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HABENULAR COMPLEX IN THE DOG'S BRAIN

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The present paper is a study on the myeloarchitectonics of the habenular complex in the dog's brain, based on seven continuous series of brain sections made in the frontal, horizontal and sagittal plane and stained by the Weigert-Wolters, the Klüver-Barrera and Nissl method.

The habenula in the dog is a paired and symmetric structure, situated on the dorsomedial side of the caudal part of the thalamus. In the dog it has been divided into two general regions: (A) the medial region, marked by a strong concentration of neurons and a well-developed fiber systems, running to the habenulointerpeduncular tract. Four nuclei have been distinguished in this region: (1) the anteromedial nucleus, (2) the mediodorsal nucleus, (3) the medioventral nucleus and (4) the posteromedial nucleus; (B) the lateral region having randomly scattered medium-sized neurons and systems of fine fibers, and consisting of four nuclei: (1) the anterolateral nucleus, (2) the centrodorsal nucleus, (3) the centroventral nucleus and (4) the central nucleus.

A. Medial region of the habenula

1. Anteromedial nucleus of the habenula. This nucleus (Fig. 1 A, MA), makes up the anterior part of the medial habenular region. It is rather small and orocaudally elongated by 0,5 mm. In the frontal section, it is shaped like a triangle with its apex slightly inclined laterally and overlapping the dorsal part of the stria medullaris of the thalamus.

The anteromedial habenular nucleus is well myelinated. Most fibers, best stained and running orocaudally, belong to the main trunk of the stria medullaris. They occur in the form of small bundles which, in the proximal part of the nucleus, are scattered all over its surface (Fig. 1 A, Stα). Further caudally, a decrease is noted in the number of these fibers situated in the ventral part of the nucleus. In the posterior end of the nucleus, these fibers are fairly abundantly represented but mostly in the mediodorsal part (Fig. 1 A).

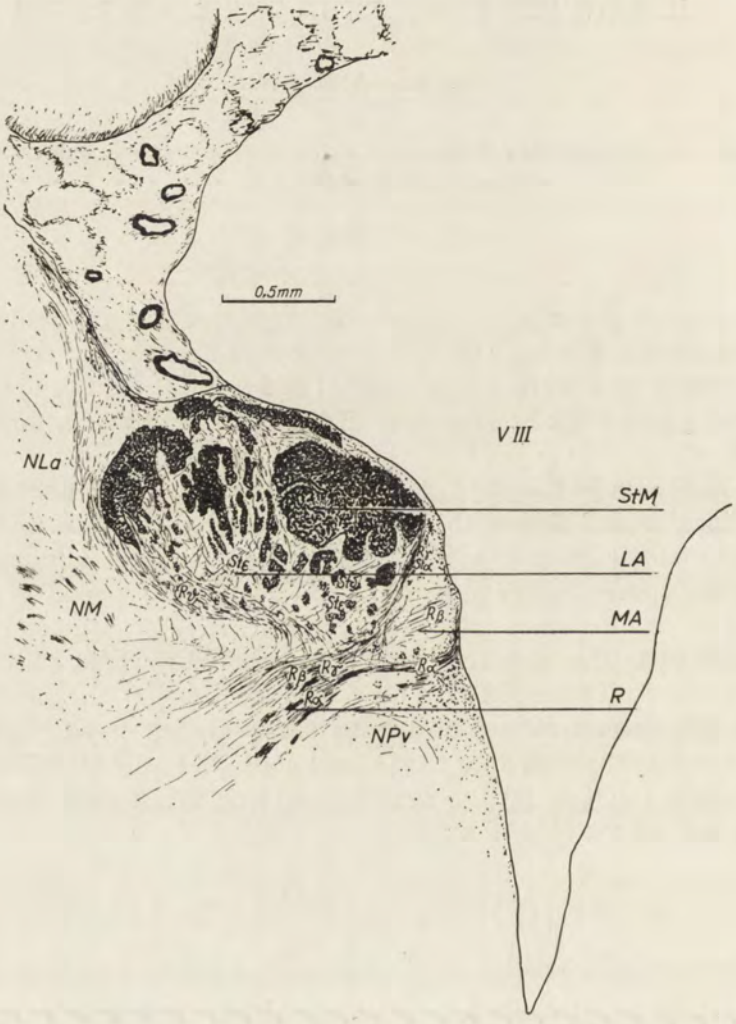

Fig. 1A. Figs. 1 A—F: a series of cross sections through the nuclei of the habenular complex in the dog's brain (Weigert-Wolters, semidiagrammatic). Distance between sections, about 0.9 mm

There is another system of fibers which also originates in the ventral part of the proximal end of the nucleus (Fig. 1 A, Rα). At first, they occur in a small number, are thin, well stained and have a lateromedial course. In the caudal part of the nucleus, they are much more numerous, better-stained, run along the ventral subdivision of the nucleus and, on its boundary with the medioventral wall of the anterolateral habenular nucleus, join each other, firming fine bundles, arching downwards (Fig. 1 A). It is also in the caudal part of the nucleus that fine, lateromedially running fibers (Fig. 1 A, Rβ), appear all over the medial surface and, on reaching the lateral margin of the nucleus, descend and join fibers, coming from the ventral part of the nucleus (Fig. 1 A).

In the posterior area of the nucleus, there also occurs a very fine bundle of fibers which run from the dorsal part of the nucleus and descend

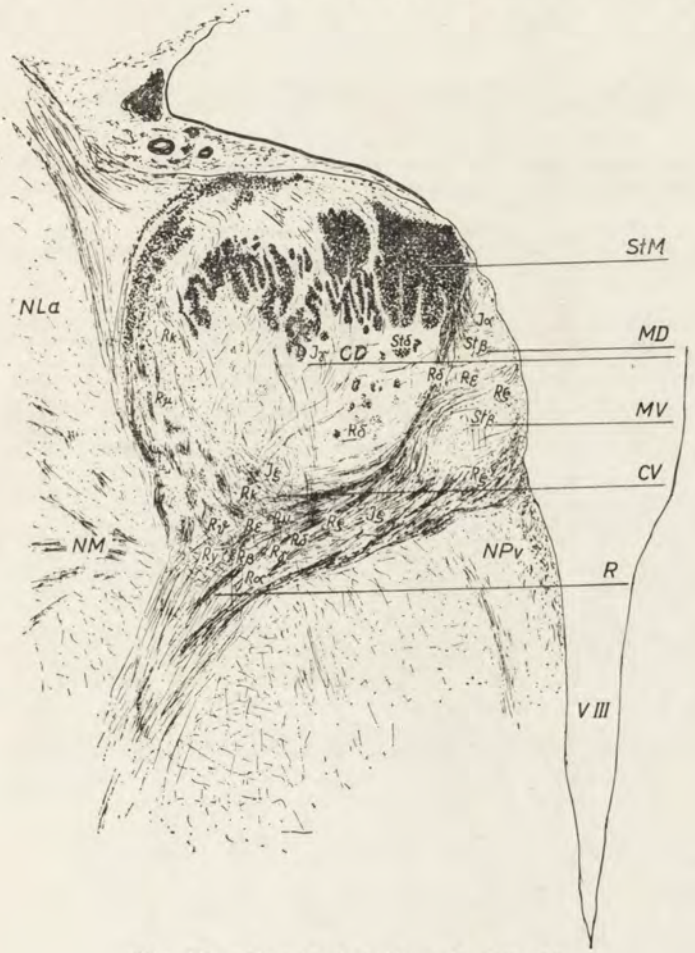

Fig. 1B — See explanations in Fig. 1A

along its lateral wall (Rγ). A part of them detaches, runs sidewards and joins the anterolateral habenular nucleus. In sections, stained according to the Klüver and Nissl method, the cells of the nucleus may be seen. At first, there are rather few of them but, more caudally, their number increases and they spread medioventrally.

The posterior wall of the anteromedial habenular nucleus passes without any sharply outlined boundary, into the mediodorsal and medioventral nuclei.

2. Mediodorsal habenular nucleus (Fig. 1 A—D, 2, MD). In the frontal section, this nucleus is shaped like an isosceles whose apex is strongly inclined laterally and overlaps the medial part of the medullar thalamic fascicle (Fig. 1 B—D, MD). This nucleus is elongated orocaudally and its length amounts to 1.9 mm.

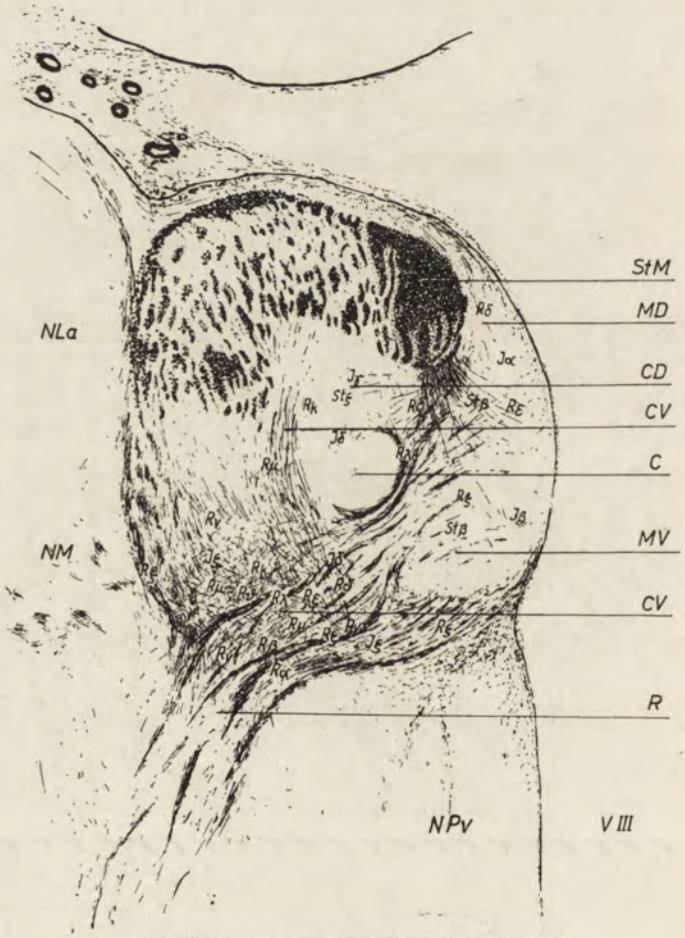

Fig. 1C — See explanations in Fig. 1A

This nucleus displays a poor myelinization of its rostral part. A thin network of fibers with indefinite direction of their trace is seen on its lateroventral side. Further caudally, other fibers arranged in systems replace the former ones which make up a network. All of them are mostly accumulated on the lateral side of the nucleus. The first system consists of a great number of very thin, fine and long fibers, coming out of the most medial, large fascicle of fibers of the stria medullaris thalami per-

