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CURRENT PROBLEMS IN RESEARCH

Attentive, Affective, and Adaptive Behavior in the Cat

Sensory deprivation of the forebrain by lesions in the brain stem results in striking behavioral abnormalities.

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This is the first report of an investigation of the effects of mesencephalic brain stem lesions on the behavior of cats. Much interest has centered, in recent years, around brain stem structures and their potential role in behavior. Particularly important in current thinking is the fundamental work of Magoun and his colleagues on the central core of the brain stem, the multineuronal, reticular formation, which receives afferent supply from all sensory systems and contributes significantly to the activation of the cortex and other forebrain structures (*1, 2*). This system, including the nonspecific thalamus, has also been implicated in the neural mechanisms for emotion, motivation, learning, and perception and even in consciousness and the integration of the highest functions of man (*3, 4*).

The lateral regions of the mesencephalic brain stem, containing the specific, highly localized, long and direct sensory pathways, have been thought by many to be restricted to the function of bearing specific information to the reticular formation and forebrain structures. Much of current neurophysiological theory does not take adequate account of other functions for these specific systems, despite the behavioral evidence to indicate the great importance of specific and meaningful sensory information in many nonsensory, as well as sensory, functions of the organism. For example, consider the very great disrupting effects of sensory isolation experiments in man where intellectual blocking, emotional disturbances, and hallucinations are reported (*5*); the importance of early sensory experience in the development of normal perceptual and emotional capacities (*6–8*); the devastating effects of extensive peripheral deafferentations on locomotion (*9*), use of individual limbs (*10*), sexual behavior (*11*), and maze learning (*12*); and the importance of sensory stimulation in hunger, thirst, specific hungers, and gross bodily activity (*13*). In some of these cases it has been implied that it is the nonspecific, activating effects of the normal sensory stimulation, through the reticular formation, that are important in the maintenance of normal, integrated behavior (*3*). But there is, at present, little direct experimental information to support this or alternative viewpoints.

The work discussed here was undertaken in an effort to make a direct attack on the problem of the respective roles of the reticular formation and the sensory pathways in behavior. To date, 35 cats have been studied extensively, both preoperatively and after lesions had been made which damaged different portions and different amounts of mesencephalic brain stem, bilaterally and unilaterally. Because lateral lesions produced surprisingly extensive defects and provided a unique opportunity to assess the contribution of the reticular formation to behavioral functions after severance of the lemnisci, most of the cases reported here sustained lateral lesions in which the medial structures of the brain stem were spared.

Procedures

The assessment of behavior in this investigation was carried out by three major methods: reflex testing, situational testing, and formal psychological testing. Preoperatively, the cats were given careful *neurological examinations* on repeated occasions, over periods as long as 6 months. Evaluations were made of tactile, visual, abduction, and chin placing reflexes; hopping, supporting reactions, and postrotatory nystagmus; responses to touch, to painful stimuli on the head and body, and to hot and cold water on the extremities; and visual and auditory reflexes. The *situational tests* were standardized insofar as possible and included responses to dogs, mice, rats, monkeys, and other cats; brief exposures to extremes of heat and cold; responses to sexual stimulation, artificial or in coitus; reactions to food (its localization in space by smell or vision and its acceptance or rejection when powdered with quinine) and the acceptance or rejection of various nonfood objects; response to catnip ball, string, crackling paper; and reaction to a variety of noxious stimuli: ether, ammonia, electric shock, water spray, and paper boots or alligator clips on the extremities. The *formal psychological tests* consisted of learning to avoid a striped card accompanied by shock; classical leg-flexion and respiratory conditioning with shock as the unconditioned stimulus and with visual,

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tactile, and auditory conditioned stimuli; avoidance conditioning in the shuttle box with visual and auditory signals; learning a simple instrumental response to obtain food; and position, black-white, and pattern discrimination for food rewards.

Lesions were made stereotaxically with electrolytic currents; the atlas of Jasper and Ajmone-Marsan (*14*) was followed. After operation, the cats were studied for up to 2½ years. They were reexamined periodically throughout the postoperative period in reflex tests, in the situational tests, and in the formal psychological tests. Brain waves were studied in a number of cases; a few animals were stimulated through implanted electrodes; and as a terminal procedure in several cases, evoked-potential maps were made of the somesthetic areas of the cerebral cortex. In the end, all animals were perfused and their brains were fixed, sectioned, and stained with Nissl and Weil stains in alternate sections. The lesions were studied histologically and reconstructed. In addition, animals were prepared for Nauta stain, after lesions had been made in the lemnisci and in other areas, both cortical and subcortical, in order to gain information on afferent and efferent projections to the midbrain area involved in the lesions.

Results

The major findings reported here relate to the animals prepared with lesions of the lateral brain stem, involving the classical, long lemniscal pathways (Figs. 1 and 2). These animals showed many marked symptoms. Most of them can be described under three headings: (i) changes in sensory capacities, (ii) changes in affect or emotionality, and (iii) changes in adaptive responses to the environment, including other animals.

Changes in sensory capacity. Quite expectedly, all animals showed marked tactile, proprioceptive, nociceptive, auditory, and gustatory defects, for the known pathways (Fig. 1*A*) serving these modalities were interrupted in their central course (*15–18*). Quite unexpectedly, the animals also showed similar visual and olfactory defects, even though the known pathways in these systems were not directly involved in the lesions. The sensory defects were perhaps best seen in the cats with unilateral lesions, on the side of the body contralateral to the lesions, for easy comparison could be made with the unaffected, ipsilateral side. Tactile and visual placing were absent or greatly reduced in the contralateral limbs; hopping was often impaired, and it was possible to place the contralateral foreleg in a contorted position over the back without inducing the prompt struggling and adjustment that the animal made when its ipsilateral foreleg was treated in similar fashion. When the animals were held with the legs pendant, the contralateral limbs were extended and immobile whereas the ipsilateral were flexed and actively searching in space. The animals fended off the examiner's hands with the ipsilateral forelegs. In chin placing, only the ipsilateral legs were placed typically, or the contralateral leg would come up very slowly and later than the ipsilateral. Response to touch or painful stimulation on the contralateral side resulted in poor activation and little or no localization of the site of stimulation; in fact, when localization occurred, it was usually to a comparable point on the opposite side of the body.

