PRIMATES from which the cortex of one cerebral hemisphere has been removed circle in walking toward the side of the lesion; such animals also show contralateral hemiparesis together with deviation of head and eyes toward the side of the lesion. With all types of progression there is rotatory movement which appears to be involuntary and purposeless and becomes accentuated under emotional stimuli such as rage, fear, or the sight of food. Deviation of head and eyes, and circling occur in hemidecorticate cats and dogs, as well as in subhuman primates. After lesions of the frontal lobes, Hitzig (16) observed the same symptoms in dogs and attributed the phenomena to paralysis of the trunk muscles of one side. In 1895 Bianchi (3) noted that monkeys with "prefrontal" ablations circle toward the side of the lesion, due, he thought, to visual and to "intellectual "disturbances. In man also conjugate deviation of the head and eyes appears after certain cortical lesions, and many focal epileptic attacks begin with turning of head and eyes (10).

In the following experiments an attempt has been made to analyze in the monkey (Macaca mulatta) the physiological factors involved in circling, and to localize the cortical area responsible for this symptom.

METHODS

In the present study lesions of area 8 were made in 12 normal rhesus monkeys (Macaca mulatta). In addition observations were made on a large number of monkeys, with lesions elsewhere in the cortex which had been operated on for other purposes. Excisions of cortical areas were made under aseptic technique and the animals were observed subsequently over a period of several months.

PRELIMINARY Cortical Ablations

In attempting to determine the region of the brain responsible for circling and head turning observations were made on animals with lesions involving various cortical areas. As these studies have an important bearing upon area 8 ablations to be described below, they may be briefly summarized.

Hemidecortication. The symptoms following hemidecortication in the monkey are well known (Hitzig, 16; Karplus and Kreidl, 19). A profound contralateral hemiparesis develops immediately together with a sensory deficit and hemianopia. The phases of recovery are also predictable; during the first week power returns to such an extent that the animal is usually able to sit and stand, and even to walk and climb awkwardly. The paretic extremities, at first flaccid, begin to show spasticity at about the third day and tend then to be held in greater extension than the normal limbs. They are less sensitive to touch and to pain on the affected side than on the normal, and the sensory deficit is also evident in progression for the animals tend to "lose" the extremities, which become tangled in awk-
ward postures. Forced grasping is prominent and tendon reflexes, at first decreased, tend ultimately to become exaggerated on the paretic side. Deviation of the head and eyes and curving of the body are marked as soon as the animals regain their feet; any emotion, excitement, fear, or rage accentuates the head deviation and tendency to circle. Although the head and eyes are usually held toward the side of the lesion, they are frequently turned in the opposite direction when the animal is not under stress, and immediately after operation the eyes can be fully deviated in both directions.

By the end of the first month improvement is considerable, but movement and posture in the paretic limbs are not normal, for there is persistent spasticity with hyperactive tendon reflexes; the sensory deficit to touch and pain is less marked. No fine movements are performed with the paretic hand or foot, and fingers and toes can not be used individually. All purposeful movements are executed either by the normal side alone, or by the normal extremities first, followed and assisted by the paretic members. At this stage deviation of the head and eyes is less marked than after operation, but is still conspicuous. The animal tends to look toward the normal side and to circle in this direction, but at times is able to move forward in a straight line.

Recovery in both motor and sensory spheres continues slowly but steadily after this for at least the first six months. Motor deficit, hemianopia and a tendency to circle have been observed to be present for a year; indeed the symptoms probably persist indefinitely, for the hemidecorticate macaque reaches a permanent motor status which can never be mistaken for normal.

In such animals the circling has been attributed to visual abnormality (Karplus and Kreidl, 19). Hemianopia, together with deviation of the eyes to the "seeing" side might produce a turning of the animal toward the objects seen. However several of these animals in which circling movements were present were blindfolded without altering motor performance. On one, a hemidecortication was performed some time after the opposite occipital lobe had been ablated. This blind animal also circled.

