Proprioception and exodeviations

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SUMMARY When a slight adductive force is applied by forceps to the straight or master eye in exotropia, the exodeviated or slave eye assumes the straight position. The nature of this phenomenon was studied. The reflex occurred in an all-or-none form and showed little dose response, that is, the slave eye did not adduct beyond the straight position even if an extreme forced adduction was applied to the master eye. Once the slave eye assumed the straight position by the reflex it maintained this position, even when the master eye was covered, except when the master eye was released from the forced adduction. This reflex movement response occurred promptly on repeated forced adduction at 9 Hz on the master eye, while the visual movement of the eye was limited to follow 1 Hz movement of the target. The reflex occurred readily in the light but hardly at all in the dark. From these facts the authors conclude that the reflex is brought about as a result of interaction between the proprioceptive impulse and the visual input, where the former may chiefly constitute the signal, while the latter restricts the threshold of the reflex pathway.

One of the authors^{1,2} found that when a slight adductive force is applied by forceps to the straight or master eye in exotropia, the deviated or slave eye assumes the straight position, and he tentatively termed this the 'magician's forceps phenomenon'. In the present report electro-oculography (EOG) was chiefly used to elucidate the clinical characteristics and the nature of this phenomenon.

Subjects and methods

Two hundred and fourteen cases of exodeviations consisting of constant and intermittent exotropia were studied. Most kinds of 'comitant exodeviations' covered with the conventional definition were included, such as, for instance, the sensory exotropia and exotropia after surgery on esotropia. Cases with muscle palsy and those with congenital anomalies, however, were excluded. Exophoria was not included. Those children were also excluded who did not wish to receive the forceps test as described below. Normal controls were used when necessary.

Forceps test

A slight adductive force was applied to the straight

or master eye by forceps after the subconjunctival injection of a small amount of 2% procaine solution. If the deviated or slave eye did not assume the straight position by one test, forced adduction was repeatedly applied to the master eye at about 1 second intervals. If the slave eye did not respond after 20 attempts of forced adduction, the forceps test was regarded as negative.

If the slave eye assumed the straight position under the forceps test, the master eye was released from the forceps. If the slave eye then promptly returned to the original exodeviated position, the forceps test was regarded as positive. However, if the master eye exodeviated on release from the forceps while the slave eye maintained the straight position, it was regarded as a case of alternation of dominance, and the forceps phenomenon was judged as negative, as has been described elsewhere.³

EOG measurement

The movement of the eyes under the forceps test was recorded by EOG in selected cases in which the reflex occurred sensitively and regularly. A cross-talk cancellation method^{2,4} was employed for the EOG recording throughout the study.

To apply repeated forced adduction a special apparatus was designed. An oscillator equipped with an oscillating rod was used. The rod was connected by a silk thread to the eyeball at the

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Fig. 1 Constant exotropia of the left eye (A). The left eye assumed the straight position under the forceps test (B). The left eye did not adduct further, even if extreme adduction was applied to the right eye (C).

insertion of the medial rectus of the master eye. Repeated forced adduction of 1 to 9 Hz was thus given to the eyeball by operating the oscillator. The amplitude of the rod movement was adjusted to about 1 mm, and the adduction of the eyeball thus obtained ranged from 5° to 10°.

As controls, EOGs of the pursuit and saccadic movements of the eye were examined by the following two methods. (i) *Spot-light target*. A spot-light was projected on to a screen and the patient was asked to follow its movement. The spot was moved at 1 and 3 Hz with an amplitude of about 8°, either sinusoidally (pursuit) or squarely (saccadic). (ii) *Spiegelraumbewegung* (G. Kommerell, personal communication). A mirror was placed in front of the master eye. By an electric device the mirror was turned about 4° at 1 and 3 Hz, so that the whole retinal image moved by about 8°. The patient was asked to look at one point in the field where a mark was placed. This method simulates the movement of the retinal image by forced movement of the eye.

