Thalamocortical Synapses of Pyramidal Cells Which Project From Sml to Msl Cortex in the Mouse

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ABSTRACT
Electrolytic lesions were made of the nucleus ventralis posterior pars lateralis thalami and of the nucleus posterior thalami in male CD/1 mice to label thalamocortical axon terminals in mouse Sml cortex. Pyramidal cells in layers II through V of Sml cortex were labeled by the retrograde transport of horseradish peroxidase injected into ipsilateral MsI. Numerous pyramidal cells, particularly in the more superficial layers of Sml cortex, were filled with reaction product so that even their dendritic spines and local axon collaterals were clearly visible. Six well-filled pyramidal cells with somata in layers III and IV were serial thin-sectioned, and portions of their dendrites in layer IV were examined with the electron microscope to determine the distribution of their thalamocortical and other synapses. It was found that, in general, different dendrites of a single pyramidal cell formed similar proportions of thalamocortical synapses and that the six pyramidal cells, as a group, also formed similar proportions of thalamocortical synapses with their dendrites in layer IV. In contrast, when the thalamocortical connectivity of the six cells was considered as a function of their depths within the cortex, a clear trend was seen for the proportion of thalamocortical synapses to increase with increasing proximity of the cell body to layer IV. A hypothesis based on the timing of developmental events is proposed to account for this observation.

Layer IV of mouse Sml cortex contains a set of multicellular units named barrels (Woolsey and Van der Loos, '70); the larger barrels comprising the postero medial barrel subfield (PMBSF) receive input from sensory receptors associated with the contralateral mystacial vibrissae (Pidoux and Verley, '79; Simons, '78; Simons and Woolsey, '79; Verley and Gaillard, '78). Each PMBSF barrel contains a dense tangle of thalamocortical afferents whose terminals form synapses with dendrites and cell bodies of a variety of neuronal types (see White, '79). Previous studies have shown these various neuronal types to differ in the numbers and proportions of their synapses which are thalamocortical (White, '78, '79; Hersch and White, '81a,b; White and Rock, '79, '80, '81); however, the variability of thalamocortical synaptic connections within a single class of nerve cells has yet to be determined. In this study, the retrograde transport of horseradish peroxidase has been used to produce Golgi-like labeling of pyramidal cells with axonal projections from PMBSF cortex\textsuperscript{1} to the ipsilateral MsI area. The projection from Sml to MsI had been demonstrated previously by the anterograde transport to mouse MsI cortex of radioactive materials injected into ipsilateral PMBSF cortex (White and DeAmicis, '77), but the neurons of origin of the pathway had not been identified. By labeling these neurons in animals with lesioned thalami, it has been possible to examine the thalamocortical and other synaptic connections of a class of neurons having in common an axonal projection to MsI. The results of this effort not only provide insight into the variability of thalamocortical synapses among different members of a single class of nerve cells, but they also provide a basis for continuing efforts to determine the variability of thalamocortical synaptic connections among different classes of neurons defined by their axonal projections.

METHODS
Electrolytic lesions were placed in the nucleus ventralis posterior pars lateralis thalami (Sidman et al., '71) of four, approximately 2-month-old, male CD/1 mice. The lesion in-

