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POST-NATAL DEVELOPMENT OF THE RETINAL AND CEREBELLAR PROJECTIONS ONTO THE LATERAL SUPRASYLVIAN AREA IN THE CAT

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SUMMARY

1. Post-natal development of the retinal and cerebellar projections onto the medial bank of the lateral suprasylvian visual area was examined by using the field potential method and, additionally, by the orthograde horseradish peroxidase method.

2. Optic nerve stimulation elicited a surface-positive, depth-negative field potential in the medial bank of the lateral suprasylvian area of adult cats. By contrast, in kittens younger than 3 weeks old, a surface-negative, depth-positive field potential was evoked. The response grew adult-like by 1 month of age. Corticocortical response, activated by stimulation of cortical areas 17 and 18, underwent a similar developmental change.

3. Cerebellar stimulation evoked a surface-negative, depth-positive wave from birth up to adulthood. Thalamocortical afferents from the ventroanterior and ventrolateral nuclei of the thalamus to the medial bank of the lateral suprasylvian area, which is presumed to be responsible for this cerebellar response, terminate mostly in layer I in both new-born kittens and adult cats.

4. The present results, and our previous morphological findings on the projections from the extrageniculate visual thalamus and visual cortical areas 17 and 18 onto the medial bank of the lateral suprasylvian area, were correlated with reference to the maturation of the neuronal circuit in the cortex.

INTRODUCTION

The medial bank of the lateral suprasylvian visual area in the cat, known as a part of the visual association cortex (Clare & Bishop, 1954; Hubel & Wiesel, 1969; Palmer, Rosenquist & Tusa, 1978), specializes in perception of motion. In fact, almost all neurones in this area respond well to moving visual stimuli rather than to stationary stimuli (Spear & Baumann, 1975; Camarda & Rizzolatti, 1976; Toyama & Kozasa, 1982). In line with such specialization for motion, this area in adult cats receives cerebellar inputs as well as retinal ones, as was revealed by using the field potential

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method (Kawaguchi, Miyata & Kato, 1983*a*): cerebellar stimulation elicits a surface-negative, depth-positive field potential and, conversely, optic nerve stimulation induced a surface-positive, depth-negative wave. Maturations of these two responses in this area have not been studied so far.

In the pattern of post-natal development, there is a sharp contrast between visual, auditory and somatosensory evoked potentials recorded from the relevant primary sensory cortices on one hand (Kawaguchi, Yamamoto, Samejima & Miyata, 1980; Miyata, Kawaguchi, Samejima & Yamamoto, 1982; Kato, Kawaguchi, Yamamoto, Samejima & Miyata, 1983), and cerebellar evoked potentials from the motor and parietal association areas on the other (Kawaguchi, Samejima & Yamamoto, 1983*b*). Generally, the sensory evoked potentials are largely surface positive, depth negative in adult cats, but at birth they are roughly surface negative, depth positive; the adult-like pattern was attained by 1 month of age. On the other hand, the cerebellar evoked potentials are rather constant in depth profile during post-natal development. In the present report, we are interested in asking whether these general rules also apply to the development of visual and cerebellar evoked potentials recorded from the visual association area, or whether the developments there follow quite a different principle which would feature the visual association area.

Furthermore, our attention is focused on discussing post-natal changes of anatomical connexions that are expected to be responsible for the development in these two evoked potentials. For this purpose, we investigate the post-natal change in cortical distribution of afferents from a putative relay nucleus of the cerebellar evoked potentials, the ventroanterior–ventrolateral nuclear complex of the thalamus (v.a.–v.l.). Also we make reference to our previous data on the development of projections from the extrageniculate visual thalamus and the primary visual cortices onto the medial bank of the lateral suprasylvian visual area (Kato, Kawaguchi & Miyata, 1984*a*, 1986). A part of the present findings were published as an abstract (Kato, Kawaguchi & Miyata, 1984*b*).

METHODS

Sixty-eight kittens aged 0–68 days old were used for the electrophysiological study. Under pentobarbitone anaesthesia (35 mg/kg intraperitoneal, I.P.), the animals were placed in a stereotaxic apparatus. Respiration was always natural. The state of anaesthesia was monitored by electrocorticogram. Whenever necessary, the anaesthesia was supplemented by giving a small dose of pentobarbitone via the cephalic vein which was cannulated. The skull and dura over the middle suprasylvian and lateral gyri and the cerebellum were opened. Monitoring the cortical evoked potential in area 18 with a silver ball electrode, we inserted a bipolar concentric electrode into an eye and placed it in the optic canal. A set of two concentric electrodes (core sleeve, contact separation 0·5 mm, shaft diameter 0·3 mm) was placed in the cerebellar nuclei with the aid of cerebellar evoked potential recorded from the crown of the middle suprasylvian gyrus. At the end of the experiments, a direct current (d.c.) (10 V for 5 s) was passed through the stimulating electrodes for identification of location of the tips. By introducing vertically a micro-electrode filled with 2% (v/v) Pontamine Sky Blue dissolved in 0·5 M-potassium citrate solution (d.c. resistance 2–10 MΩ) with the aid of a micromanipulator, we recorded potentials at various cortical depths. During the recording, dye spots were frequently made by passing direct current (5 μA for 10 min), especially at the depth where potentials reversed their polarity or showed highest amplitude. After the recording, the brain was perfused with 10% (v/v) formalin containing 0·2% (w/w) potassium ferricyanide, removed, frozen, then cut at 70 μm in the frontal plane. The dye spots, which directly show locations of some of the recording sites, were identified by microscopical examination of the

sections. Unmarked recording sites were estimated on the basis of micromanipulator reading. Locations of the tips of the stimulating electrodes in the cerebellar nuclei were also examined.