Smell and vision were similarly defective on the side opposite the lesion. When fresh meat was presented on the ipsilateral side, the hungry cat would sniff and bat at it with its paw. When the meat was passed to the contralateral side, however, sniffing ceased and there was no sign of orientation toward it. This difference between the two sides occurred when both of the cat's eyes were masked—a finding that showed

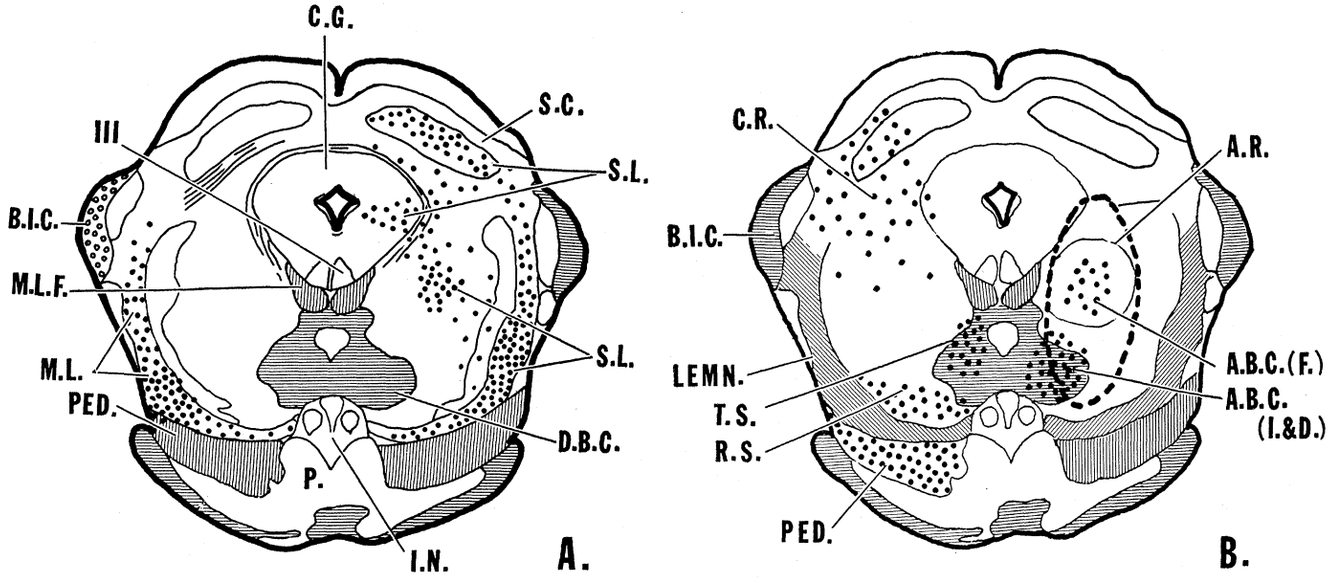

Fig. 1. Midbrain of the cat, at the level of the lesions, showing the position of the long ascending and descending pathways, based on anatomical and physiological studies. *A*; Ascending lemniscal tracts (see *15–18*); *B*; ascending cerebellar (*46*) and reticular (*17*, *47*) paths and descending corticoreticular (*16*), tectospinal (*20*), and rubrospinal (*17*) tracts and descending cortical paths in the basis pedunculi (*16*); *A.B.C.(F)*, ascending cerebellar path from fastigial nucleus; *A.B.C.(I. & D.)*, ascending cerebellar path from interpositus and dentate nuclei; *A.R.*, ascending reticular paths outlined by broken line with central focus shown by solid line; *B.I.C.*, brachium of inferior colliculus (auditory); *C.G.*, central gray matter; *C.R.*, corticoreticular path; *D.B.C.*, decussation of brachium conjunctivum (cerebellum); *I.N.*, interpeduncular nucleus; *LEMN.*, lemniscal paths; *M.L.*, medial lemniscus; *M.L.F.*, medial longitudinal fascicle; *P*, pons; *PED.*, basis pedunculi; *R.S.*, rubrospinal path; *S.C.*, superior colliculus; *S.L.*, spinal lemniscus (spinothalamic, spinotectal, spinoreticular); *T.S.*, tectospinal path; *III*, oculomotor nucleus.

