EFFECT OF INCISIONS IN THE BRAINSTEM COMMISSURAL NETWORK ON THE SHORT-TERM VESTIBULO-OCULAR ADAPTATION OF THE CAT

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Abstract—This study was intended to test the adaptive plasticity of the vestibulo-ocular reflex before and after either a midsagittal or parasagittal incision in the brainstem. Eye movements were measured with the electromagnetic search coil technique during the vestibulo-ocular reflex (VORp) in the dark, the optokinetic reflex (OKN), and the visuo-vestibular adaptive training procedure. Two types of visual-vestibular combined stimulation were applied by means of low frequency stimuli (0.05 to 0.10 Hz). In order to increase or decrease the VORp gain, the optokinetic drum was oscillated either 180° out-of-phase or in-phase with the vestibular stimulus turntable. This "training" procedure was applied for 4 hours. Initial measurements of the VORp were normal with a mean gain value of 0.92 ± 0.08. After 4 hours of "training" with the out-of-phase condition (180°), VORp gain reached mean values of 1.33 ± 0.11 (n = 6 cats). In the in-phase combination, the mean VORp gain decreased from 1.0 to 0.63 ± 0.02 (n = 2 cats). No significant change of VORp phase was found in any of the cats. Midsagittal or parasagittal pontomedullary brainstem incisions were performed in 4 cats. Recovery of the VOR was tested on the 2nd, 7th, and 30th day after operation. After the 30th day, recovery of the VORp gain stabilized at about 66% of the initial preoperative value. At this stage of the recovery, the optokinetic response (OKN) of the midsagittal-lesioned cats was practically normal: in the parasagittal-lesioned cats, the postoperative OKN responses were asymmetric. After stabilization of recovery, lesioned cats were trained with the same adaptation procedure. Although the direct effect of the visuo-vestibular combined stimulation during the training was still operative in all lesioned cats, the adaptive plasticity was completely abolished by the lesions. These results suggest that the commissural brainstem network may play a crucial role in the acquisition of the forced VOR adaptation.

Keywords—vestibulo-ocular adaptation; brainstem commissural incisions; cat.

Introduction

The vestibulo-ocular reflex (VOR) stabilizes retinal images during self-induced and artificially induced rotational head movement by generating smooth eye movements that are opposite in direction and nearly equal in amplitude to head movement.

It is now well accepted that the VOR can be adaptively modified by artificial alteration of the normal visual stimulation produced during rotation of the head (for references, see reference 1).

Until now, many studies have been devoted to identifying the neuronal circuit responsible for the adaptive visual-vestibular interaction. However, the site of the short-term and long-term vestibulo-ocular motor learning is currently a controversial issue. On the one hand, the flocculus hypothesis supported by Ito's group (2-4) was first advanced

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on the basis of bilateral flocculectomy preventing any adaptation (5-6) and secondly reinforced on the basis of Purkinje cell recordings before and after adaptation (7). On the other hand, the brainstem hypothesis, put forward by Mile’s group (8-11) on the basis of the fact that the changes of Purkinje cells’ output were in the wrong direction to produce VOR adaptation. In the light of more recent experiments, these two conflicting hypothesis were reanalyzed by Lisberger (12) who suggested in 1988 that there may be 2 sites of synaptic adaptation: a primary site in the brainstem (the flocculus target neurons) and a secondary site in the floccular cortex. In this context, another reconciling hypothesis based on a theoretical model was advanced by Galiana (13,14). In this model, the commissural pathway interconnecting the 2 sides of the brainstem was put forward as a powerful putative site for adaptive modulation of the VOR.

The aim of the present article is to test experimentally the effects of a commissural incision on VOR adaptation behavior. This approach, while theoretically possible, presents practical problems since the lesion may interfere with basic components of the VOR or of the OKN adapting stimulation. For example, the vestibular commissural pathway plays an important role in the VOR integrating process (theoretically suggested in 1984 by Galiana and Outerbridge [15]). We recently demonstrated (16) that each time a brainstem incision reached or went past the rostral border of the 6 nuclei, all the vestibular commissural fibers crossing dorsally at the level of the medial vestibular nuclei were interrupted; the vestibular neural integrator was found to be disabled without any later recuperation. In this context, testing with the classical adaptation procedure could not answer correctly the basic question raised about a commissural contribution to adaptation of the VOR.