Four kittens and an adult cat were used for the horseradish peroxidase (HRP) study. The animals were anaesthetized and placed in the same manner as for the electrophysiological study. The skull and dura were opened over the lateral sulcus. Micro-electrodes were filled with a 5% (w/v) solution of wheat-germ-agglutinin-conjugated HRP (L-9800, Sigma) in 0·1 M-Tris-HCl buffer. Monitoring field potentials and unit activities in the thalamus on cerebellar stimulation, we placed the micro-electrode tip in the v.a.–v.i., which was then injected with HRP by passing direct current (5–10 μm for 20–30 min). The animals survived for a further 24–36 h, then, they were deeply anaesthetized with pentobarbitone (65 mg/kg I.P.) and perfused through the heart with a fixative (7% (v/v) formalin solution in phosphate buffer). Brains were removed, soaked in 30% (w/v) sucrose solution, then frozen and cut at 70 μm in the frontal plane. The sections were treated with benzidine dihydrochloride (DeOlmos & Heimer, 1977). They were examined under microscope initially without counterstaining to prevent HRP reaction products from fading; later, they were stained with neutral red and examined again.

RESULTS

Post-natal change in the response evoked by stimulation of the optic nerve

By analysis of laminar field potential, the medial bank of the lateral suprasylvian visual area was found responsive to stimulation of the optic nerve from birth. However, depth profile of the response was quite different in new-born kittens from that previously reported for adult cats (Kawaguchi *et al.* 1983*a*). The response was surface negative, depth positive at birth, in sharp contrast with that recorded from adult cats which is surface positive, depth negative. The adult-like pattern of response was shown to emerge by 1 month of age.

Fig. 1*A* shows the developmental change in depth profile of the response. Recording electrodes were inserted, from the surface of the middle suprasylvian gyrus, through the white matter into the medial bank, as illustrated in a surface view (Fig. 1*B*) and in a frontal section of the brain (Fig. 1*C*). Filled circles along the electrode track in Fig. 1*C*, marked by capital letters, give the depths at which the responses marked by the same letters in Fig. 1*A* were recorded. During the penetration of electrodes, dye injection was often made at a depth where the polarity of the potential reversed or the potential was largest in amplitude. Later, locations of the dye spots within the cortex were identified by histological examination. Locations of the other recording sites, where no dye spots were made, were estimated by considering distance from the dye spots. As expected from Fig. 1*C*, the more medially the recording electrode is introduced, the farther it must advance to reach the surface of the medial bank of the lateral suprasylvian area. For this reason, even though the size of the brain grows larger as age increases, equivalent recording sites marked by the same letter do not necessarily become deeper in parallel with the increase in age.

In the 31- and 65-day-old kittens, as in adult cats (Kawaguchi *et al.* 1983*a*), the response evoked by optic nerve stimulation consists largely of a surface-positive, depth-negative potential (Fig. 1*A*). Polarity of the potential reversed in the deep cortical layers of the medial bank. This pattern of depth profile was obtained in all kittens older than 27 days of age. In the 0-day-old kittens, by contrast, the response was surface negative, depth positive. In all kittens younger than 16 days of age, the response provided this type of depth profile. Therefore, the adult-like profile is