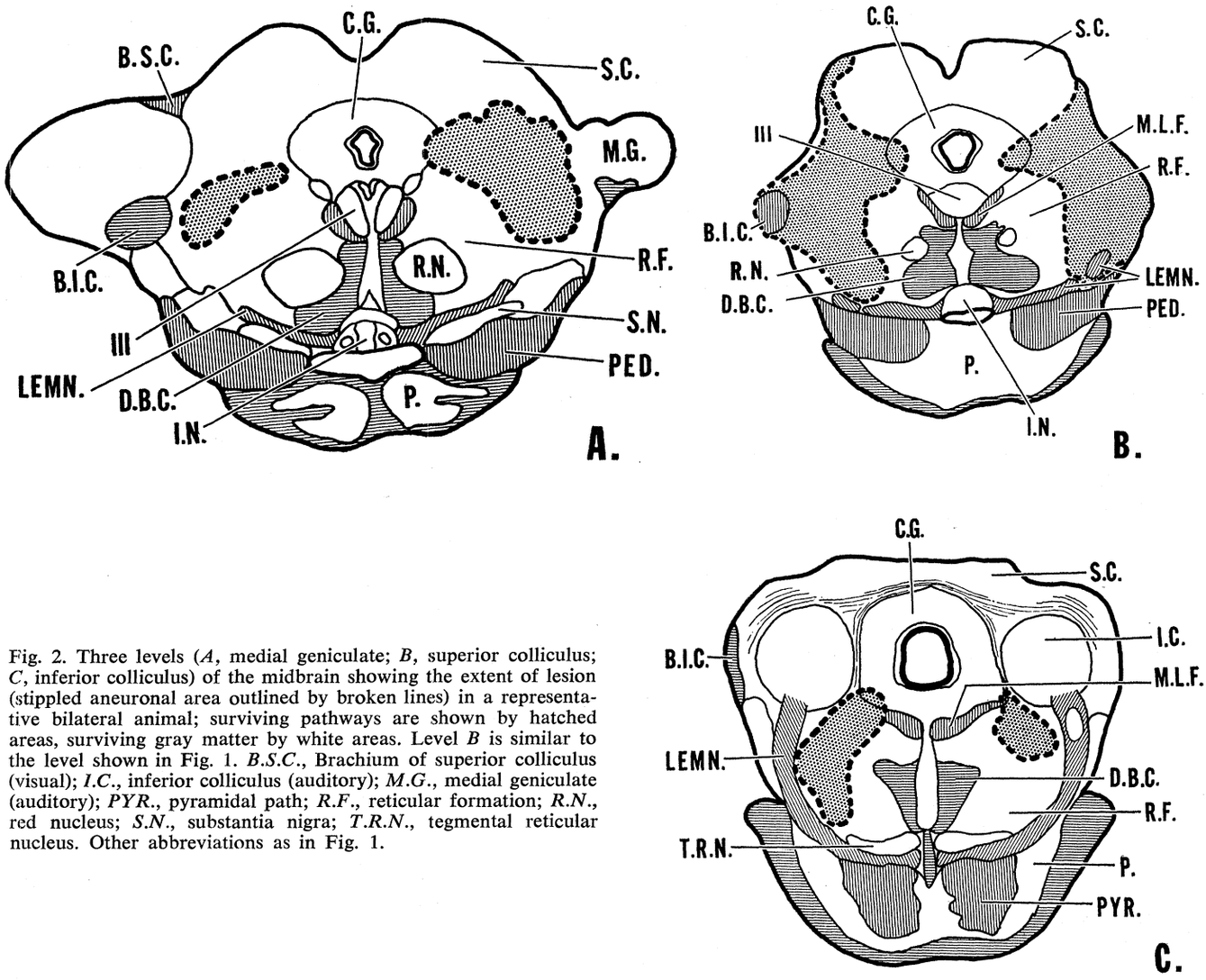

Fig. 2. Three levels (*A*, medial geniculate; *B*, superior colliculus; *C*, inferior colliculus) of the midbrain showing the extent of lesion (stippled aneuronal area outlined by broken lines) in a representative bilateral animal; surviving pathways are shown by hatched areas, surviving gray matter by white areas. Level *B* is similar to the level shown in Fig. 1. *B.S.C.*, Brachium of superior colliculus (visual); *I.C.*, inferior colliculus (auditory); *M.G.*, medial geniculate (auditory); *PYR.*, pyramidal path; *R.F.*, reticular formation; *R.N.*, red nucleus; *S.N.*, substantia nigra; *T.R.N.*, tegmental reticular nucleus. Other abbreviations as in Fig. 1.

the olfactory component of the deficit. Careful testing with first one eye masked and then the other showed a failure to respond in the large (70- to 90-percent), temporal visual field on the contralateral side. Within the smaller (10- to 30-percent), nasal visual field on that side, response to fresh meat was actually quite normal and accurate even though the meat was held out far enough to minimize olfaction (20 to 30 inches). The ipsilateral eye turned out to be deficient in the nasal field and normal in the temporal field.

Despite these marked sensory defects, it was possible to demonstrate responsiveness, on the contralateral side, to visual, tactile, and auditory stimulation by prolonged and intensive training. It appeared from these and other data that the defect here was not so much a simple sensory deficit as it was a failure in the capacity to utilize sensory information in making adaptive responses to the environment, in attending to relevant stimuli, and in localizing stimuli in space or on the body surface. For example, it was very difficult to develop a conditioned flexion response in the foreleg contralateral to the lesion, and when a response did occur, it was usually not a discrete response but a generalized one involving both forelegs. In one extreme case, tactile stimulation of the contralateral leg failed completely, over many hundreds of trials, to yield a conditioned flexion response in that leg (Fig. 3). Yet the animal was responsive to touch on that leg, for the conditioned tactile stimulus elicited a respiratory conditioned response and, early in training, a flexion response in the previously trained, opposite leg. Furthermore, it was possible to train the animal to orient its head to touch on the contralateral leg by feeding it repeatedly near the point touched. After this additional training, discrete conditioned flexion responses were frequently obtained in the contralateral leg, but only when the animal oriented or attended to this leg. If attention was not directed to the leg in this way, the animal did not give conditioned flexion responses. Thus, it appeared that the failure of this animal with a unilateral lemniscal lesion was primarily in attention rather than in sensory capacity as such. It is interesting to note in this connection that conditioned responses were also elicited in the contralateral leg when the tactile conditioned stimulus was paired with subthreshold stimulation of the opposite motor cortex through an implanted electrode.

In situational tests, the cats seemed to fail to appreciate the significance of a mouse or an aggressive dog or cat on the contralateral side and thus re-

sponded inappropriately to these stimuli. For example, the cat in pursuit of a mouse on the ipsilateral side would lose it and appear to forget it when it passed into the contralateral field. Or more dramatically, while the cat that was attacked by a dog on the unaffected, ipsilateral side showed normal defensive reactions, it was not uncommon for the cat to turn its contralateral side toward the dog and then remain in that position without defense or emotion. Similarly, there was little or no response to threatening movements of the examiner's hand toward the contralateral eye; when the tail was pinched, the animals attacked objects held in the ipsilateral visual field like normal cats but ignored objects in the contralateral field.

These same deficits were seen on both sides in cats with bilateral lemniscal lesions. They failed to show any defense and showed only occasional, weak escape reactions to a dog; they were deficient in their reactions to a mouse and in localization, if any, of painful clips on the body, and they were grossly deficient in many of the reflexes tested. Such animals also showed gustatory deficiencies, for early in recovery they accepted and ate nonfood objects and meat soaked in quinine powder.