Thus, we must produce a partial commissural incision, where there is a satisfactory recovery of VOR integration; then and only then can we apply the adaptation procedure to study whether these partially commissural fibers are necessary for VOR gain adaptation.

**Methods**

**General Procedure**

The experiments were performed on 10 cats. Under general anaesthesia (xylidindihydrothiazin, Rompun, Bayer 3 mg/kg and pentobarbitone, Nembutal, Abbott, 20 mg/kg) and aseptic conditions, 2 devices were chronically implanted. A scleral search coil was implanted subconjunctivally on both eyes (17). Two transverse tubes were placed on the skull in the horizontal plane and embedded in dental acrylic cement to immobilize the head during the experiments.

When an animal had recovered from the effects of this first surgery (about one week), it was loosely restrained in a body box to which the head was fixed. A week later control records of the eye movements and the adaptation procedure were performed.

In order to avoid some possible change of the central parameters controlling the VOR when the cat was trained with the visuo-vestibular combined stimuli before the commissural incision, most of the data were obtained from naive cats. Only one animal (CF3) was tested both before and after the lesion. The others were tested either before (CF2, C5/88, C9/87, C7/88, C4/88, C6/88) or after (C16/87, C13/87, C8/87) surgery.

A midsagittal or a parasagittal pontomedullary brainstem section was performed in 4 cats. A small piece of razor blade was fixed to a guide. The angle between the guide and the knife was 135°. The guide was handled using a manipulator fixed to a stereotactic frame. The guide was tilted to be parallel to the floor of the fourth ventricle. A suboccipital craniotomy was performed. The vermis was gently retracted dorsally in order to expose the fourth ventricle. Then, the knife was inserted into the brainstem (on the midline or 2 mm laterally), advanced cranially and withdrawn. Care was taken that the guide did not touch the ventricle. Bleeding was slight. Antibiotics and prednisolone were given intramuscularly during the first 5 postoperative (p.o.) day. Postoperative controls of the ves-
Vestibulo-Ocular Adaptation

The vestibular and optokinetic system were performed on the 2nd, 7th, and 30th p.o. day. After this recovery period, we again tested the adaptive ability of these brainstem-lesioned cats.

Recording of Eye Movements

The eye movement measurement system has a bandwidth of 0 to 1000 Hz and a sensitivity of 0.25°. Eye movements were recorded simultaneously on an electrostatic recorder (Gould ES 1000, overall Bandwidth 0 to 1 kHz) and on FM tape. Eye velocity signals were also recorded from an analog differentiator (0 to 10 Hz). All data were analyzed by hand from the recorded tracings. Calibration was obtained by keeping the untrained cat (in a body box to which the head was fixed) stockstill in space while the surrounding magnetic field was rotated sinusoidally (1 Hz; ± 5°) in the horizontal plane. During the calibration procedure, spontaneous saccades were abolished by intramuscular injection of a neuroleptic (xylinidodihydrothiazin, Rompun, Bayer, 3 mg/kg).

Behavioral Testing

In order to elicit the VOR, the head of the cat was put in the center of a turntable and placed so that the horizontal semicircular canals were about horizontal (nose 20° down). Before the animal had obtained any experience with visual-vestibular combined stimulation, the gain of the VOR was measured in total darkness (40° peak-to-peak at 0.10 Hz or 0.05 Hz rotation).

The gain of the VOR was estimated as average peak-to-peak slow phase eye velocity divided by peak-to-peak head velocity. The phase of the VOR was estimated by averaging the time difference between the zero crossing of the eye and chair velocity records. For eliciting optokinetic responses, a random pattern of lighted circles was projected on the drum surrounding the cat.

The projector was rotated sinusoidally for the adaptation procedure and rotated at a steady-state velocity of 30° for the OKN and OKAN testing procedures. Optokinetic responses were quantified by measuring the gain of the OKN during its steady-state and the time constant of OKAN. The time constant of OKAN was estimated by measuring the time it took for the slow-phase velocity of OKAN to drop to 37% of its initial value.

Visual vestibular stimulation was performed by means of low frequency oscillation in order to remain in the working range of cat's optokinetic system. Two types of visual-vestibular combined stimulation were applied: 1) 40° or 80° peak-to-peak at 0.05 Hz or 0.10 Hz, respectively, turntable rotation combined 180° out-of-phase with 40° or 80° peak-to-peak screen rotation (out-of-phase combination). 2) 40° peak-to-peak at 0.05 Hz turntable rotation combined in phase with 80° peak-to-peak screen rotation (in-phase combination).