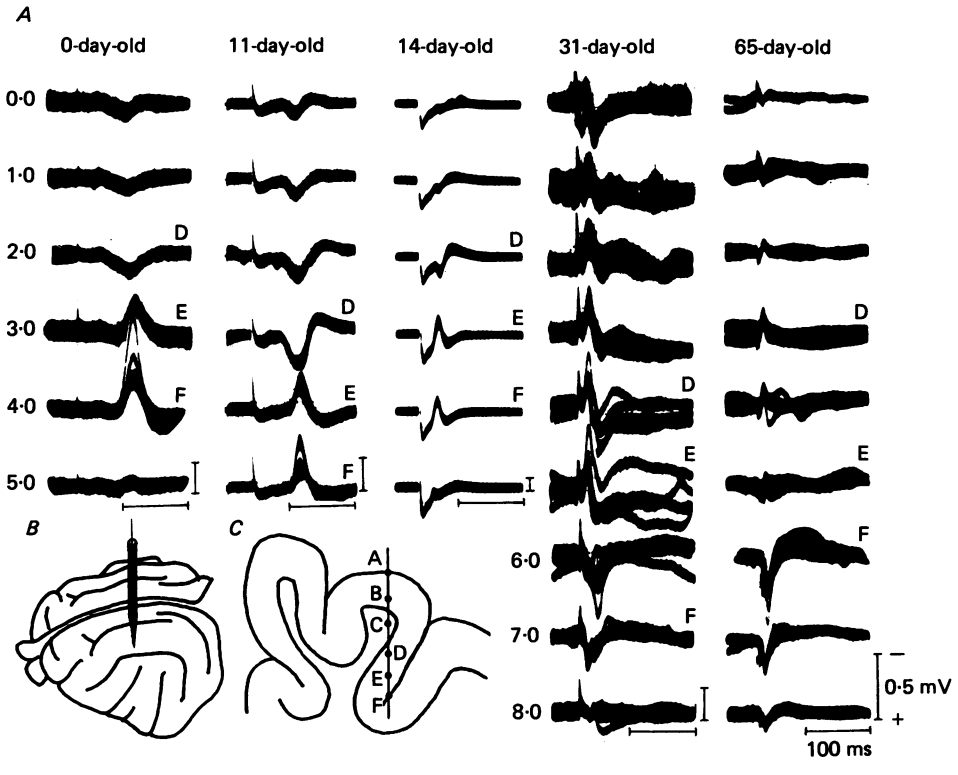

Fig. 1. *A*, post-natal change in depth profile of field potential that is elicited by optic nerve stimulation and recorded from the middle suprasylvian gyrus. Numerals to the left of specimen recordings indicate the depths (mm) from the surface of the middle suprasylvian gyrus. Letters to the right of recordings correspond with those in *C*, and give the approximate depths at which the potentials were recorded in this and the other Figures. *B*, an illustration showing insertion of a micro-electrode which is introduced perpendicularly to the crown of the middle suprasylvian gyrus. *C*, a schematic illustration of recording sites along an electrode track in a frontal section of the parietal cortex. *A* and *B* are located in the grey matter of the crown of the middle suprasylvian gyrus; *C* in the white matter; *D*, *E* and *F* in the grey matter of the medial bank of the lateral suprasylvian area.

supposed to be achieved between 17 and 26 days of age. During this period, individual variation in the configuration of response was great. In an extreme example, the profile was new-born-like in a 21-day-old kitten, but was adult-like in another 21-day-old kitten. This suggests that the change of potential configuration appears to occur rather rapidly around 3 weeks of age. It is worth noting that the response was generally unstable in kittens around 3 weeks of age as compared with far younger or older kittens.

Post-natal change in the response evoked by stimulation of cerebellar nuclei

Stimulation of cerebellar nuclei elicited a surface-negative, depth-positive potential in the medial bank of the lateral suprasylvian area from birth, as in adult cats (Kawaguchi *et al.* 1983*a*). Histological examination showed that when the potential

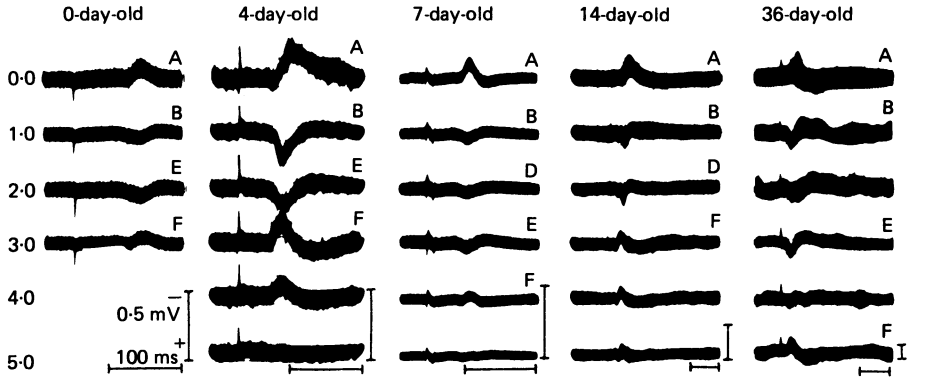

Fig. 2. Post-natal development in depth profile of field potential that is elicited by stimulation of cerebellar nuclei and recorded from the middle suprasylvian gyrus. The depth profile of the response is much the same throughout the development. Letters to the right of potentials correspond with those in Fig. 1*C*. Numerals to the left of specimen recordings indicate the depths (mm) from the surface of the middle suprasylvian gyrus.

was sufficiently elicited, the tip of the stimulating electrodes was always placed in or around the lateral or interpositus nucleus, as reported for adult cats (Kawaguchi *et al.* 1983*a*). However, no further attempt was made to specify in detail the structure that is responsible for evoking the potential, because the possibility of stimulation by current spread complicates evaluation of the specification especially in young kittens. For this reason, we refer to the stimulated structure collectively as cerebellar nuclei in the present report.

Fig. 2 shows similarity in the depth profile of the response among animals of various ages; letters to the right of some of the potentials indicate the recording sites shown in Fig. 1*C*. With a micro-electrode placed on the surface of the middle suprasylvian gyrus, a negative potential was recorded. As the electrode advanced, the potential turned into positive within the grey matter of the crown part of the middle suprasylvian gyrus, indicating that the crown is responsive to stimulation of cerebellar nuclei as previously reported (Kawaguchi *et al.* 1983*b*). When the electrode further advanced, the polarity of the potential reversed again; by histological examination, the reversal was found to occur within the medial bank of the lateral suprasylvian area. This clearly showed that the medial bank was responsive. The cerebellar-induced response tended to habituate and was much more unstable than the response evoked by the optic nerve.

