.55).

TORSIONAL EYE MOVEMENTS After occlusion of the *non-fixating eye*, in 4 out of the 5 subjects, the elevation of the occluded eye was accompanied by an extorsional movement. Subject no. 3 did not display torsion. Subjects no's 1 and 2 also displayed *in*torsion of the *fixating* eye, although this eye did not show a change in horizontal or vertical position (Figs. 1 and 2, upper panels). The torsion in subject 2 was partly in the form of a cycloversional nystagmus with the slow phase in extorsional direction in the elevating eye. When the cover was removed, the original torsional position was restored (Fig. 2, upper panel). Subjects nos. 4 and 5 did not display torsion in the fixating eye (Fig. 3, upper panel).

After occlusion of the *fixating eye*, subjects nos. 1 and 2 displayed

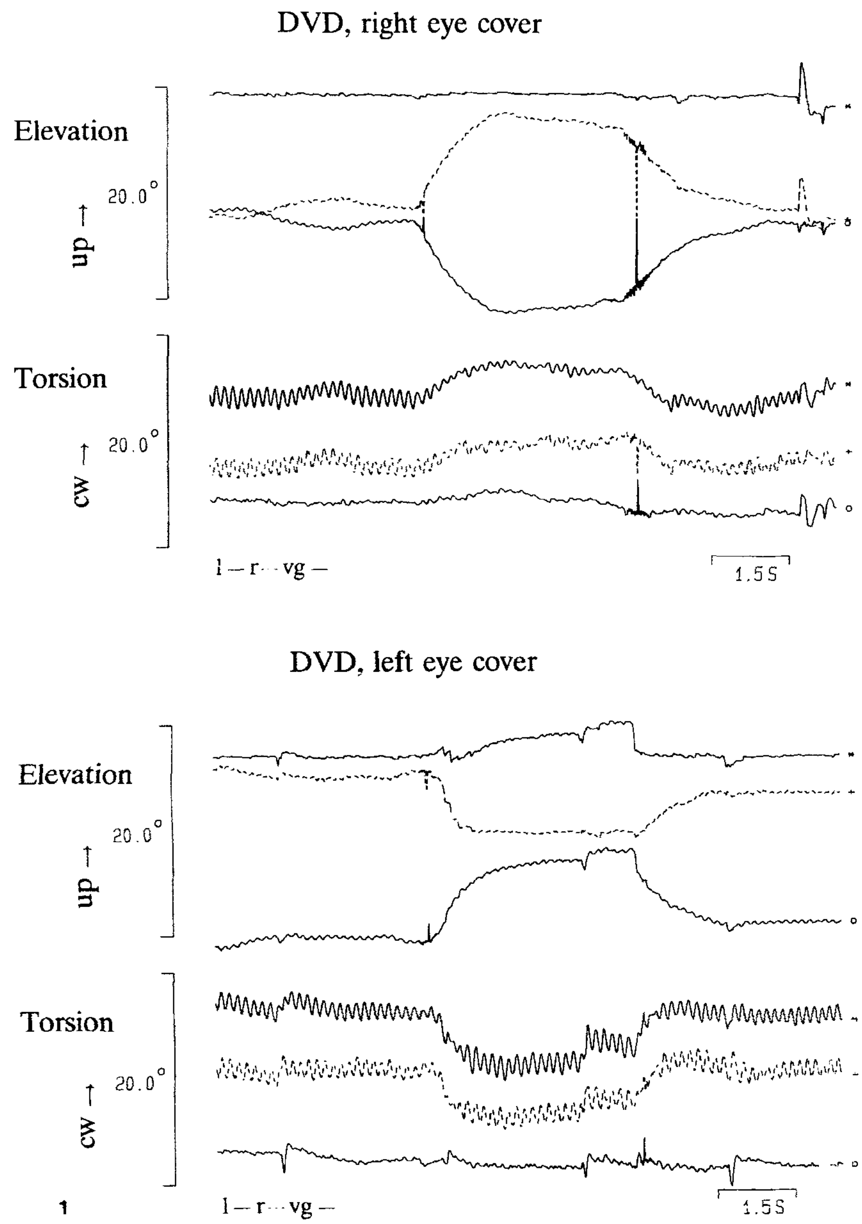
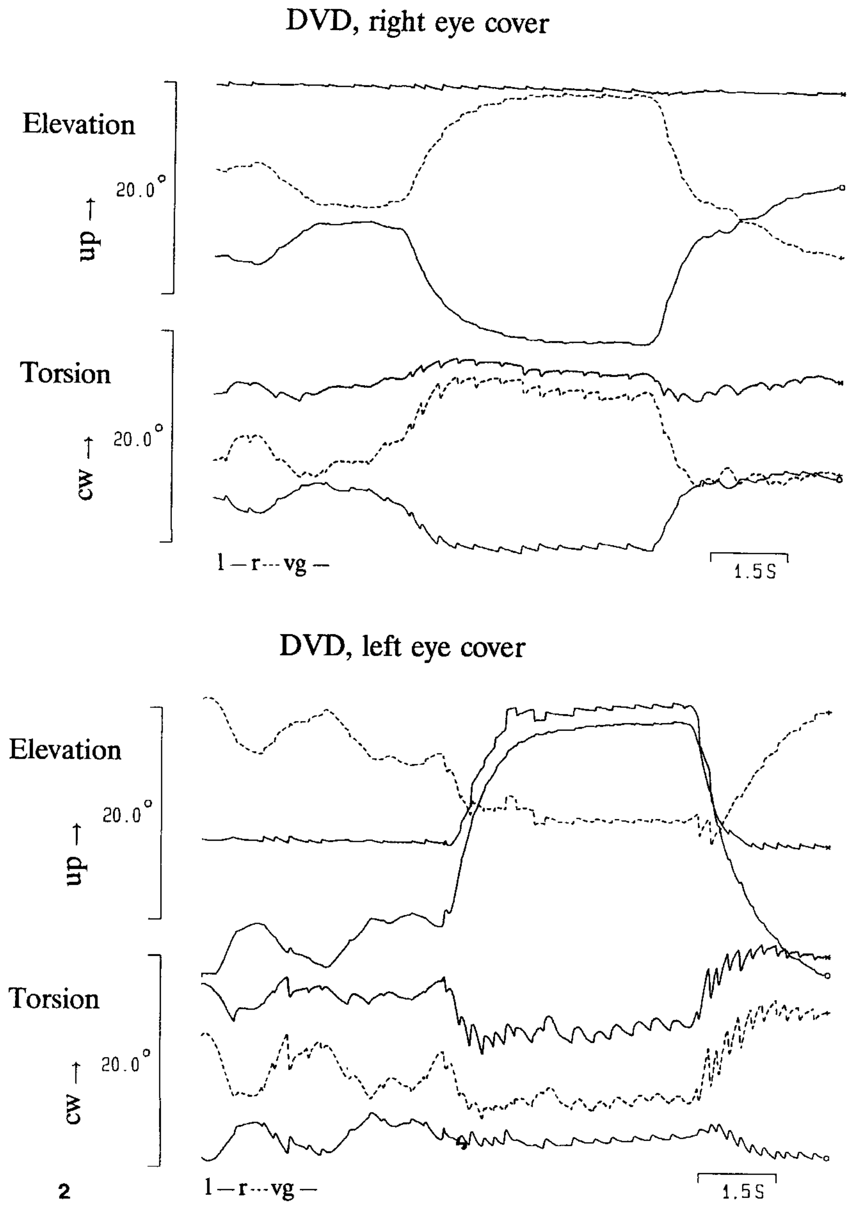