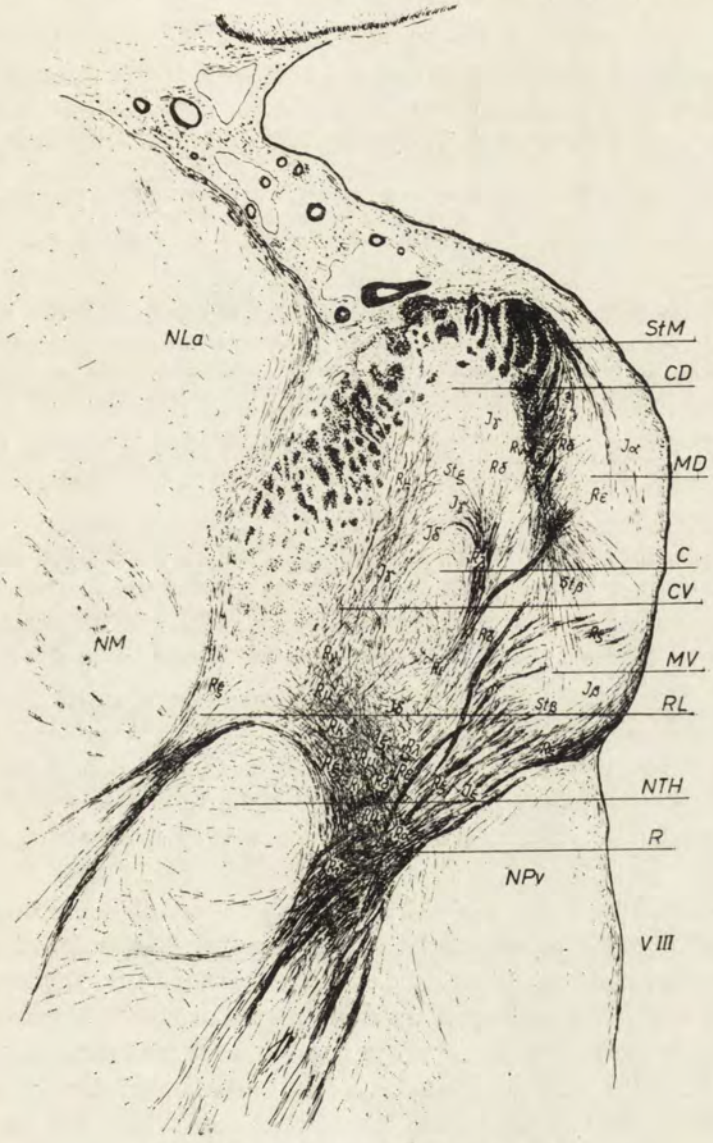

Fig. 1D — See explanations in Fig. 1A

pendicular to this system (Fig. 1 B—D, Stβ). The main bulk of these fibers runs along the lateral wall of the nucleus and reaches as far as the mediodorsal habenular nucleus. Further caudally, their number considerably increases. Most of them run downwards along the lateral wall of the nucleus as far as the medioventral habenular nucleus. Part of them radiate towards the medial wall of the nucleus (Fig. 1 B—D). In the middle part of the nucleus these fibers are very numerous and well stained. The course of these fibers is identical with that described above.

The second system, which emerges from the proximal part of the nucleus, consists of fibers somewhat thicker than those described above. These fibers stain well and run from the apex of the nucleus towards its bottom (Fig. 1 B—D, Rδ). They intersect fibers which come from the medullar thalamic stria. In the middle part of the nucleus, one may observe that their number is much larger and that they are thicker and better stained. Some of them run downwards below the medial medullar stria of the thalamus and pass to the centrodorsal habenular nucleus, whereas others parts run perpendicularly downwards. Both parts join each other in the fiber bundles which form the habenulointerpeduncular tract (Fig. 1 B—D). Yet more caudally, number of fibers increases again and part of them, arching downwards, run below the medial fascicle of the medullar thalamic stria, intersecting fibers that run from the latter and pass into the dorsal parts of the centrodorsal habenular nucleus (Fig. 1 B—C).

The third fiber system (Fig. 1 B—D, Rε) runs in the middle and ventral parts of the nucleus from its medial to its lateral wall. They intersect fibers, coming from the medullar thalamic stria and, in thick arching bundles runs to the habenulointerpeduncular tract (Fig. 1 C—D).

Fibers which form the fourth system occur in a small number and transverselly intersect the nucleus (Fig. 1 B—D, Iα). They come out of its medial wall, run to the lateral wall and, in this place, disappear between other fibers which emerge from the medullar stria and to which they are perpendicular. The fibers of this system are very thin, short and well--stained.

In its caudal part, the nucleus is strongly stretched ventrodorsally. Its lateral part is more myelinated than the medial (Fig. 1 D). A group of fibers coming from the apical part of the nucleus run downwards almost parallel to those originating in the stria medullaris and, intersecting the latter from bundles which enter the habenulointerpeduncular tract. The medial wall of the nucleus contains a small number of thin, short fibers, running transversely and joining fibers that come from the apex of the nucleus (Fig. 1 C).

3. Medioventral habenular nucleus. Viewed in frontal sections, this nucleus is at first round, in middle acquires an oval shape and, towards the caudal part, is round again (Fig. 1 B—D, MV). Orocaudally it is strongly elongated, its axis being about 1,9 mm long. Its dorsal wall borders, without any sharply outlined boundary, on the ventral part of the mediodorsal habenular nucleus.

Three fiber systems may be distinguished in the sections stained according to the Weigert method. The first of them (Fig. 1 B—D, Rζ) consists of a vast number of thick, long and well stained fibers. It makes up a large component of the habenulointerpeduncular tract. In the initial part of the nucleus, the number of fibers that belong to this system is relatively small. They run from the dorsal part of the nucleus along its medial wall and, hereafter, they arch and turn sidewards under its base where they join each other, forming thin bundles, and pass to the medioventral parts of the centrodorsal habenular nucleus. Further caudally, an increase is observed in the number of these fibers. It may be also seen that identical fibers start to run from the ventral part of this nucleus and joining each other they form bundles, running to the habenulointerpeduncular tract.

Further towards the center the nucleus becomes very strongly myelinated in its medioventral part. In this place, there is a great number of fibers that run from the apex of the nucleus, along its medial wall and joining an equally great number of other ones which come from the ventral part of the nucleus. Gathering in broad bundles, they bend down towards the habenulointerpeduncular tract (Fig. 1 D). In the central part of the nucleus these fibers are the most abundant. Further caudally, the number of fibers of this system that run along the nucleus wall, starts to decrease whereas other fibers appear, running almost perpendicularly downwards through the nucleus center. They gather in thin bundles and, enter the habenulointerpeduncular tract. In the distal part of the nucleus, there is a decreased number of fibers of this system, running along the medial and ventral walls of the nucleus, the bundles being much narrower and their course more vertical.

The second fiber system (Fig. 1 B—D, Stβ), comes from the medial fascicle of the medullar stria. It consists of thin, long fibers, running at first along the lateral wall of the mediodorsal nucleus and, hereafter, entering the medioventral nucleus through its apical part where they radiate towards its ventral part. They occur in greatest number in the central part of the nucleus. Their course is approximately dorsoventral. These fibers are gathered in very thin fascicles and, at an angle of about 60°, cross other fibers which run from the medioapical part of the nucleus (Fig. 1 C). In this area they are the longest and reach the most ventral parts of the nucleus. Further caudally, their number becomes smaller.

The third system of this nucleus is built of few thick, well-stained fibers (Fig. 1 C, Iβ). They originate in the medial portion of the nucleus, transversely cross the nucleus and terminate on the boundary between this nucleus and the centroventral habenular nucleus. They are most abundant in the middle area of the nucleus.

The medioventral habenular nucleus is a place where the neurons are most concentrated. They are almost round, slightly fusiform and well-stain-

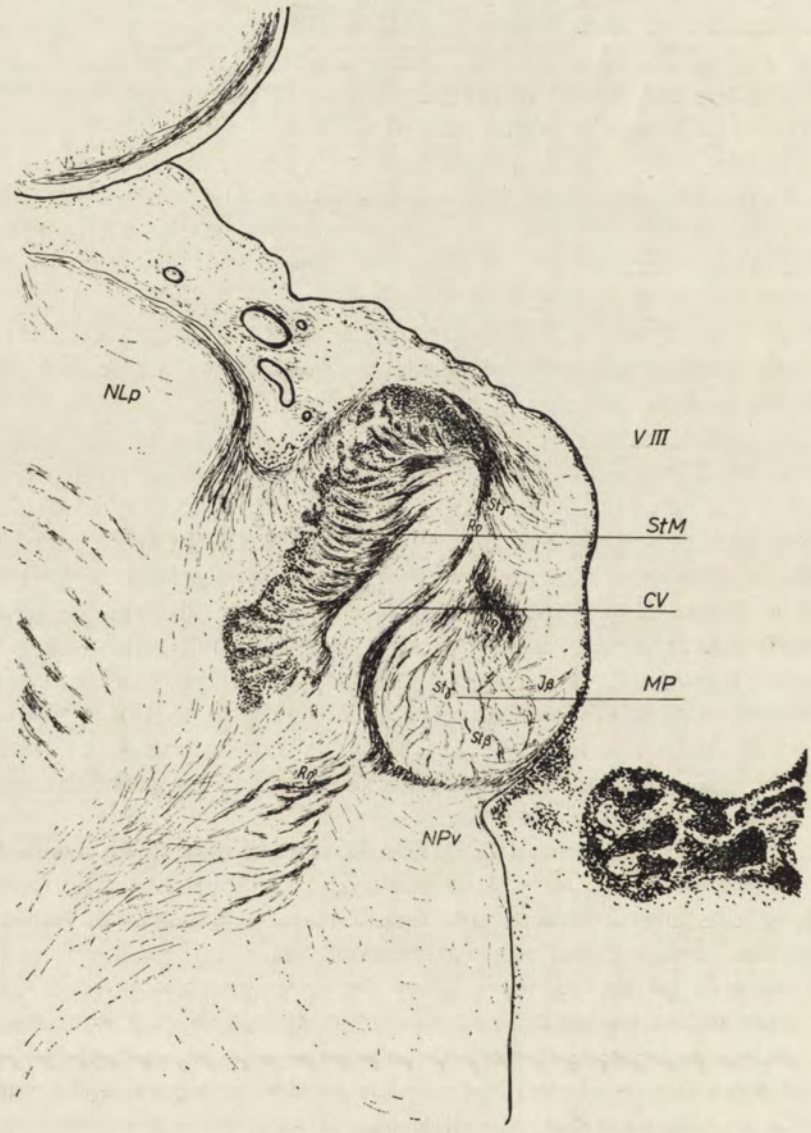

Fig. 1E — See explanations in Fig. 1A

ed. In the proximal parts of the nucleus they are fairly densely and uniformly distributed. Caudally, nearer the middle of the nucleus, their density increases, especially so in the periferal parts of the nucleus, whereas in the center, they form small groups. Further caudally, the neuron concentration gradually decreases, although their number is still very large as compared with the number of neurons in other nuclei.