Extent of the regions responsive to the cerebellar and optic nerve stimulations within the medial bank of the lateral suprasylvian area

In all the examined kittens including those at birth, as previously reported for adult cats (Kawaguchi *et al.* 1983*a*), the rostral and caudal portions of the medial bank of the lateral suprasylvian area were best responsive to stimulations to the cerebellar nuclei and optic nerve, respectively, and the caudal half of the bank did not respond to the cerebellar stimulation. The two responsive areas, as in adult cats,

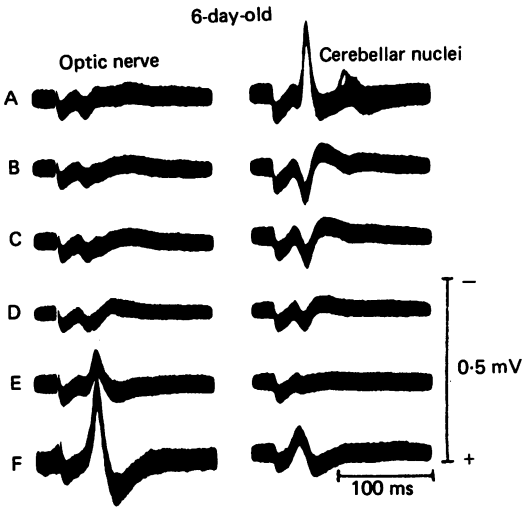

Fig. 3. Field potentials recorded along one and the same electrode track penetrating through the middle suprasylvian gyrus in a 6-day-old kitten, on stimulation of the optic nerve and cerebellar nuclei. Letters to the left correspond with the same letters in Fig. 1*C*.

already overlapped at birth. However, the overlap was immature in the following senses. First, the overlap was not found in every new-born kitten. Secondly, the rostracaudal extent of the area that responded to both of the stimulations was relatively smaller in kittens than in adult cats, in which about the rostral half of the medial bank is responsive to both.

Fig. 3 shows field potentials elicited by cerebellar and optic nerve stimulations, which were obtained during one and the same penetration of a micro-electrode around the middle of the rostral half of the medial bank of the lateral suprasylvian area in a 6-day-old kitten. Both of the evoked potentials reversed their polarity, indicating that the region around the track is responsive to both stimulations. In contrast, when penetrations were made 1 mm rostrally and caudally in this kitten, cerebellar stimulation alone and optic nerve stimulation alone, respectively, elicited field potentials that reversed polarity within the medial bank. Therefore, the rostrocaudal extent of the responsive area is believed to be less than 2 mm. Since the extent in adult cats is 8 mm (Kawaguchi *et al.* 1983*a*) and the rostrocaudal length of the medial bank in adult cats is merely one and a half times as large as that in new-born kittens, it is concluded that the area responsive to both stimulations occupies a much smaller portion of the medial bank in new-born kittens than in adult cats. Even within the common responsive area, the amplitude of both responses was smaller than in the more rostral or caudal portion that was responsive to either of the two stimulations and not to both. In none of the examined kittens of up to 68 days old was the area that responded to both as large as previously reported in adult cats (Kawaguchi *et al.* 1983*a*).

Occasionally, we examined whether the response evoked by either of the two

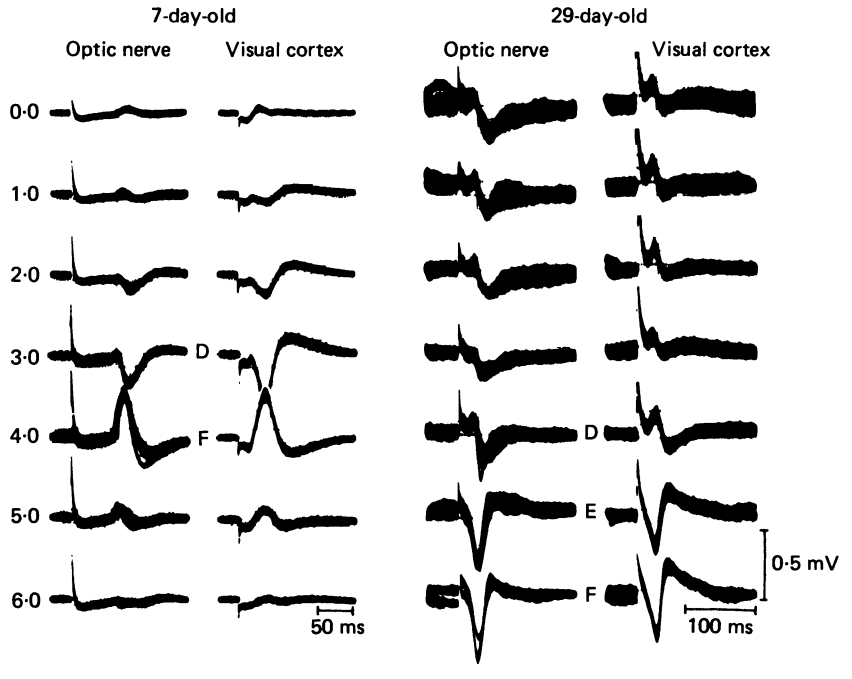

Fig. 4. Comparison between the field potentials elicited by stimulations to the optic nerve and cortical areas 17 and 18, in 7- and 29-day-old kittens. Note that the depth profiles of the responses differ between the two kittens, and that in each kitten the responses elicited by the two stimulations are of virtually the same configuration except that the cortical evoked potential has the shorter latency. Numerals to the left of specimen recordings indicate the depths (mm) from the surface of the middle suprasylvian gyrus.

stimulations was influenced when the other stimulation occurred first as a conditioning stimulus. However, no evidence of suppression or facilitation was obtained; actually, fluctuation of amplitude of the response in the time domain was much larger than the difference in amplitude between the control and conditioned responses.