Frontal lobe. Isolated extirpation of the frontal lobe in monkeys (areas 4, 6, 8, 9, 10, 11 and 12) produces similar forced turning with deviation of head and eyes. These symptoms however are neither as extreme nor as enduring as in the hemidecorticate preparations and recovery from the hemiparesis also is quicker and more complete. During the first postoperative week the monkey without one frontal lobe recovers sufficiently to walk, climb and run adequately, although all movements on the paretic side show clumsiness and incoordination, spasticity and hyperextension. The fingers and toes are not used for fine movements at this stage. Forced circling is conspicuous as is deviation of the head and eyes; these last symptoms are present for several weeks but become less noticeable during this interval. A tendency to rotate when excited persists for months, being detectable long after deviation of the eyes or head has entirely disappeared.

The "visual" defect present following frontal lobe ablation will be described later in the discussion of the effects of lesions of area 8.

Areas 4 and 6. Ablation of the motor and premotor areas (areas 4 and 6, upper part, Fig. 1) together or in series, is followed, as is well known, by contralateral motor paresis (11). It has been suggested that circling movements occur because of weakness of the extremities of one side; however, these animals show no circling even at the height of their motor paresis. After isolated ablation of face and neck fields (areas 4 and 6, lower part), the resultant imbalance of the neck musculature does not cause forced circling and the head and eyes remain in the mid-line in spite of noticeable facial weakness.

Ablation of the remaining parts of the frontal lobe exclusive of areas 4 and 6 (i.e., areas 8, 9, 10, 11 and 12), is always accompanied by deviation of the head and eyes, and by forced circling without attendant paresis of the face and limbs. When various of the frontal association areas were then ablated singly and seriatim it developed that removal of fields 9, 10, 11 and 12 caused no one of the three symptoms, and that motor performance following such ablation could not be differentiated from that of a normal animal.
Other cortical areas. Removal of an occipital lobe is followed by hemianopia which differs from the visual defect of frontal lesions in that it is a permanent object-vision blindness. Such hemianopia is not accompanied by forced turning. There are times when these animals turn, because, as is obvious in watching them, they can see only to one side, and must therefore look only in that direction. The performance, however, is quite different from the regular circling movements of which follow ablation of a frontal lobe with area 8 removed. In true hemianopia turning is only occasional and is clearly visual in origin; it is never purposeless.

The effect of removal of the other centers for eye movements (Graham Brown, 12) has not as yet been investigated fully. In a few animals from which the parietal lobe had been removed and in which there was no hemianopia, deviation of the head and eyes has been noted, but without the forced and purposeless turning movements.

Ablation of Area 8

Ablation of a small area inside the curvature of the arcuate sulcus of the macaque (Fig. 2) roughly corresponding to area 8 of Brodmann (Fig. 1) is invariably followed by a definite syndrome which includes turning of head and eyes and circling. Area 8 as described by Brodmann in cercopithecus lies within the arcuate sulcus along its anterior lip (Fig. 1). Stimulation of this region produces movement of the eyes—usually conjugate—horizontal and away from the side stimulated, and is followed after an interval by turning of the head as well. Mesial to the arcuate sulcus in an area corresponding with the junction of areas 6 and 9, eye and head movements can also be obtained by stimulation. Here the head movement is most often primary and followed by that of the eyes. Widening of the pupils is also produced on stimulation here (Graham Brown, 12; Beevor and Horsley, 2; Leyton and Sherrington, 21; Wilbur Smith, 26). The mesial limb of the arcuate sulcus in the macaque is very deep and extends both mesially under area 6 and caudally deep to area 4. It is variable as to exact shape and depth as are all the cortical sulci in this species. Lesions of area 6 on the mesial side of the sulcus produce no turning...
of the head and no eye symptoms, unless area 8 as well is inadvertently damaged.