4. Posteromedial habenular nucleus. This nucleus is strongly compressed orocaudally. Viewed in the frontal plane, this nucleus has a shape of an inverted comma with its point inclined laterally and overlapping the medial part of the medullar stria (Fig. 1 E, MP).

In its anterocentral part the posteromedial habenular nucleus is well--myelinated. Towards the caudal end, smaller and shorter, fiber systems are, however, observed. In sections stained by the W e i g e r t method the following fiber systems have been distinguished. The first of them consists of long, well-stained fibers (Fig. 1 E, Rη), running, in the form of a broad band, from the mediodorsal part of the nucleus downwards, passing to its lateral wall and reaching its medioventral part. Most fibers terminate in this place but few of them pass to the centroventral part of the nucleus. In the frontal plane, the course of this system looks like a question mark in the right habenula (Fig. 1 E). In the caudal part of the nucleus, the lenght of this system is considerably decreased. Few fibers of this system are visible in the medioventral part of the nucleus.

The second fiber system of this nucleus is formed by long, well-stained fibers, running from the medial fascicle of stria medullaris towards the ventral parts of the nucleus (Fig. 1 E, Stγ). Fibers are gathered in thin bands which, in the ventral part of the nucleus, diverge in a broom-like fashion and a part of them run to the medial wall of the nucleus. Near its end, their number decreases.

The third system of fibers (Fig. 1 E, Iβ) consists of a small number of thick, short and mediolaterally running fibers. Cytoarchitectonically, the mediocaudal nucleus is a place of a medium concentration of neurons in the habenulae. They are distributed in this nucleus almost uniformly. Their shape is different, spindle-like, triangular, oval or round.

B. Lateral region of the habenula

1. Anterolateral habenular nucleus. The anterior part of this nucleus is situated somewhat posteriorly to the anteromedial habenular nucleus. Its dorsal boundary is very irregular, its outline depending on the shape of the ventral part of the medullar stria. The anterolateral habenular nucleus, viewed in frontal sections, is strongly flattened dorsoventrally

in its anterior and middle parts (Fig, 1 A, LA). Its length amount to 0,8 mm.

In this nucleus one may notice that it is well-myelinated, in particular from its center up to the caudal part. Several types of fibers may be distinguished in this nucleus. In its anterior part, fine fiber bundles are scattered all over its surface. They belong to the main trunk of the medullar stria (Fig. 1 A, Stδ) on which the nucleus borders. Viewed in frontal sections, these bundles are round in shape and, in horizontal sections, orocaudally elongated. Towards the middle of this nucleus, the volume if these bundles increases, in particular in its dorsal part, and they shift dorsally. In the caudal part of the nucleus, they join the main trunk of the stria medullaris, whereas fine bundles, which initually are observed in the ventral part of the nucleus, run towards the centromedial side. In addition to clearly seen fiber hundles, mentioned above there is also a network of thinner or thicker fibers. In the anterior part of the nucleus the network is very fine, situated mostly on its lateral side and consisting of two principal fiber systems. The first is built of very fine fibers, running from the dorsal and lateral parts of the nucleus towards its ventral part. Further towards the center of the nucleus, this fiber system extends dorsoventrally, the number of fibers suddenly increases and they become thicker and better-stained. All of them run from the dorsolateral and dorsal parts of the nucleus towards the ventral side (Fig. 1 A, R) where they gather in a bundle of parallel fibers. This is the portion of fibers which makes up the habenulo-interpeduncular tract. In the caudal part of the nucleus the fibers of this bundle cross the fiber bundles that come from the mediodorsal and medioventral habenular nuclei and both of them form the habenulo-interpeduncular tract.

The second fiber system, which forms the network of the nucleus, comes from the main trunk of the medullar stria (Fig. 1 A, Stε) and from its lateral fascicles. In the anterior part of the nucleus, there are very few of these fibers and they are mostly observed running from the lateral parts of the medullar stria. Towards the center of the nucleus, the number of these fibers slightly increases. In this place, new fibers appear which come from the ventral side of the trunk of the stria medullaris. They run over the dorsal surface of the nucleus towards its lateroventral part. Towards the posterior end of the nucleus, a sudden decrease is noted in the number of fibers, coming from the main trunk of the stria medullaris.

In the caudal parts of the nucleus, a few rather thin fiber bundles may also be seen. These fibers run from the dorsal area of the anterior part of the mediodorsal habenular nucleus. They detach from their main pathway which runs along the lateral boundary of the nucleus and enter the centroventral part of the anterolateral nucleus, mildly descending and

joining other fibers of the nucleus which run to the habenulo-interpeduncular tract. Since these three fiber systems meet in the ventral part of the nucleus, the latter constitutes a place of a considerable fiber concentration.

Viewing the anterolateral habenular nucleus in sections, stained according to the Klüver-Barrera and Nissl methods, affords a possibility to observe the distribution of neurons in this nucleus. In addition to a vast number of small glia cells which occur all over the nucleus, middle-sized, widely scattered cells have also been noted. In the entire nucleus, there occur round cells, intermingled with subtriangular and elongated, fusiform ones. In the anterior part of the nucleus, there are only few neurons. They occur mostly in its dorsal part and are poorly stained. The number of neurons increases towards the center of the nucleus, most of them occurring in the laterodorsal part where, however, they are very poorly stained. In the ventral part of the nucleus, neurons occur in a very small number but they are large and well-stained. In the caudal part of the nucleus, the neurons are uniformly distributed all over its surface.

2. *Centrodorsal habenular nucleus.* Rostrally this nucleus borders on the posterodorsal part of the anterolateral habenular nucleus. Its dorsal boundary is irregular since its shape depends on the distribution of the ventral part of fibers of the medullar stria of the thalamus between which it is pressed in (Fig. 1 B—D, CD). In the anterior parts of the nucleus, it passes fluently into the dorsal part of the centroventral habenular nucleus. The shape of the nucleus is difficult to determine. It is a solid with very irregular walls which are strongly elongated orocaudally. Its main axis is 2.4 mm long. The oral and middle parts of the nucleus are slightly shifted medially, whereas the caudal part is strongly shifted laterally.

The centrodorsal nucleus is a very poorly myelinated area of the habenular complex as compared with other nuclei (Fig. 1 B—D, CD) although it contains several fiber systems. However, these are very fine, thin and poorly stainable fibers. Over its entire length, the nucleus is built, in its medial part, in the form of a thin network, consisting of a vast number of poorly stainable, fine fibers, whereas its lateral part contains samewhat thicker and better-stainable fibers which also form a network. The number of fibers in the oral and middle parts of the nucleus is very large but towards the caudal end, their density sharply decreases.

The first system is formed by very fragile and poorly stainable fibers which, in frontal sections, have a dorsoventral trace. They are very short. These fibers come from the most dorsal part of the nucleus which adjoins the medial and central fiber fascicles of the medullar stria. The fibers of

the system described take their origin in the areas situated between these fascicles, enter the dorsal part of the nucleus, scatter all over its surface and, hereafter, run perpendicularly downwards as far as its ventral boundary. In the middle part of the nucleus, they are somewhat longer (Fig. 1 C—D, Iγ), reach the dorsal boundary of the central habenular nucleus, cross the fibers belonging to the latter and, hereafter, a part of them run slightly downwards, terminating half-way the height of this nucleus. In the caudal part of the nucleus, these fibers are almost never met with.

The fibers of the second system are situated in the most medial part of the nucleus (Fig. 1 C—D, Rγ). They are somewhat thicker than those, described above. These are long fibers with a mediodorsoventral course. In the oral part of the nucleus they do not occur at all. They come from the dorsal part, run along the medial boundary of the nucleus below the medial fascicles of the medullar stria of the thalamus, descend along the medial boundary of the central habenular nucleus and, below it, enter medioventral part of the ventral habenular nucleus, joining in their course with that of the fibers which form the habenulointerpeduncular tract. In the middle part of the nucleus and slightly towards its caudal part, their number increases, they deviate from the medial fascicle of the medullar stria of the thalamus, run to the middle of the nucleus and form a fairly broad bundle, running vertically downwards and directed to the habenulointerpeduncular tract in the ventral part of the centroventral habenular nucleus. However, in the most caudal part of the nucleus, their number is much smaller.

The third fiber system in this nucleus is formed by thicker fibers than those, described above, and well-stainable (Fig. 1 B—C, RK). Their slightly oblique course is directed dorsolateroventrally. This system is most numerously represented in the oral and middle parts of the nucleus. Its fibers, coming out of the dorsoventral part of the nucleus, run downwards below the lateral fascicle of the stria medullaris. Hereafter, they deviate from the stria and a part of them (shorter fibers of this system) run obliquely towards the ventromedial part of the nucleus. Another part, consisting of longer fibers, run downwards so far as the ventrolateral part of the centroventral habenular nucleus, reaching the habenulointerpeduncular tract. In the caudal parts of the nucleus, the number of fibers of this system decreases. A small number of longer fibers of this system are visible in the oral parts of the posteromedial habenular nucleus.

The fourth system of this nucleus (Stξ) consist of a small number of short, transversely running fibers. These are very fine fibers, belonging to the stria medullaris of the thalamus which sends them forth from its lateral and medial parts. Reaching the middle of the nucleus, they des-

cend from this area by a short oblique pathway towards the ventral part of the nucleus.

In the anterior part of the nucleus, a small number of fibers, running mediolaterally (Rδ) are seen in its medial region which they reach, coming from the dorsal parts of the mediodorsal habenular nucleus.

In sections, stained according to the Nissl and Klüver-Barrera methods, it has been observed that it contained middle-sized, not very abundant neurons loosely scattered all over its surface. In the middle part of the nucleus they are more concentrated.

3. Central habenular nucleus. This nucleus is the smallest one as compared with other habenular nuclei. In frontal sections, it is oval in the oral and middle part (Fig. 1 C—D, C) and rounding towards the caudal end. Orocaudally it is strongly elongated and its length along this axis amounts to 1.8 mm. Orally it is shifted somewhat medially but, towards the caudal end, it changes its place rather violently and enters the middle part of the habenular complex. The whole of this nucleus is situated amidst the nuclei of the lateral part of the habenular complex.

The central habenular nucleus is very characteristic and, regardless of the method of staining, is well-visible. Viewed in sections, stained according to the Weigert method, it looks like an oval, very poorly myelinated field, surrounded by a fiber ring (Fig. 1 C—D, C). A part of this ring which surrounds the mediodorsal wall of the nucleus is a broad bundle, consisting of thick, well-stained fibers (Fig. 1 C—D Rη). They originate in the most ventral part of the centrodorsal habenular nucleus. In this place, they are scattered and directed towards the dorsal part of the central nucleus where they gather in the form of a bundle which descends along the medioventral wall of this nucleus. In the ventral part of this nucleus, they slightly arch towards the ventral parts of the centroventral habenular nucleus, join fibers, coming from the medial part of the habenular complex and run to the habenulointerpeduncular tract.