\textsuperscript{1}The term PMBSF cortex is used to refer to the entire thickness of that region of Sml cortex containing the PMBSF within its fourth layer.
cluded part of the nucleus posterior thalami and all of its projection to PMBSF cortex, but did not damage any other pathways to or from PMBSF cortex (see White and DeAmicis, '77). Three days later, three closely spaced injections, each of 0.025 to 0.03 μl of 40% horse-radish peroxidase (HRP, Miles Laboratories Ltd.), were placed in the region of MsI cortex which receives a projection from neurons in ipsilateral PMBSF cortex. On the day following these injections, each animal was perfused with a solution containing 2.0% glutaraldehyde and 0.5% paraformaldehyde buffered to pH 7.3 with 0.1 M Sorensen's phosphate. Shortly thereafter, the thalamus was removed and frozen-sectioned to assess the placement and extent of the lesion. Within 6 hours of the death of the animal, the cerebral hemisphere ipsilateral to the injection and lesion sites was tissue-chopped in the coronal plane and the 125-μm-thick sections reacted for HRP by the diaminobenzidine/cobalt chloride technique of Adams ('77). Our procedure differed from that described by Adams in that the sections were soaked for 20 minutes in 0.05% diaminobenzidine and then placed for an additional 20 minutes in a fresh solution of 0.05% diaminobenzidine containing 0.01% H₂O₂. The sections were then rinsed with 0.1 M phosphate buffer and stained for one-half hour with 0.2% OsO₄ and 2.4% K₂Cr₂O₇ in 0.1 M phosphate buffer followed by one-half hour in 1.0% OsO₄ dissolved in the same buffer. This procedure avoided the excessive darkening which occurs when 125-μm-thick sections are exposed directly to 1.0% OsO₄. Following osmication, tissue-chopped sections through PMBSF cortex were stained for 1 hour with 1.0% uranyl acetate dissolved in 70% methanol, dehydrated in graded alcohols and propylene oxide, and embedded in epon/araldite. Six neurons in PMBSF cortex whose dendritic trees were well filled with HRP were photographed and drawn, and selected portions of these neurons examined in unbroken series of thin sections mounted on formvar-coated slot grids and stained with lead citrate. Every profile of selected, labeled dendrites was photographed in each thin section of the series at an initial magnification of 6,000 ×. The electron micrographs of each thin section were montaged and placed in “best-fit” registration with montaged micrographs of adjacent sections. The outlines of labeled profiles and their synapses were then traced from successive montages onto a single sheet of paper. This procedure enabled the spatial and synaptic relationships of the labeled dendrites to be determined.

Thalamocortical axon terminals were identified by the high degree of electron density characteristic of the later stages of terminal degeneration in mammalian cerebral cortex (e.g., Jones and Powell, '70), and in particular, in mouse PMBSF cortex following survival times of 4 days (White, '78). The possibility that some degenerating axon terminals belonged to axons injured at the injection sites in MsI was discounted, because large lesions of MsI produce no degenerating terminals in PMBSF cortex following 1-day survival periods (E.L.W., personal observation).

RESULTS

Light microscopy

The injections were placed at mid-depth in MsI cortex so that the white matter was not damaged. Dense HRP reaction product extended for a radius of about 0.75 mm around the injection sites and little cellular detail was evident within this region. A few labeled neurons occurred at the periphery of the densely stained area, but no labeled cells were observed between this region and the focus of retrogradely labeled cells situated about 2 mm away in ipsilateral PMBSF cortex. In PMBSF cortex, many pyramidal cell somata in layers II through V were lightly labeled by a granular deposit of HRP; however, numerous pyramidal cells, particularly in the more superficial layers of PMBSF cortex, were filled with reaction product in such a way that their cell bodies, dendrites, spines, and axons were clearly visible with the light microscope (Figs. 1, 2). The majority of these cells occurred in layers II and III and usually they had no dendrites extending into the main zone of termination of thalamocortical afferents within layer IV. Since one of the principal goals of this investigation was to examine thalamocortical synapses in layer IV with identified neurons, cells selected for further examination were those HRP filled cells having at least part of their dendritic tree within that layer. Drawings of the dendritic configurations of the six pyramidal cells examined and their spatial relationships with layer IV of PMBSF cortex are given in Figure 3.

Electron microscopy

Portions of the six HRP-filled neurons were easily recognizable in thin sections because their profiles contained a high concentration of electron-dense HRP reaction product. Certain organelles, including the Golgi apparatus, mitochondria, and microtubules usually were visible within their somata and dendrites (Figs. 4, 6), but others, such as ribosomes and endo-
Fig. 1. Light micrograph of a coronal section through PMBSF cortex showing pyramidal cells labeled by HRP injected into ipsilateral MsI cortex. Cortical layers are indicated at the left. Cell C (arrow), whose soma occurs at the layer III/IV border (see Fig. 3), has dendrites in layer IV whose synaptic connections were examined with the electron microscope. In general, many more neurons in layers II through IV than in layer V are fully and heavily labeled with retrogradely transported HRP. × 260.
Figure 2
plasmic reticulum, often were not identifiable in the blackness of the HRP reaction product filling the labeled profiles. Synapses with labeled profiles were identified as asymmetrical (e.g., Fig. 5) or symmetrical (e.g., Fig. 6) according to the usual criteria (Colonnier, '68); however, in some instances, the differentiation of synaptic types was complicated because an extensive deposit of electron-dense material adjacent to the cytoplasmic surface of the post-synaptic membrane could be interpreted either as HRP reaction product or as the plaque of postsynaptic dense material characteristic of an asymmetrical synapse. In these instances, the type of synapse was tentatively identified by presuming that flattened synaptic vesicles and narrow synaptic clefts were associated with symmetrical synapses and round vesicles and wider synaptic clefts with asymmetrical synapses (see Peters et al., '76). The identity of these unclear synapses was later resolved by tracing the presynaptic element in the series of sections until it made unequivocally asymmetrical or symmetrical synapses with unlabeled postsynaptic elements, the presumption being that individual axons consistently form the same type of synaptic junction. The possibility that single axons form heteromorphic synapses has been raised by Kane ('73) in her study of the central synapses of VIIIth nerve fibers in the cat, but in our experience, this does not occur in barrel cortex.