In both methods described above the recording was done under the following 2 conditions. (i) *Conventional conditions*. The movement of the retinal image under conventional conditions differs from

that under forced duction, because in the former the movement of the retinal image is corrected by the movement of the eye while it is not corrected in the latter. Conventional conditions involve feedback and therefore may be considered closed-loop conditions. (ii) The master eye was fixed by forceps during measurement to interrupt its movement. These conditions may constitute *open-loop conditions*. The Spiegelraumbewegung under open-loop conditions may most truly simulate the conditions of forced duction in regard to the movement of the retinal image. This experiment was designed at the suggestion of Professor G. Kommerell, of Freiburg University.

Results

OCCURRENCE AND CLINICAL CHARACTERISTICS OF THE FORCEPS PHENOMENON

Of the 214 cases of exodeviations the forceps phenomenon was positive in 85% or 184 of the cases. Not all of the positive cases showed the phenomenon after only one test. At least 20 repetitions of forced adduction were necessary before the result was regarded as negative.

The clinical characteristics of the phenomenon are as follows: (1) The required adductive force to the master eye is so slight that the adduction of this eye is hardly recognisable by inspection (Figs. 1B, 2B, and 3B). In positive cases the slave eye assumed the straight position in some cases (Fig. 1B) and slightly behind the straight position in others (Fig. 2B). (2) The slave eye did not adduct further even if extreme adduction was applied to the master eye, regardless of whether the slave eye had assumed the straight position (Fig. 1C) or a position slightly behind it (Fig. 2C) by the forceps phenomenon. (3) Once the straight position was attained, the slave eye did not return to the original exodeviated position when the master eye was covered, unless the master eye was released from the forceps, regardless of whether the vision of the slave eye was good or not (Fig. 3C).

The EOG which monitors these clinical characteristics of the forceps phenomenon is shown in Fig. 4.

RESPONSE TO REPETITION OF FORCED ADDUCTION

By the forceps test the slave eye reacted promptly on repeated forced adduction on the master eye up to 9 Hz. Application of more frequent adduction was technically difficult. An example of the punctual response is shown in Figs. 5 and 6. Fig. 5 shows the EOG of the repeated forceps phenomenon recorded at a slow paper speed. Forced adduction of 1, 3, 6,

Fig. 2 Constant exotropia of the right eye (A). This eye assumed a position slightly behind-the-straight position under the forceps test (B), and did not adduct further, even if extreme adduction was applied to the left eye (C).

Fig. 3 Constant (sensory) exotropia of the left eye (A). This eye, which had no sight, assumed the straight position under the forceps test (B), and did not return to the original exodeviated position, even if the right eye was covered (C).

and 9 Hz was given successively to the left (master) eye. The right (slave) eye responded promptly on repeated forced adduction. A high-speed recording for 6 and 9 Hz forced adduction in this case is shown in Fig. 6. The promptness of the response at 9 Hz is clearly seen.

The pursuit and saccadic movements of the eye were limited to follow 1 Hz movement of the target under any test conditions. The spot-light method and the Spiegelraumbewegung method gave similar results. Under open-loop conditions the eye movement became more irregular in amplitude than that under closed-loop conditions. Fig. 7 shows the EOG of the pursuit movement of the eye measured by the Spiegelraumbewegung method under closed-loop conditions. A 1 Hz movement of the target is promptly followed by the eyes but a 3 Hz movement is not. Fig. 8 illustrates result of the same measurement under open-loop conditions, where the movement of the master eye was interrupted by fixation of this eye by forceps. Here the associate eye responded to 1 Hz movement of the target in frequency, but the amplitude of each movement is irregular.