As a measure of the animal's level of alertness the number of quick phases was controlled throughout each adaptation period. A high level of alertness of the cat was maintained by intramuscular injection of amphetamine (0.5 mg/kg) and by auditory and tactile stimulation. The gain of the VOR was measured every hour in the dark during the 4 hours of the combined stimulation period.

To assess if the direct visual control of the VOR was still operative after commissural fibers incision, we compared the gain of the VOR measured in the dark and during the visual-vestibular combined stimulation (out-of-phase combination) both in normal and in lesioned cats.

The VOR gain-increasing ability was calculated as the ratio of the VOR gain measured during the visual-vestibular out-of-phase combination divided by the VOR gain measured in the dark.

Histological Controls

At the conclusion of an experiment, the cat was anesthetized and perfused through the aorta with a 10% formalin solution. The
brainstem was embedded in paraffin. Serial sections, 20 μm thick, were made. Every 10th section was mounted and stained with Cresyl Fast Violet. The atlas of Berman was used to help to interpret the location of histological lesions.

Results

Adaptive Plasticity in Normal Cat

Of the 10 cats tested in this study, 6 of them (C5/88, C9/87, C7/88, C4/88, C6/88) were tested only as controls and were not lesioned. Three others (C16/87, C13/87, C8/87) were tested with the adaptation procedure only in the postoperative state, and the last one (C3) was tested with the adaptation procedure in both the preoperative and postoperative state.

In all animals, the typical compensating sinusoidal eye movements illustrated in Figure 1A were observed. For the 6 cats used as controls, the initial measurements of the \( \text{VOR}_D \) (at 0.05 Hz or 0.10 Hz) were normal with a mean gain value of 0.92 ± 0.08 and 6.3° ± 3.1 phase lead. All 6 cats demonstrated in the out-of-phase (Figure 2A and B) and in the in-phase (Figure 2C and D) combination procedure a very stereotyped pattern of \( \text{VOR}_D \) gain changes during adaptation, as has been previously reported by other authors (18-20). The most significant change in the \( \text{VOR}_D \) gain was seen during the first 2 hours of the training session. These results are shown in Figure 2B as \( \text{VOR} \) gain normalized to that value measured just before the combined visual-vestibular stimulation started. The mean gain in these 6 intact cats reached a value of 1.41 ± 0.08 after 4 hours. No significant change of phase was reported in any of the cats. Figure 1 illustrates the recordings of the sinusoidal \( \text{VOR}_D \) before (A) and after 4 hours of the visual-vestibular out-of-phase combined stimulation (C). During the training period (Figure 1B), this visual-vestibular interaction produced in the out-of-phase combination a gain increase to a mean value of 1.49 ± 0.11. In the cat illustrated in Figure 1 (CF3), 4 hours’ rotation under the out-of-phase combination increased the horizontal \( \text{VOR} \) gain in darkness by 0.47 (from control values 0.82 ±
Vestibulo-Ocular Adaptation

Figure 2. Time course of adaptation of VOR gain absolute and normalized to out-of-phase (A and B) and in phase (C and D) combination. Filled circles linked by continuous line represent for the individual normal cat the increment (A) and the decrement (C) in gain (normalized in B and D) to the value measured just prior to the start of training) as a function of hours of training. Open circles linked by continuous line represent the unchanged gain during adaptation for each lesioned cat. a = CF2, b = CF3, c = C4/88, d = C9/87, e = C7/88, f = C5/88, g1,2 = C16/87, h = C13/87, i = C8/87, j = C6/88.

Location of the Lesions

Careful examination of the cerebellum in our 4 lesioned cats revealed some minor lesions of the caudal vermis due to its manipulation during surgery, but rules out any lesion of the two flocculi (there was no evidence of gliosis or Purkinje cell atrophy) (see Figure 3, cat C16/87). Despite the variation in the lo-
cation of experimental lesions, it is worth pointing out that we observed a relationship between the disturbance of pathways and the well-known divergence of the commissural projection extending from the rostral border of the 6th nucleus to the caudal part of the prepositus nucleus.