Another part of the ring, encircling the laterodorsoventral wall of the central nucleus is formed by thinner and less stained fibers (Fig. 1 C—D, Iδ) which originate on the dorsal boundary of the nucleus where they cross fibers which form the opposite part of the ring. These fibers descend from the dorsal part of the nucleus, running along its lateral wall, ventrally suround of the nucleus and, hereafter, most of them pass to the medial wall of the nucleus, whereas a small number of these fibers deviate from it and descend to the ventral part of the centroventral habenular nucleus, not reaching the habenulointerpeduncular tract. Thus the ring, encircling the central habenular nucleus consists of two fiber systems which cross each other in its ventral and dorsal parts. The inside of the nucleus constains a small number of very thin, poorly myelinated fibers

that form a network in the oral and caudal parts of the nucleus (Fig. 1 C—D, Iδ). The middle part of the central nucleus is almost devoid of fibers.

Viewing the central habenular nucleus is sections, stained according to the Nissl method, one may see that, in its oral and middle parts, it has a larger number of loosely distributed neurons than in the caudal part. These cells are round, fairly well-stained, smaller in the centrodorsal part of the nucleus and somewhat larger in the ventral part of the nucleus where they occur, however, in a very small number.

4. Centroventral habenular nucleus. This nucleus is the largest as compared with other habenular nuclei (Fig. 1 B—D, CV). It occurs in the form of an irregularly shaped solid, most extended in the mediodorsal and contracting in the ventral part which makes up a starting area of the habenulointerpeduncular tract. The centroventral habenular nucleus is very strongly elongated orocaudally (3.1 mm long) and covers an almost entire ventromedial area of the lateral part of the habenular complex.

Orally, the ventral boundary of this nucleus borders on the dorsal wall of the paraventricular nucleus of the posterior thalamus and, further on, adjoins the lateral and medial nuclei of the habenulointerpeduncular tract (S i n g e r 1962). Caudally, this nucleus is very strongly flattened lateromedially and is wedged between the lateral part of fibers of the medullar stria and the lateral wall of the posteromedial habenular nucleus, which, in this place, is strongly developed (Fig. 1 E, CV).

The centroventral habenular nucleus makes up the most myelinated area of the habenular complex. This is caused by the fact that is has its own, strongly developed fiber systems and, in addition, it constitutes a place, entered by fiber systems, crossing each other and which belong to all other habenular nuclei. This results in a myeloarchitectonic pattern resembling a strongly tangled network. The ventral wall of this nucleus makes up a starting area of the habenulointerpeduncular tract which is the widest and most strongly developed in the middle part of this nucleus. A few fiber systems have been noticed in the centroventral nucleus. The first of them consists of long, not very thick fibers. They occur abundantly almost over the entire nucleus (Fig. 1 C—D, Rμ). A gradual decrease may be noticed in the number of fibers of this system up to their complete disappearance in the caudal part of the nucleus. The fibers that form this system as a broad but very loose bundle run from the most dorsal region of the nucleus vertically downwards to its ventral part where they join the habenulointerpeduncular tract (Fig. 1 C—D). In the most oral parts of the nucleus they do not reach it directly but they turn along its ventromedial boundary. Near the middle of the nucleus, the fibers of this system, coming out of the ventral part of the nucleus directly enter the

habenulointerpeduncular tract. In the caudal parts of the nucleus, these fibers occur in small numbers, are much shorter and originate in the lateroventral region of the nucleus. They run somewhat obliquely towards the ventromedial wall of the nucleus.

The system described is the largest fiber bundle of the centroventral habenular nucleus, being part of the habenulointerpeduncular tract and, at the same time, it is the largest component of the nucleus, coming from the lateral part of the habenular complex. Although it consists of a large number of fibers, it has been noted that it was less developed than the fiber systems of the nuclei of the medial part of the habenular complex, entering the ventromedial area of the centroventral habenular nucleus and joining the habenulointerpeduncular tract. The fiber systems of the nuclei of the medial part of the habenular complex, decsribed above, are formed by thicker and better stained fibers and are gathered in broad bundles, entering the habenulointerpeduncular tract. This allows one to consider them a main component of the habenulointerpeduncular tract.

The second fiber system of the centroventral habenular nucleus consists of poorly stained and thin fibers. These are fibers, coming out of the lateral part of the nucleus and running slightly obliquely downwards (Fig. 1 C—D). This system may be divided into two parts: the first comes from the laterodorsal part of the nucleus, having a course like that described above and containing few but thicker and fairly well-stained fibers which terminate upon reaching only the ventromedial boundary of the nucleus (Fig. 1 B—D, Iζ). The second part consists of a much larger number of fibers which are less stained, thinner and directed mostly towards the ventromedial wall of the nucleus. It has however, been noticed that a part of them, mostly in the middle part of the nucleus, descend and — arching — enter the habenulointerpeduncular tract (Rγ).

In the middle part of the centroventral habenular nucleus a convexity has been noticed in its lateroventral area. This is probably related to the lateral branch of the habenulointerpeduncular tract, formed in this place (Fig. 1 D, RL). This lateral branch occurs in the form of a small bundle of fibers which, run almost parallel to the habenulointerpeduncular tract to the caudal part of the mediodorsal thalamus. Hereafter, towards the caudal end, this bundle approaches the habenulointerpeduncular tract and, finally, joins it. Between this bundle and the main habenulointerpeduncular tract, there is situated a nucleus, called, the nucleus of the lateral habenulointerpeduncular tract (S i n g e r 1962). The fibers of this nucleus have a lateromedial course and make up a conjunction of the habenulointerpeduncular tract with its lateral branch (Fig. 1 D, Rζ). In addition to the fiber systems of the centroventral habenular nucleus, described above, certain systems coming from adjacent nuclei have been found in

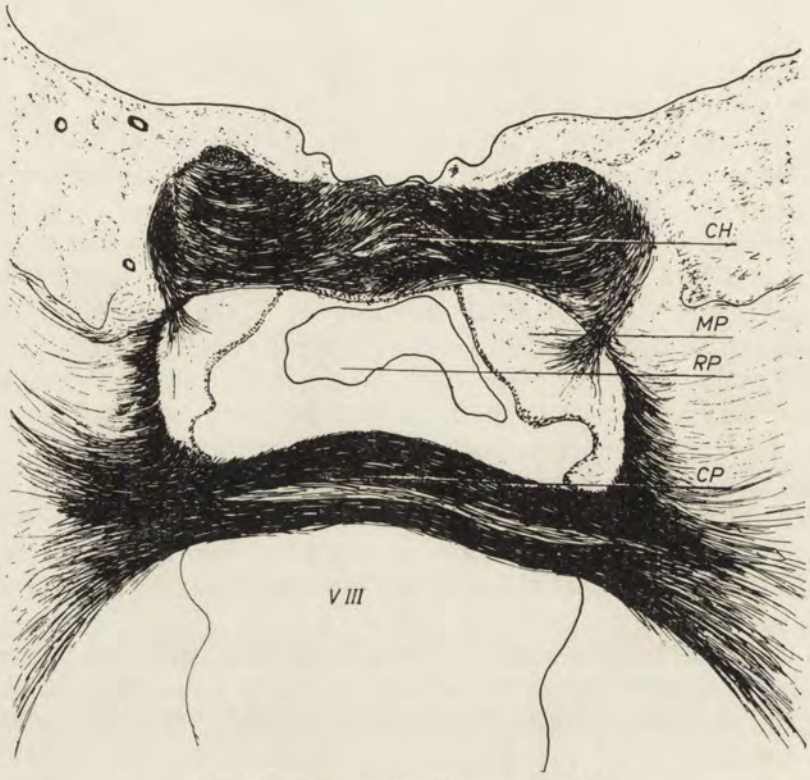

Fig. 1F — See explanations in Fig. 1A

this nucleus. Cytoarchitectonically, the centroventral habenular nucleus is not uniform. A considerable number of middle-sized neurons loosely distributed, round and oval have been noticed in its centrodorsal part. In the ventral part of the nucleus neurons are few but very large (about 20μ) round and well-stainable.

Habenular commissure

The habenular commissure is a thin bundle, stretching dorsally between both habenular nuclei in their caudal part (Figs. 1 F and 2, CH). This bundle consists of fibers, belonging to the stria medullaris of the thalamus. It has been noticed in sections viewed in horizontal planes, that fibers of this system, running along the dorsal boundary of the thalamus, enter rostrally the habenular complex and initially occupy their laterodorsal surface. They have rostrocaudal direction. Beginning with the middle region of the habenular complex, the main bulk of the fibers of the medullar stria of the thalamus starts to shift towards the lateral side of the habenular complex. In the caudal part of the habenular complex,

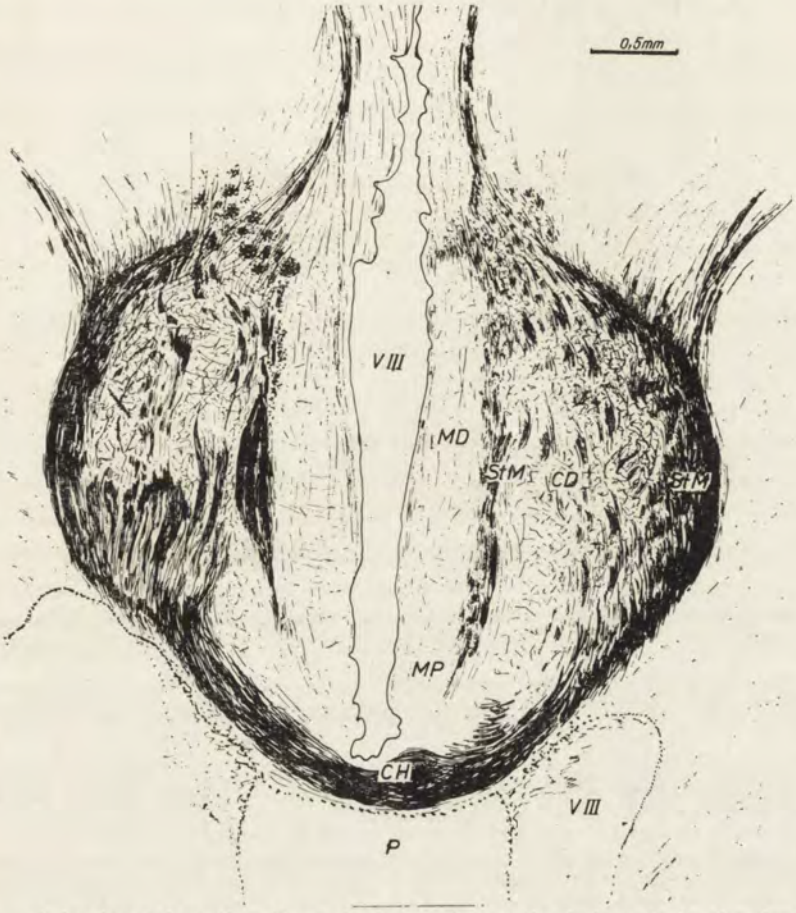

Fig. 2. — A horizontal section through the nuclei of the habenula in the dog's brain. (Klüver-Barrera, semidiagrammatic)

the fibers of the medullar stria of the thalamus are completely shifted to the lateral walls of the habenular nuclei and change their direction into the lateromedial one (Fig. 2). In this area, they form thin bundles, arching towards the mediodorsal walls and the habenula. In the caudal end of the habenular complex they join each other, forming single, broader bundles which make up a sort of a bridge between the left and the right habenula.