Comparison between the responses elicited by stimulations of the optic nerve and the primary visual cortex

Field potentials evoked by stimulation of cortical areas 17 and 18 were recorded from the medial bank of the lateral suprasylvian area, and compared with those elicited by stimulation of the optic nerve. Like the response evoked by optic nerve stimulation, the corticocortical response was surface negative, depth positive in all kittens younger than 2 weeks old, and was surface positive, depth negative in all kittens older than 1 month of age. Fig. 4 shows such potentials obtained from 7- and 9-day-old kittens. The numerals to the left of recordings indicate depths from the surface of the middle suprasylvian gyrus. In both kittens, the corticocortical response had virtually the same wave configuration and depth profile as the response elicited by optic nerve stimulation, but was elicited at a shorter latency.

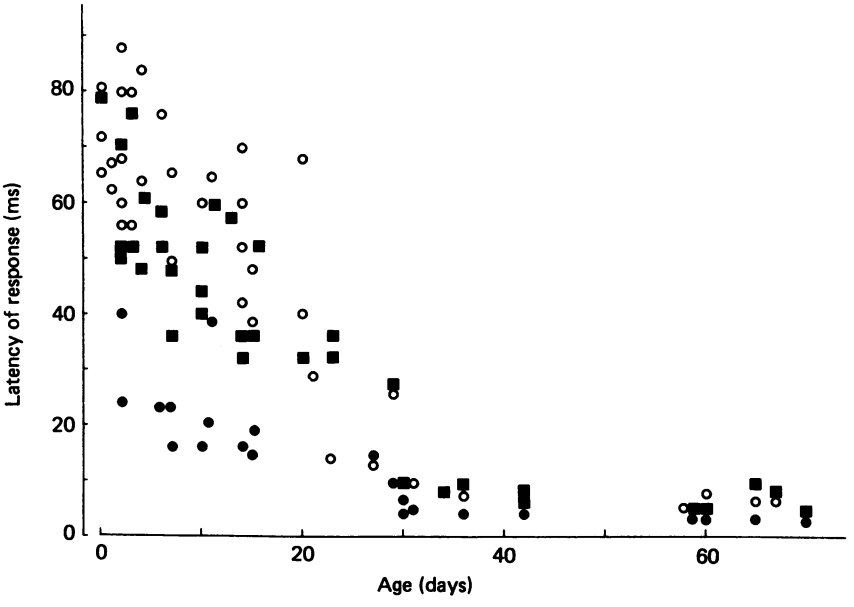

Fig. 5. Post-natal development of the latency of the responses elicited by stimulations of the optic nerve (○), cerebellar nuclei (■) and cortical areas 17 and 18 (●). The latency was measured at the onset of the potential.

Post-natal change in latency of the responses

Fig. 5 illustrates the post-natal change of the latencies of responses elicited by stimulations to the optic nerve, cortical areas 17 and 18, and cerebellar nuclei. The latency of the responses was measured at the initial deflexion of the potential. Generally the latencies decrease rapidly for the first post-natal month and, afterward, continue to decrease gradually until the adult-like values are attained around 2 months of age. In more detail; for the two responses related to visual inputs, the rapid decrease occurs with much the same time course during the second half of the first month; the averaged values of the latency of evoked responses from optic nerve and areas 17 and 18, respectively, are 70 and 32 ms for kittens of 0–2 days old, 60 and 28 ms for kittens of 10–12 days old, 10 and 5 ms for kittens of 30–35 days old. Our previous report (Kato *et al.* 1983) showed a similar pattern of decrease in latency of the optic nerve evoked response recorded from area 17: namely, the latency remains virtually unchanged (28–30 ms) from birth until 2–3 weeks of age, then, decreases abruptly to reach 4–5 ms at 1 month of age, after which it continues to decrease gradually. It is worth noting that the latency of the optic nerve evoked response recorded from area 17, plus that of the visual cortex evoked response recorded from the medial bank, is always nearly the same as, but slightly smaller than, the latency of the optic nerve evoked response recorded from the medial bank of the lateral suprasylvian area.

Post-natal change in the distribution of thalamocortical afferents in the medial bank of the lateral suprasylvian area arising from the ventroanterior–ventrolateral nuclear complex of the thalamus (v.a.–v.l.)

In an attempt to correlate the development of the cerebellar evoked response in the bank with its morphological substrate, we investigate the post-natal change in the distribution of the thalamocortical afferents from the v.a.–v.l., which receives much denser cerebellar afferents than any other thalamic nucleus and projects onto the bank in both kittens and adult cats (Sugimoto, Mizuno & Itoh, 1981; Kato *et al.* 1984*a*, 1986; Kawaguchi, Miyata & Kato, 1986). The distribution of the afferents was found basically constant throughout post-natal development. In two 1-week-old kittens, two 1-month-old kittens and an adult cat, injection of HRP was confined to the v.a.–v.l. In the parietal association area of all the animals, terminals of the projection from the v.a.–v.l. were orthogradely labelled in the medial bank of the lateral suprasylvian area and the adjoining crown part of the middle suprasylvian gyrus. In both cortical areas, the labelled terminals were always distributed mostly in layer I, with a few labelled terminals in the other cortical layers. The finding in the crown was the same as reported previously (Kawaguchi *et al.* 1983*b*).

