Vestibular Connections of the Brain Stem

B. E. GERNANDT AND C.-A. THULIN

From the Department of Physiology, School of Medicine, Gothenburg, Sweden

The afferent stream of impulses in the vestibular nerve elicited in response to stimulation of the receptors of the vestibular organ impinges upon the vestibular nuclei situated in the medullary and pontile portions of the brain stem. These nuclei give origin to fibers going to different regions and they are concerned with the completion of vestibular reflex arcs. It has been postulated that the nuclei of both labyrinths influence each other and also act on the motor nuclei by means of some internuncial relay (reticular formation). Histological studies (1–3) have shown the existence of fibers connecting the primary vestibular nuclei of one side to those of the other side.

Furthermore, numerous anatomical connections have been demonstrated between the vestibular nuclei and the reticular formation (3–6). Recent studies by Kempinsky and Wård (7) have shown that the vestibular nuclei contribute to the activity of this facilitatory region (8).

The present investigation is an attempt to study, by electrophysiological techniques, the influence of the connecting fibers upon the activity of the four pairs of vestibular nuclei and to record the activity which is released in the reticular formation when the receptors in the crista ampullaris are adequately stimulated by movement of the endolymph produced by acceleratory rotation.

Methods

All the experiments have been performed on cats which either were decerebrated or under light Dial anesthesia (0.35–0.40 cc. of Dial Ciba per kg. body weight being injected intravenously). A tracheal cannula was introduced in the usual way. Skin and muscles over the occipital bone were excised and the bone removed in order to expose the cerebellum which then was sucked out, uncovering an area, that included the fourth ventricle, from the inferior colliculi to a point just below the obex. This decerebellate preparation permitted easy access to the eighth nerves which could be sectioned as required. To prevent drying and cooling of the exposed part of the brain stem the tissue was covered by a layer of paraffin oil at body temperature. The temperature was maintained by occasional irradiation with an infrared lamp placed at a suitable distance from the cat's head.

The differential electrode consisted of a fine, enameled needle electrode with a diameter not exceeding 0.03 mm., the insulation of which had been removed from a minimal area at the very tip. A micromanipulator was used to place the electrode within the medulla oblongata or pons. The micromanipulator was provided with direct-reading scales showing the distance traversed by the electrode holder. In the first exploring experiments the exact site of the electrode tip in the brain stem was in addition checked by subsequent histological examination.

Electrical recording was done by means of a capacity-coupled amplifier and a

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cathode-ray oscillograph. The impulse discharge was observed on the screen of the
cathode-ray tube and listened to in a loud-speaker at the same time. At first the needle
electrode usually picked up activity from many units, but by handling the micro-
manipulator very gently while listening to the loud-speaker one could nearly always
adjust the electrode so as to make some impulses appear singly against the back-
ground activity.

Adequate stimulation (angular acceleration) of the vestibular organ was ensured
by placing the animal in an apparatus enabling the impulse traffic to be recorded
while stimulation actually is being applied (9, 10). Improvements recently added to
the apparatus now make it possible also to give artificial respiration throughout the
course of an experiment. The principle of the arrangement is that the air hose from
the Starling pump is coupled to a fixed holder directly above the upper drive shaft,
and air enters the hollow shaft via a coupling which bears against the aforementioned
holder. This device allows air from the pump practically without loss to reach the
animal during rotation.

RESULTS

Recording From Vestibular Nuclei. It is a fairly simple matter to record ac-
tivity from the vestibular nuclei during adequate stimulation of cats with intact
ipsilateral innervation. With the aid of the needle electrode activity can be recorded
from the cell bodies (9, 11, 12). Searching with the electrode is made easy by the
spontaneous activity which almost always is present and which is due chiefly to the
constant postural labyrinthine stimuli. By altering the position of the cat the head can
be placed so that the three pairs of semicircular canals can be brought into their
optimal position in turn; by this simple means it is possible to select the canal wanted.
On the whole, however, this investigation was confined to neurons activated by the
crista of the horizontal semicircular canal.

When recording from the vestibular nuclei (13), or from cell bodies in the ves-
tibular nerve (9), while angular acceleration of the animal's (cat) head influences
the horizontal semicircular canal, rotation towards the side of the unit from which
the discharge was recorded proved excitatory whereas rotation in the opposite di-
rection was inhibitory (type I response). Occasionally, however, it was possible to
record an excitatory response to rotation in both directions (9). Adrian (13) on the
other hand, observed excitation in response to bidirectional stimulation only when
recording the activity of the anterior semicircular canal of the cat. Such a discharge
(type II) in response to rotation in both directions was found once again in the
present investigation while recording from the vestibular nuclei with the horizontal
semicircular canal in the horizontal plane and the cat's head being located above the
axis of rotation. It occurred, however, only in a very small percentage of cases
(fig. 1).

