Stereotaxic mapping of brainstem areas critical for memory of visual discrimination habits in the rat

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An attempt was made to map those pathways of the brain that are necessary for the performance of visual discrimination habits. This was accomplished by damaging different parts of the brain in previously trained rats and subsequently testing for retention. The map was constructed by plotting those areas of the brain damaged in rats showing a serious loss in retention. The resulting map could be separated into a specific (visual) division consisting of the lateral geniculate nuclei, occipital cortex, and lateral half of the cerebral peduncle at nigral levels, and a nonspecific division. Clearly represented within the latter were the ascending fiber systems associated with both the brainstem reticular formation and the substantia nigra.

With the use of the lesion method, it is possible to map anatomical pathways of the brain that are necessary for the memory (expression) of a learned response. This can be accomplished by canvassing many different cortical and subcortical areas with lesions (using, of course, different subjects for different lesion placements) and subsequently testing the subject's retention of a previously learned response. The distribution of individual lesions found to induce serious amnesic effects would delineate those pathways which are relevant (either directly or indirectly) for the normal expression of that learned response.

For the past 15 years, my associates and I have been using the foregoing method to map those regions of the brain which are essential for the memory of previously learned visual discrimination habits in the white rat. Summaries of some of these results have periodically been published (Thompson, 1963, 1969; Thompson & Massopust, 1960; Thompson & Thorne, 1973), and, in each case, the brain regions under investigation were broadened and the critical areas more precisely defined.

In the current paper, a detailed description of the critical brainstem (and telencephalic) areas for visual discrimination performance will be given in the form of a stereotaxic map. The data from which the map was constructed were derived from over 500 brain-damaged rats and gathered in the period between 1965 and 1975. The data on approximately half of these subjects were briefly reported in earlier papers scattered throughout the literature.

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MATERIALS AND METHODS

Adult male albino rats of the Wistar strain were used. These subjects were trained on either a brightness discrimination (approach a white card and avoid an adjacent black or dark gray card), a pattern discrimination (approach a horizontally black and white striped card and avoid an adjacent vertically black and white striped card), or both. Following learning, most of the subjects were subjected to bilateral one-stage cortical or subcortical lesions under deep chloral hydrate anesthesia. In some cases, surgical brain damage was performed in two stages (unilateral lesion followed by a contralateral lesion) with an interoperative period of 10 to 15 days. Destruction of neocortical, cingulate, or cerebellar areas was accomplished by the aspiration method. All other lesions were made stereotaxically with reference to the rat atlas of Massopust (1961). Depending upon the area to be destroyed, a constant anodal current of 2-5 mA was passed for 5-15 sec through an implanted stainless steel electrode with 1.0-2.0 mm of the tip exposed. Three types of electrocoagulative lesions were made. Type I lesion consisted of a single insertion of the electrode into the brain followed by the application of current. This type of lesion was made to destroy structures at the midline, such as the interpeduncular nucleus and the raphe nuclei. Type II lesion consisted of typical bilateral destruction of a nucleus or tract involving the insertion of the electrode on one side to produce a lesion, and then repeating the procedure on the contralateral side. Type III lesion consisted of multiple insertions of the electrode on each side for the purpose of enlarging the overall size of the lesion. Following a recovery period (or rest period in the case of the normal controls) of 2 to 3 weeks, all rats were required to relearn the problem (problems) mastered preoperatively. At the conclusion of the relearning test, each brain-damaged animal was sacrificed with an overdose of Nembutal, its vascular system perfused with normal saline followed by 10% Formalin, and the brain removed and stored in 10% Formalin for 2 days. For cortical injuries, the lesion was reconstructed on Lashley-type brain diagrams prior to sectioning. With a freezing microtome, each brain was sectioned frontally at 90 microns in the stereotaxic plane of Massopust (1961). Every third section showing the lesion was photographed at 10X-14X by the method of Gusman-Flores, Alcaraz, and Fernandez-Guardiola (1958). These photographs of unstained sections yield differentiation of the brain field similar to that obtained with a fiber stain (see Figures 1-5) and readily permit identification of the three major zones of the lesion—the vacuolated area, the narrow rim of severely coagulated tissue, and the surrounding gliosis.