The synaptic patterns of labeled profiles were consistent with the known distribution of synaptic types on superficial pyramidal cells (Peters and Kaiserman-Abramof, '69; LeVay, '73; Parnavelas et al., '77; Christensen and Ebner, '78; Davis and Sterling, '79): Cell bodies formed only symmetrical synapses and these predominated on dendritic shafts and spines, whereas asymmetrical synapses predominated on spines. On several occasions, spines of HRP-labeled pyramidal cells formed synapses with axon terminals which also contained HRP reaction product. Presumably, these labeled terminals belonged to afferents from MsI labeled by the anterograde transport of HRP or, alternatively, they belonged to axon collaterals of pyramidal cells in PMBSF cortex labeled by the retrograde transport of HRP.

Each neuron examined possessed dendrites in the fourth layer of PMBSF cortex, and some of these dendrites were graphically reconstructed from serial electron micrographs to determine the distribution of their synapses (see Fig. 3). Most reconstructed dendritic segments were contained within layer IV, but short proximal lengths of dendrite belonging to cells A and B occurred in the border region between layers III and IV. Specific information on the synaptic relations of the reconstructed dendrites is given in Table 1, which provides the lengths of the reconstructed dendrites, data on the total number of symmetrical and asymmetrical synapses with their shafts and spines, the number of thalamocortical synapses, and percentages showing the number of thalamocortical synapses as a function of the total number of asymmetrical axospinous synapses per dendrite.

Thalamocortical synapses with the reconstructed dendrites were all of the asymmetrical type and were made only with spines. Most reconstructed dendrites formed few thalamocortical synapses (Figs. 3, 7, 8), and usually these represented small proportions of their total axospinous synaptic input (Table 1). Other reconstructed dendrites formed larger numbers and proportions of thalamocortical synapses. To determine if the number of thalamocortical synapses formed by the reconstructed dendrites was related to the concentration of thalamocortical synapses in the fields of neuropil through which they passed, counts were made of all synapses occurring in small volumes of neuropil at 10- to 20-μm intervals along the reconstructed processes. Results showed the percentage of thalamocortical synapses in 14 samples of neuropil taken from a region including the layer III/IV border and upper layer IV to average 9.16% ± 0.69 S.E., whereas the percentage of thalamocortical synapses in 22 samples obtained from a region spanning approximately the lower eight-tenths of layer IV averaged 16.18% ± 0.62 S.E. A consideration of the specific counts in conjunction with the distribution of thalamocortical synapses with the reconstructed dendrites indicated that neither the number nor the proportion of thalamocortical synapses impinging on

Fig. 2. Montage of two light micrographs taken at different planes of focus showing, in coronal section, a pyramidal cell retrogradely filled by HRP injected into MsI cortex. Even fine processes, such as the axon (ax) and dendritic spines are labeled with HRP. Portions of the cell's dendritic tree which occur beyond the planes of focus shown are depicted in Figure 3 (cell D). Figure 4 shows a thin section through the soma of this neuron. × 700.
Fig. 3. Drawings of six HRP-filled pyramidal cells whose somata occur in layer III (cells A and B), at the layer III/IV border (cells C and D) or in layer IV (cells E and F). Spines and the distal portions of apical dendrites have been omitted from the drawings. Dendrites enclosed by dotted lines were examined in serial thin sections to determine their lengths and synaptic relationships (see Table 1). Stars indicate synapses with degenerating thalamocortical axon terminals. For cell C, $d_1$ refers to a short length of proximal dendrite giving rise to daughter branches $d_1$ and $d_2$. Here, and elsewhere, the designation for a dendrite (e.g., "$d_1"$) refers to the entire dendrite from where its proximal end first crosses the dotted line. Thus, for example, $d_1$ of cells C, D, and F includes in each instance two tertiary dendritic branches and the relatively short secondary dendrite giving rise to them. The local axon collaterals of cells E and F were traced in serial sections and their synapses identified (see text). $a_x$, Axon. bar (between III and IV) equals 40 μm.

