sensory" on the basis of both corticocortical connectivity and neuronal responses to more than one modality of sensory stimulation (13) also showed relatively high levels of [3H]naloxone binding. These fields included the superior temporal polysensory cortex (Fig. 2a), the ventral temporal polysensory cortex (14), part of the inferior parietal lobule (15), and the orbital frontal cortex (Fig. 3a) (14). The ventral temporal and orbital frontal fields had among the highest levels of binding in the cortex.

If increased opiate receptor density indicates greater functional importance, then the laminar and areal patterns of opiate receptors shown by the present investigation indicate that opiates are important in the modulation of specific cortical elements. It appears that opiates may predominantly influence the outflow of cortical fields and those fields involved in polymodal information processing and limbic functions.

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References and Notes


7. Although we refer only to opiate receptors in this report, it is recognized that the present binding conditions and ligand were selected to demonstrate the 3H-opiate receptor (8). The peptide-prefering 6 opiate receptor is thought to be distributed relatively homogeneously in the monkey cortex (3).


9. The cerebral cortex can be divided into three strata. These are, in order of increasing depth, the supragranular layers (layers I, II, and III), the internal granular layer (layer IV), and the infragranular layers (layers V and VI).

10. The term "perisrurate visual cortex" indicates area OB of (14), p. 73.


14. G. von Bonin and P. Bailey, The Neocortex of Macaca mulatta (Univ. of Illinois Press, Urbana, 1947). The ventral temporal polysensory cortex corresponds to their areas TF and TH, while the orbital frontal cortex is the inferior part of area FD.


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Retinogeniculate Terminations in Cats: Morphological Differences Between X and Y Cell Axons

Abstract. We injected horseradish peroxidase into single, physiologically identified, optic tract axons of X and Y cells in cats and studied their termination patterns in the lateral geniculate nucleus. All X cell axons innervate lamina A or AI in narrow zones, and some sparsely innervate the medial interlaminar nucleus. All Y cell axons have broad terminal zones in laminae A and C (from the contralateral retina) or lamina A1 (if ipsilateral), and most innervate the medial interlaminar nucleus densely.

The cat's retinogeniculocortical pathways are represented by W, X, and Y cells in the retina and in the lateral geniculate nucleus. These form three parallel, largely independent neural systems that appear to analyze different features of the visual scene (1). We know a great deal about physiological differences among these cell classes but little about morphological differences that underlie the physiology. This is because of the difficulty of directly identifying W,
X, or Y cells for morphological analysis. Such morphological knowledge is essential for our understanding of how these different neural systems are functionally organized. The different morphological features of geniculate W, X, and Y cells in cats (2) have been examined by the technique of intracellular injection of horseradish peroxidase (HRP) into physiologically identified neurons (3). We now describe our use of the same techniques to study the functional organization and morphology of X and Y cell retinogeniculate terminals. We found a number of morphological differences between these two physiological pathways, and these differences are important to the way retinal X and Y cells transmit visual information centrally.

Our general experimental methods have been described (2, 4). Optic tract axons were recorded first extracellularly within or ventral to the lateral geniculate nucleus (see Figs. 1, A and B, and 2, A and B), and they were identified as X cell or Y cell by standard criteria (5). They were then impaled. Identification was verified intracellularly, and then HRP was injected into the axon by iontophoresis with depolarizing pulses of up to 20 nA at 4 to 8 Hz for several minutes. After a 2- to 20-hour survival for each injected axon, the cat was killed for histological examination.

We have thus obtained structure-function correlates for 16 X cell and 12 Y cell axons. In this report, we describe the appearance of terminal zones within the main geniculate laminae [that is, the A and C laminae (6)]. The morphology correlates well with the X cell or Y cell physiological classification, but we found no obvious morphological correlate to on and off center responses. Figure 1, B to D, shows the morphology of a typical X cell terminal zone, and Fig. 2, B to D, does likewise for a typical Y cell terminal zone. Our data for Y cells confirm and extend those of Bowling and Michael (7). Five major morphological differences can be described between retinogeniculate X cell and Y cell axons. These include differences in axon diameter, axon location within the optic tract, regions of termination, geometry of terminal fields, and the structure and arrangement of individual boutons.