**Unilateral ablation.** Unilateral excision of the region anterior and lateral to the arcuate sulcus (i.e., area 8) is followed by deviation of the head and eyes and circling progression toward the side of the lesion. The symptoms are extreme during the first two or three postoperative days and all motor progression is accompanied by circling and turning of the body. During the succeeding two or three weeks the eye and head turning gradually becomes less and then disappears. A tendency to circle toward the side of the lesion persists for several months. However, this syndrome occurs only if area 8 is removed in its entirety, including all the gray matter in the depths of the arcu-
ate sulcus. Removal of the superficial cortical tissue produces only a fleeting trace of the syndrome.

The term "forced circling" has been used to describe this performance both because the animals are unable to move except in circles, and also because they seem to move more but with less purpose than the normal animals; thus, any emotional stimulus incites great motor activity and consequent revolving of the animal. When the conjugate deviation and the circling have disappeared the purposeless activity continues and the animals are restless, easily excited and hyperactive. At no time do they show any abnormal posture or paresis of the extremities.

In addition to the above symptoms these macaques present a transient condition which is difficult to distinguish from hemianopia. That is, they apparently do not see in the contralateral visual fields. They pay no attention to food placed in this side of their cage, they do not respond by blinking to threats made in this field and when small bits of food are brought into the field of vision from this side no response occurs until the mid-line of vision is approached. This defect disappears gradually, but persists for a time after the disappearance of conjugate deviation. The duration and intensity of the abnormality are both affected by lesions elsewhere in the frontal lobe, for the deficit lasts longer and is more pronounced following frontal lobe extirpation than after ablation of area 8 alone.

**Bilateral ablation.** If area 8 is removed first from one side and then from the other the same syndrome develops; after the symptoms from the first ablation become less marked, removal of the second area will temporarily reverse the direction of head and eye deviation, and of circling movements.

When area 8 is ablated from both sides simultaneously, or one shortly after the other, the picture which develops is striking, and quite different from that seen following any other type of discrete cortical extirpation. Immediately following operation such animals show all the motor symptoms seen after bilateral extirpation of the frontal association areas plus area 8. There is no paresis or postural deficit but the animal sits motionless at first. The head is sunk between the shoulders, and the gaze fixed and straight ahead; blinking is infrequent, movements of the eyes are almost absent. Eye movements in either direction are possible, for the eyes tend to follow an object, but always return to a fixed central stare. Such animals sometimes appear to be blind, although they follow moving objects and although visual stimuli produce frequent rage reactions. They walk into objects, forcefully striking their heads against the side of the cage. They will reach for and grasp any type of object offered, but then do nothing with it. It is difficult to feed them for they do not seem to know what to do with food. This inability to appreciate objects in the normal manner seems to be due to tactile as well as to visual disturbances for many times things held in the hand are not recognized.

During the first week these animals become more alert and begin to distinguish between objects seen. After a period of a few weeks they become nearly normal except that they continue to have a "wooden" expression and
fixed gaze. Circling movements in bilateral preparations occur and may take place in either direction, the animals often turn one way and then reverse and turn the other for a time. The circling is not as prominent as it is in the unilateral preparations, but the stereotypy and the forced character of all movements are conspicuous and there develops a restless and purposeless behavior in which the general activity seems to be increased.

**DISCUSSION**

Discrete ablation of area 8 in the monkey is thus followed by a definite syndrome which is composed of two groups of symptoms: first a change in motor activity which consists of involuntary circling, appearing in the absence of postural or paretic changes in the extremities; and second, a defect in the visual apparatus consisting, when the lesion is unilateral, in: (a) a deviation of the eyes toward the lesion, and (b) a contralateral defect in vision. The two groups of symptoms are always part of the same syndrome for neither occurs in animals in which the other has not also existed. The symptom complex seems to be identical with that described by previous authors in animals from which all tissue rostral to the motor areas has been removed (Bianchi, 4), although in the present series only the small portion of these areas known as area 8 is injured.