Changes in affect or emotionality. In addition to these sensory defects, the animals with bilateral lesions showed greatly changed emotional responses. We have already pointed out the great deficiencies in their reactions to an attacking dog or cat and their limited response to a mouse. While painful stimulation elicited generalized struggling, it produced none of the visible autonomic accompaniment of emotion—very few typical affective responses such as hissing, spitting, clawing, and biting; what little struggling did occur did not long outlast the stimulus. These animals showed very little autonomic and emotional response to electric shock in a shuttle box even though the current was high enough to be tetanizing. They could be slapped, shaken, and suspended by one leg without protest, defense, or attack. On two occasions when this kind of treatment was carried to the extreme and prolonged over many minutes, explosive autonomic discharge was seen, including panting, piloerection, defecation, urination, batting, and clawing all at once. But even this massive response terminated immediately upon cessation of stimulation.

These cats with bilateral lesions were also deficient in their response to noxious fumes. It was possible to etherize them with only the mildest restraint, and they tolerated a cone saturated with ammonia without protest, even though they sneezed and lacrimated. Also, the females in heat were grossly deficient in sexual responses. Artificial vaginal stimulation would cause tail deflection, rump elevation, and treading; there was sniffing but no estrual cry and only a limited after-reaction, and during stimulation the head could be engaged in other activities.

Thus, the cats with bilateral lesions showed a great change from their preoperative style of affective responding. Two animals that were intractably vicious before operation became docile and easy to handle postoperatively. Preoperatively friendly and affectionate cats did not solicit affection postoperatively, did not respond to it, and rarely purred. All cats were typically mute and lacking in facial expression, presenting a blank, staring, masklike look. Almost all sense of danger seemed to be lost, and in some cases the animals would repeatedly approach attacking dogs or cats, only to be rebuffed again and again.

Changes in adaptive response. In addition to maladaptive lack of emotional behavior these cats showed adaptive falures in other ways. In the early postoperative period they became hyperactive, walking incessantly, usually about the periphery of a room. Actually this appeared to be hyperexploratory activity rather than randon hyperactivity per se, for the head and eyes made constant searching movements and the cats would stop periodically at objects and sniff repeatedly, only to go on to the next place and sniff again. Never was it possible to find any stimulus that could have set off the searching behavior, and never could an adequate olfactory stimulus be found, nor were the points sniffed ones that attracted normal cats. The hyperexploratory behavior was markedly stereotyped; the same ground was gone over again and again, and it was difficult to distract the cats from this activity. However, putting out the lights or placing the cat in

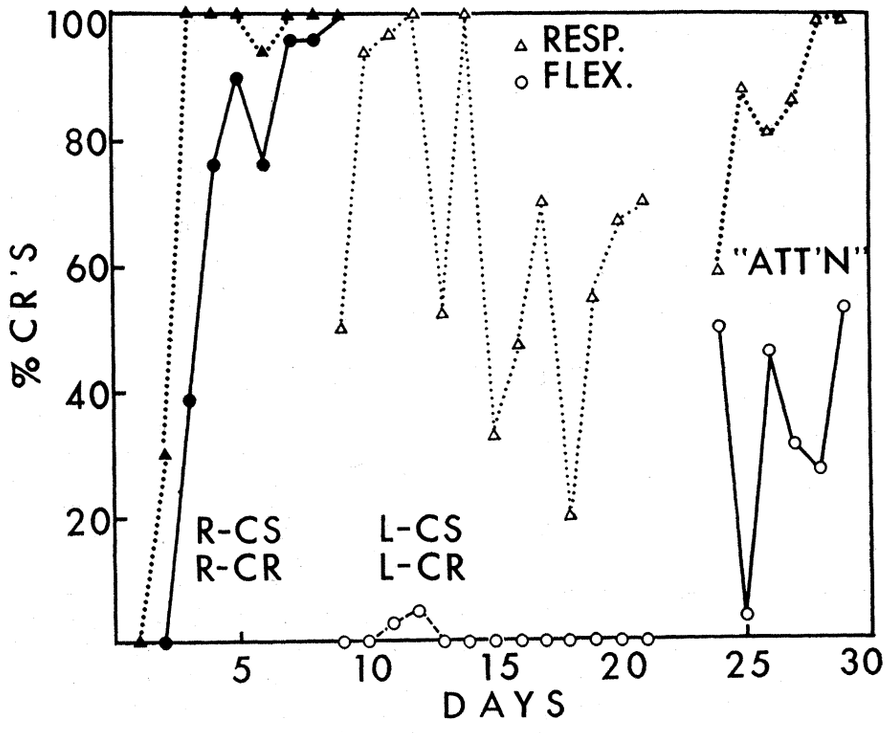

Fig. 3. Course of respiratory (dotted line) and leg-flexion (solid line) conditioned reflexes (*CR*) to a tactile stimulus (*CS*) in a cat with a large right, unilateral lemniscal lesion. Note the rapid acquisition and stability of the conditioned responses when the normal, right foreleg was used (*R–CS, R–CR*). When the affected, left foreleg was subsequently used (*L–CS, L–CR*), flexion conditioned reflexes were virtually absent and respiratory conditioned reflexes were unstable. Note the improvement in both conditioned responses when the animal was trained to attend (*"ATT'N"*) the tactile stimulation of the left leg; the dip in the curve on day 25 occurred because attention was directed to the food cup instead of the leg.

a small box or cage or in a strange room would usually dampen this activity.

When confined to a cage or small box the animals spent a great deal of time licking and biting at hair and skin on selected parts of their bodies, usually the middle of the lower back. They did not groom normally or keep clean, but it was easy to prevent skin irritations by frequent brushing or powdering. One animal licked and sucked the tip of its tail incessantly until all the skin was removed and the muscles and tendons were exposed.

Both male and female animals also exhibited a curious mounting of other animals, usually approaching from the side, seizing them on the back of the neck with the teeth, and then rolling over. This was incomplete as a sexual response and was not a really typical playful response; it was repeated over and over with vigor on male and female cats even after severe rebuffs, was usually directed toward the most actively moving cat in the room, and was also directed toward a dog, a monkey, and a rat. A catnip ball elicited a similar response from these animals; a cat would seize it and hold it in its mouth, and the ball could be removed only by forcibly prying the cat's jaws apart; sometimes the animal held it for several hours, and occasionally part of the response was to push the ball between the hind legs in a kind of mounting action. Also similar was the way in which these cats would hold a dead mouse in the mouth for long periods; in such cases, the mouse would be eaten only if cut up in small pieces.