Fig. 1. Individual response of subject no. 1 to either occlusion of the right (non-fixating, upper panel) or left (fixating, lower panel) eye. In each panel, the first 4 s reflect viewing with both eyes unoccluded. The subsequent 4 s reflect occlusion of the right (upper panel) or the left (lower panel) eye. In the remaining 4 s, both eyes were unoccluded. In each group of 3 tracings the upper solid line represents the left eye, the dashed line the right eye, and the lower solid line eye vergence. Vergence is calculated as (left eye–right eye). Hence positive vertical vergence is *left-over-right* and positive cyclovergence is intorsion in both eyes.

The *upper panel*, upper tracings, show the monocular exponential elevation of the occluded, non-fixating eye. The fellow, unoccluded eye remains directed at the fixation point. The lower tracings show the associated cycloversion, in extorsional direction in the elevating eye. The peak at 8.3 s is caused by an artifact. A concurrent finding is the binocular torsional congenital nystagmus.

The *lower panel*, upper tracings, show that occlusion of the fixating eye is associated with a binocular refixational saccade and a superimposed, exponential deviation of the covered eye. The lower tracings show the associated cycloversion, again in extorsional direction in the elevating eye.

cycloversion. The direction was extorsional in the elevating (covered) eye and intorsional in the depressing (refixating) eye (Figs. 1 and 2, lower panels). Again, in subject 2 part of the torsion was in the form of a cycloversional nystagmus with the slow phase in extorsional direction in the elevating eye. The nystagmus reversed its direction when the cover was removed (Fig. 2, lower panel). Prior to any occlusion, subject no. 3 displayed a small spontaneous cycloversional nystagmus, with the slow phase in dextroversional direction. After occlusion of the non-fixating, right eye, this nystagmus was enhanced. Subjects nos. 4 and 5, after occlusion, displayed a steplike excyclovergence followed by a gradual incyclovergence towards the previous torsional position during the remaining time of occlusion (Fig. 3, lower panel).



2

Fig. 2. Individual response of subject no. 2 to either occlusion of the right (non-fixating, upper panel) or left (fixating, lower panel) eye. For legend of tracings see Fig. 1.

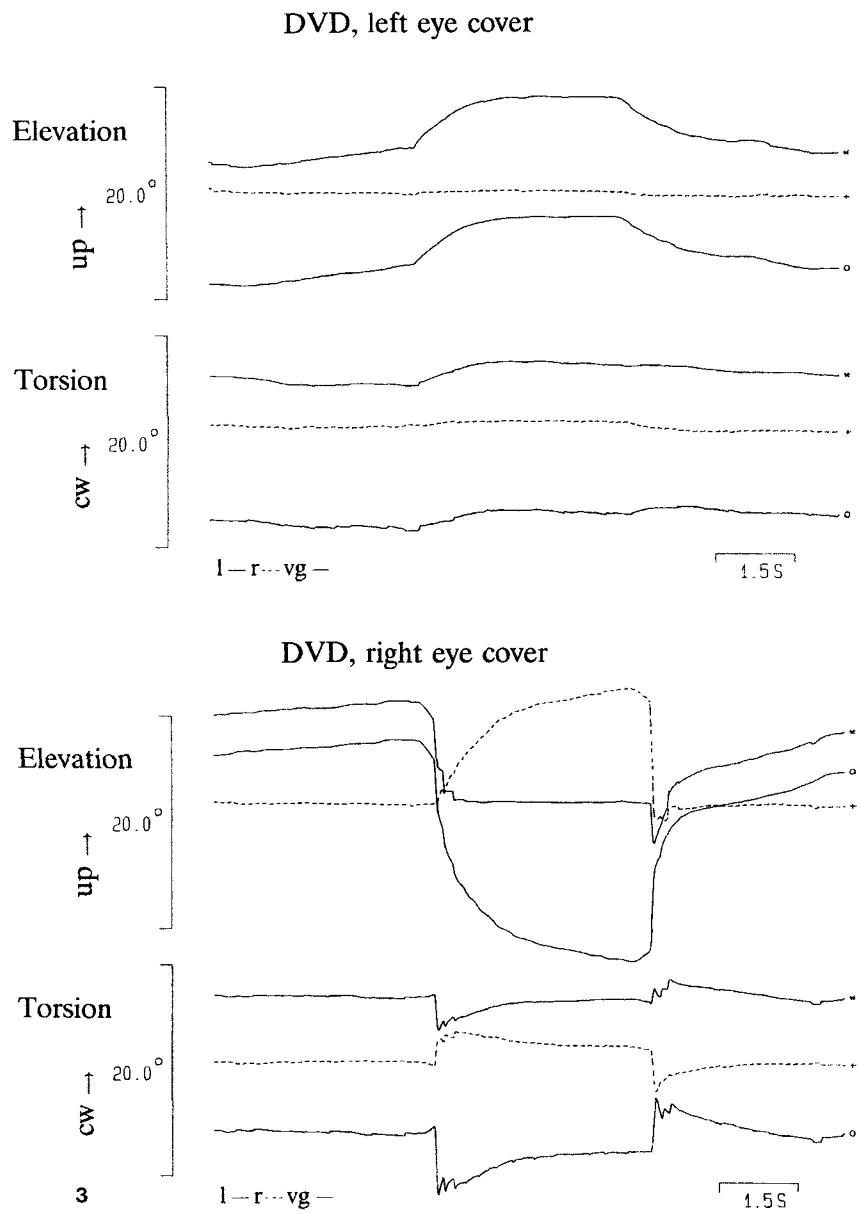
In the *upper panel*, the upper tracings show vertical movements that are similar to those in subject no. 1 (Fig. 1). The lower tracings show cycloversion, in extorsional direction in the elevating eye.