The reconstructed dendrites was directly related to the concentration of thalamocortical synapses in the surrounding neuropil. For example, the secondary dendrites $d_1$ of cells C and D form essentially the same numbers and proportions of thalamocortical synapses ($\text{Chi}^2 = 0.052, P = 0.82$, and see Table 1)\(^3\), and yet $d_1$ of cell C passed through fields having a concentration of thalamocortical synapses 70% higher (three samples averaging about 12%) than that contained within the fields through which $d_1$ of cell D passed (three samples averaging about 7%). A second example is provided by the thalamocortical connections of basal dendrites $d_1$ and $d_2$ of cell F. These dendrites, of nearly equal length and endowed with similar numbers of spines, each passed through neuropil in which about 18% of the synapses were made by degenerating thalamocortical axon

\(^3\)Chi² tests assess the significance of the difference between the observed results and what would be expected if the populations were identical in the characteristics being tested. The higher the value of Chi², the greater the probability that the populations differ significantly in the characteristic being tested, and conversely, the lower the value of Chi², the greater the chance that the populations are the same.
terminals (three samples per dendrite), but one dendrite ($d_1$) formed only two thalamocortical synapses whereas the other ($d_2$) formed 13. Incidentally, the small proportion of thalamocortical synapses formed by dendrite $d_1$ of cell F was one of two exceptions to the general rule confirmed by $\chi^2$ tests that dendrites of a single neuron formed similar proportions of thalamocortical synapses. The other exception was the large proportion of thalamocortical synapses formed by the short primary dendrite ($d_p$) of cell C.

Data shown in the last two columns of Table 1 indicate a tendency for the proportion of thalamocortical synapses with the reconstructed dendrites to increase in direct relation to the depth of the parent cell body within the cortex (see footnote 2, Table 1). This tendency was confirmed by the results of two $\chi^2$ tests. One was a three-category test comparing the proportion of thalamocortical synapses formed by cells A and B with the proportion formed by cells C and D, and by cells E and F: $\chi^2 = 5.75$, $P = 0.056$. The same test excluding dendrite $p$ of cell C yielded a $\chi^2$ of 7.16, $P = 0.027$. The second test compared the thalamocortical connectivity of cells A and B, whose somata occurred in layer III, with that of cells E and F, whose somata occurred in layer IV: $\chi^2 = 3.54$, $P = 0.059$. That the values of 0.056 and 0.059 are nearly statistically significant at the 0.05% level indicates a strong tendency toward a real difference in the thalamocortical connectivity of cells at different cortical depths. Other $\chi^2$ tests showed insignificant differences in the proportions of thalamocortical synapses formed by reconstructed dendrites whose somata were situated at similar depths within the cortex. For this analysis, data on the proportion of thalamocortical synapses formed by...
Fig. 4. Electron micrograph of a thin section through the soma and apical dendrite of cell D (Fig. 3). The Golgi apparatus (g) and mitochondria (m) are visible within the cytoplasm as are microtubules (unlabeled) in the apical dendrite, but most other cytoplasmic organelles are obscured by the HRP reaction product. × 8,000.
Fig. 5. Electron micrograph of a thin section through dendrite (D) d of cell C showing the asymmetrical synapse of an axon terminal (A) with one of the dendrite's spines (S). Inset at upper right printed to better show postsynaptic dense material. × 78,500.

Fig. 6. Electron micrograph showing a symmetrical synapse between an axon terminal (A) and dendrite (D) d of cell D. m. Microtubules. × 82,500.
TABLE 1.

<table>
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<tr>
<th>Cell</th>
<th>Length in μm</th>
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<th>Spinal synapses</th>
<th>Thalamocortical synapses</th>
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1In this column, thalamocortical synapses are expressed as a percentage of all asymmetrical axospinous synapses with the reconstructed dendrite. Generally, lesion-induced degeneration is considered unreliable for the quantification of thalamocortical synapses because of the varied time course of thalamocortical axon terminal degeneration. However, in mouse PMBSF cortex, thalamocortical axon terminals degenerate simultaneously, and so in this system lesion-induced degeneration may reliably indicate the numbers of thalamocortical synapses (for discussions of this issue, see White, '78, '79).