Eating was also affected in these animals. Soon after the operation they would not eat voluntarily, but a touch of the lips evoked brisk snapping and swallowing. Such eating apparently did not produce satiation and was indiscriminate, for the cats would also seize and swallow nonfood objects such as orange skin, wood shavings, and cigarettes. One cat behaved in this way for over a year postoperatively and never ate normally. Others resumed voluntary eating but always ate voraciously and in abnormally large quantities, so that they eventually became somewhat obese.

The abnormal adaptation of these animals also was apparent in simple learning situations. Typically, these cats worked well in the sense that they were highly motivated for food, were not disrupted by strong electric shock, and were not easily distracted. Yet many of them never mastered even simple problems at normal rates and often never reached high levels of performance even after prolonged training. Typically, their performance would wax and wane; sometimes they showed a considerable tendency to forget from one testing session to another, even though in some cases the tests were separated by only 2 hours. Errors would not disturb them, and unlike normal cats they would go on for many trials at chance levels of success, for example, and continue to work without reduction in vigor of running and without the refusal to eat and the licking, grooming, and balking (displacement) so often seen in normal animals when they make frequent errors.

Discussion

Quite clearly, lesions in the lateral or lemniscal region of the mesencephalic brain stem result in an extensive and consistent syndrome of symptoms. Animals with large bilateral lesions show marked tactile, auditory, proprioceptive, nociceptive, and gustatory as well as visual and olfactory defects. Such animals are typically mute and lack facial expression. They are almost completely without affect, showing on the one hand little sense of danger and only minimal aversive reactions and on the other hand no pleasurable responses to petting or sexual stimulation and no solicitation of either, unless the mounting behavior can be considered as such. Aggression and rage are almost completely absent, as measured by somatic and autonomic responses, although temperature regulation is only slightly impaired. Much of their waking activity consists of aimless, stereotyped wandering—an apparent visual and olfactory searching, hallucinatory in nature and very difficult to break into.

In summary, the sensory inattention, the lack of affect, and the ceaseless hyperexploratory behavior result in a great reduction in the richness and variability of behavior and give these animals an automaton-like character. Preoperative individual differences in behavior are largely wiped out; on most occasions the animals are out of contact with the external environment and their behavior seems internally or centrally directed and grossly inadequate in its adaptive value. Yet they are awake, active, and essentially normal in their basic motor capacities, and their electroencephalograms are similar to those reported by Magoun and his co-workers in their studies of lateral lesions (*19*).

Because the lesions in our studies are chiefly lateral, involving the lemniscal or specific sensory pathways, it is important to try to understand the symptoms in terms of sensory deprivation, particularly of forebrain structures. To begin with, it is easy to understand the interference with normal tactile, proprioceptive, nociceptive, auditory, and gustatory functions in terms of direct severance of the sensory projection pathways, as defined by anatomical and physiological studies (Fig. 1). The survival of functions in these modalities may be ascribed to (i) intact reflex mechanisms below the level of the lesion, (ii) routes to the thalamus and cortex through the reticular formation, or (iii) incomplete lemniscal section, particularly of the trigeminal portion, much of which lies scattered in the reticular formation.

The visual and olfactory defects are more difficult to understand than those in the other modalities, for there is virtually no involvement of the known afferent visual and olfactory pathways. These deficits may be due to (i) the involvement of unknown pathways in these sensory systems, (ii) the deleterious effects on vision and olfaction of so much specific sensory deprivation in other modalities, and (iii) (an alternative to the sensory deprivation hypothesis), the interruption of descending paths from the forebrain into the brain stem in the region of the lesions (Fig. 1*B*).

Let us consider the visual defects first. We know from control lesions, where no current was passed, that damage from electrode tracks going through the visual cortex, optic radiations, and superior colliculi was without effect. In lesions where current was passed, the superior colliculi were spared from major damage although the lesions severed many of the efferent paths (tectobulbar, tectospinal) as they leave the colliculus (*20*). In all cats showing visual symptoms, however, the destruction of the lemniscal systems was accompanied by undercutting of the superior colliculi (see the extension of the lesion into the central gray matter in Fig. 2*B*). One cat with a large lemniscal lesion largely escaped undercutting of the colliculi, and this animal was free of visual symptoms although it showed all

the others. Furthermore, three cats in which the colliculi were undercut in the absence of major lemniscal lesions showed mild visual defects (Fig. 4). It seems, then, that appearance of the full range of visual symptoms in our test animals was dependent upon damage to *both* the lemnisci and the area under the superior colliculi.

Although Blake (*21*) has reported some visual defects after large lesions of the superior colliculi were made in the cat, Myers (in the cat) (*22*) and Porter (in the chimpanzee) (*23*) found visual symptoms only when the area just beneath the superior colliculi was destroyed. In evaluating this area beneath the superior colliculi, it is of interest to note that, after illumination of the retina, evoked potentials can be recorded from the subcollicular area and central gray matter (long latency) as well as from the colliculi themselves (short latency) (*24*). This subcollicular area, however, does not show terminal degeneration in the cat after removal of the eyes or visual cortex, so the pathways shown physiologically from these structures must be indirect (*18*, *25*). However, the subcollicular area receives direct projections from association cortex (Fig. 1*B*) (suprasylvian and anterior lateral gyri) and sensorimotor, sigmoid, and anterior ectosylvian cortex (*16*). It is also relevant to note that in the monkey (*26*) there are projections to the area beneath the superior colliculi from certain cortical association areas whose ablation produces visual deficits—parietal (*27*) and temporal (*27, 28*).

Another very intriguing possibility for the interpretation of the visual symptoms comes from the work of Arden and Söderberg (*29*), who found that the resting electrical activity in the lateral geniculate, after removal of the eyes, was dependent upon the integrity of the upper midbrain at the level of the lesions. The visual symptoms of our animals, together with the above evidence, strongly suggest that normal visual functions may depend upon the integrity of a midbrain mechanism receiving projections from the lemnisci, ascending reticular pathways, and cortical as well as subcortical areas.