The *lower panel*, upper tracings, shows vertical movements that are similar to those in subject no. 1. (Fig. 1) The lower tracings show that the cycloversion is partly in the form of a nystagmus, with its slow phase in extorsional direction in the elevating eye. After removal of the cover (after 8 s.) the nystagmus has a reversed direction.

Discussion

VERTICAL EYE MOVEMENTS Our results confirm previous reports[2] that the vertical deflection in DVD is a slow movement. In addition, our results strongly suggest an exponential nature of the DVD response. Even in trials that contained a refixation saccade (in occlusion of the fixating eye), the vertical vergence showed this exponential behaviour. The fact that refixation resulted in a slightly shorter time constant, may reflect facilitation of vertical vergence by movements in other directions, similar to facilitation of horizontal vergence[12,13]. On a previous occasion, we reported on this phenomenon[14].

TORSIONAL EYE MOVEMENTS In three of our subjects the eye torsion, associated with the vertical deflections, was essentially *binocular* in nature. This may particularly be illustrated in subjects 1 and 2 in those trials in



3

Fig. 3. Individual response of subject no. 4 to either occlusion of the left (non-fixating, upper panel) or right (fixating, lower panel) eye. For legend of tracings see Fig. 1.

The *upper panel* shows that occlusion of the non-fixating eye is associated with exponential elevation and extorsion of the occluded eye. The fellow, fixating eye does not show any movement.

In the *lower panel*, the upper tracings show that after occlusion of the fixating eye, the fellow eye displays a refixation saccade that is almost exclusively monocular. The lower tracings show that after occlusion there is a steplike cyclovergence followed by a cyclovergence drift in the direction of the original cyclovergence position. After removal of the cover, both step and drift are in opposite direction.

which the non-fixating eye was being covered: although the fixating eye did not show any horizontal or vertical movement (it remained directed at the fixation point), *this fixating eye displayed torsion that was virtually identical to that of the fellow, elevating eye.* In addition, in subjects 1 through 3, after occlusion of the fixating eye, the torsion in both eyes showed a close resemblance although vertical movements were clearly different: there was a downward refixation saccade in both eyes accompanied by a slow, exponential elevation in the covered eye. The results in these three cases are in agreement with a previous report[6] about cycloversion in DVD.

In contrast, in subjects nos. 4 and 5, in occlusion of the non-fixating eye, the associated torsion seemed essentially *monocular* in nature: Occlusion of the non-fixating eye was associated with extorsion whereas the fellow, fixating eye did not display movements in any direction.

In these latter two subjects, after occlusion of the fixating eye, together with a refixation saccade, a steplike cyclovergence was observed. In a previous study it was demonstrated that in normal subjects, cyclovergence is proportional to both elevation and horizontal vergence, whereas it is not related to horizontal version[15]. This may explain why this cyclovergence was only observed in subjects with significant vertical squint angles, leading to vertical refixation movements (Table 1). However, this relation between cyclovergence and elevation until now has not been studied in subjects with strabismus. In addition, this phenomenon does not explain the cyclovergence drift that was observed after the initial cyclovergence step. The exact nature of this phenomenon remains to be elucidated in future studies.

RELATION WITH DISPARITY-INDUCED VERTICAL VERGENCE Previously, a study was performed on vertical divergence, induced by vertical disparities, in subjects without ocular abnormalities. Vertical vergence displayed an exponential course with a time constant of 0.94 ± 0.48 s. Vergence elimination had a time constant of 0.60 ± 0.12 s. In 4 out of 6 subjects, there was an associated cycloversion that was in extorsional direction in the elevating eye. Part of this cycloversion was in the form of a nystagmus with the slow phase in extorsional direction in the elevating eye. The time course of the vertical divergence in our present DVD subjects is similar to that observed in disparity-induced vertical vergence. Also, the reported associated cycloversion bears close resemblance to the cycloversion that we found in subjects 1 through 3.