The habenular commissure is, therefore formed by distincly visible, fibers of the stria medullaris of the thalamus, belonging to both habenular nuclei. These fibers interlace and cross each other. In frontal sections, the habenular commissure is also very distinctly visible. It has been noticed the arcuate bending of the fibers, belonging to the stria medullaris of the thalamus of which the commissure consists starts with most medially

disposed fibers (Fig. 1 E). Towards the caudal parts of the habenular complex, this process includes all fibers of the stria medullaris of the thalamus.

The habenular commissure is situated below the pineal gland and above the posterior commissure from which it is separated by the subpineal recess (Fig. 1F). No distinct connection has been found between the habenular complex and the pineal gland, although certain very fine fibers, detaching from the habenular commissure and entering the pineal gland, have been observed in few sections.

DISCUSSION

So far, the habenular complex has not been studied in detail. In this work, its myeloarchitectonic division has been carried out on the basis of sections, stained by the Weigert-Wolters method and with application of the Klüver and Nissl methods. The lateral and medial areas have been generally distinguished and the differences in trace thickness and connections of fibers, as well as distribution and shape of neurons that occur between these areas have been taken into account. This is in conformity with the views of authors who divided the habenulae into medial and lateral habenular nuclei. Such a division has already been applied to the fish (Ariëns Kappers et al. 1936, Schnitzlein 1962) and higher vertebrates (König and Klipper 1963), man included (Kühlenbeck 1954, Clara 1959, Crosby et al. 1962). McRioch (1929, 1931), observing the habenulae in the dog's brain, has found that the lateral nucleus, from its middle towards the caudal end, was divided into the ventral part, consisting of middle-sized neurons and the dorsomedial part, consisting of more concentrated neurons. Such a division approximately corresponds to our cytoarchitectonic observations.

On the basis of the Nissl sections, the lateral habenular nucleus of the monkey's brain has been divided by Olszewski (1952) into the lateral, magnocellular and medial, parvocellular parts. A certain similarity may be seen in the views of Hassler (1959). The views, presented above, cannot be compared with the observations concerning the lateral habenular nuclei in the dog's brain, although it has been found that giant but differently distributed (the ventral part of the centroventral nucleus) cells also occur in them. The divergences in views are probably the result of specific differences of the material under study. In this study, the central nucleus has also been distinguished. This nucleus cyto- and myeloarchitectonically is very characteristic of the dog's brain.

As to the medial part of the habenular complex, a considerable con-

currence of opinions based on cytoarchitectonic studies, has been recorded. Thus, for instance, Ariëns Kappers et al. (1936) has distinguished the dorsal and ventral areas in the oral part of the habenula. Craigie (1925) and Gurdjian (1925) have also found the medial nucleus divided into the dorsal and ventral parts. The correctness of these views has been confirmed by the results, shown in the present work.

In the dog's brain, a fine lateral branch of the habenulointerpeduncular tract has been found (Fig. 1 D). It consists of fibers, coming out of the ventrolateral wall of the middle region of the centroventral nucleus. The fiber bundle of this tract, at first runs almost parallel to the main habenulointerpeduncular tract over the caudal surface of the dorsomedial thalamic nucleus. Further caudally, the bundle approaches this tract and joins it, in the caudal end. No mention of this bundle can be found in the neuroanatomical literature.

SUMMARY

A small, medial area with a considerable concentration of neurons and very strongly developed fiber systems, running to the habenulointerpeduncular tract, as well as a much larger, lateral area, containing middle-sized and randomly distributed neurons, have been found in the habenular complex.

In the medial area of the habenular complex, the following nuclei have been distinguished.

1) The anteromedial nucleus which contains fibers, belonging to the main trunk of the stria medullaris of the thalamus. In addition, there are a small number of thick mediolateral fibers which form the beginning of the habenulointerpeduncular tract. This nucleus contains a small number of very fine neurons.

2) The mediodorsal nucleus has a few fiber systems, running towards its lateral wall and forming along it a bundle directed towards the habenulointerpeduncular tract. It contains a large number of very fine neurons.

3) The medioventral nucleus (Fig. 1 B—D, MV) has, in its inside, a very fine meshwork structure, whereas, in its ventromedial part, thick fibers gather in broad bundles, running to the habenulointerpeduncular tract. Here is the greatest concentration of neurons in the habenulae.

4) The caudomedial nucleus is an area in which the fiber systems, described above, terminate. A considerable decrease in the number of neurons may be observed in it.

Four nuclei have been also distinguished in the lateral area.

1) The anterolateral habenular nucleus is marked by a large number

of orocaudally running fibers which belong to the stria medullaris of the thalamus and by a small number of short, fine fibers forming the meshwork structure. The neurons of this nucleus are middle-sized and fairly randomly distributed.

2) The central habenular nucleus, situated in the middle part of the habenular complex, is surrounded by fibers arranged in a ring-like tract. It has a small number of round, middle-sized neurons.

3) The centrodorsal habenular nucleus (Fig. 1 B—D, CD) presents a meshwork structure, formed by a small number of very fine fibers which, on the whole, run dorsoventrally. It contains differently shaped, middle-sized and randomly distributed neurons.

4) The centroventral habenular nucleus is a place of the greatest concentration of fibers in the habenular complex. The structure of this nucleus makes a compact tangled network of fibers which, passes into the habenulointerpeduncular tract. The neurons of this nucleus are larger than those, mentioned above.

The lateral branch of the habenulointerpeduncular tract has been located. It originates from the middle part of the centroventral habenular nucleus, runs initially almost parallel to the main (classical) habenulointerpeduncular tract in the caudal part of the mediodorsal nucleus of the thalamus and further on, approaches once more the habenulointerpeduncular tract.

ABBREVIATIONS

C, Central habenular nucleus
CD, Centrodorsal habenular nucleus
CH, Habenular commissure
CP, Posterior commissure
CV, Centroventral habenular nucleus
I α—ζ, Interhabenular fascicles (explanation in text)
LA, Anterolateral habenular nucleus
MA, Anteromedial habenular nucleus
MD, Mediodorsal habenular nucleus
MP, Posteromedial habenular nucleus
MV, Medioventral habenular nucleus
NLa, Anterior part of the lateral nucleus of the thalamus
NLp, Posterior part of the lateral nucleus of the thalamus
NM, Mediodorsal nucleus of the thalamus
NPv, Paraventricular nucleus
NTH, Nucleus of the habenulointerpeduncular tract
P, Pineal body
R, Habenulointerpeduncular tract
R α—ζ, μ, Fascicles forming the habenulointerpeduncular tract (explanations in text)
Rl Lateral habenulointerpeduncular tract

RP, Subpineal recess
St α—ζ, Branches of the stria medullaris of the thalamus (explanations in text)
StM, Stria medullaris of the thalamus
V III, Ventricle III

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THE CORPUS CALLOSUM OF THE DOG [1]

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The corpus callosum in the dog's brain is shaped like a plate, running almost horizontally through the middle part of the brain. Both in the anterior and the posterior part, the corpus callosum is arched dorsally. The anterior bending passes into a vertical, ventrally tapering rostrum (Fig. 1).

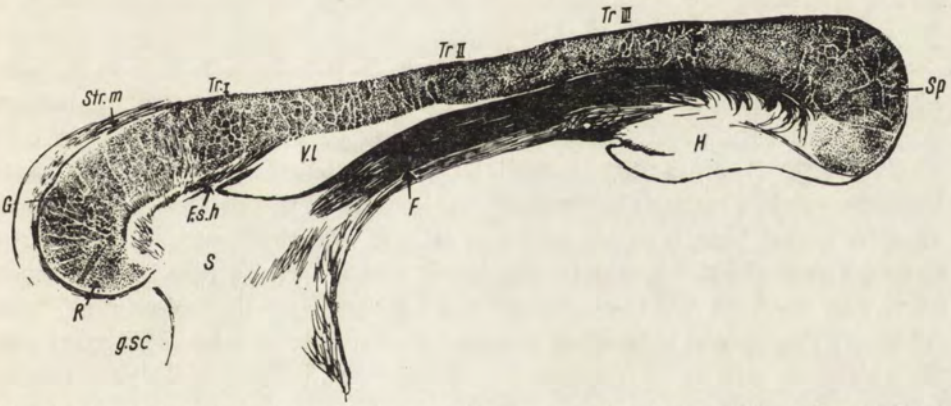

Fig. 1. Sagittal section through corpus callosum in the midline. Stained by Weigert-Wolters method

The corpus callosum can be divided (Déjérine 1895, Kölliker 1896, Ramon y Cajal 1904, Ariëns Kappers et al. 1936,

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Villiger 1946, Clara 1959, Crosby et al. 1962 and Zenan 1963) into four parts: the rostrum, the genu, the trunk and the splenium. The forceps minor, the radiatio corporis callosi and the forceps major are formed by fibers that run from the callosal commissure to the cerebral cortex. The transition from the callosal commissure to the callosal radiation is continuous and, therefore, the boundary between them is only conventional. In the present paper, the places where callosal fibers converge and cross those coming from adjacent regions, in particular from the internal capsule, are considered boundary areas. Most of the dorsal portion and the entire ventral part, except for a short section of the splenium, can be sharply separated off from adjacent structures. Thus, dorsally, the corpus callosum forms the bottom of the longitudinal fissure and the ventral wall of the sulcus corporis callosi. Two longitudinal striae, the medial and the lateral (striae Lancisii mediales et laterales), as well as the indusium griseum are visible in this wall. Laterally to the longitudinal fissure, the callosal commissure borders on the cingulum and cingulate gyrus. Anteriorly, the ventral part of the callosal commissure borders, in its medial part, on the septum and, laterally, forms — together with the tapetum — the "roofs" of the lateral ventricle. Approximately half-way in its course the callosal commissure is joined ventrally by the trunk of the fornix. More posteriorly, the ventral side of the splenium borders on the hippocampal commissure. In the lateral parts, the callosal commissure forms, still together with the tapetum, the "roof" of the lateral ventricle (Figs. 1, 2 and 3, 4, 7, 12, 13, 14).

