

Increased spine density in auditory cortex following visual or somatic deafferentation

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(Accepted February 24th, 1975)

Numerous investigations have demonstrated that the sensory systems of young animals are sensitive to experimental manipulations. In particular, the dendritic spines of cortical pyramidal cells have been shown to undergo changes following alterations in sensory input. Eye enucleation results in a reduced incidence of spines along the apical shafts of pyramidal cells in visual cortex, while light deprivation causes spine reductions or deformation in this same region of dendrite^{4,5,16,17}. Conversely, increased spine incidence has been demonstrated in rats reared under 'enriched' environmental conditions^{3,12}. The importance of such observations has been underlined by electron microscopic studies which have shown that dendritic spines are postsynaptic specializations and major sites of synaptic input to cortical pyramidal cells^{1,2,6,7}. Current evidence thus suggests that changes in spine density may reflect modifications in synaptic input.

In the present investigation we have concerned ourselves not with the changes occurring within a sensory system following deafferentation, but with changes occurring in intact sensory modalities. If spine density is reduced in a cortical area which has been partially deafferented, what changes occur in remaining cortical areas? Is the reduction in spine density limited to the sensory cortex of the deprived modality? Is there evidence of compensatory development in intact sensory modalities, expressed as increments in spine density? In order to explore these possibilities, we have observed the responses of pyramidal cells in primary sensory cortex to eye enucleation or mystacial vibrissae removal.

Three litters of rats, each containing 9 animals, were employed in the present study. Three animals from each litter served as control subjects. The remaining 6 animals were divided equally between the 2 experimental treatments: bilateral eye enucleation or mystacial vibrissae removal performed one day after birth by cauterization. One subject was later rejected when a normal eye developed. Subjects were sacrificed at 25 days of age, and sections of cortex were stained by the rapid Golgi technique⁴. Slides of auditory, visual and somatic sensory cortex were coded to prevent experimental bias, and spines were counted at $\times 500$ magnification (numerical aperture of objective 0.75). Only completely impregnated layer V pyramidal cells

whose soma were located 600–850 μm below the cortical surface were included in this study. In auditory and somatic sensory cortex, spines on a 40 μm segment of apical dendrite between 460 and 500 μm below the cortical surface were counted. This region corresponds to layer IV, the zone of specific thalamic input as determined by anterograde degeneration techniques^{9,10}. In visual cortex, spines on the segment of apical dendrite between 400 and 440 μm were counted. This also corresponds to the zone of specific thalamic input. (Killackey and Winslow, unpublished observation.) A minimum of 9 cells per subject was counted, and the median spine count for each subject was computed.

Fig. 1 presents individual counts and medians for auditory cortex. Significant increments in spines are noted in both experimental groups as compared with control subjects (enucleated *vs.* control group, $U = 0$, $P < 0.002$; vibrissaeless *vs.* control group, $U = 8$, $P < 0.02$; Mann–Whitney U-test, two-tailed analysis¹⁵). Based on group medians, these data suggest an increase of approximately 0.2 spines/ μm in experimental groups (control group = 1.19 spines/ μm ; enucleate group = 1.46 spines/ μm ; vibrissae removal group = 1.43 spines/ μm). In contrast with these findings, spine counts in somatic sensory cortex following eye enucleation or in visual cortex following vibrissae removal did not reveal any significant differences when compared with the same cortical area of normal rats (Mann–Whitney U-test, two-tailed analysis).

