1) Objective/Significance
Vestibular inputs to the cerebral cortex are important for orientation in space, controlling body equilibrium and head and eye movements. However, vestibular representation in the cerebral cortex is poorly defined compared with other sensory modalities. The localization of the cortical vestibular area in the monkey was first determined around the rostral tip of the intraparietal sulcus by recording surface potentials evoked by electrical stimulation of the labyrinth. Later, two additional vestibular areas, one in the parietal and the other in the insular cortex, were identified in the monkey cortex. More recently, vestibular input to neurons in the periarcuate cortex was reported, but the exact location of the vestibular receiving areas, the relative strength of their vestibular input, and the existence of otolith input have not yet been determined.

Vestibulothalamic projection has been controversial. Vestibulothalamic projection was originally described by the degeneration method, but other studies failed to find this projection. The existence of vestibulothalamic projection was established by autoradiographic studies, and subsequently by retrograde axonal tracing methods, but there is still considerable disagreement between the various studies regarding the origin in vestibular nuclei and the termination in the thalamus.

The present study was performed to systematically survey vestibular-projection areas in the buried gyri in the periarcuate cortex of the monkey, and to characterize the termination and thalamocortical nature of the vestibular-projection area in relation to the smooth pursuit-related frontal eye field, by analyzing laminar field potentials evoked by vestibular-nerve stimulation.

2) Methods
Experiments were performed in six Japanese monkeys (Macaca fuscata) weighing 4.5–7.5 kg. The animals were anesthetized with ketamine hydrochloride (Ketalar, Parke-Davis; 10 mg/kg im) followed by α-chloralose (100-120 mg/kg iv initial dose) or pentobarbital sodium (Nembutal, Abbot, Switzerland; 5-10 mg/kg iv). Stimulating electrodes were placed on the oval and round windows on each side to stimulate the vestibular nerve, and one to three stimuli of 0.2 msec in duration were usually delivered between them at a maximum intensity of 500 µA. Cortical evoked potentials were mapped with a silver ball electrode on the surface of the cortex, and a tungsten electrode insulated in a glass micropipette was used to recording field potentials in the depth of the cortex.

3) Results
To characterize vestibular input to the periarcuate cortex in the monkey, we analyzed laminar field potentials evoked by stimulation of the vestibular nerve. We sought to determine whether the vestibular-projection area involved the smooth pursuit-related frontal eye field. Surface-potential mapping showed that vestibular potentials were evoked bilaterally in the periarcuate cortex around the junction of the spur and the superior and inferior rami of the arcuate sulcus. Laminar field potential analysis in the depths of the cortex showed that vestibular-evoked potentials consisted of early-positive and late-negative potentials and early-negative and late-positive potentials in the superficial and deep layers of the periarcuate cortex, respectively.
These potentials were evoked bilaterally. Selective section of the cochlear and facial nerves did not affect evoked potential profiles, indicating that these potentials were of vestibular origin. These potentials were distributed continuously in the fundus of the spur, and the fundus of the most caudal superior and the most medial inferior ramus of the arcuate sulcus including both the prearcuate and postarcuate areas. This vestibular-projecting area corresponded well to the distribution of corticovestibular neurons that were retrogradely labeled by injection of a tracer into the vestibular nuclei. Furthermore, the area of the vestibular projection overlapped the distribution of smooth pursuit-related neurons recorded in the pericruciate cortex including area 8 in the same monkey.

4) Potential for space experiment

The present result gives neurophysiological basis for understanding neural mechanisms of integrating information about space orientation and controlling movement under vestibular influences. This kind of fundamental knowledge is indispensable for our interpretation of findings on space orientation obtained from applied experiments in human not only in space but also on the earth. Information about the axis of gravity is sensed by vestibular receptors and this information is used for orienting the axis of the body relative to the earth. Cognitive processes for space orientation and central mechanisms of movement in space under 1G condition on earth have been learned. To reveal the important role of vestibular information for these functions, the research in zero G condition will be required in both higher mammals and humans in near future.

9. Publication List

1) Ebata, S., Sugiuchi, Y., Izawa, Y. and Shinoda, Y.: Vestibular inputs to parietal and insular cortices in the monkey - Laminar field analysis of vestibular-evoked potentials. (J. Comparative Neurology)

2) Sugihara, I., Ebata, S. and Shinoda, Y.: Functional compartmentalization in the flocculus and ventral dentate and infracerebellar nuclei; a study with analysis of single cerebellar axonal morphology. (J. Neurophysiology)


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