The variable size of the corpus callosum in the dog depends on the size of the individual. In middle-sized dogs, the length of the corpus callosum (measured on the sections, stained according to the Weigert-Wolters method), amounts, in medial part, to about 27 mm, lateral parts being somewhat longer (30 mm). The thickness of the callosal commissure over its entire length is not uniform either. The thinnest part is the rostrum, being about 0.9 mm in the lower and about 2.0 mm in the upper part. The thickset are the genu (about 2.9 mm) and the splenium (about 2.7 mm). The trunk, somewhat thicker near the genu (about 2.2 mm) and the splenium (about 1.6 mm) becomes thinner in the middle part (about 1.1 mm).

Myeloarchitecturally, the callosal commissure was viewed on the sections, stained according to the Weigert-Wolters method, the Klüver method and the Landau silver method. The frontal, sagittal and horizontal section planes were analyzed. Some observations were made on brains in which degenerative changes occurred in the callosal commissure as a result of previously placed cortical lesions. A total of seven normal and four degeneration brains were examined.

Fig. 2. Parasagittal section through corpus callosum showing the joint of the middle part of the trunk with the substantia medullaris. Stained by Weigert-Wolters method

General observations

The corpus callosum contains a vast number of very well stainable nerve fibers which mostly run transversely to the main axis of the brain and are, in general, medium sized in thickness (about 2—3 μ). However, some of them are very thick (about 5 μ) and some — very thin (about 0.8 μ). The callosal fibers run usually in compact bundles or separately, while interlacing and crossing each other. The glia and blood vessels are seen between them, their direction being mostly sagittal. The density of fibers is not uniform in all parts of the corpus callosum. The anterior part, i.e., the genu, the rostrum and the anterior portion of the trunk, contains slightly less fibers than the splenium and the middle and the caudal parts of the trunk. Likewise, the dorsal part of the trunk contains somewhat more fibers than the ventral. This picture becomes clearer if we observe it from the medial part of the corpus callosum towards its lateral parts. This is not caused by the decrease in the number of fibers but by loosening of bundles, which are strongly compressed in the middle. On the other hand, such a decrease is noted laterally from the cingulum where many bundles emerge from the corpus callosum and penetrate the cingulum.

The main direction of fibers in the callosal commissure is transverse to the main axis of the brain. This principle, however, may be strictly applied only to the middle portion of the corpus callosum. After leaving

the middle portion, all fibers at first run upwards either sharply or only in conformity with the curve of the corpus callosum and, hereafter, either laterally, or posteriorly, or anteriorly (Fig. 3). In the anterior (the rostrum and the genu) and posterior (the splenium) part of the corpus callosum,

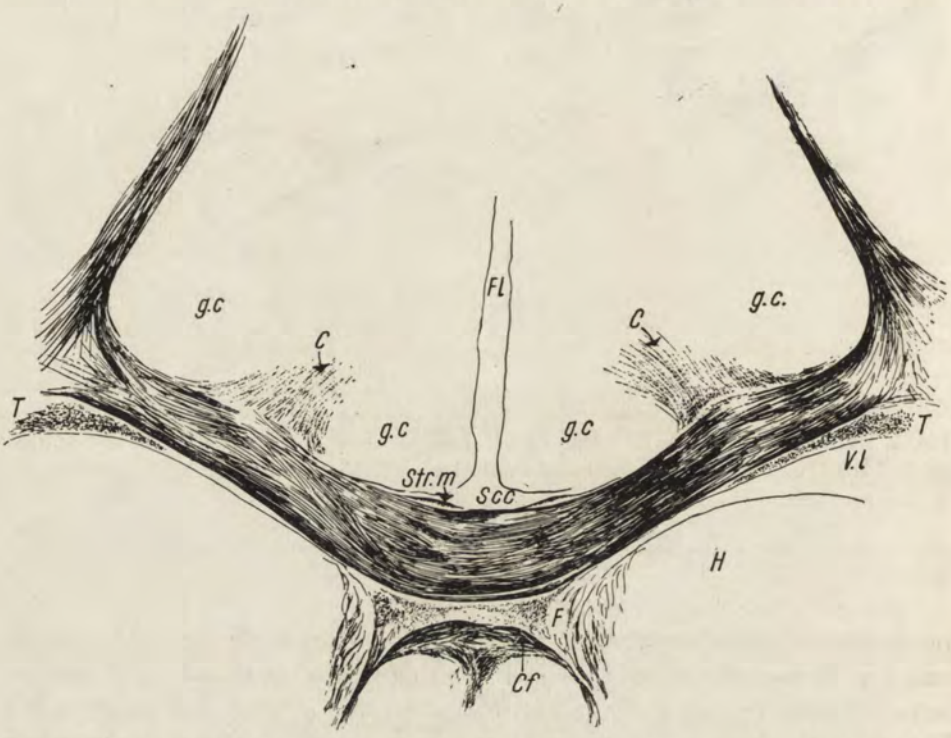

Fig. 3. Frontal section through the front part of the splenium corporis callosi. Stained by Weigert-Wolters method

part of fiber bundles run downwards (Figs 4 and 5). Observing the direction of the downward bending of the fibers in the sections, as well as the length of the visible oblique part, one may conclude which fiber bundles of the callosal commissure correspond to particular portions of the cortex.

The rostrum of corpus callosum

The rostrum is the smallest part of the callosal commissure, situated ventrally to the genu. Anteriorly, in its medial part, the rostrum is confined by the indusium griseum, bundles of striae longitudinales Lancisii and fiber bunches of the cingulum which encircle the genu of the corpus callosum and, along the rostrum, run downwards and slightly posteriorly,

hereafter scattering in the gyri of the ventral part of the brain. These gyri make up an extended limit of the rostrum.

Laterally to the cingulum, the rostrum extends slightly anteriorly, forming a plate which may be observed up to its disappearance when it joins the fiber bundles of the anterior part of the centrum semiovale. The latter

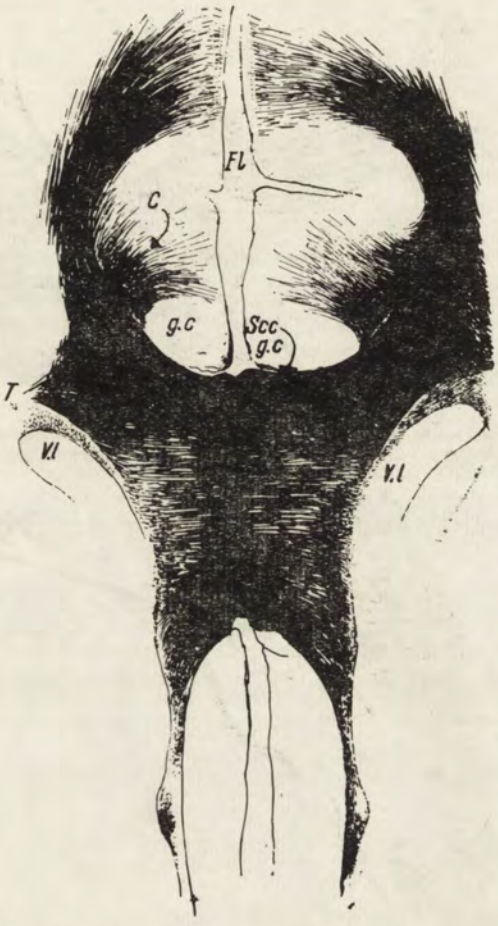

Fig. 4. Frontal section through the genu corporis callosi. Stained by Weigert-Wolters method

confines the rostrum laterally and from the lateral part of the anterior end. Posteriorly, the rostrum borders on the lateral ventricle from which it is separated by the tapetum and on the anterior part of the precommissural hippocampus with which it is not, however, connected.

The rostrum is shaped like a triangular plate, situated in the axial plane between the anterior part of the centrum semiovale and the lateral

ventricle. This plate, strongly extended downwards, is about 3 mm long, 2 mm wide and 15 mm deep (a downward depth).

In the area of the rostrum plate, there are nerve fibers of a medium thickness (about 1.5—2.5 μ), well-stainable and running in fairly compact

Fig. 5. Frontal section through the splenium corporis callosi. Stained by Weigert-Wolters method

bundles, separated from each other by the glia substance. Considering the directions of these bundles, one may distinguish a dorsal and a ventral region of the rostrum. They differ from each other in their myeloarchitecture structure.

In the ventral part, all bundles run downwards, slightly anteriorly and

laterally. They are parallel to and separated from each other by the glia substance.

The nearer the dorsal part, the more horizontal becomes the course of the fiber bundles, although, on the whole, they keep running downwards. It is very likely that the bundles of this part run further anteriorly than those of the ventral part.

In the dorsal region, more or less half-way the length of the rostrum, a change is observed in the direction of the fiber bundles. The dorsal region contains mixed bundles. Part of them runs anteriorly, slightly laterally and ventrally. The more upward the direction of bundles, the milder becomes their ascent, gradually approaching a horizontal course. Other bundles at first interlace those, described above, and run upwards. Their number increases towards the genu (Figs. 6 and 7).

Fig. 6. Parasagittal section through corpus callosum. Stained by Weigert- Wolters method

The dorsal part of the rostrum plate is directly connected with the genu. Stripes which at first are rather narrow and contain fibers, running almost transversely to the main axis of the corpus callosum, appear on the boundary between the plate and the genu. On both sides, these fibers descend anteriorly. They start a system of bundles running (within the corpus callosum) virtually sidewards from the middle line, hereafter, upwards and further on, anteriorly, laterally or posteriorly, depending on their destination. The number of these bundles, at first small, becomes

predominant in the trunk. However this system does not occur at all in the rostrum of the corpus callosum.

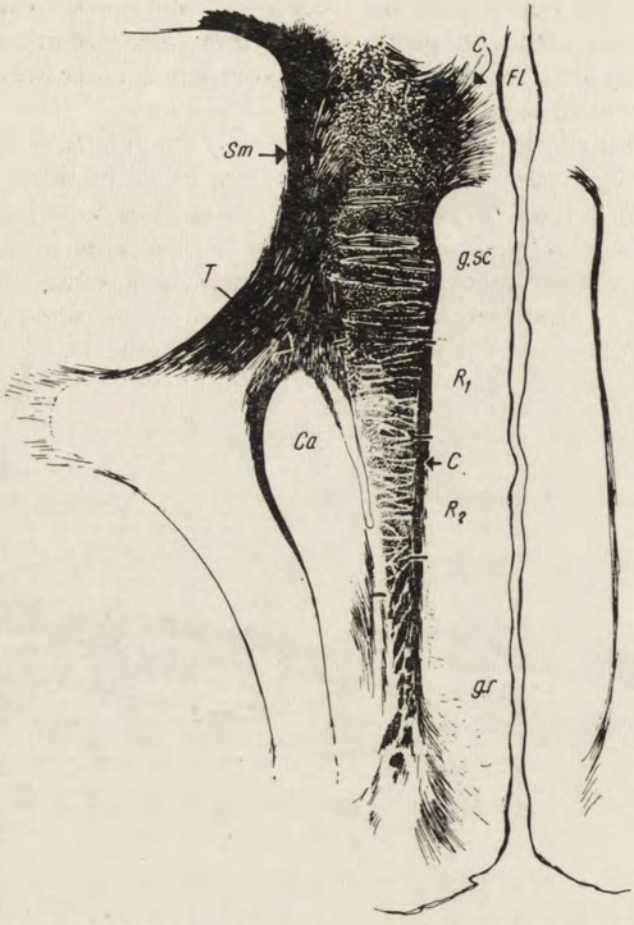

Fig. 7. Frontal section through the rostrum corporis callosi. Stained by Weigert-Wolters method

The genu of the corpus callosum

The genu, forms the anterior bending of the corpus callosi. In the sagittal section, it is shaped like a sector of a circle with its arc facing the anterior portion of the brain. Dorsally and orally, it is encircled by the cingulum which is accompanied by the bundles of the stria Lancisii and the indisium griseum. The ventral part of the genu medially borders on the septum pellucidum and laterally forms — together with the tapetum — a roof of the lateral ventricle. The lateral side of the genu broadly joins with the forceps minor and with the radiatio corporis callosi.