Table 1
Mean Savings Scores for All Groups and Percentage of Rats from Each Group Earning Zero or Negative Savings Scores

Group	N	Lesion Type	Mean Savings	Percentage Rats Earning Zero or Negative Savings
Control	90		95.2	0
Anterior neocortex	9	Suction	80.3	0
Posterior neocortex	8	Suction	-83.0	75.0
Cingulate cortex	4	Suction	61.2	0
Infralimbic cortex	3	Suction	95.0	0
Rostral caudoputamen	6	III	70.3	0
Caudal caudoputamen	3	III	20.0	33.3
Globus pallidus	6	III	-1.5	50.0
Entopeduncular area	8	II	-15.2	62.5
Septal area	6	II	98.3	0
N. accumbens septi	3	II	91.0	0
Amygdaloid area	5	III	93.4	0
Dorsal hippocampus	7	III	74.3	0
Hypothalamus				
Anteromedial	4	II	100	0
Posteromedial	9	II	88.0	0
Anterolateral	11	II	94.5	0
Posterolateral	10	II	1.9	50.0
Thalamus				
Anterior	6	III	81.8	0
Lateral	5	II	75.5	0
Ventral	9	II	80.0	0
Dorsomedial	8	II	85.1	0
Ventromedial	6	II	75.5	0
N. parafascicularis	6	II	19.7	50.0
N. posterior	12	II	18.7	41.7
Lateral geniculate	2	II	-90.0	100
Medial geniculate	9	II	84.2	0
Subthalamic nucleus	7	II	-94.4	42.9
Zona incerta	5	II	75.0	0
Pretectal area	10	II	24.0	40.0
Superior colliculus	8	III	63.5	0
Inferior colliculus	6	III	80.2	0
Subcollicular area	7	III	97.1	0
Central gray	6	II	83.3	0
Ventral tegmentum	9	II	-6.7	44.4
Substantia nigra	21	II	-3.1	52.4
Lateral cerebral peduncle	13	III	-24.2	53.8
Red n.	10	II	-44.4	70.0
Rostral interpeduncular n.	10	I	78.6	0
Caudal interpeduncular n.	5	I	10.0	40.0
Rostral central tegmentum	10	I	80.0	0
N. medianus raphes	10	I	-5.8	50.0
Midbrain reticular formation				
Rostral	21	II	-10.5	47.6
Suprarubral	5	II	90.0	0
Supranigral	6	II	70.5	0
Ventrolateral	14	II	25.7	35.7
Caudal	13	II	-2.0	46.2
Lateral midbrain lemniscal area	10	II	91.0	0
Pontine reticular formation	11	II	-16.4	72.7
Lateral pontine lemniscal area	10	II	89.9	0
Cerebellum	3	Suction	71.3	0

The two-choice discrimination apparatus and related training procedures have already been described (Thompson, 1969). Briefly, under the motive of escape from (or avoidance of) footshock, each rat was trained to approach the positive stimulus card (white in the case of the brightness problem and horizontal stripes in the case of the pattern problem) and avoid the adjacent negative stimulus card. A response to the unlocked positive card (correct response) admitted the rat to the goalbox, whereas a response to the locked negative card (error) was followed by the automatic administration of mild footshock. Eight trials were given daily with an intertrial

interval of 60 sec. Fifteen correct responses within 2 consecutive days constituted the criterion of learning.

The retention test, which consisted of relearning the problem (problems), utilized the same procedures as those involved in original learning. The retention measure was expressed in terms of percentage error savings which relates the individual relearning score with the corresponding original learning score.

In terms of savings scores, three general outcomes are possible. First, the brain-damaged animal may relearn the problem about as fast as the normal controls and, as a consequence, achieve a high

Figure 1. Photographs of unstained sections derived from three rats showing bilateral lesions within the rostral caudoputamen (A), amygdala (B), and subcollicular area (C). (All three rats earned positive savings scores.)

positive savings score (80% of the 90 control rats earned savings scores in excess of 90%). Second, the brain-damaged animal may show some transient difficulty in regaining the habit, but will relearn at a faster rate than in original learning. In this case, the savings score will be lower than that associated with the first outcome, but still positive. Finally, the brain-damaged animal may show an enduring disturbance in reaching the criterion to the extent that the problem is relearned at a slower rate (or at the same rate) in comparison to original learning. In this instance, the savings score will be zero or negative. Since the poorest control rat earned a positive savings score (30%), there is little doubt that zero or negative savings reflects a serious loss in the expression of the previously learned visual discrimination problem. Therefore, it was decided that the critical areas for visual discrimination deficits will be defined as those brain structures damaged in rats achieving zero or negative savings scores.