The question as to the significance of the commissural fibers from the primary
nuclei of one side for the activity of the vestibular complex of the other side was
approached by cutting the eighth nerve ipsilaterally and contralaterally. However,
adequate stimulation of the contralateral vestibular organ produced no response
whatever from the ipsilateral vestibular nuclei after section of the ipsilateral nerve.
The result remained negative despite thorough and systematic searching throughout
the region where responses from vestibular nuclei could be found. The vertical semi-
circular canals, set in their optimal positions, were subjected to angular acceleration
in some experiments, but searching, if not quite as thorough as in the previous case,
produced no results this time either.
It should be noted, however, that a manifest difference was found between the vestibular nuclei of the two sides with regard to the spontaneous electrical activity. On the side of afferent nerve section this activity was appreciably reduced if not wholly eliminated. This obviously makes any attempt to isolate units a very hazardous game of chance. The electrode had to be inserted randomly into the various regions of the vestibular nuclei, before angular acceleration could be applied. Exceptionally the needle electrode encountered units exhibiting some degree of spontaneous activity. Yet the vestibular centers possess an activity which, being partly automatic, persists even after extirpation of the labyrinth (14, 15). Conceivably, too, the spontaneous activity might have been due to mechanical pressure by the electrode on the cell body in question. The activity was uninfluenced even by great angular accelerations. The needle electrode was never inserted deeper than about 1 mm. below the surface of the brain stem in order to obviate the risk of piercing the reticular formation or possibly the sensory trigeminal nucleus (9).

When the nerve on the contralateral side was cut, the responses to adequate vestibular stimulation which were recorded from vestibular nuclei with intact innervation were not appreciably altered. The isolated units showed, as before, an increased impulse frequency in response to rotation towards the recording side and an inhibition when the direction of rotation was reversed. Neither from this region nor from the vestibular nerve (9) was there at any time a contrary response to be recorded. Painstaking attempts were made to isolate units responding with an increased impulse discharge to rotatory stimulation in both directions, when the horizontal semicircular canal lay in the horizontal plane. It proved possible in seven instances to isolate this type of response. Clearly, therefore, these rather rare responses are truly peripheral in origin and not due to any interaction between the two vestibular organs. Considering the implications of the rarer type of response, mechanical principles would of course furnish the simplest explanation of the results obtained. The ability of the vestibular apparatus to signal rotation in either direction is presumably a useful faculty.

**Recording From the Reticular Formation.** When the impulse activity in the
reticular formation was recorded it proved possible to verify the existence of the interconnections demonstrated histologically between the vestibular nuclei and the reticular substance. Recording was done from the lateral reticular formation. Here the risks of interference from the crossed paths in the medial longitudinal fasciculus are not so great as in the medial part of the reticular formation. In this series of experiments the position of the electrode tip was at first checked histologically whenever the nature of the response was at variance with our knowledge of the responses recorded from the primary vestibular nuclei, thus confirming that the tip of the electrode had passed through the nuclei and into the reticular formation. If recording is done from the lateral reticular formation and the eighth nerves are intact, it will usually not take too long before the needle electrode encounters a well isolated unit whose activity can be influenced by adequate stimulation of the receptors in the horizontal semicircular canal. The responses now recorded, however, were not characterized by the relationship usually seen otherwise between the direction of the cupular deviation—ampullopetal or ampullofugal—and excitation and inhibition of the impulse activity. Sometimes the responses admittedly followed the rule \(\text{(type I)}\), but the contrary response might well be recorded when another unit was isolated in the reticular formation. In other words, rotation of the animal towards the side of recording completely inhibited the spontaneous activity and rotation in the opposite direction gave rise to an increase of the impulse discharge \(\text{(fig. 2)}\). The explanation of these results, which were so difficult to reconcile with the direction of rotation, could be that the stimulation affected the flow of endolymph not only in the horizontal semicircular canal, but in either or both of the other canals as well. It has been shown previously that this hardly can be the case \(\text{(16, 17)}\). In an earlier paper it has been demonstrated \(\text{(10)}\) that the activity in the reticulo-spinal pathways is influenced by a bilateral vestibular contribution. The primary nuclei of both labyrinths are connected to the reticular formation which forms a kind of internuncial relay acting as a fundamental element in the reflex arc. The bilateral impulse contributions from both labyrinths are transformed in this relay into excitatory and inhibitory impulses.
capable of influencing the primary motor neurons of the spinal cord. Additional confirmation was sought by cutting the eighth nerve on the side of recording. This excluded the possibility that the needle electrode within the reticular formation could have been recorded from units which would produce responses to angular acceleration conforming to the rule (type I). Nevertheless it was possible, after some searching, to find units whose responses indicated that the excitation was elicited by vestibular stimulation of the organ on the contralateral side. Although the reticular formation occupies quite a large portion of the brain stem, it can be demonstrated, by making local incisions in the middle line of the medulla, that the fibers of the crossed contribution to the reticular formation run fairly close together. A mid-line incision about 5 mm. long and 4 to 5 mm. deep at the level of the vestibular nuclei completely eliminates all signs of crossed contribution (fig. 3). During these experiments the animals were given artificial respiration. Responses indicating contralateral excitation could only be recorded from a comparatively limited part of the reticular formation. This suggests that the crossed fibers lie close together. Among the responses recorded from 63 isolated units in the reticular formation of cats with the eighth nerves intact, 42 obeyed the rule when vestibular stimulation was applied (type I). The remainder did not; suggesting a contralateral influence. The type responding with an increased impulse discharge irrespective of the direction of rotation (type II) was not encountered. However, since no particular search was made for such responses in this series of experiments, and considering that they in any case must be very rare, it would be unwarranted to rule them out. After the contralateral eighth nerve had been sectioned only the standard response (type I) was recorded from those isolated units which responded to angular acceleration of the receptors in the horizontal semicircular canal.