Discussion

The so-called magician's forceps phenomenon seen in exotropia elicited prompt response on repeated forced adduction of 9 Hz. The pursuit and saccadic movements of the eye were limited to follow 1 Hz movement under any conditions. These conditions included open-loop conditions by the Spiegelraumbewegung method, which simulates the visual conditions of the forceps test. It is well known that the proprioceptive reflex responds promptly on frequently repeated stimulations and the Ia-fibre of the proprioceptor reacts on up to 100 Hz stimuli.⁵ It is assumed, therefore, that in the forceps phenomenon in exotropia proprioception plays an important role. As reported elsewhere,^{2,3} the change in the electromyogram (EMG) due to this phenomenon occurs only in the slave eye, indicating that the phenomenon is not a comitant movement of both eyes against the direction of the forced adduction but is a monocular movement of the slave eye in the direction of orthophorisation. This kind of movement may hardly occur as a visual reflex. The phenomenon occurred in an all-or-none form showing little dose

Fig. 4 A DC-EOG monitoring clinical characteristics of the forceps phenomenon in a case of the left eye exotropia of 15° . A photocell was placed on the lid of the master eye. 1. Slight adductive force was applied by forceps to the master eye. 2. The master eye was released from the forceps. 3. An extreme adduction was applied to the master eye. 4. The master eye was covered. 5. The master eye was uncovered. FP. The forceps phenomenon appeared in the slave eye. For detail see the text.

response. Once the phenomenon occurred, the slave eye maintained the straight position even if the master eye was covered, unless the master eye was released from the forceps. This happened even in cases in which the slave eye had no sight. These

facts may also suggest that the phenomenon is not of a visual nature. On the other hand, however, the phenomenon is readily brought about in the light but hardly at all in the dark.² The visual input, therefore, must also be an important factor. In all

Fig. 5 EOG of repeated application of the forceps test. The slave eye responded promptly upon 9 Hz repetition of the forced adduction applied on the master eye. AC-EOG, time constant 2 seconds.

Fig. 6 The same as Fig. 4 recorded at a higher paper speed showing the promptness of the response at 9 Hz. AC-EOG, time constant 2 seconds.

Fig. 7 EOG of pursuit movement of the eye. The stimulation was given by Spiegelraumbewegung under closed-loop conditions. Visual movement can follow a 1 Hz movement but not a 3 Hz movement. AC-EOG, time constant 2 seconds.

Fig. 8 EOG of a visual movement of the eye. The stimulation was given by Spiegelraumbewegung under open-loop conditions, where the movement of the fixing eye was interrupted by holding the eye with forceps. A 1 Hz movement was followed as in the case of closed-loop conditions but the amplitude of the movement is not uniform. AC-EOG, time constant 2 seconds.

probability the phenomenon is a result of interaction between proprioception and visual input, where the proprioceptive impulse chiefly constitutes the signal and the visual input restricts the threshold of the reflex pathway. The interaction of both afferents at the superior colliculus has been suggested by a series of animal experiments.⁶⁻⁷

The problem whether the phenomenon is an excitation of a reflex concerns us here. Intermittent exotropia does not show exodeviation in the dark.² In some cases of constant exotropia the degree of the deviation decreases in the dark.⁸ By intensive retrobulbar anaesthesia of the master eye with 4% procaine solution, which does not block visual input, the exodeviation of the slave eye disappears and the forceps phenomenon ceases to occur.² (4 ml of 4% procaine solution is divided into 4 doses and each 1 ml is injected retrobulbarly from 4 directions. Then the active movements of the eye vanish, but the visual acuity is not much impaired. When 2% lignocaine solution is used, the visual input is completely blocked in most instances.) Master eye surgery is very effective in the treatment of exo-

deviations,³ because it is not only effective in correcting the eye position but it also rapidly improves the vision of the slave eye and its visually evoked cortical potential, and the normal pattern of the EMG results after surgery. The normal pattern of the EMG also results from the forceps phenomenon.² All of these findings can be explained if it is assumed that in cases of exodeviation an abnormal proprioceptive impulse persists that originates from the master eye to cause abnormal contraction of the slave eye lateral rectus, and that the forceps phenomenon is the result of cancellation of this abnormal standing impulse of proprioception.

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