In cat C16/87 (Figure 4A) a midsagittal cut was performed, between P10 and P4, the depth of the incision was of 3 mm at the level of the caudal part of the 6th nuclei. In this cat, the vestibular commissural fibers crossing at the level of the rostral part of the 6th nuclei were spared by the incision, and the inter-nuclear pathways linking the 3rd and the 6th nuclei were only slightly affected by the lesion. More caudally, the commissural fibers originating in the caudal part of the PH nuclei and crossing at this level were equally spared by the lesion. Between these two extreme levels, all the commissural fibers were cut.

In cat C8/87 (Figure 4B), the incision produced a more laterally extended lesion on the midline area, but this incision was only localized on the caudal part of the brainstem between P7 and P12, leaving intact the vestibular commissure crossing at the rostral level between P7 and P5. In this case, there was a clear lesion of all the commissural fibers from P9 to P12 and a partial lesion of the deeper commissural fibers from P7 to P8. The vestibular commissure crossing at the level of the 6th nuclei was completely spared in this cat.
Vestibulo-Ocular Adaptation

In 2 cats, a parasagittal lesion was performed on the right side (cat CF3), (Figure 5A) and on the left side (cat C13/87, Figure 5B). In cat CF3, the cat (illustrated in Figure 5A) was made at 2.6 mm from the midline. The razor blade began to run into the medulla at P9 level, split the MVN nucleus, and penetrated the more rostral part of the brainstem at a deeper level up to P6 without destruction of the superficial rostral MVN-PH complex. In this cat, the contingent of the lesioned commissural fibers was certainly less pronounced than in the 3 other cats, but the MVN was destroyed in its middle body, producing an unilateral disruption of the intrinsic MVN circuitry. In cat C13/87, the cut (illustrated in Figure 5B) was made at a laterality of 1.3 mm. In this cat, the razor blade began to run into the medulla at P9 to split the PH between P9 and P7. A maximum depth of 3.46 mm was attained at P7, and the cut ended between P4 and P5. The vestibular commissural pathway crossing at the level of the 6th nuclei was severed only partially in cat C13/87 and was certainly completely spared in cat CF3.

General Physical Status during the Early Recovery

During the 4 days of recovery that followed the brainstem incision in the 4 lesioned cats, the management of the animals necessitated a close monitoring with intensive care to avoid accidental falls and general depression. During this period the sense of equilibrium was greatly perturbed and the walk was very
unsteady. However, during the next 3 weeks, the cats recovered normal motor behavior (normal walk and normal jump).

Recovery of the Oculomotor Function

In cat C16/87, the horizontal and vertical saccade and the subsequent gaze holding were greatly altered the 2nd postoperative day. At this time, the main sequence of the saccadic movement was not conserved, and the altered horizontal and vertical saccades were followed by a bilateral postsaccadic drift (time constant: 0.5 s). On the 7th postoperative day, the main sequence (amplitude-velocity relationship) of the saccadic eye movement was normal but accompanied by a weak bilateral postsaccadic drift in complete darkness (time constant: 3 s). Finally, cat C16/87 could make normal saccade without any subsequent drift on the 30th day. At this time the recovery of the integrator function has reached a stable state.

The preoperative value for the sinusoidal VOR$_D$ (Table 1A) tested at 0.10 Hz was around 0.65 and dropped to 0 at the 2nd postoperative day. The recovery processing increased the gain up to 0.43 at the 7th day and maintained it at this level at the 30th day. The control values (preoperative) of the optokinetic reflex (OKN) and OKAN were low in this cat, but...
the recovery was practically complete at the 30th p.o. day for the OKN gain and mid reduced for the time constant of the OKAN (Table 2A).

In cat C8/87, the gaze holding was moderately altered on the 2nd postoperative day, the postsaccadic drift was relatively greater for the vertical than for the horizontal saccade. This vertical–horizontal difference in the gaze holding persisted at the 30th. At this time of the recovery, the gaze holding of the horizontal saccade was normal while the gaze holding of the vertical saccade presented a moderate drift. The second day after the operation, the VORp gain dropped from 0.90 to 0.15. A rapid recovery increased this value up to 0.72 at the 7th day and stabilized the gain at this value. Paralleled to this good VORp recovery, the OKN and OKAN were practically normal at the 30th postoperative day (Table 2A).