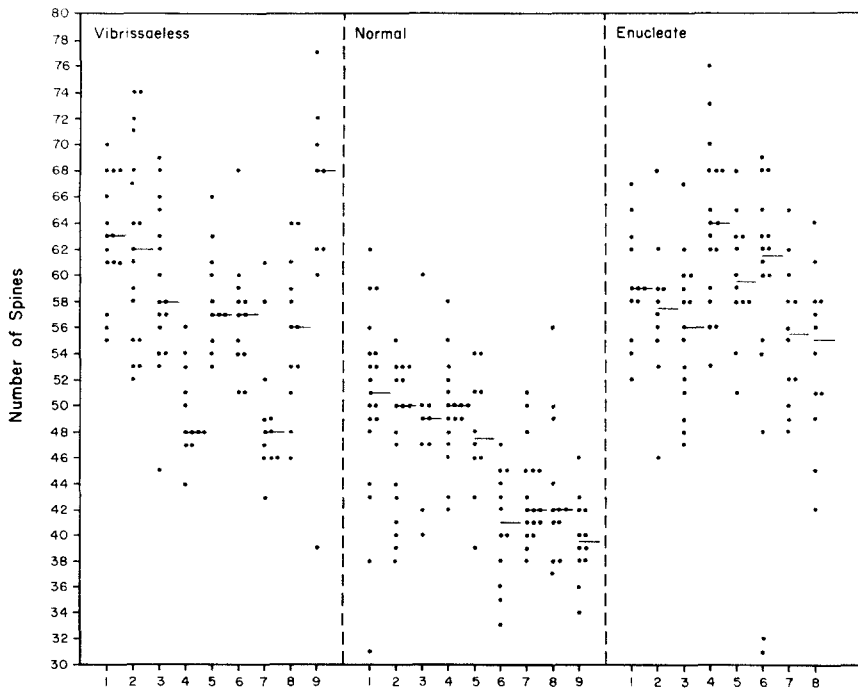


Fig. 1. Spine counts on 40 μm segments of layer V pyramidal cells in auditory cortex. Each dot represents a single pyramidal cell count and the solid lines represent the median for a single subject.

These results raise two important points for consideration. First, they suggest that spine losses following deafferentation are restricted to the cortical area of the afflicted sensory modality. Spine reductions were noted in somatic sensory cortex following vibrissae removal (Ryugo *et al.*, unpublished observations) and in visual cortex after eye enucleation¹¹. However, spine incidence remained unchanged in both cortical areas following damage to the other sensory modality. Similar results have been reported in light-deprived mice. Dark-rearing results in spine decrements in visual cortex, while spine density in the area prima temporalis (a region corresponding to somatic sensory cortex in the mouse^{18,19}) is unaltered¹⁶.

A second major point raised by the present results is the apparent sensitivity of the pyramidal cells of auditory cortex to deafferentation in either the somesthetic or visual system. This finding is in agreement with a previous experiment based on the Nissl stain which reported that cells within auditory cortex of the mouse undergo alterations in nuclear volume during the course of long-term light deprivation⁸. The present results, in conjunction with evidence that spines are a postsynaptic specialization^{1,2,6,7}, extend these findings and suggest either an increase or redistribution of synapses on auditory cortex pyramidal cells following damage to other sensory systems. However, our results shed no light on the extent of alterations undergone by auditory cortex pyramidal cells; likewise, the mechanisms underlying such changes are equally unclear. One possible interpretation is that increased spine incidence is a response to some 'trophic factor' released by a deafferented cortical area. Since auditory cortex lies adjacent to both visual and somatic sensory cortices, it may be particularly sensitive to trophic alterations in these cortical areas.

An alternative interpretation is that increased spine incidence reflects an increased use of the auditory system. Blinding or vibrissae removal may be interpreted as a form of auditory 'enrichment'. In this case the effect may be restricted to auditory cortex because of the early development and use of the auditory system in the rat. Behaviorally, it has been reported that high frequency sounds are the basis of a communication system between mother rats and their pups. In the course of normal rat development, this mode of communication becomes much less important following eye opening, possibly because it is supplanted by other sensory modalities^{13,14}. In the rat deprived of somatic or visual sensory input, the auditory system may assume heightened importance, resulting in increased utilization of the auditory modality. This increased use may be reflected in spine density increments, and in this sense may resemble responses previously noted in rats reared in 'enriched' environments^{3,12}.

This research was supported by N.S.F. Grant No. GB 41294 to H.P.K.

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