The olfactory defects are even more puzzling than the visual because the primary olfactory paths are even farther from the site of the lesions. It is known, however, that olfactory sensitivity is greatly reduced by elimination of the sympathetic outflow to the olfactory mucosa (*30*). Since our test animals have such poor autonomic activity, it is possible that their olfactory impairment can be understood in terms of such reduced sympathetic output. It is also suggestive that the electrical activity of the olfactory bulb is influenced by the activation of other sensory systems (*31*), but as yet we have made no effort to study the electrical activity of the olfactory system.

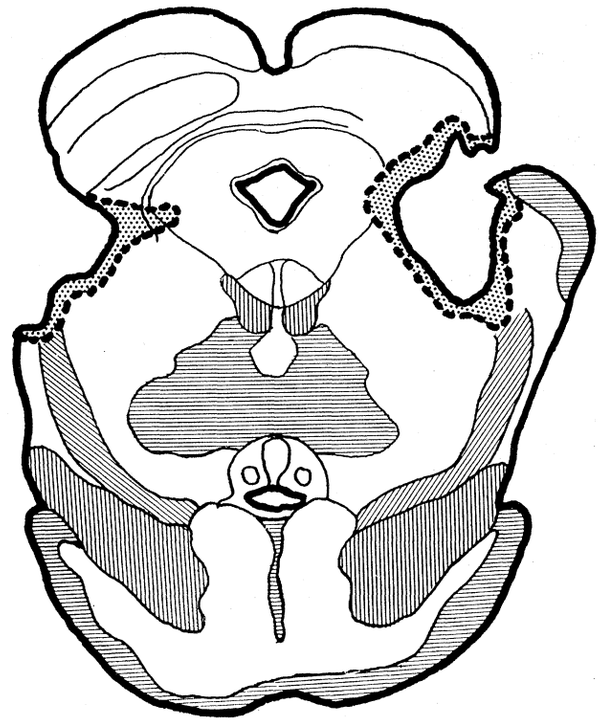

Fig. 4. Midbrain of one of three cats, with minimal visual symptoms, showing destruction of the dorsolateral tegmental area below the superior colliculus, the lemnisci being largely spared. Structures shown as in Figs. 1 and 2.

Something of the general character of the sensory defects in our test animals may be understood if one considers that the animals may be generally aroused by strong stimuli in all modalities but fail in localization of and attention to stimuli. On the one hand, this constitutes behavioral evidence to show that the reticular pathways that survive after lemniscal lesions are capable of only diffuse arousal, as data from electroencephalographic recordings suggest (*1*, *19*). On the other hand, the sensory inattention and poor localization are remarkably reminiscent of the effects of posterior parietal cortex lesions in primates, including man. Like the primate with unilateral lesions in the parietal lobe, our cats with unilateral lesions ignore all events on the side of the body contralateral to the lesion, regardless of modality, yet they show some signs of receiving all stimuli on this side. Particularly striking is the case of simultaneous bilateral stimulation of corresponding receptive points, where "rivalry" heightens the inattention on the affected side. It is as though the lemniscal lesions, at the midbrain level, were impairing cortical function by removing the possibility of patterned afferent input to cortical structure.

It is also possible to look at the great reduction in affect of our animals as a consequence of the sensory deprivation produced by lemniscal lesions. The failure of our animals to show emotional or autonomic responses may, in part, be a failure to attend sensory events in the environment, a failure to localize dangers and threats, a failure to make sustained and adaptive reactions to stimuli—in short, a failure to "appreciate" the significance of sensory stimuli. That sensory deprivation per se may produce such changes in affect is shown by Melzack's finding (*8*) that dogs reared in sensory isolation are grossly deficient in their emotional and adaptive reactions to noxious stimulation and in their ability to learn avoidance responses in simple training situations.

The peculiar, stereotyped, hyperexploratory behavior of these test animals also makes some sense in terms of sensory deprivation. Here it is of interest to note that human beings who have been subjected to sensory isolation frequently suffer hallucinations and sensory "hunger" (*5*). The searching behavior of our cats seemed to have a hallucinatory quality, for no eliciting

stimuli could ever be found. It is as though their behavior were centrally determined, for it was stereotyped and ceaseless, unaffected by the sensory events that normally stop and start the behavior of cats. In fact, it sometimes appeared as though the cats, like the isolated human beings and dogs, were "seeking" out stimulation as a result of their sensory deprivation. Their endless wandering not only could provide proprioceptive feedback through surviving medial pathways (*32*) but also would increase the possibilities of visual and olfactory stimulation. In the dark, the wandering ceased. In a cage or small box, the hyperactive locomotion also stopped, but it was replaced by endless licking and chewing of hair and skin on the back and by overeating, if food was present.

Both the hyperexploratory activity and the increased licking might also be interpreted as "release" phenomena, as though some inhibitory influence had been removed. This same interpretation could also apply to the abnormally brisk snapping these animals show when their lips are brushed, to their seizing of other moving animals by the back of the neck, and to their clamping bite on the catnip ball. In all of these cases the behavior appears to be without affect and without any obvious adaptive end. Thus the cat with midbrain lesions does not seek out the moving animal but simply responds when stimulated by it; when rebuffed, it "explores" the room until stimulated by the moving cat again.

While any parallelism is purely speculative, it is worth noting here that the behavior of our cats with midbrain lesions bears striking resemblance to the behavior of certain autistic children. These children are very inattentive and may be unresponsive to many forms of sensory stimulation. They are typically flat in their affect and often have little facial expression. And they frequently walk or wander endlessly or engage in other highly repetitive, rhythmic activities from which it is almost impossible to distract them. Unfortunately, little is known of the neurological or psychological basis of this disorder, although it is often considered to be one form of early schizophrenia, related to deprivation of normal emotional experiences during development (*33*). This interpretation of autistic behavior, taken together with the effects of human isolation (*5*), the effects of early sensory deprivation in dogs (*8*) and monkeys (*6*), and the behavior of our cats with lemniscal lesions, suggests the importance of rich and varied sensory stimulation in the development and maintenance of attentive, affective, and adaptive behavior. The studies reported here suggest further that it is the specific, the patterned and localized, sensory information, carried to the forebrain via the lemnisci (*34*), that is essential.