The cat CF3 presented at the 2nd postoperative day, in the dark, an oblique nystagmus with the slow phases directed to the side...
of the incision (left) and to the top. In the light, the horizontal nystagmic component disappeared, and the horizontal holding system was practically normal, but the vertical nystagmus remained unchanged. At the 30th day the horizontal and vertical saccade and the subsequent gaze holding were normal without any nystagmus. The sinusoidal VORgain (tested at 0.10 Hz) dropped from 0.89 (before) to 0.26 (2nd day after). A rapid recovery of the VOR increased the gain to 0.62 at the 7th day and stabilized the gain around this value. In cat C13/87, the parasagittal incision did not produce any nystagmus, but a clear asymmetry in the gaze-holding system was present during the first 7 days after the operation. The horizontal saccade directed to the side of the lesion was followed by an exponential drift (time constant around 1 s), while the gaze holding following the saccade directed to the other side was perfectly normal. On the 30th day, this asymmetrical gaze-holding system was less pronounced but clearly present (time constant around 3 sec). The sinusoidal VORgain tested at 0.10 Hz dropped on the 2nd day from 1.21 to 0.17. A rapid recovery of the VOR stabilizes the gain at the 7th day at 0.80.

There was a strong reduction of the OKN responses (Table 2B) on the 2nd day in these 2 later cats, but this was followed by a significant recovery. The postoperative OKN responses were asymmetric: the OKN response to a rotation of the drum towards the intact side was stronger than that to a rotation of the drum towards the lesioned side. In spite of differences in the placement of the lesions in these two cats, the OKAN disappeared and did not reappear.

Adaptive Plasticity in Lesioned Cats

Figure 2A shows that none of the 4 animals lesioned produced any increase of the VORgain after the out-of-phase adaptation procedure. The adaptive plasticity was completely destroyed by the commissural brainstem incision. This result was also illustrated in one cat (Figure 6) where the postoperative reduced VOR gain (Figure 6A) was clearly not modified after the 4 hours adaptation (Figure 6C) in spite of the fact that the visual-vestibular combined effect (VOR gain measured during the adaptation procedure) was not significantly altered by the lesion (Figure 5B).

Figure 7 shows for comparison the 3 de-
Figure 7. Time course of VOR gain in response to a 0.05 Hz sinusoidal oscillation in the 3 determinant periods of testing (Cat CF3). A. During the adaptation performance in the preoperative state. B. During the recovery. C. During the abolished adaptation performance in the out-of-phase (o) and in the in-phase (o) combination. Note that the direct visuo-vestibular combined effect (CE) is preserved after the lesion (the VOR gain level during training is represented by hatched bar).

In the 3 cats (CF3, C13/87, C16/87) tested with the in-phase combination paradigm, 2 of them, CF3 and C16/87, showed a clear absence of any decrease in the VOR gain and cat C13/87 showed a mild decrease in VOR gain.
(23%) of the VOR<sub>D</sub> gain from 0.62 before to 0.48 after 4 hours of training (Figure 2B, C, and D).

**Discussion**

The principal conclusion of our experiments is that cats who have a commissural brainstem section are not able to adapt their VOR gain with the classical visual-vestibular stimulation procedure. To validate this result, we must be able to prove, on the one hand, that the visual pathways mediating the visual input to the presumed center of VOR plasticity were not abolished and, on the other hand, that the VOR system after the recovery was still able to operate the performance asked by the adaptation stimulus.

**The Preservation of the Direct Visual Control of the VOR**

The preserved visual input to the VOR brainstem convergent circuit was clearly demonstrated by the optokinetic response recovery. Further the VOR gain in our lesioned cats was modified by visual information. The known anatomical relations between our incisions and the visual pathways also leads to the expectation that the visual input is preserved. Retinal-image slip signal is relayed via the accessory optic tract to the direction-selective cells of the contralateral nucleus of optic tract (21,22) from which visual signals reach vestibular and prepositus nuclei and travels via the central tegmental tract to the dorsal cap of the inferior olive. The inferior olive is considered an important pathway in the flocculus hypothesis of VOR adaptation (23-25) and also in the motor learning that compensates for vestibular damages (26). The visual afferent pathways to the inferior olive were not lesioned by our commissural section.

The efferent axons from the inferior olive (climbing fibers) cross the interolivary commissure and run along the lateral aspect of the contralateral medulla (27,28) before reaching the flocculus via the inferior cerebellar peduncle. The climbing fiber decussation is situated at the depth level of the inferior olive, and our midsagittal incisions never penetrated this lower part of the brainstem. Moreover, our surgical operation avoided any lesion of the lateral travel of the climbing fibers. Also another visual pathway reaches the flocculus via the mossy fiber projection from the nucleus reticularis tegmenti pontis (29). This rostral pathway (reaching the flocculus at the level of the brachium pontis and the trigeminal nerve) (30) is certainly not lesioned by our incisions.