1) Within the optic tract, X cell axons are thinner than Y cell axons. We measured axon diameters to the nearest 0.5 μm (2). The mean diameter for 13 X cell axons that we could trace through the optic tract was 2 μm, and the range was 1.5 to 2.5 μm. The corresponding values for the 12 Y cells were 3 μm and 2 to 4 μm. Within the lateral geniculate nucleus, however, X cell and Y cell axons branch repeatedly before terminating. Since the preterminal branches of X cell and Y cell axons are equally fine, fiber diameter within the lateral geniculate nucleus should not be used to infer cell type.

2) Within the optic tract, X cell axons tend to lie dorsal to Y cell axons, with little or no overlap. All of the 13 X cell axons lie in the dorsal third of the optic tract. All of the 12 Y cell axons lie ventral to the X cell axons. These observations are consistent with prior reports that thicker axons are more ventrally located than thinner ones in the optic tract (8).

3) Y cell axons have more extensive and more widely branching terminal fields than do X cell axons. Every X and Y cell axon in our material exhibits a terminal zone in lamina A or A1, although terminal zones elsewhere are more variable (see below). From the contralateral retina, Y cell axons branch extensively to provide large terminal fields in laminae A and C and in the superior colliculus. Those from the ipsilateral retina branch to innervate lamina A1 and the superior colliculus. Most of the Y cell axons also densely innervate the medial interlaminar nucleus (a subdivision of the lateral geniculate nucleus), but a minority (5 of 12 in our sample) do not (Fig. 2B). In the earlier description (7), each of the nine recovered Y cells innervated the medial interlaminar nucleus. To date, we have not seen obvious physiological differences between Y cells that innervate the medial interlaminar nucleus and those that do not, nor do these groups of Y cells obviously differ with regard to their terminal zones within the A laminae. In contrast to the Y cell terminal zones, those of X cells lie only in lamina A or A1. However, 2 of the 12 X cell axons from the contralateral eye branch to yield a few terminals in lamina C. Eleven X cell axons continue posteriorly into the brachium of the superior colliculus (Fig. 1B). Of these, four issue sparse terminals into the medial interlaminar nucleus.

4) Perhaps the clearest difference between X cell and Y cell terminal zones lies in their geometry within the A laminae (see Figs. 1 and 2). The terminal zones of X cells are small and typically cylindrical, with the long axis perpendicular to the geniculate laminae. Y cell terminal zones are more variable in...
shape and much larger (roughly two to three times wider and almost an order of magnitude larger in volume than those of X cells). The mean width and range of terminal zones for X cell axons are 140 μm and 100 to 170 μm, and for Y cell axons are 293 μm and 220 to 410 μm. On average, more of the terminal zone of Y cell axons is distributed in the bottom half of lamina A or A1, whereas no such division is seen for the X cell axons. Within the medial interlaminar nucleus, Y cell terminations spread predominantly dorsoventrally.

5) The terminal boutons of X cell and Y cell axons generally differ (Figs. 1, D and E, and 2, D and E). Both have small spherical (< 2 μm in diameter), medium-sized spherical (2 to 5 μm), and large (> 5 μm) crenulated boutons (9). The X cell terminals more homogeneously consist of the medium-sized boutons, whereas the Y cell terminals are more heterogeneous. Furthermore, X cell boutons tend to cluster together, whereas those of Y cells tend to occur singly or on short, fine stalks (Figs. 1E and 2E). Consequently, X cell axons tend to have fewer boutons that occur in higher density than do those of Y cells.

Several of these morphological features can be related to those described for geniculate neurons (2, 10). (i) The narrower and more vertically arranged terminal zones of X cell axons closely match the dendritic geometry of geniculate X cells, whereas the wider terminal zones of Y cell axons are more closely related to the radial arrangement of geniculate Y cell dendrites. (ii) The observation that Y cell terminal zones are larger and more widely distributed than X cell terminal zones is consistent with the suggestion that more divergence occurs in the retinogeniculate Y cell pathway than in the X cell pathway, so that more geniculate Y cells than X cells are innervated by each optic tract axon. (iii) The clustering of X cell terminal boutons might be related to the clustered dendritic appendages that are a much more common feature of geniculate X cells than of Y cells.