Plate 1 shows the labelled afferents in the medial bank of the lateral suprasylvian area of 1-week-old (*A*) and 1-month-old (*B*) kittens. In both kittens, the afferents are seen mostly in layer I (indicated by arrows). Besides the afferents, corticothalamic neurones were also labelled, which are located in the bottom of Pl. 1 *A* and *B*.

DISCUSSION

The present findings revealed that retinal and cerebellar inputs have access to the medial bank of the lateral suprasylvian area already at birth with their targets overlapping there, and that the depth profile of potential configuration undergoes a post-natal change for optic nerve evoked potential but not for cerebellar evoked potential.

Correlation between the developments of afferent distribution and optic nerve evoked potential in the medial bank of the lateral suprasylvian area

Prior to discussing the correlation, the anatomical development of the distributions of thalamocortical and corticocortical afferents is briefly stated. Among the various afferents conveying visual inputs to the medial bank of the lateral suprasylvian area, those from the lateral posterior nucleus (l.p.), in particular its lateral portion (l.p.l), and from cortical areas 17 and 18 are by far the heaviest in both kittens and adult cats (Anker & Cragg, 1974; Tong, Kalil & Spear, 1982; Berson & Graybiel, 1983; Raczkowski & Rosenquist, 1983; Symonds & Rosenquist, 1984; Kato *et al.* 1984*a*, 1986). Each of the two main afferents undergoes a post-natal change in cortical laminar distribution (Kato *et al.* 1984*a*, 1986). The two afferents are distributed mostly in and around layer IV in adult cats (Sugiyama, 1979; Symonds & Rosenquist, 1984) and also in kittens after 1 month of age. However, during an early post-natal period, the afferents from the l.p.l are distributed much more densely in layer I than

in the deeper layers, and the cortical afferents from areas 17 and 18 terminate densely in superficial as well as in deep layers.

These morphological changes in the corticocortical and thalamocortical afferents, previously reported, are well correlated with the development of the optic nerve evoked potential, reported here. At early post-natal ages, the optic nerve evoked potential consists of a surface-negative, depth-positive wave, indicating that an electrical dipole is formed in the cortex with the negative and positive poles located near the cortical surface and at depth, respectively. This dipole is regarded as reflecting a large e.p.s.p. current which sinks into the distal part of apical dendrites of pyramidal neurones and the corresponding current source in the depth, which is passively produced in the soma or proximal dendrites of the neurones by the current sink (Sasaki, Staunton & Dieckmann, 1970; Sasaki & Prelevic, 1972; Mizdorf & Singer, 1978). As for the generation of the dipole, two possibilities arise. First, such a current sink can be made by an electrical volley that reaches the superficial, but not deep, layers; this is compatible with the dense thalamocortical afferents in layer I of the medial bank at birth which were revealed in the previous study (Kato *et al.* 1984*a*, 1986). Secondly, the sink can be caused by an e.p.s.p. current that is distributed in both superficial and deep cortical layers with an emphasis on the superficial layers; then, the passive source ought to be located in the deep part of the cortex. In this event, the corticocortical afferents, which were found distributed in both the superficial and deep cortical layers during an early post-natal period (Kato *et al.* 1984*a*, 1986), are probably responsible for generation of the potential at early post-natal ages. These two possibilities, however, do not exclude each other; instead, the actual response is likely to be a summation of the two sorts of current sink, which are distributed throughout the cortical depth with a particular emphasis on the superficial layers. By 1 month of age, the evoked potential grows surface positive, depth negative, indicating that e.p.s.p. current sinks in the superficial and deep layers become smaller and larger, respectively. In good agreement with these changes, the thalamocortical and corticocortical afferents become distributed densely in and around layer IV and sparsely in layer I by 1 month of age.

The pathway from the retina to the medial bank of the lateral suprasylvian area

From the preceding attempt to correlate the development of the optic nerve evoked potential with that of the afferent distribution in the cortex, it is concluded that both the afferents from the l.p.l and from areas 17 and 18 can possibly serve as the final path through which the retinal inputs have access to the medial bank of the lateral suprasylvian area. In fact, given the fact that these two afferents are by far the densest projections onto this area, either of them, or both, is likely to be the final path. Also, it is possible that one might serve as the final path at birth and the other in adulthood.

The other structures that might serve as a relay nucleus are the pulvinar, the C complex of the lateral geniculate nucleus, the medial interlaminar nucleus, each of which directly receives retinal afferents, and the medial part of the l.p., which receives them indirectly via the superior colliculus. However, their possible roles as relay nuclei can be ruled out because, both in new-born kittens and adult cats, the projections from these nuclei onto the medial bank of the lateral suprasylvian area

are much less dense than those from the l.p.l and from areas 17 and 18, as shown in our previous HRP studies (Kato *et al.* 1984*a*, 1986). Considering that only a massive spatial summation of temporarily synchronized e.p.s.p. current can generate the field potential and that this applies especially to the animal anaesthetized with pentobarbitone (Kyuhou & Kawaguchi, 1985), these nuclei are unlikely to be responsible for the field potential recorded in the present study. In both kittens and adult cats, electrical stimulation of areas 17 and 18 elicited a response similar to that evoked by optic nerve stimulation except that the latency of the response was longer in the latter. This suggests that area 17 or 18 may relay the pathway from the optic nerve to the medial bank of the lateral suprasylvian area. The present data on the change in the latencies appears in favour of this: the latency of the response elicited by optic nerve stimulation and recorded from area 17 plus the latency of the response elicited by areas 17 and 18 and recorded from the medial bank of the lateral suprasylvian area approximately equals the latency of the response that is elicited by optic nerve stimulation and recorded from the medial bank. As a morphological substrate for the path from areas 17 and 18 to the medial bank of the lateral suprasylvian area, there may be two possibilities: one is a direct corticocortical path, the other is a cortico-thalamo-cortical path via the l.p.l which receives dense projection from the visual cortex and provides the medial bank with dense afferents.