The genu is marked by a considerable thickness which becomes clear if we consider the fact that the bundles, running through it, come from the entire anterior part of the cortex. Both along the midline and laterally, this thickness amounts to about 3 mm (Figs. 2, 4, 6, 7, 11).

The main course of fibers in the genu is laterodorsoral. It is only a small part of fibers that, on the boundary with the trunk of the corpus callosum, is directed caudally. The differences in the angle of deviation of fibers from the horizontal line allow one to distinguish two systems of fibers which, hereafter, are visible on the entire area of the corpus callosum. 1. The bundles which, within the corpus callosum, run transversely to the main axis of the brain, adjusting themselves to the shape of the callosal plate. These bundles leaving the corpus callosum, mildly diverge in a fanwise manner, form a system which is called in the present paper, a transverse system. 2. The bundles which, within the corpus callosum, run independently from its shape and after crossing of the middle line, sharply deflect upwards and very often distinctly turn orally or caudally. These bundles form a system of fibers, called here an oblique system.

A strongly developed oblique system is observed in the genu. In the sagittal sections, one may note a stellate divergence of these fibers which run from the internal to the external bending of the genu. In lower parts, they run sagittally with a slight lateral deviation. In the middle of the genu they have a typically laterodorsoral course. Towards the posterior part of the genu, the course of the oblique system becomes ever more verticoventrodorsal and, on the boundary with the trunk of the corpus callosi, some fibers deviate caudally. The densest concentration of oblique fibers occurs under the cingulum which is joined by most of them forming the fasciculus callosus anterior (K r e i n e r 1962). A sudden disappearance of oblique fibers is recorded laterally to the cingulum.

The transverse system is developed in the genu to a lesser degree. The transverse fibers appear on the outer perimeter of the lower part of the genu in the form of thin bands, crammed between oblique bundles. The number of bands increases dorsally. The bundles form wedges with their bases resting on the outer perimeter of the genu and apexes disappearing among the oblique bundles before reaching the inner perimiter of the genu. It is only on the boundary with the trunk of the corpus callosum that the transverse fibers reach the ventral surface of the corpus callosum (Figs. 6 and 7).

The mutual relation of both these fiber systems, running through the genu of the corpus callosum may be best observed in frontal sections through the anterior and middle part of the genu and in parasagittal sections. The bundles of the oblique system diverge from the center in

a stellate manner forming the letter U which, in the lower part of the genu, is situated horizontally and, hereafter, is raised to an almost vertical position with a slight backward inclination, resembling a spread fan. Transverse fibers are wedged between the radii. All these form a very characteristic structure of this region.

The directions of the fiber course indicate that the fibers of the oblique system run to the forceps minor where they keep their laterooral direction and to the cingulum where, together with fibers, coming from the anterior part of the trunk, they form the fasciculus callosi anterior (K r e i n e r 1962), while the fibers of the transverse system run to the anterior part of the radiatio corpus callosi.

The trunk of the corpus callosum

The trunk is the widest part of the corpus callosum. Its shape may be compared with a fairly thick plate, in its middle bent downward and forming a sort of a wave trough. The radiatio corporis callosi adheres bilaterally to both crests of this wave. This plate is orocaudally stretched along the bottom of the oblong fissura longitudinalis cerebri and, in the posterior part, slightly deviates dorsally. The trunk of the corpus callosum is sharply marked off from the adjacent regions of the brain.

On the dorsal side, the trunk is encircled over its entire length by the cingulum. As mentioned above, the longitudinal medial and lateral striae, as well as indusium griseum also are situated on the corpus callosum.

Along the midline, the anterior part of the ventral side borders on the septum and the posterior on the fornix which, with its dorsal side, is coalescent with the trunk of the corpus callosum. Laterally, the trunk together with the tapetum form the roof of the lateral ventricle. The boundaries of the trunk with other parts of the corpus callosum such as, the genu, the splenium and the bilateral radiation are not sharply outlined. The boundaries between the trunk and the genu, as well as between the trunk and the splenium are determined on the basis of a change in the direction of most nerve fibers. A conventionally accepted boundary between the trunk and the radiatio corporis callosi, is situated at the intersection of the callosal bundles with the bundles of the corona radiata and the association fibers of the cortex.

On the basis of the myeloarchitecture, the trunk has been divided into three parts in the longitudinal aspect and into three layers in the vertical aspect. The vertical, more or less distinct, layers repeatedly occur in all parts and, therefore, they are discussed as the first.

The dorsal layer contains the largest number of fibers, perfectly stained and running transversely to the main axis of the brain. Its fibers from very

compact bundles almost parallel to each other (Fig. 4). This layer reaches to 1/3 of the trunk thickness. Crossing the midline of the corpus callosum, all fibers keep their lateral direction. Behind this line (sidewards from it), they slightly deviate upwards in conformity with the curve of the corpus callosum. It is more or less at the level of the cingulum that part of fibers mildly or, sometimes, sharply deflect mostly anteriorly. The rest of them fibers kees their laterodorsal course.

In the middle layer, which extends up to about 3/4 of the trunk thickness, a somewhat smaller number of fibers is observed than in the dorsal layer but their system is more complex. Fiber bundles interlace each other in all directions and apparently at random. Regardless, however, of the question whether they are directed anteriorly or posteriorly, all of them run downwards to the midline and upwards from the midline. This forms a picture of a tangle of wave troughs different in depth with both the entire waves and their sides (right and left) being disposed in different planes (Fig. 8). Very shallow waves which run downwards and upwards only in conformity with the bending of the plate of the corpus callosum, form the transverse system, described in the chapter on the genu of the corpus callosum. Deeper waves, running sharply downwards and upwards independently from the shape of the trunk of the corpus callosum, form the oblique system. The latter is visible in parasagittal sections in the form of almost parallel bands, running ventrodorsally between those of the transverse system (Figs. 3, 11, 14).

The ventral layer, the thinnest of them and constituting at the most 1/6 of the lower thickness of the trunk, contains more compact bundles than those in the middle layer but somewhat more loosely formed than those in the dorsal layer. Their course is much more uniform than in the middle layer. There is a greater number of transverse fibers that run parallel or almost parallel to each other and, after crossing the medial line, curve dorsally in conformity with the bending of the trunk of the corpus callosum, running mildly or, sometimes, sharply towards the anterior or posterior end. The tapetum is seen ventrally to this layer.

The trunk is also longitudinally divided into the anterior, middle and posterior part.

The anterior part directly adjoins the genu of the corpus callosum. The plate of the corpus callosum is thick, compact and less stretched to the sides than the next part. The boundary between the genu and the trunk is not sharply outlined. In parasagittal sections, it is anatomically marked out by the appearance of a certain number of fibers of the oblique system which bend caudally. The fact that the bands of oblique fibers do not diverge in a fanwise manner as in the genu but run more parallel to each other make up another determinant of this boundary. Most fibers of the

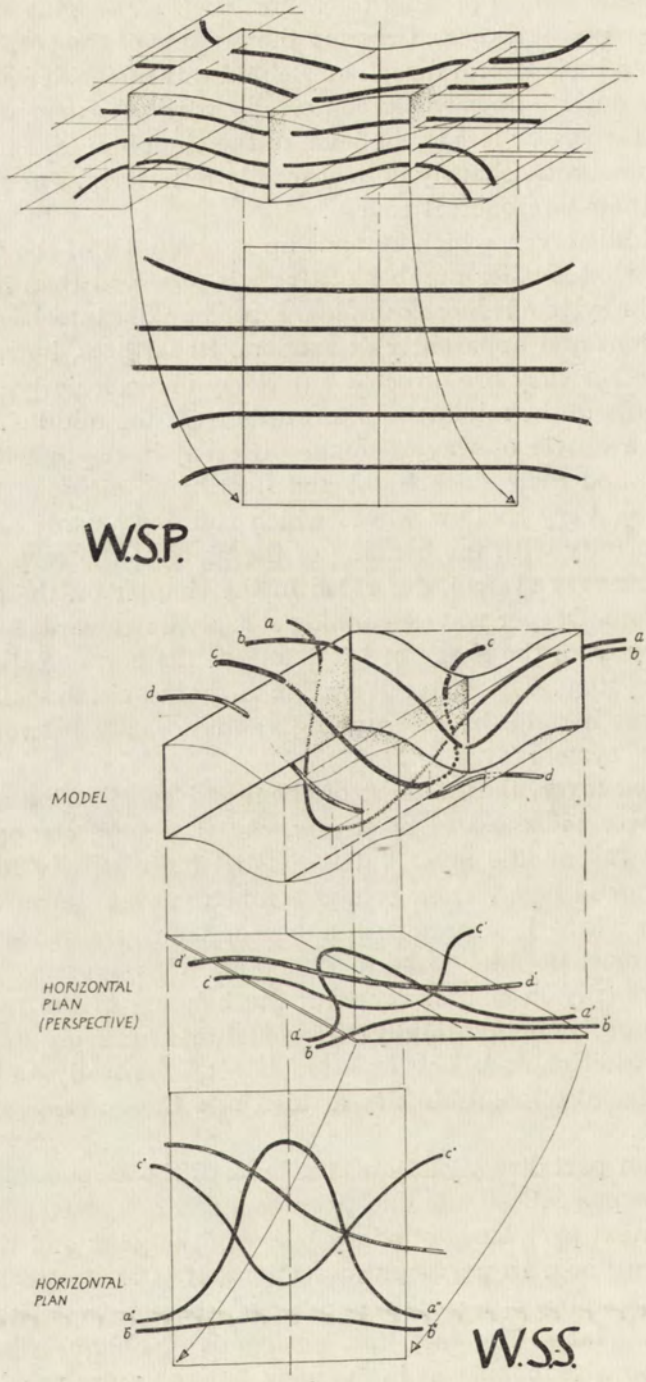

Fig. 8. Scheme of the course of callosal fibers in the dog's brain

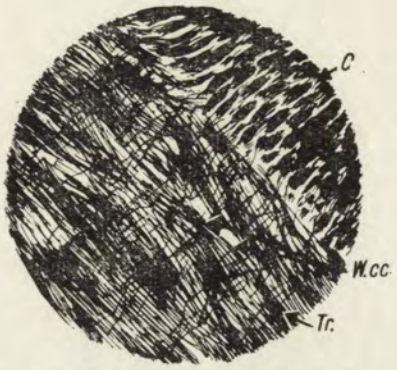

Fig. 9. Fragment of the hind part of truncus corporis callosi. Delicate fibrillets penetrating through the corpus callosum into the cingulum are shown. Stained by Weigert-Wolters method. 160 ×