Mapping the critical subcortical areas was done in the following manner. For each rat, the photograph of the brain section through the "center" of the lesion was selected. The central necrotic zone of the lesion (the vacuolated and severely coagulated areas) was then reconstructed on the right side of a frontal section derived from the Massopust (1961) atlas¹ that most closely corresponded to the frontal level shown in the photograph. If the rat earned zero or negative savings, the central necrotic zone of the lesion was also reconstructed on the left side of the same corresponding section.

The specific naming of structures and tracts within the text followed the international convention of nomenclature and was guided by the rat atlas of Skinner (1971).

RESULTS

General Findings

Table 1 presents the mean savings scores for all

groups and the percentage of rats from each group that earned zero or negative savings. (In those cases where the animal earned two savings scores—one for the brightness problem and one for the pattern problem—only the lowest savings score was considered). It will be noted that only 20 of the 49 brain-damaged groups contained animals earning zero or negative savings.

Figures 1 and 2 show subcortical lesions in six rats derived from groups that did not contain any animals earning zero or negative savings. Figures 3, 4, and 5 show subcortical lesions in 11 rats that earned negative savings.

In all subsequent figures describing the results, those areas of the brain convassed with lesions are shown in stipples on the right side of each section (or diagram). The left side of each section shows the composite areas of the brain damaged (large black dots) in those rats that failed to earn a positive savings score. For convenience, the combined critical areas marked with black dots will be termed the "visual discrimination memory system" (VDMS).

Neocortex and cerebellum. As shown in Table 1 and Figures 6A, 6B, and 6C, ablations of the occipital areas caused serious retention disturbances (thus, the occipital cortex is a component of the VDMS), while

Figure 2. Photographs of unstained sections derived from three rats showing bilateral lesions within the anterior thalamus (A), dorsal hippocampus (B), and ventral thalamus (C). (All three rats earned positive savings scores.)

Figure 3. Photographs of unstained sections derived from three rats showing bilateral lesions within the globus pallidus (A), entopeduncular area (B), and subthalamus (C). (All three rats earned negative savings scores.)

ablations of the more anterior regions of the cerebrum did not.

All three rats with virtually total destruction of the cerebellum achieved positive savings scores. Therefore, the cerebellum is not a component of the VDMS.

Limbic forebrain areas. In no case did lesions of the cingulate cortex and/or infralimbic region (Figure 6D), septal (Figures 7A, 7B, and 7C), or septofornix (Figure 7D) area, nucleus accumbens septi (Figure 7A), hippocampus (Figures 2B and 8H), or amygdala (Figures 1B and 8H) lead to savings scores below 25%.

Brainstem areas. Figures 7 to 10 summarize the results on the canvassing of the brainstem. It will be seen that the most caudal extent of the VDMS occupies the pontine reticular formation in regions corresponding to the nucleus reticularis pontis oralis, nucleus reticularis tegmenti pontis, and the nucleus medianus raphes (Figure 10R). At more rostral levels, the VDMS broadens to include the lateral and medial portions of the mesencephalic reticular formation (ventral portions of the nucleus cuneiformis), the caudal half of the interpeduncular nucleus, and the overlying central tegmentum (Figure 10P). Further rostrally, the VDMS shifts somewhat laterally to incorporate the red nucleus, ventral tegmental area of