**DISCUSSION**

Histological studies (1, 3) have disclosed connections between the vestibular complex of one side and that of the other side. The root or commissural fibers are distributed to the upper end of the medial vestibular nucleus, to the medial half of the lateral nucleus, and to the descending nucleus (2). Perhaps, because of the small number of fibers involved and of their scattered distribution, it was not possible in the present work to record any electrical activity from them. It is scarcely reasonable to suppose that the intranuclear cell bodies receiving such connections are so small that the needle electrode cannot isolate them well enough to record a response adequate for further analysis. The lateral vestibular nucleus of Deiter is distinguished by its abundance of large cells of the motor type. The other three nuclei are composed of small and medium-sized cells. It would seem that such an assumption is scarcely tenable in view of the relative ease whereby isolation can take place from cell bodies within the vestibular nuclei, the ease whereby their activity can be influenced by stimulating the ipsilateral labyrinthine receptors, or by the simplicity of recording from cell bodies within the reticular formation. It is reasonable to assume that the existing structural differences between the various vestibular nuclei might bear some relation to the difference in function; but at the present time we are still far from being able to interpret these features.

Results directly opposed to those generally obtained when recording from vestibular nuclei with adequate stimulation of the receptors in the horizontal semicircular canal (type I) have neither been found by Adrian nor by the present author. Even the rare responses of type II cannot be attributed to bilateral influence from two
vestibular centers. Therefore it is hard to conjecture what functional significance can be attached to the fibers found by histological methods. The intimate interplay essential for the delicate reflex pattern which takes the form of compensatory movements of eyes and limbs consequently seems to bear little or no relation to the few direct connections between the two groups of vestibular nuclei. To accomplish this interplay there are available both the ascending and the descending, secondary vestibular pathways (crossed and uncrossed) which serve to place the motor neurons under the reflex control of the vestibular apparatus. We know, moreover, that the primary vestibular nuclei are connected to the reticular formation, which forms an internuncial relay, and from here the excitatory and inhibitory impulses also influence the primary motor neurons of the spinal cord.

Experiments have shown that the medial reticular formation is suppressor in function (18) while the lateral reticular formation is concerned with facilitatory activity (8). Kempinsky and Ward (7) were able to show that this facilitatory region is activated, at least partly, from the vestibular nuclei; and anatomical connections between the vestibular nuclei and the reticular formation have been demonstrated (3, 5, 6). Additional experimental confirmation of this was provided by the present work. It was shown by recording the impulse activity from the reticular formation in response to vestibular stimulation that the reticular formation is in connection with the vestibular nuclei on the same side as well as on the contralateral side. Isolation of cell bodies with modifiable activity in the reticular formation did not prove very difficult, but then there were in addition available the extremely numerous fibers from the vestibular nuclei to the reticular substance which contains a large amount of large and medium-sized polygonal nerve cells of motor type. The cells scattered throughout the formation account for numerous reflex connections within the brain stem and also give rise to reticulo-spinal fibers influencing the ventral horn cells of the spinal cord.

Starzl, Taylor and Magoun (19) have shown by electrical recording that the brain stem reticular system receives impulses relayed from somatic and auditory sensory structures. It is of interest from this point of view to be able to add the vestibular organs to the rest. However, our evidence is not in line with their assumption that the reticular system acts diffusely and indiscriminately as an excitatory or inhibitory regulator of mass effects. The vestibular responses are very definitely organized for reciprocal action on flexors and extensors, even when initiated from the reticular level by means of adequate vestibular stimulation and when the vestibulo-spinal path was sectioned (10).

**Summary**

Earlier histological studies have shown the existence of fibers connecting the primary vestibular nuclei of one side to those of the other. That these few and scattered fibers would mediate some of the activity from one group of nuclei to the other group of nuclei is an assumption which is not borne out by the present investigation involving electrical recording from these nuclei during simultaneous and adequate vestibular stimulation.

Anatomical connections between the vestibular nuclei and the reticular formation have also long been known. By recording the impulse activity generated in response to vestibular stimulation from isolated units in the reticular formation, it has been demonstrated experimentally that the formation is connected to both the homolateral and the contralateral vestibular nuclei.
REFERENCES