Finally, a question may arise whether the pathways discussed above are actually functional at birth. At least one pathway from the optic nerve to the medial bank of the lateral suprasylvian area, and one pathway from areas 17 and 18 to the medial bank do work, because field potentials, which are known to reflect a synaptic current, are generated in the medial bank in response to stimulation of the optic nerve or areas 17 and 18. For a comparable reason, the retino-geniculo-cortical path to area 17 and 18 is functionally connected (Kato *et al.* 1983). However, it is still unanswered whether every synaptic linkage in the possible relay structures from the optic nerve to the medial bank is already established at birth. For instance, although neurones in areas 17 and 18 established contact with geniculocortical inputs already at birth, it is possible that those inputs may not be transmitted to the output neurones projecting from areas 17 and 18 onto the medial bank before the later post-natal period. In this connexion, it is worth mentioning the autoradiographic study (Luskin & Shatz, 1985) on the neurogenesis in area 17 of the cat. Their study revealed that the neurogenesis in area 17 is pre-natally accomplished, but that it does not uniformly occur: neurogenesis in layers II and III, where future corticortical neurones are situated, proceeds later than that in the other layers. This may possibly mean that corticortical projections are established later than the other corticofugal projection systems, e.g. corticothalamic projections and, therefore, that at an early post-natal period the cortico-thalamo-cortical projection may play a larger part in transmission of retinal inputs from areas 17 and 18 to the medial bank than the corticocortical projection.

Developments of the cerebellar evoked potential and of its morphological correlate

The present results on the cerebellar evoked potential and on the relevant thalamocortical projection agree with each other. The cerebellar evoked potential is largely surface negative, depth positive throughout post-natal development, indi-

cating that the strong e.p.s.p. current sink remains existing in the superficial cortical layer as age increases. This potential is supposed to be relayed by the v.a.–v.l. or central lateral nucleus of the thalamus (c.l.) or both, because the target of the cerebellar afferents and the origin of the thalamocortical projection to the medial bank of the lateral suprasylvian area overlap in these nuclei for both kittens and adult cats (Sugimoto *et al.* 1981; Kato *et al.* 1984*a*, 1986; Kawaguchi *et al.* 1986). The v.a.–v.l. appears likely to be the main mediator of the potential for the following reasons. First, cerebellar afferents are much more dense in the v.a.–v.l. than in the c.l. in both kittens and adult cats (Sugimoto *et al.* 1981; Kawaguchi *et al.* 1986). Secondly, the present result that the cerebellar evoked potential remains surface negative, depth positive during development indicates the occurrence of an e.p.s.p. current sink in layer I after cerebellar stimulation irrespective of age, which agrees with the present finding that the afferents from the v.a.–v.l. always terminate mostly in layer I from an early post-natal period to adulthood. Thirdly, the autoradiographic result obtained by Kaufman & Rosenquist (1985) appears to exclude, at least for adult cats, the possibility that the c.l. plays an essential part in the thalamic transmission of the cerebellar evoked potential recorded from the medial bank of the lateral suprasylvian area. Their results revealed that the c.l. projects much more heavily onto the crown of the middle suprasylvian gyrus than onto the medial bank of the lateral suprasylvian area, and that the terminals of the projections are distributed in deep layers as well as in layer I. If the c.l. should serve as a main relay nucleus, the cerebellar evoked potential recorded from the medial bank would have to be much less marked than that recorded from the crown. In reality, however, the potentials recorded from the two areas are of a similar amplitude. Moreover, this cortical laminar distribution of the terminals from the c.l. appears to require that the potential that would be evoked via the c.l. should consist of both surface-negative, depth-positive and surface-positive, depth-negative potentials, which reflect the presences of strong e.p.s.p. current sinks in layer I and deep layers, respectively. In the present experiment, this was not the case; instead, the potential was purely surface negative, depth positive. Therefore, the v.a.–v.l. is the most probable candidate for the relay nucleus. However, this does not rule out the possibility that the c.l. serves as an additional relay nucleus. Also, since the functional significance and anatomical strength of projections need not necessarily be in parallel with each other, there is at least a possibility that the c.l. might play an important part in the transmission of some types of cerebellar outputs which would not noticeably contribute to generation of a field potential.

Finally, the cerebello-pulvino-cortical path, reported originally by Itoh & Mizuno (1979), should be mentioned because this path connects the cerebellum and a portion of the visual thalamus which might project onto the medial bank of the lateral suprasylvian area. This path arises from small neurones located in the lateral part of the cerebellar lateral nucleus, and terminates in area 20 but not in the lateral suprasylvian area. The possibility that this path conveys the cerebello-cerebral field response to the medial bank of the lateral suprasylvian area is most unlikely. First, the bank is not the cortical target of the path. Secondly, the density of the cerebello–pulvinar projection is far smaller than the projection onto the v.a.–v.l. and even that onto the c.l.