Tsai, substantia nigra, medial lemniscus, lateral half of the cerebral peduncle, and the ventral portions of the mesencephalic reticular formation (Figures 9M and 10N). At the dimesencephalic juncture (Figures 9K and 9L), the VDMS appears to bifurcate, one branch coursing dorsally toward the thalamus and the other maintaining a ventral course toward the hypothalamus and subthalamus. The posterior diencephalic level shown in Figure 9J discloses the largest extent of the VDMS in cross section, but just 0.5 mm more anteriorly (Figure 9I), the VDMS constricts to a small region in and around the medial portion of the cerebral peduncle, and maintains this position and size rostrally through the area of the entopeduncular nucleus (Figure 8H). Due to incomplete (or unsuccessful) canvassing of brain structures at anterior diencephalic levels (Figures 8E, 8F, and 8G), the VDMS does not make an appearance, but does reappear within the globus pallidus (Figure 7D) and the caudal portions of the caudate-putamen complex (Figure 7C). No further trace of the VDMS is seen at more rostral levels.

Summary

As shown above, the VDMS consists of the caudal half of the cerebrum (occipital areas) and a more or less continuous subcortical "pathway" of varying breadth extending from the pontine reticular formation to the corpus striatum. The only break within this pathway occurs between the entopeduncular area and the globus pallidus.

It is conceivable that the internal capsule

Figure 4. Photographs of unstained sections derived from four rats showing bilateral lesions within the parafascicular area (A), nucleus posterior (B), rostral midbrain reticular formation (C), and red nucleus (D). (All four rats earned negative savings scores.)

constitutes the link in the VDMS pathway between the entopeduncular area and the globus pallidus. A dozen rats sustaining bilateral two-stage lesions within the internal capsule all manifested serious aphagic-adipsic disturbances and a profound akinesia, which lasted until death (from 5 to 9 days following the second operation). Three of these rats were given a retention test on the brightness problem starting on the fifth postsurgical day, and all showed no evidence of relearning. Due to the poor physical health of these rats during the retention test, no definitive conclusions can be made. However, when these data are combined with the frequent observation that the globus pallidus, internal capsule, and entopeduncular area are common sites through which many ascending and descending fiber systems traverse (Hedreen, 1971; Knook, 1966; Lynch, Smith, & Robertson, 1973; Morgane, 1961; Shimizu & Ohnishi, 1973; Ungerstedt, 1971), the possibility that the internal capsule is included within the VDMS must be seriously considered.

DISCUSSION

Preliminary Considerations

As far as can be determined, this is the first attempt to use the lesion method to map pathways of the brain critical for the performance of a learned response and to present the results in stereotaxic form. It must be emphasized at the outset that the results of this study, like those of most other neuroanatomical and neurophysiological investigations, are intimately tied

Figure 5. Photographs of unstained sections derived from four rats showing lesions within the substantia nigra (A), ventrolateral midbrain reticular formation (B), interpeduncular and raphe nuclei (C), and pontine reticular formation (D). (All four rats earned negative savings scores.)

Figure 6. Schematic drawings of the dorsal (B) and lateral (A, C) surface of the cerebral cortex and a parasagittal section (D) of the rat brain. (Stippled areas indicate the composite of lesion placements investigated. Areas covered by large black dots indicate composite of lesion placements leading to zero or negative savings scores.)

to the methodology used. It is conceivable that increasing the size of the lesions investigated, exclusively using two-stage surgical procedures, lengthening the recovery period, using a different kind of discrimination apparatus, administering a large number of overlearning trials prior to surgery, varying the previous experience and/or age of the subject, or establishing a different set of criteria for the determination of a "serious amnesic disturbance" might alter the composition and extent of the resulting map. Therefore, the VDMS mapped in the current study must be viewed with these constraints in mind.

On the other hand, there are reasons to believe that the major portion of the VDMS may be invariant over a wide range of conditions. For example, negative savings scores were obtained in some rats sustaining either occipital, pallidal, posterior thalamic, rubral, nigral, or ventral tegmental lesions whether or not the lesions were performed in one or two stages. Furthermore, except for two subcortical areas, the character of the VDMS would be the same if only those brain-damaged rats trained on the brightness (or the pattern) discrimination were selected for the construction of the map.² Perhaps the most persuasive finding is that virtually all of the critical subcortical areas shown in Figures 7-10 (except for the lateral geniculate nuclei and the lateral half of the cerebral peduncle) have recently been demonstrated to be necessary for the expression of latch box problems, a nonvisual discrimination problem, a conditioned