Houtman and co-workers[16] compared velocities of vertical vergence and DVD. They found velocities of 20 sec arc/sec and 5 deg/sec for disparity induced vertical vergence and DVD respectively. Because of this difference they concluded that both phenomena are different. Their results may be explained by the fact that in an exponential time course the initial velocity is proportional to the total amplitude of the deviation. From the figure in their paper it can be seen that the deviation in their DVD subject was much larger than that in their subject with disparity induced vertical vergence.

POSSIBLE MECHANISM The results from these experiments suggest that two different mechanisms may lie at the basis of the observed phenomena.

The resemblance of the movement pattern observed in subjects 1 through 3 with the pattern observed in disparity induced vertical vergence suggest that in these cases the DVD is caused by an abnormal vertical vergence signal. The maintained relation between vertical vergence and cycloversion is in favour of the hypothesis that the proposed abnormal vertical vergence signal is supranuclear in origin[2]. In general, an exponential time course suggests that the driving force is proportional to the deviation from some optimum. In disparity-induced vertical vergence it is clear that the optimum is full retinal correspondence. It is as yet unclear, however, why in DVD the optimum should be the state in which one eye is elevated. This remains to be elucidated.

In two subjects, after occlusion of the non-fixating eye, the observed torsion was essentially monocular in nature. In the literature, several authors have reported about the occurrence of dissociated horizontal deviations, as well as dissociated torsional deviations[5]. The results in these two subjects may reflect the simultaneous occurrence of a dissociated vertical and dissociated torsional deviation.

References

1 Bielschowsky A. Die einseitigen und gegensinnigen ("dissoziierten") Vertikalbewegungen der Augen. Von Graefe's Arch Ophthalmol 1930; 125: 493-553.

2 Helveston EM. Dissociated vertical deviation. A clinical and laboratory study. Trans Am Ophthalmol Soc 1980; 78: 734-779.

3 Verhoeff FH. Occlusion hypertropia. Arch Ophthalmol 1941; 25: 780-795.

4 Lang J. Congenital convergent strabismus. Intern Ophthalmol Clins 1972; 11(4): 88-92.

5 Raab EL. Dissociated vertical deviation. Intern Ophthalmol Clins 1985; 25(4): 119-131.

6 Inoue M, Kita Y. Eye movements in dissociated vertical deviation. Nippon Ganka Gakkai Zasshi (J Japanese Ophthalmol Soc) 1993; 97: 1312-1319.

7 Enright JT. Unexpected role of the oblique muscles in the human vertical fusional reflex. J Physiol 1992; 451: 279-293.

8. van Rijn LJ, Collewijn H. Eye torsion associated with disparity induced vertical vergence in humans. Vision Res 1994; 34: 2307-2316.

9. Leigh RJ, Zee DS. The Neurology of Eye Movements, 2nd edn; Philadelphia: Davis, 1991.

10 Ferman L, Collewijn H, Jansen TC, Van den Berg AV. Human gaze stability in the horizontal, vertical and torsional direction during voluntary head movements, evaluated with a three-dimensional scleral induction coil technique. Vision Res 1987; 27: 811-828.

11 Carpenter RHS. Movements of the Eyes. London: Pion, 1988.

12 Erkelens CJ, Steinman RM, Collewijn H. Ocular vergence under natural conditions. II Gaze shifts between real targets differing in distance and direction. Proc Royal Soc London B 1989; 236: 441-465.

13 Enright JT. Facilitation of vergence changes by saccades: influences of misfocussed images and of disparity stimuli in man. J Physiol 1986; 371: 69-87.

14 Simonsz HJ, Van Rijn LJ. Facilitation of vertical vergence by horizontal saccades, found in a patient with dissociated vertical deviation. Strabismus 1994; 2: 143-146.

15 Van Rijn LJ, Van den Berg AV. Binocular eye orientation during fixations: Listing's law extended to include eye vergence. Vision Res 1993; 33: 691-708.

16 Houtman WA, Roze JA, De Vries B, Letsch MC. Alternating hyperphoria. Dissociated vertical deviation (DVD) 'occlusion hyperphoria'. Doc Ophthalmol 1991; 78: 135-140.