The clear morphological differences between X and Y cell axons indicate that the X and Y cell pathways differ markedly in their retinogeniculate projections. Previously, morphological differences have been described between geniculate X and Y cells (2) and their cortical terminations (11). These data, then, reinforce the significance of the organization of the central visual pathways into cell types that can be physiologically distinguished. The anatomical differences in the X and Y cell pathways show that these indeed represent distinctly different neural circuits.

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References and Notes
4. The cats were anesthetized, paralysed, artificially ventilated, and optically refocused. Fine micropipettes filled with 3 percent HRP plus 0.2 M KCl and 0.05M tris and beveled to an impedance of 90 to 100 MΩ. The microelectrodes were placed through a hydraulically sealed cranial window and durotomy. Bipolar stimulating electrodes were placed across the optic chiasm to stimulate optic tract fibers. After the physiological data collection and HRP injections, the cats were given a large dose of barbiturate and perfused transcardially with saline and fixative. The brains were then removed, cut coronally at 100 μm, and reacted with 3.3'-diaminobenzidine. The reaction product was intensified by treatment with cobalt chloride. Further details can be found in (2).
5. X cell and Y cell axons were distinguished by the following criteria (see K.-P. Hoffmann, J. Stoner, S. M. Sherman, J. Neurosci. 38, 518 (1972); S. Hochstein and R. M. Shapley, *J. Physiol.* (London) 262, 237 (1976); M. H. Rowe and L. Stone, *Brain Behav. Evol.* 14, 185 (1977); S. Lehmkuhl, K. E. Kratz, C. S. Mangel, S. M. Sherman, J. Neurophysiol. 43, 420 (1980)). X cells respond linearly to counterphased, sine-wave gratings, whereas Y cells respond nonlinearly. X cell axons respond with a preference to optic chiasm stimulation than do Y cell axons (mean and range for X cells, 0.8 msec and 0.7 to 1.0 m sec; for Y cells, 0.4 to 0.7 m sec); X cells tend to have smaller receptive field centers than do Y cells; Y cell rounds respond to faster moving targets than do those of X cells.
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Hemispheric Asymmetries in the Behavioral and Hormonal Effects of Sexually Differentiating Mammalian Brain

Abstract. Estrogen pellets were placed in either the right or left hypothalamus of newborn female rats so that only one side of this brain area was exposed to the postsynaptic masculinizing and defeminizing effects of the hormone. The effects of estrogen on gonadotropin secretion and reproductive behavior depended on both the region and the side of implantation. Exposure of the left hypothalamus to estrogen resulted in defeminized development. Exposure of the right hypothalamus to estrogen resulted in masculinized development. Thus the response of the developing hypothalamus to gonadal steroids may be asymmetric.

During a restricted period of perinatal development, gonadal steroids act on the mammalian hypothalamus to masculinize or defeminize reproductive functions, including behavior (1). Masculinization increases male sexual behavior in adult males or females exposed to testosterone or its metabolite, estradiol (E2); defeminization decreases female sexual behavior and eliminates positive-feedback effects on the secretion of luteinizing hormone (LH) in adults exposed to E2. These two aspects of sexual differentiation are independent processes involving separate regions of the hypothalamus (2). We suggest here that the hypothalamus develops asymmetrically with respect to sexual differentiation. When we exposed only the left side of the hypothalamus of neonatal rats to gonadal steroid, development was defeminized. When we exposed only the right side of the hypothalamus to gonadal steroid, development was masculinized.

Between 24 and 48 hours after birth, 91 female rat pups received bilateral intrahypothalamic implants of steroid (3). Thirty control pups received implants of cholesterol. Experimental females received E2 on one side (31 right, 30 left) and cholesterol on the other. We used E2 as the hormonal stimulus for sexual differentiation because it is the active metabolite of testosterone for this process