**The Recovery of VOR<sub>D</sub> Mechanisms**

The next element in the scope of this discussion is related to the VOR<sub>D</sub> gain recovery after the commissurotomy. It is well known, that following nerve cell injuries, there can be molecular and neural events that restore functional operation of the system (reactive synaptogenesis) (31). For example, in the hemilabyrinthectomized cats, Korte and Friedrich (32) showed in the partially deafferented superior vestibular nucleus that the lesion might involve reactive synaptic reorganization of the unlesioned converging pathways. The same process of functional restitution could have operated in our brainstem incision. Nevertheless, other processes like substitution or functional shift (33) could also be implicated in the VOR<sub>D</sub> gain recovery.

We have recently showed in another series of commissural incisions (16) that when an incision was made up to the rostral part of the 6th nuclei only very little or no VOR and optokinetic gain recovery was possible. In these conditions the visual-vestibular combined testing is inappropriate to analyze any VOR adaptation. In this pathological situation, the cat cannot initiate any optokinetic response; we have no proof of the existence of the conventional retinal slip error input signal, fundamental for normal adaptation behavior. Nevertheless, these results show the importance of this rostral part of the commissural
fibers in the recovery process. Moreover, the comparison between these “nonrecovery” cats and the “recovery” cats tested in our present study point to the fact that recovery is possible only when a component of commissural fiber remains unlesioned. In this case the unsectioned fibers could mediate, via reciprocal connections in the whole integrator network (14,34), a readjustment of the VOR gain to a more convenient value. This VOR gain recovery process after brainstem lesion could be understood as an innate property of the integrator circuitry (35). For this view of the situation, our results prove that direct visual control of the VOR and the ability to increase VOR gain were not modified by the lesion.

In addition to a lesion of commissural fibers, the parasagittal incision also destroyed a part of the right MVN in cat CF3 and a part of the rostral left PH in cat C13/87. Recent neuroanatomical studies emphasized the reciprocal connections between the PH-MVN complex and the flocculus (36,37). These brainstem structures implicated in the final integrator (38-41) could be involved in the long latency modifiable VOR pathways (11,42), particularly if one also considers the PH-MVN projections to the dorsal cap of Kooy in the inferior olive (43,44).

The Absence of VOR Adaptation

The absence of adaptation to visual-vestibular forced stimulation could be explained by a “locked state of plasticity” acquired during the recovery. If the gain increase produced by some restorative function of the system had reached the highest physiologically possible level (saturation effect), then no further gain increase would have been possible even if the adaptive mechanism were intact. But if this were true, how can we explain the impossibility of gain decrease in the in-phase combination?

One possibility is that the lesioned animals are starting the adaptation training at relatively low gain values (around 0.6). The fact that most unlesioned animals have asymptotic gains of about 0.6 suggests that the adaptive mechanism might be able to tolerate that much retinal image motion. Since lesioned animals start at gain values around 0.6, even a perfectly intact adaptive mechanism might not be able to reduce adaptively the gain of the VOR.

A “locked state of plasticity” could also be created by aberrant neural circuitry which, even if functional for gain recovery, still might further prevent another kind of new artificial gain modulation (increased or decreased).

The Extent of the Lesion and the Vestibular Commissure

Classically, the vestibular commissure is thought to consist mainly of reciprocal connections between homonymous nuclei (45,46). But, in fact we must take into account some divergence of axons to more than one contralateral subnucleus (47-49). These latter studies favor a vestibular commissure model characterized by divergent contralateral projections. In accordance with this model, it was found in the cat (50) and in the monkey (51) that secondary vestibular neurons (HC) situated in the ventral part of the rostral medial vestibular nucleus mediating the horizontal VOR, HC neurons, and projecting to contralateral abducens nucleus gave rise to collaterals that emerged from abducens nuclei to terminate in the adjacent part of the rostral medial vestibular nucleus and on the prepositus nucleus PH. Other HC collaterals coursing caudally in the MLF, gave rise to branches that terminated in several areas, notably the caudal PH. The particular course of this part of the vestibular commissure could imply that any midline incisions (cats C16/87, C8/87), although situated caudally to the 6th nuclei, disrupted collateral arborizations and perturbed the divergent commissural projection.