Histological identification of this cortical area is at present difficult. Grossly it is well defined in the macaque (Fig. 2) as the region lying within the arcuate sulcus that is, anterior and lateral to the sulcus, and roughly corresponding to the area 8 demarcated by Brodmann for the cercopitheque. The histological structure of this area is transitional from the agranular motor cortex of area 6 to the granular cortex of the true frontal association area 9 (von Economo, 27; Campbell, 6).

The physiological evidence is also that this region extends to the mid-line in macaque, anthropoid, and man, for eye movements may be elicited from stimulation of all of this strip of tissue although their character changes in the different parts, much as in areas 6 and 4 specific regions subserv different muscle groups for limbs. On the other hand removal of the mesial part of this strip designated to area 6 is followed by no appreciable alteration in head or eye performance. The forced circling appears only when the more lateral part now designated as 8 has been damaged.

**Motor defect.** In 1868 J.-L. Prévost published a Paris thesis entitled: “De la déviation conjuguée des yeux et de la tête dans certains cas d’hémiplégie” (24). In it he cites 58 human cases of hemiplegia, which showed deviation of
the head and eyes. The lesions were widely distributed within the central nervous system and were for the most part diffuse—four only being limited to cerebral cortex, and only one to the frontal lobe. He also cites the scanty experimental literature concerning deviation of the head and eyes in animals; symptoms infrequently noted at that time following cerebral hemispherectomy and remarks on the circling movements which accompany this deviation.

In 1874 Hitzig (15), and in 1875 Ferrier (7) first elicited movements of the eyes from stimulation of the cerebral cortex. The region of the sigmoid gyrus of the dog (Hitzig) and the "base of the superior frontal convolution" in the monkey (Ferrier, 8) were the regions from which such movements were produced. In human beings deviation of the head and eyes have long been known to accompany hemiparesis, and to be a part of some attacks of Jacksonian epilepsy. In 1926 Foerster (9) was able to stimulate a series of human brains under local anesthesia, and then reported conjugate turning of the eyes from stimulation of areas 8α, 8α and 8β, and, from the region more mesial (area 6α), adverse turning of head, eyes and body.

In the lower primates, the monkey or anthropoid, functional differentiation here, as in other regions of the cortex, is not so discrete as it is in man. After stimulation of more lateral cortical eye centers of the monkey (area 8) eye movement is primary, and followed often by head. Repeated stimulation of the anterior portion of area 6, on the other hand, will in the same animal, tend to give primary head movement, which is followed by movement of the eyes. It is rare, however, in these animals that movement of the head can be produced without eye movement as well.

Activity. Greater specificity of cortical localization in the human is further demonstrated by the fact that increase in motor activity has never been correlated with head and eye deviation in man whereas in the monkey after lesions of area 8 one is accompanied by the other. In man, hyperactivity is known to be a factor in certain types of "mental" disorders such as the over-activity of the manic, or the restlessness of some post-encephalitic patients, and these changes have been attributed to changes in the frontal lobe, but no more discrete localization has been possible.

In animals, restlessness and an increase of purposeless activity following bilateral frontal lesions are described by many authors (Hitzig, 16; Bianchi, 4). Jacobsen (17) has found it in lesions limited to the frontal association areas in monkeys; and recently Richter and Hines (25) have observed hyperactivity following both prefrontal and striatal lesions in monkeys. They find that in pure cortical lesions removal of area 9 alone produces maximum hyperactivity, although some appears following lesion of area 8 as well, but that the greatest increase is seen only when the tip of the caudate nucleus is damaged. They do not record associated turning movements. At present, in our studies, there is evidence to indicate in corroboration of Richter and Hines, that there is greater increase in activity following extirpation of all the frontal association areas together with area 8, than of area 8 alone, and that this may occur
without injury to the caudate. Further investigation of this point is in progress. The head and eye symptoms which follow discrete lesions of area 8 are also pronounced and more enduring when other parts of the frontal lobe are removed in addition to area 8 (18). The motor eye fields of parietal and occipital lobe (Graham Brown, 12), probably also play a part in the intensity of this reaction.