Figure 7. Frontal sections at successive levels of the brainstem are based upon the Massopust (1961) stereotaxic atlas and the corresponding coordinates (in millimeters) rostral to the interauricular line are given below each section. (Those areas of the brain canvassed with lesions are shown in stipples on the right side of each section, while those areas of the brain damaged in rats earning zero or negative savings scores are shown as large black dots on the left side of each section. Abbreviations: AC = anterior commissure; AM = amygdala; AT = anterior thalamus; BC = brachium conjunctivum; CG = central gray; CI = inferior colliculus; CP = caudoputamen; DM = dorsomedial thalamus; EP = entopeduncular nucleus; FX = fornix column; GL = lateral geniculate nucleus, pars dorsalis; GM = medial geniculate nucleus; GP = globus pallidus; H = habenula; HC = hippocampus; HP = habenulopeduncular tract; IC = internal capsule; IP = interpeduncular nucleus; L = lateral thalamus; LH = lateral hypothalamic area; LM = medial lemniscus; MB = mamillary bodies; MRF = midbrain reticular formation; MT = mamillo-thalamic tract; NAS = nucleus accumbens septi; NP = nucleus posterior; OC = optic chiasma; PF = parafascicular nucleus; PP = cerebral peduncle; PRF = pontine reticular formation; RN = red nucleus; S = septal area; SC = superior colliculus; SN = substantia nigra; ST = subthalamic nucleus; V = ventral thalamus; VM = ventromedial thalamus; VT = ventral tegmental area.)

avoidance response, and a maze habit (see Thompson, 1974).

On the basis of the foregoing data, it is reasonable to expect that the anatomical limits of the VDMS mapped in the current study will not be disturbingly capricious from one replication to the next. In fact, the second attempt to map the VDMS in 1963 yielded results which bear a striking resemblance to those presented in the current study (Thompson, 1963).

It should be apparent that the pattern of results obtained in this study are inexplicable in terms of a "mass action" effect—the size of the lesion independent of its anatomical locus determines the magnitude of the behavioral deficit (Lashley, 1929). Those animals having lesions of the rostral caudoputamen (Figure 1A), hippocampus (Figure 2B), anterior thalamus (Figure 2A), or dorsal midbrain (Figure 1C), for example, sustained at least twice as much damage to neural tissue as those having entopeduncular (Figure 3B), subthalamic (Figure 3C), posterior thalamic (Figures 4A and 4B), ventral mesencephalic (Figures 4C, 4D, 5A, and 5B), or pontine reticular formation (Figure 5D) lesions. Yet, the former brain-damaged animals failed to show serious retention deficits, while the latter, in many cases, earned negative savings scores. Further evidence of the importance of "lesion locus" rather than "lesion size" in determining the loss of visual discrimination habits in the rat may be found in experiments on the cerebral cortex (Horel, Bettinger, Royce, & Meyer, 1966; Lashley, 1929), posterior thalamus (Thompson, Lukaszewska, Schweigerdt, & McNew, 1967), ventral midbrain (Craddock & Thompson, 1971; McNew, 1968), and brainstem reticular formation (Petit & Thompson, 1974; Thompson & Thorne, 1973).

Functional Divisions of the VDMS

The VDMS may be separated into two major functional divisions: a "specific" (visual) division,

Figure 8. Frontal sections at successive levels of the brainstem (See Figure 7 for description.)

consisting of the occipital cortex, lateral geniculate nuclei, and the lateral half of the cerebral peduncle at nigral levels, and a "nonspecific" division, containing the remaining components of the VDMS.

As shown in earlier studies, lesions damaging either the occipital cortex (Thompson, Malin, & Hawkins, 1961) or the lateral half of the cerebral peduncle (Thompson & Craddock, 1972) do not seriously impair retention of a nonvisual (incline plane) discrimination habit. In contrast, lesions damaging any one of the remaining (nonspecific) components of the VDMS drastically impair retention of a nonvisual discrimination habit³ and other habits as well (Thompson, 1974).

In the light of the foregoing findings, it would be appropriate to discuss each division separately.