It is clear from the above discussion that we believe the symptoms obtained from lateral lesions in the midbrain discussed in this article are due primarily to a sensory deprivation. The concept of sensory deprivation proposed here is not limited to the thalamic relay nuclei and their cortical receiving areas. Some of the defects of the animals with lemniscal lesions are similar to the classical signs following ablation of the cortical receiving areas (for example, the loss of tactile placing and searching and tactile localization). There are, in addition, some similarities between the symptoms of our test animals and symptoms that follow rhinencephalic lesions (*35*, *36*), but in general the two cases are quite different, for the cat with rhinencephalic lesion shows little sensory defect and may show exaggerated emotion and sexuality. Most significant, however, is the striking similarity of deficits in reflexes and affective behavior in the animal with lemniscal lesions and in the total neodecorticate, reported by Bard and Mountcastle (*35*). The similarities strongly suggest that the lemniscal lesion produces many of its effects through a deafferentation of the forebrain which greatly impairs normal neocortical function. The disruption in behavior produced by lemniscal lesions thus appears to be due more to a sensory deprivation of the neocortex than of the rhinencephalon; were both regions equally affected, one might expect in the cat with lemniscal lesions the sham rage that is seen in the cat which lacks both cortex and rhinencephalon. If these suppositions are correct, there should be a significant change in the affect of the animal with lemniscal lesions after a subsequent removal of the rhinencephalon unless the lemniscal lesions have impaired the midbrain mechanism for rage.

The sensory deprivation of the forebrain that follows lemniscal lesions is extensive, for the lemniscal paths terminate widely in many of the nonspecific as well as in the specific thalamic nuclei, supplying sensory, motor, and associational cortex and many subcortical structures. These severed paths also terminate directly in the subthalamus, and in the tectum and tegmentum of the rostral midbrain. Therefore, by severance of the lemniscal projections, the lesions in our test animals impaired the function of subcortical as well as cortical structures. One specific example of the possible effects of direct deafferentation of subcortical structures is seen in the deficit in faciovocal activities produced by lemniscal lesions. These same effects have previously been reported after direct destruction of the central gray matter and adjacent tegmentum (*37*). Since there was only minimal involvement of the central gray matter in the lesions in our test animals (Figs. 2 and 4) and since stimulation of the lemniscal paths (Fig. *1A*) evokes faciovocal activity (*38*), the faciovocal deficits in these animals may be due in large part to deprivation of afferent input into the central gray matter and tegmentum via the lemniscal pathways.

Finally, it should be noted that among other structures that are partially deafferented by lesion of the lemnisci (or actually invaded by the lesion) is the reticular formation of the rostral midbrain. We have already pointed out that the lesions in our test animals extended into the dorsolateral tegmentum beneath the superior colliculi. This limited area seems to be involved in visual function and is the site of interaction of many ascending and descending pathways, including the medial parts of spinal (*15*, *17*, *39*) and trigeminal lemnisci (*17*, *40*), ascending reticular paths (*17*), descending subthalamic and pallidal paths (*41*), and corticifugal paths (*16*, *42*). In trying to assess the role of the dorsolateral area of the reticular formation in the symptoms noted it should be remembered that lesions largely restricted to this area produced only mild, partial defects (Fig. 4). This finding, taken together with the fact that a large part of the reticular formation is intact and is fully innervated below the lesion, leads us to believe that the symptoms in our test animals are not primarily due to reticular involvement.

In support of this conclusion is the additional finding that large lesions of the midbrain reticular formation produce results different from those described here (see also *43*). One animal with a lesion in the lateral part of the

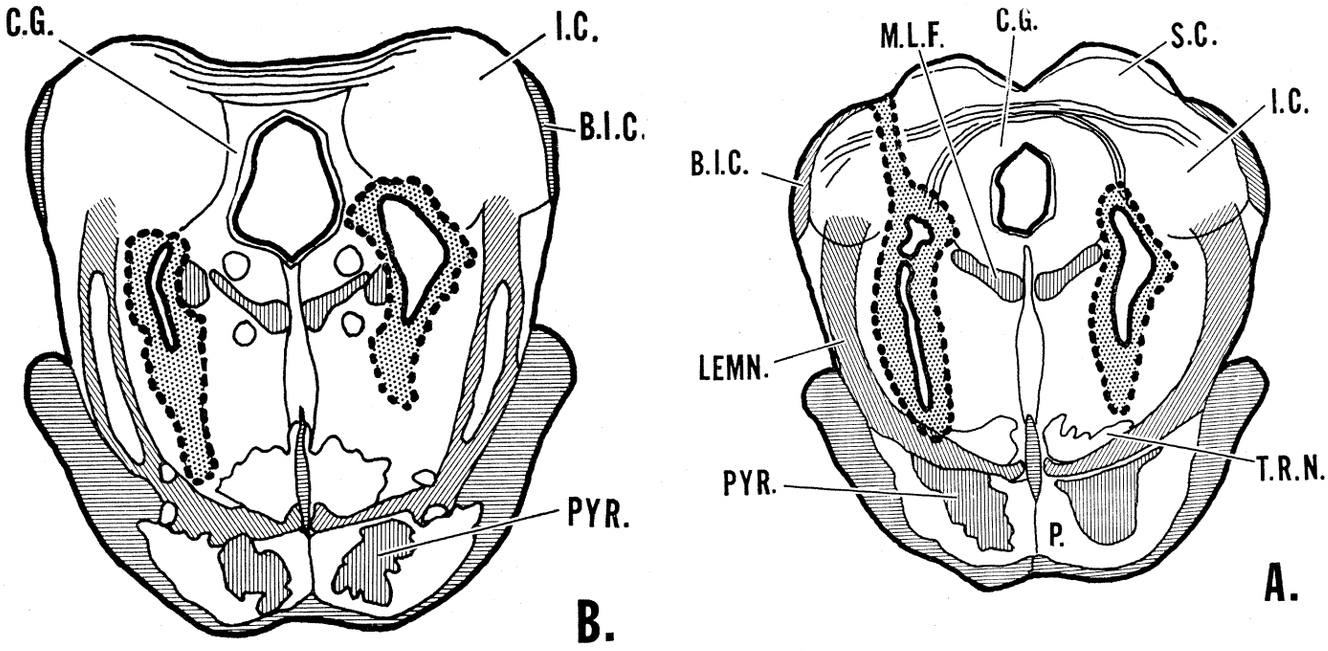

Fig. 5. Two levels of the midbrain of a cat, showing lesions in the lateral part of the reticular formation. Abbreviations as in Figs. 1 and 2. The extent of the lesions is shown by heavy, broken lines; included is a stippled aneuronal area surrounding a cavity.