Convergence of the retinal and cerebellar inputs

The cerebellar and retinal inputs at birth already converge on the medial bank of the lateral suprasylvian area. However, the convergence is immature at birth, because merely the edges of the two responsive areas slightly overlap and amplitudes of the responses recorded from the common responsive area are smaller than the maximal value recorded from the non-overlap area. In 2-month-old kittens, the area where the two inputs overlap is wider than at birth; however, even at this age, the common responsive area is narrower than in adult cats, and the two responses recorded from the overlap area were less marked than the most prominent cerebellar and retinal responses which were recorded from the more rostral and caudal areas, respectively. By contrast, in adult cats, the responses of the maximal amplitude are recorded from the wider regions including the common responsive area, which is itself much wider than in kittens. Thus, the development of convergence of the two inputs appears to take place largely at a late post-natal period, during which interactions are likely to begin functioning between the two inputs.

The development of the visual evoked potentials in the medial bank of the lateral suprasylvian area follows a common principle which applies to the post-natal developments of visual, somatosensory and auditory evoked responses recorded from the relevant primary sensory areas (Kawaguchi *et al.* 1980; Miyata *et al.* 1982; Kato *et al.* 1983): a surface-negative, depth-positive wave prevails from birth up to about 3 weeks of age and, afterward, a surface-positive, depth-negative wave takes over. The pattern of the cerebellar evoked potential in the bank is in common with those reported for the motor and parietal association areas: a surface-negative, depth-positive potential remains conspicuous throughout development. Therefore, the developments of the visual and cerebellar inputs may be two independent processes rather than affect each other. One approach to test this would be to examine whether deprivation of either the retinal or cerebellar input has any influence upon the development of the other input.

Finally, it is worth noting that the development of the visual and cerebellar inputs in the medial bank of the lateral suprasylvian area can be regarded as a mixture of two apparently opposite processes: functional separation and integration. As far as cortical distribution of the inputs in the vertical plane is concerned, convergence of the two inputs in the superficial layers is on a much larger scale at birth than in adult cats. As age increases, cortical layers become functionally separated into the superficial cerebello-recipient layers and the deep retino-recipient layers. On the other hand, in the horizontal plane, the area that responds to stimulation of either the optic nerve or cerebellar nuclei becomes gradually integrated into the common target that responds to both of the two stimulations.

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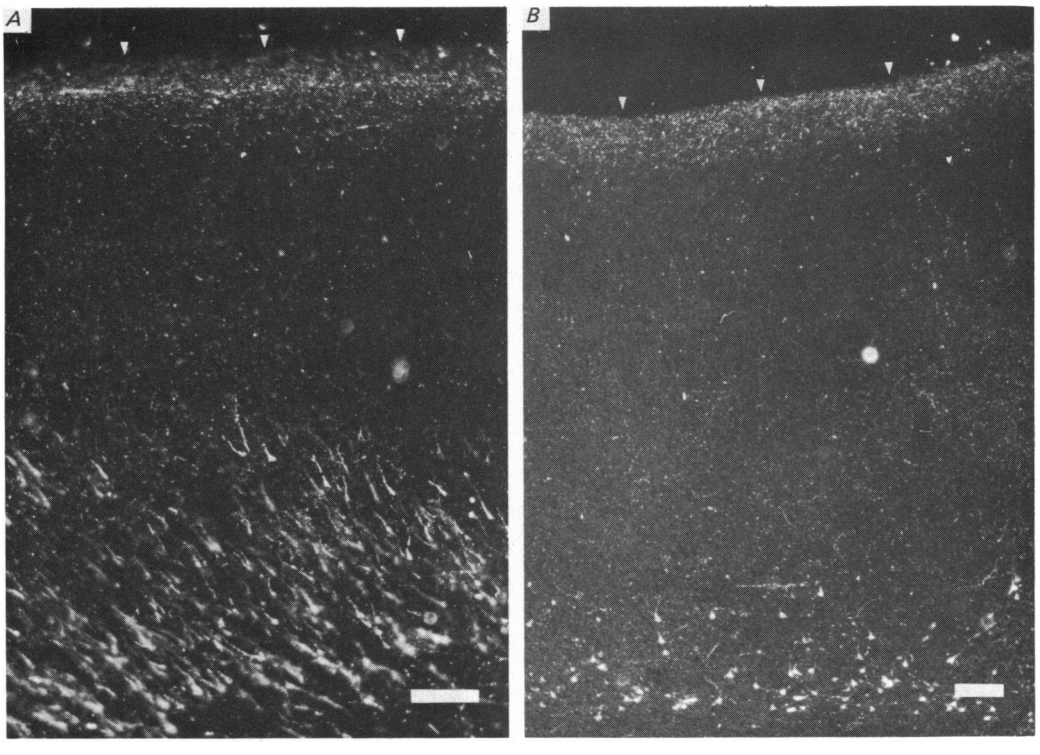
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EXPLANATION OF PLATE

Dark-field photomicrographs showing frontal sections of the medial bank of the lateral suprasylvian area, after HRP injection into the v.a.–v.l. of the thalamus. *A*, in a 1-week-old kitten; *B*, in a 1-month-old kitten. HRP-labelled terminals are found mostly in layer I (indicated by arrow heads) in both kittens. Retrogradely labelled neurones are located largely in layer VI. Scale bars, 0·1 mm.