Specific division of the VDMS. It is well established that the retino-geniculo-occipital pathway functions specifically in visually guided behaviors and that lesions placed anywhere along this pathway will disrupt the execution of visual discrimination habits (Lashley, 1929, 1935, 1950). On the other hand, there is no general consensus about the pathways beyond the occipital cortex that support visual discrimination habits (Geshwind, 1965; Lashley, 1950; Mishkin, 1966; Myers, 1965; Pribram, Spinelli, & Reitz, 1969; Thompson, 1965).

The finding that lesions of the lateral half of the cerebral peduncle hinder learning and retention of visual discrimination habits, while having little or no

Figure 10. Frontal sections at successive levels of the brainstem. (See Figure 7 for description.)

Figure 9. Frontal sections at successive levels of the brainstem. (See Figure 7 for description.)

effect on learning and retention of a nonvisual discrimination habit (Howze, 1974; Thompson & Craddock, 1972), provides a possible clue for the resolution of this important problem, at least with respect to the rat. The lateralmost portion of the cerebral peduncle in the rat is known to contain occipitofugal fibers en route to the brainstem (Knook, 1966; Krieg, 1947; Nauta & Bucher, 1954; Valverde, 1962), and one investigator (Valverde, 1962) has observed some of these fibers terminating within the nucleus cuneiformis and the nucleus reticularis pontis oralis. Since the latter two reticular regions are included within the nonspecific division of the VDMS, the possibility exists that visual discrimination habits are mediated by a retino-geniculo-occipito-reticular pathway. Some support for this possibility has recently come from studies examining retention of visual discrimination habits in rats sustaining unilateral damage to the occipital cortex and contralateral damage to the nucleus cuneiformis (Petit & Thompson, 1974). If subsequent anatomical investigations confirm the existence of occipito-reticular projections, then there would be grounds for reexamining the notions of Penfield (1954) concerning the presence of a centrencephalic mechanism within the brainstem which serves to coordinate and integrate the activities of the cerebral hemispheres.

Nonspecific division of the VDMS. This division (N-VDMS) is extensively represented throughout most of the neuraxis investigated, covering brainstem structures ranging from the pontine reticular formation to the corpus striatum. The very extensiveness of this division forbids any detailed analysis of all possible pathways contained therein. However, two major ascending fiber systems are clearly recognizable within the N-VDMS and probably contribute in a very important way to the performance of visual discrimination habits.

One of these is the ascending brainstem reticular system. The correspondence between the N-VDMS and the trajectory of the ascending reticular fibers as described by the Scheibels (1958) is conspicuous, particularly in connection with the bifurcation at posterior diencephalic levels. In a recent study by Lynch, Smith, and Robertson (1973), using the Nauta-Gygax and Fink-Heimer methods, ascending pathways from the ponto-mesencephalic reticular formation have been described which coincide even more remarkably with the major portions of the N-VDMS. Specifically, they traced fibers passing through or near the brachium conjunctivum (including a crossing component at or near the decussation), traversing dorsal to the red nucleus, and then bifurcating at posterior diencephalic levels, one branch projecting to the pretectum and thalamus and the second coursing through the subthalamus, entering the internal capsule, and terminating within (or passing through) the ventral aspect of the corpus striatum. As might be expected from the foregoing observations, the ascending catecholaminergic (Lindvall & Björklund, 1974; Ungerstedt, 1971) and ascending cholinergic (Shute & Lewis, 1967) fiber systems associated with the brainstem reticular formation also pass through the major components of the N-VDMS.

The second major ascending fiber system which appears to be represented within the N-VDMS has its origin within the substantia nigra and adjacent tegmentum. The nigro-striatal (dopaminergic) pathway, as described by Ungerstedt (1971) with histofluorescence method and confirmed by Shimizu and Ohnishi (1973) with the Fink-Heimer method, passes through the ventral tegmental area, then courses rostrally through the lateralmost portions of the medial forebrain bundle, enters the internal capsule and globus pallidus, and subsequently ramifies within the neostriatum. An even more striking correspondence appears in relation to the pathways originating within the nondopaminergic cells of the substantia nigra. According to Hedreen (1971), these cells send their fibers not only to the neostriatum, but to the entopeduncular nucleus, globus pallidus, posterior thalamus, and pontine reticular formation as well.