"Visual" defect. The nature of the disturbance in response to visual stimuli as a component of this syndrome is difficult to explain. The head and eye deviation may be produced by removal of normal motor innervation to the muscles of the head and eyes and may thus be analogous to the paresis induced by removal of a specific part of the true motor areas 4 and 6. In this respect area 8 is a region elaborating complex motor performance for the head as does area 6 for the extremities. The unilateral visual defect is more difficult to analyse. It is of such a nature that objects in the contralateral field of vision are disregarded. Since, however, the defect is transient, and, when bilaterally present, does not result in blindness, it cannot be a defect in the afferent visual apparatus as in true hemianopia due to occipital lesions. Similarly, it cannot be merely an apparent visual defect due to loss of motor power in eye muscles, since eye movements are present in all directions at a time when the visual defect also exists. Unilateral absence of the blink response to threat at a time when other types of lid closure are bilaterally equal also precludes pure motor deficit. The defect obviously lies in the cortical connections between sensory and motor regions, and it can only be described at present as a lack of recognition of or an inability to respond to afferent visual stimuli.

There are a number of earlier descriptions of "hemianopia" related to lesions of the frontal lobe. In 1895 Bianchi, extirpating one frontal area in monkeys, described a visual defect which he recognized as transient, and which he thought to be a hemianopia. The dogs of Minkowski (23) and of Hitzig (16) exhibited unilateral visual defects after lesions in one sigmoid gyrus. L. Bard (1) in 1904 described such an abnormality occurring in association with conjugate turning of the eyes and head in hemiplegic humans. These patients, like our monkeys, did not blink in response to threat in the defective eye field. Bard believed that the defect was sensory.

The bilateral syndrome. The striking alterations in general performance of animals after bilateral removal of area 8 is in every respect like that following ablation of all the frontal lobe areas exclusive of 4 and 6. Bianchi marvels at his monkeys in this state, and at the great "intellectual" deficit which they display as they sit motionless and apparently dazed following operation, and then evolve a purposeless overactivity and tendency to rage. The same emotional instability has appeared to a marked degree in our animals.

We have as yet no evidence as to the relationship of changes in activity to caudate injury such as have been described by Richter and Hines (25), for, in the present series, the caudate nucleus was not damaged. In view of the physiological and direct anatomical connections which exist between area 8 and the striate nuclei (Hirasawa and Kato, 14), it is pertinent to draw at-
tention to the similarity in symptoms between the monkey deprived of area 8 and the human post-encephalitic in whom striatal disease is present. Restlessness, "drivenness," immobility of facial expression and noticeable diminution of blinking and of eye movements are symptoms which may be common to both conditions.

It is of interest also that much of the "stuporous" behavior described in frontal animals is undoubtedly due to disorder of the components discussed in this paper. Clearly the bilateral production of this visual deficit might result in the tendency to sit still, to walk slowly, to bump into objects and to blink seldom in response to threat. Thus also the circling of the unilaterally ablated preparation which appears in relation to deviation of the eyes and head, and which is of a forced and purposeless nature may, in the bilateral preparation, result in the constantly increasing forced overactivity of the first postoperative months.

**SUMMARY**

1. The unilateral and bilateral ablation of area 8 in monkeys is followed by a characteristic syndrome similar to that produced by removal of the entire frontal lobe, rostral to area 6 (areas 8, 9, 10, 11 and 12).

2. A deviation of the head and eyes toward the side of the lesion is produced by lesions of area 8, which becomes less marked during the first postoperative weeks. A tendency to turn the head in this direction persists much longer.

3. Forced purposeless circling movements appear coincident with head and eye deviation. They also diminish in intensity but persist as hyperactivity for as long as a year.

4. A "visual" defect is present contralateral to the lesion which is not a hemianopia but which has to do with inability to respond to visual stimuli.

5. The picture of "intellectual" deficit described by Bianchi following bilateral frontal lobectomy may be attributed to the alterations in vision and in motor performance just described.

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