reticular formation which largely spared the adjacent lemnisci (Fig. 5) was asymptomatic. In a second case, a cat with an extensive and more medial lesion of the reticular formation (Fig. 6) showed no sensory deficits. The animal was somnolent for over a week, with synchronized electroencephalograms (*19*), and remained catatonic and sluggish for over a month. After recovery from this phase, the cat tended to be drowsy when undisturbed, but it was easily aroused to alert wakefulness and reacted appropriately to various situations (dog, mouse, food, other cats, home cage, and so on). This cat was hyperexcitable and showed well-organized and well-localized affective reactions (hissing, batting, clawing, growling, piloerection, pupillary dilatation) in response to painful stimuli or to any sudden visual, auditory, vibratory, or tactile stimulus, even though mild in intensity (see *44*). Because its threshold for emotional response was so low, this cat was also highly distractible in contrast to normal cats and, particularly, in contrast to the animals with lateral lesions. Possibly because of this and the accompanying hypokinesia, the animal performed poorly in formal learning tests.

Thus, it appears that after interruption of much of the classical, lemniscal paths at the rostral midbrain, the cat shows generalized, largely unadaptive and unlocalized arousal to even strong stimulation, with little attention and affect, despite the fact that the animal is wakeful and active and has good motor capacity. In contrast to this picture, a large reticular lesion sparing the lemnisci results in an animal whose general behavior is much like that of a normal cat except for chronic hypokinesia or drowsiness and for strong and easily aroused affect to mild stimulation. Certain formal conditioning procedures showed that animals with lesions of either type could learn to discriminate and make adaptive responses, although they differed greatly in their performance and were in all cases abnormal.

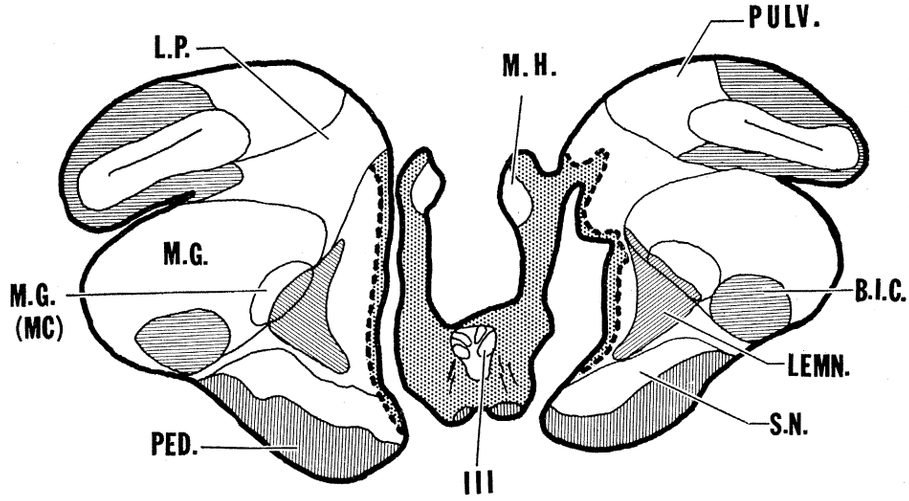

Fig. 6. Rostral midbrain showing the extent of a lesion in the medial part of the reticular formation. *L.P.*, Lateral posterior nucleus of the thalamus; *M.G.(MC)*, magnocellular part of the medial geniculate nucleus; *M.H.*, medial habenular nucleus; *PULV.*, pulvinar. Other abbreviations as in Figs. 1 and 2.

Summary

Lesions of the lateral portion of the upper midbrain, involving medial, lateral, spinal, and trigeminal lemnisci primarily, result in a consistent syndrome of symptoms in the cat. (i) There is a marked *sensory deficit*, characterized mainly by sensory inattention and poor localization in the tactile, proprioceptive, auditory, gustatory, and nociceptive modalities, where direct pathways are interrupted. Similar defects appear in vision and olfaction where no known direct or primary paths are interrupted. (ii) These cats are characterized by a *lack of affect*, showing little or no defensive and aggressive reaction to noxious and aversive situations and no response to pleasurable stimulation or solicitation of affection or petting. The animals are mute, lack facial expression, and show minimal autonomic responses. (iii) They show a *hyperexploratory activity* characterized by incessant, stereotyped wandering, sniffing, and visual searching, as though hallucinating. This behavior appears to be centrally directed and is very difficult to interrupt with environmental stimuli. (iv) They also demonstrate *exaggerated oral activities*: they snap in response to tactile stimulation of the lips, seizing and swallowing small objects even if inedible; they overeat; they hold objects too large to swallow (a mouse, a catnip ball) firmly clamped in the mouth for long periods of time; they mount and seize other animals (rat, cat, dog, monkey) by the back or the neck; they lick and chew the hair and skin of the back or tail incessantly when confined in a cage.

In interpreting these results we emphasize the view that the syndrome is due chiefly to the extensive, specific, sensory deprivation produced by interruption of the lemnisci at the rostral midbrain. The relation of these findings to the effects of sensory isolation in man and animals, to the effects of midbrain lesions and neodecortication, to parietal lobe syndrome in primates, and to the behavior of autistic children is discussed. It is our belief, from these studies, that the symptoms produced by interruption of the lemnisci, characterized by a high degree of somatotopic and modality localization, are due to a loss of patterned sensory input to the forebrain, particularly to the neocortex and to the rostral midbrain. Without a patterned afferent input to the forebrain via the lemnisci, the remaining portions of the central nervous system, which include a virtually intact reticular formation, seem incapable of elaborating a large part of the animal's repertoire of adaptive behavior (*45*).

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