Other Functional Considerations

There is little doubt that the performance of a

previously learned response constitutes a highly complex act on the part of the organism, requiring the simultaneous engagement of many functional systems of the brain. On these grounds alone, it can be argued that the VDMS is no more than a conglomerate of discrete anatomical foci, each contributing in a specialized way to the performance of visual discrimination habits. For example, one component (or group of components) would play a role in the motivational process, a second in the attentional process, a third in the sensory-perceptual process, etc.

Clearly, the VDMS can readily be parceled into a specific (visual) and a nonspecific division. Further functional parceling, particularly of the N-VDMS, may also be possible. At the same time, however, the remarkable degree of morphological continuity which characterizes the N-VDMS suggests the presence of a highly organized nervous substratum whose function may be more aptly expressed in terms of the dynamic interactions between its constituent parts. In other words, the N-VDMS may constitute the "memory system" of the brain to the extent that it may contain those integrated circuits necessary for the adaptiveness of behavior especially reflected in the performance of learned (and unlearned) responses (see Thompson & LeDoux, 1974). Perhaps the most persuasive support of this notion comes from the recent neurophysiological studies of Olds and his associates (Disterhoft & Olds, 1972; Olds, Disterhoft, Segal, Kornblith, & Hirsh, 1972) on the identification of those units of the brain that exhibit "conditioned responses" with the shortest latencies. Although these "learning units" were identified at various levels of the neuraxis, their distribution within the brainstem strikingly coincides with the N-VDMS.

CONCLUSIONS

There has always been a need in the neurosciences for information showing a correspondence between a behavioral deficit and the destruction of a specific anatomical pathway within the brain. In the design of most lesion experiments focusing on such problems, the investigator constructs a specific hypothesis concerning the functional significance of a specific pathway, and then proceeds to canvass that part of the brain with lesions. In contradistinction to this approach would be one in which no specific hypotheses are formulated and no discrete parts of the brain singled out for investigation; virtually the entire brain would be canvassed with lesions. Although the latter approach is considerably more time-consuming, it ultimately provides a complete "functional" map of the brain for any given behavioral response from which correspondences to known neuroanatomical pathways can be inferred.

As demonstrated in the current study, it is feasible to construct a functional map of the brain with the use of the lesion method even when the behavioral response under investigation is a learned one. The

map for the expression of previously learned visual discrimination habits was found to be both extensive and complex, but not abstruse. To illustrate, an analysis of the map disclosed the following: (a) it appears to be composed of a specific division (lateral geniculate nuclei, occipital cortex, and lateral half of the cerebral peduncle at nigral levels) having visual functions and a nonspecific division having perhaps arousal and integrative functions; (b) clearly recognizable within the nonspecific division are ascending fiber systems associated with the brainstem reticular formation and the substantia nigra; and (c) the intermediary link between the two divisions may be provided by occipitoreticular projections.

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NOTES

1. It was necessary to extend the atlas at more rostral and caudal levels in order to accommodate all of the data.

2. Lesions of the pretectal area tend to produce greater losses on the brightness problem than on the pattern problem. The opposite effect tends to occur in the presence of ventrolateral midbrain reticular formation lesions.

3. In a recently completed experiment by Thompson, Arabie, and Sisk, the lesion method was used to map those brain areas critical for the expression of the incline plane discrimination habit in the white rat. Unlike the results on visual discrimination habits, the performance of the incline plane problem is dependent upon the integrity of the parietal cortex, cingulate cortex, septal nuclei, anterior, ventromedial, lateral, and ventral thalamic nuclei, medial

longitudinal fasciculus, and the cerebellum. On the other hand, the incline plane discrimination habit is similar to visual discrimination habits to the extent that it is abolished by lesions of either the caudoputamen-pallidum complex, entopeduncular nucleus, posterolateral hypothalamus, subthalamus, posterior thalamus, ventral tegmental area, substantia nigra, red nucleus, interpedunculo-central tegmental area, midbrain reticular formation, or nucleus reticularis pontis oralis.

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