We must also take into account the fact that any functional specificity that was attributed to the commissural system is not in accordance with the anatomical organization of these connections (49). For example, the ven-
central part of the HC nucleus, containing preoc-
ulomotor neurons, receiving excitatory input
from ipsilateral vestibular nerve, was not a
termination site of the vestibular commissure
(49). In this case, the influence of the com-
missural input on these premotor neurons can
only be mediated via the intrinsic connections
of the contralateral side. In this context, it ap-
peared that our parasagittal incision (in cats
CF3 and C13/87) disrupted these intrinsic
connections that probably are implicated in
the commissural function.

The Flocculus Hypothesis and the
Brainstem Commissurotomy

Careful histological examination of the
cerebellum ruled out any lesion of the 2 flocculi in our 4 lesioned animals. This is sup-
ported by a number of preserved physiological
functions. First, the gaze-holding system of
the brainstem lesioned cat was not modified;
flocculectomy produces a clear exponential
postsaccadic drift with a time constant of
1.5 s (52). Second, the excellent optokinetic
responses to sinusoidal full-field stimuli at
0.1 Hz for our midsagittal lesioned cats
(C16/87, C8/87) were clearly not comparable
with the very low gain OKN observed in the
cerebellecctomized cat (see Figure 3 in refer-
ence 53). Third, the flocculus appears to be
involved in the direct visual control of the
VOR. Ablation of the flocculus interferes
with the ability to produce this visual effect
(6,54). Thus, the preservation of direct visual
mechanisms related to the VOR in our le-
sioned cats was in accordance with an unle-
sioned flocculus. If gain modulation was
exerted by Purkinje axon activity on the VN
neurons, our commissural incision would not
directly change the Purkinje output modula-
tion. Unfortunately, the floccular machinery
was not capable of producing a new VOR
gain retention without commissural network
contribution.

Another explanation could be that the ad-
aptation processing in the flocculus is only
possible if all the input projections from the
VOR brainstem circuitry structures (ipsilat-
eral and contralateral prepositus and medial
vestibular nuclei) (55) are maintained intact.
Moreover, an absence of primary vestibulo-
cerebellar projection in the flocculus was re-
cently demonstrated in the rabbit (56). This
was also the case in the cat (Gerrits, personal
communication, 5 June 1990), as reported
previously by Brodal and Hoivik in 1964 (57)
and by Carpenter et al (58). These anatomical
observations stressed the importance of the
secondary vestibulocerebellar mossy fibers in
the transmission of the head velocity input to
the flocculus. In our lesioned cats, around
50% of these fibers were probably inter-
rupted, a fact which could greatly perturb the
floccular function.

Recently, Lisberger (12) proposed that one
of the sites of the motor learning is located at
the flocculus target neurons in the brainstem.
Moreover, on the basis of the study of Miles
et al (8,9), Lisberger suggests two sites of mo-
tor learning: (i) a primary site in the brain-
stem that mediates the change in the VOR
gain, (ii) a secondary site in the flocculus that
maintains contribution of the cerebellum to
eye movement at the appropriate level. This
dual conception was not contradicted by the
results of our commissural lesion. Indeed,
the floccular target cell recently identified by
Sato et al (59) and localized in lateral part of
the MVN could be involved in the positive
commissural feedback loop proposed by the
Galiana's model. This model shows that small
parametric changes in closed loop network
could have important repercussions on the
VOR adaptation processing (14). Further-
more, in a conceptual way Galiana's model is
not restricted to the vestibular commissure,
but could include a general transmidline sys-
tem through reticular pathways.

Commissurotomy and Reconciling
Views on VOR Adaptation Sites

At first sight, the absence of the forced
VOR adaptation in our commissurotomized
cat could be interpreted by the destruction of
the transmidline closed loop system. This implies a powerful role of the commissural system in the adaptation processing, but does not necessarily prove that the synapses involved in this loop were the only sites of the new VOR gain retention. However, the adaptive VOR plasticity could be considered like a widely distributed system working together and including the brainstem commissural pathways and the flocculus. Moreover, we could also imagine that the flocculus machinery works normally, but that the retention process in the brainstem is not possible without the commissural system.

The choice between these unproven possibilities requires alternative experimental approaches to better understand the relationship between the Purkinje cells, their vestibular target neurons, and the commissural brainstem network.

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