We propose to the reader that this is an abnormally high, unrepresentative value considering the length of the dendrite is so short and the number of spines on it very small. Excluding this value yields an average of about 4% for thalamocortical synapses formed by cells C and D whose somata occur at the layer III/IV border. In contrast, the percentage of thalamocortical synapses formed by dendrites of layer III cells A and B averages about 2.4, and that of dendrites belonging to layer IV cells E and F about 6.5.

The axons of cells E and F were followed in serial thin sections from their respective somata until the origins of their axon collaterals shown in Figure 3. The axon of cell E became myelinated about 20 μm from its cell body, and then emitted the collateral shown in Figures 9 and 10, whereas the axon of cell F gave off its collateral and, only then, became myelinated about 60 μm from the cell body. Both collaterals remained unmyelinated for the approximately 40 μm they were followed, and their terminals formed only asymmetrical synapses (e.g., Figs. 11, 12) whose postsynaptic elements, 12 in all, were evenly divided between dendritic spines and the shafts of nonspiny dendrites. Each nonspiny dendrite formed numerous other asymmetrical and symmetrical synapses. These results are consistent with synaptic connections previously elucidated for the axon collaterals of pyramidial cells in rat visual cortex (Parnavelas et al., '77; Somogyi, '78) and in monkey visual (LeVay, '73) and motor cortex (Sloper and Powell, '79).

One terminal of the axon collateral of cell E synapses with a spine which, like its parent dendrite, was lightly labeled with HRP (Fig. 12). We interpret this to mean that direct synaptic connections exist between pyramidial cells in PMBSF cortex which project ipsilaterally to MsI.

**DISCUSSION**

Pyramidal cells of layers II through V of mouse PMBSF cortex were labeled by the
retrograde transport of HRP injected into ipsilateral MsI cortex and the synaptic connections of portions of six well-labeled pyramidal cells were examined. Before discussing various aspects of these synaptic relations, it seems necessary to briefly discuss this hitherto uncommon application of the HRP retrograde transport method to the study of synaptic organization.

Since its introduction in 1972 (LaVail and LaVail), the HRP retrograde transport method has been utilized extensively at the light microscopic level to identify the types of neurons giving rise to axonal projections. Most often, only neuronal somata and proximal dendrites are labeled by the retrograde transport of HRP, but under certain conditions, the HRP completely fills the labeled neurons, producing a Golgi-like picture in which even fine processes such as dendritic spines are visible (Adams and Warr, '76; DeOlmos and Heimer, '77; Keefer et al., '76; Hedreen and McGrath, '77; Vanegas et al., '77; Keefer, '78; White et al., '80). This phenomenon has only recently been used to study specific synaptic connections of identified neurons (Hornung and Garey, '80; White et al., '80); the technique more commonly employed for this being the Golgi-gold toning method developed by Fairén et al., '77 (see White, '79). Each method has its advantages: Under the right conditions, injections of HRP consistently produce large numbers of well-labeled neurons which can be demonstrated in far less time than is usually required for the Golgi impregnation of neurons and, in addition, the HRP method provides information on the distant axonal projections of the labeled cells. Furthermore, in our experience, local axonal projections, whether myelinated or not, are demonstrated much more frequently by the HRP than by the Golgi method (White et al., '80). However, as yet, no way is known to control the intensity of HRP labeling, which in some neurons is great enough to cause difficulties in studying their fine structure and synaptic connections. This is much less of a problem with the Golgi-gold toning method, in which the intensity of the gold label can be controlled by varying the lengths of certain steps in the procedure. Recently, Somogyi et al. ('79) employed the Golgi-gold toning method to fill in extrasomatal parts of neurons which had been only incompletely filled by retrograde transport of HRP. This approach should prove valuable when conditions prevent the complete filling of neurons by the retrograde HRP method.

Each pyramidal cell labeled with HRP projects to the area of ipsilateral MsI cortex presumed to be involved with the large mystacial vibrissae (see White and DeAmicis, '77). This projection had been demonstrated previously by the anterograde transport to mouse MsI cortex of radioactive materials injected into ipsilateral PMBSF cortex (White and DeAmicis, '77). Similar projections have been shown by this method, and by anterograde degeneration, to occur in the rat (Akers and Killackey, '78), cat (Jones and Powell, '68), and in monkey (Jones and Powell, '69; Vogt and Pandya, '77; Jones et al., '78). In the monkey, the retrograde transport of HRP has likewise shown the SmI to MsI projection to arise from pyramidal cells of layers II, III, and V (Jones and Wise, '77). These findings indicate that neurons in primary motor cortex have direct access to sensory information relayed through SmI and derived initially from peripheral sensory receptors. The possibility that neurons in primary motor cortex receive sensory input via pathways which do not pass through SI is likely (see e.g., Kruger and Porter, '58); however, the basic premise that sensory messages emanating from the periphery ultimately impinge on motor cortex in order to guide the performance of motor acts appears sound. For more extensive discussions of this thesis the reader is referred to papers by Jones and Porter (70) and Jones et al. ('78), who point out that direct projections from sensory to motor areas of the cerebral cortex may, for example, form the substrate for a mechanism whereby sensory feedback could inform neurons in motor cortex of any mismatch between actual and intended movements. The existence in the mouse of a direct pathway from SmI to MsI provides the anatomical basis for such a mechanism in this animal, which may operate to help direct whisking, facial, or body movements elicited in response to input from sensory receptors associated with the mystacial vibrissae.

Dendrites of each of the six pyramidal cells examined with the electron microscope form thalamocortical synapses. Considered as a group, these pyramidal cells form similar proportions of thalamocortical synapses; however, it seems reasonable to conclude that cells such as E and F which have most of their dendritic fields confined to layer IV, form overall a significantly higher proportion of thalamocortical synapses than neurons such as cells A and B, which have most of their dendritic trees outside of layer IV. Moreover, many superficial pyramidal cells projecting from SmI to MsI have no dendrites within layer IV, and although their apical dendrites might form some thalamocortical synapses in layer I, presuma-
bly, these would not be as effective a stimulus as the large numbers of thalamocortical synapses formed with dendrites of the layer IV pyramids. For these reasons, it seems likely that the pathway from SmI to MsI cortex contains axons of neurons which are influenced to markedly different extents by ascending thalamocortical input.

The finding that each pyramidal cell examined forms thalamocortical synapses is consistent with previous studies indicating thalamocortical synapses to be formed in layer IV of mouse PMBSF cortex with all cells having dendrites in this layer (White, '78, '79; White and Rock, '79, '80, '81; Hersch and White, '81a,b). These studies also show individual neurons to differ considerably in the proportion of thalamocortical synapses they form (see especially White and Rock, '80; Hersch and White, '81b), but until now, there has been no concerted effort to examine the variability of thalamocortical synaptic connections among members of a single class of neurons. Present results indicate that superficial pyramidal cells projecting from mouse PMBSF cortex to ipsilateral SmI form similar proportions of thalamocortical synapses with their dendrites in layer IV. However, when the thalamocortical connectivity of these cells is considered as a function of their depth within the cortex, there is an evident trend for the proportion of thalamocortical synapses to increase with increasing proximity of the cell body to layer IV. This tendency might be related to differences in the concentrations of thalamocortical synapses in different regions of the layer IV neuropil. For example, descending dendrites arising from pyramidal somata situated in layer III must pass for relatively long distances through fields of neuropil containing comparable concentrations of thalamocortical synapses (about 9%). By contrast, layer IV dendrites belonging to pyramidal somata situated within this layer consistently traverse neuropil containing much higher concentrations of thalamocortical synapses (about 18%), and for this reason might be expected to form higher proportions of thalamocortical synapses than dendrites belonging to more superficially located somata. The problem with this interpretation is that the available evidence suggests the proportion of thalamocortical synapses formed by a neuron to be largely independent of the concentration of thalamocortical synapses within the fields through which its dendrites pass. For instance, a study of thalamocortical input to two non-spiny cells whose dendrites course within a single PMBSF barrel, through fields of neuro-

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unpublished results using the Golgi method to study the development of neocortical neurons suggest this to be true (M. Miller, personal communication).
In general, different dendrites of single pyramidal cells form comparable proportions of thalamocortical synapses. Previous studies have yielded similar results in that the several dendrites of a layer IV spiny stellate cell each form about 13% of their asymmetrical axospinous synapses in layer IV with thalamocortical afferents (White and Rock, '80), and the different dendrites of two nonspiny neurons form, respectively, about 3 and 17% of all their synapses in layer IV with thalamocortical afferents (White and Rock, '81). These findings imply that the dendrites of individual neurons are specified to receive a certain proportion of their synaptic input in layer IV from the thalamus. Whether this specification is intrinsic to the neuron in the sense that each cell is genetically programmed to form a certain proportion of thalamocortical synapses, or whether the proportion of these synapses simply reflects the timing of developmental events such as outlined above, or both, remains to be determined.

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