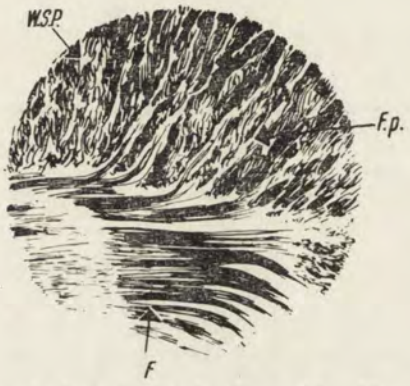

Fig. 10. Fragment of the ventral part of splenium with „fibrae perforantes" joining the septum with the hippocampus. Stained by Weigert-Wolters method. 400 ×

anterior part of the trunk run anteriorly. The majority of fibers, belonging to the transverse system, occupy the dorsal and ventral layers, run parallel to each other in conformity with the shape of the corpus callosum and, eventually, mildly bend anteriorly. The fibers of the oblique system, which mainly occupy the middle layer, sharply bend upwards immediately on crossing the middle line of the corpus callosum. They form compact, well-stained bundles. The outlines of callosal layers become slightly blurred at the level of the cingulum where a considerable number of fibers enters the cingulum as the fasciculus callosum anterior (K r e i n e r 1962). The rest of them pass to the anterior part of the radiatio corporis callosi (Figs. 2, 4, 6, 7, 11).

The middle part of the trunk of the corpus callosi is not distinctly marked off from the anterior part. In parasagittal sections, it is marked

Fig. 11. Parasagittal section through corpus callosum, laterally from the cingulum. Stained by Weigert-Wolters method

out by a small number of fibers which run in a pronouncedly caudal direction. The plate of the corpus callosum is, in this part, thinner than that in the anterior part but wider and more extended to the sides. There are only few fibers of the oblique system, as well as few ones which enter the cingulum. The layers are fairly well-outlined, the dorsal and ventral being dark and the middle layer — much brighter. The course of fibers along the middle line of the corpus callosum is, in all layers, almost uniform and transverse to the main axis of the brain, single fibers running parallel to each other. In parasagittal sections, the differences occur slightly medially from the level of the cingulum. A small number of fibers, belonging to the oblique system, sharply bend upwards. The fibers of the transverse system also differentiate but this takes place under the cingalum and somewhat laterally to it. A part of fibers, mostly belonging to the ventral layer, bend, in conformity with the shape of the corpus callosum, at first, slightly upwards and, hereafter, laterooorally or laterocaudally. Another part bends sharply upwards, forming fairly thin parallel bands. In observing successive parasagittal section, one may note a convergence of the so far parallel bundles of which the anterior ones bend posteriorly and the posterior ones — anteriorly. At the same time, these bundles gradually pass to the dorsal layer of the corpus callosum. They keep running dorsally and thus reach the dorsal side of the middle part of the callosal radiation.

The posterior part of the trunk is the shortest of them and slightly thicker than the middle one and its general aspect resembles that of the

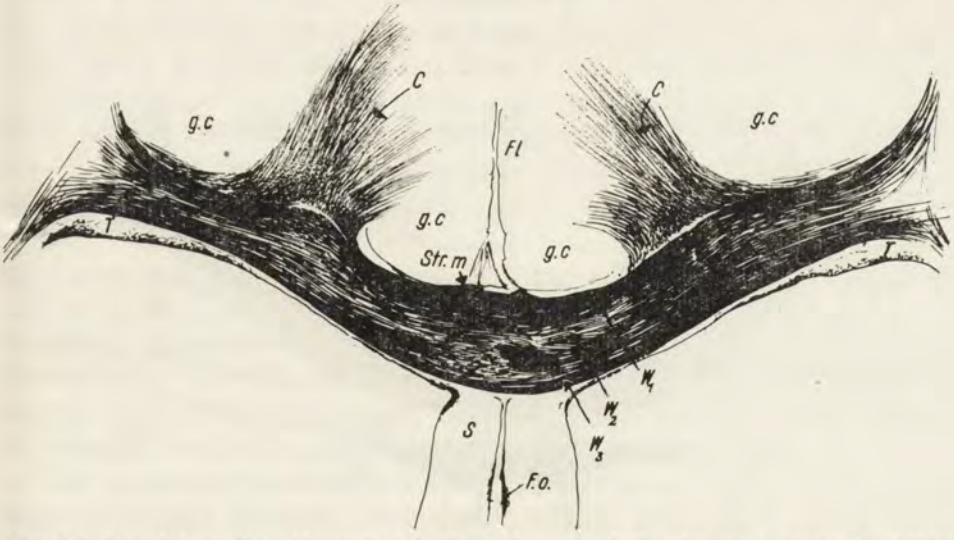

Fig. 12. Frontal section through the frontal part of the truncus corporis callosi. Stained by Weigert-Wolters method

anterior part. The boundary between the posterior and the middle part is very unstable, being expressed by the gradual disappearance of the differentiation of the transverse system and the occurrence of a larger number of fibers that bend caudally. Many fibers join the cingulum as parts of the fasciculus callosus posterior (K r e i n e r 1962). The division into layers is fairly well-visible (Figs. 2, 4, 6, 7, 11, 12, 13, 14).

In addition to the two fiber systems, described above, which occur all over the corpus callosum, there is also the third one, met with in the

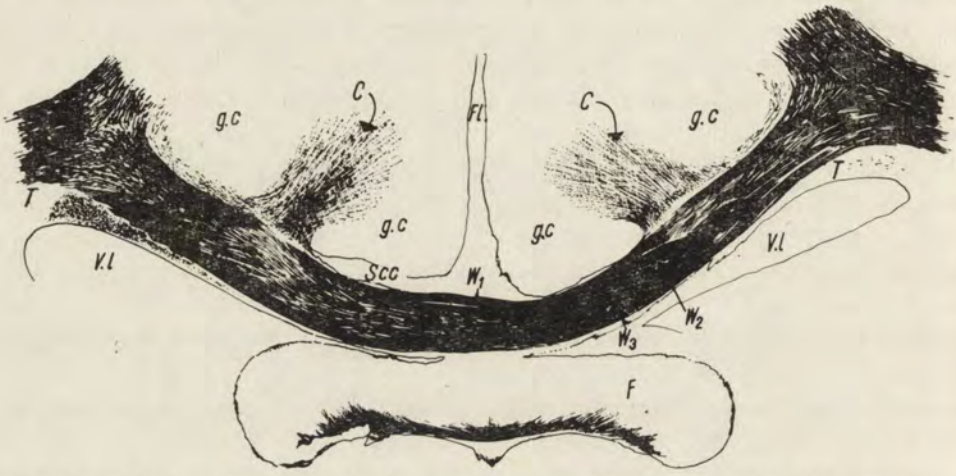

Fig. 13. Frontal section through the middle part of the trunk. Stained by Weigert-Wolters method

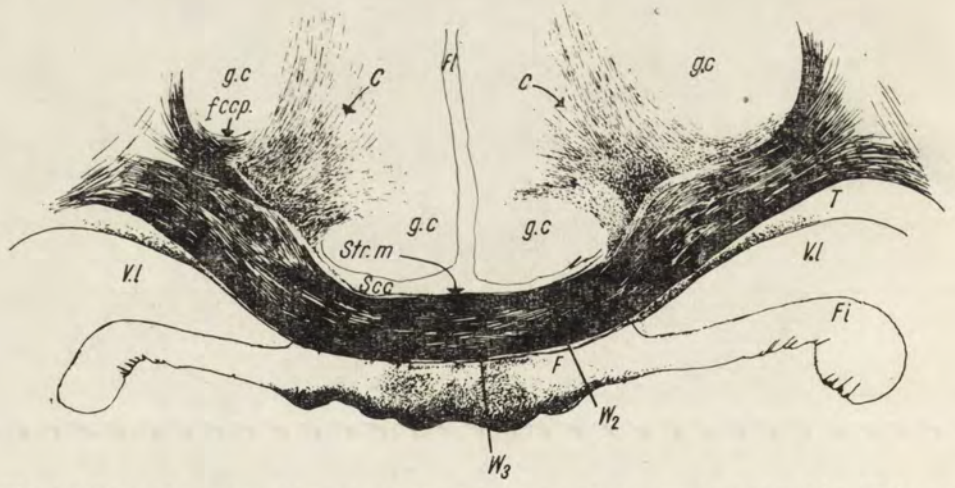

Fig. 14. Frontal section through the posterior part of the trunk. Stained by Weigert-Wolters method

anterior and posterior parts of the trunk. It consists of thin, fine fibers which pierce the corpus callosum, run ventrodorsally and enter the middle bundles of the cingulum. Within the corpus callosum they are first noted more or less half-way its thickness. They were never observed to bend either towards the middle line of the corpus callosum, or towards the radiation (Fig. 9).

The splenium or the corpus callosum

The splenium, arches downwards like the genu. On the inside, this bending borders, along the middle line, on the fornix and, laterally, forms — together with the tapetum a roof of the lateral ventricle. The external arch of the splenium is accompanied by a bending of the cingulum together with the indusium griseum and the striae Lancisii. Laterally, the splenium of the corpus callosum passes into the posterior part of the radiatio corporis callosi and the forceps major. In contradistinction to the forceps minor which, viewed in the horizontal aspect, forms a sort of the letter U facing the anterior part, the forceps major runs more sidewards. In the frontal section, this forceps forms an obtuse angle.

The anatomical boundary between the trunk and the splenium of the corpus callosum is not clearly outlined. It is situated more or less posteriorly to the level of the nucleus habenulae and the corpus pineale and is expressed by a change in the direction of the callosal bundles. If in the callosal trunk, fibers are directed anteriorly, laterally or posteriorly, in the splenium of the corpus callosum most fibers run pronouncedly posteriorly. There is a sort of a border zone in which a decrease is observed in the number of fiber bundles with a lateral and oral course and, at the same time, a sudden increase in the number of fiber bundles that run caudally and, in the trunk of the corpus callosum, are represented by few bundles (Figs. 2 and 10).

Myeloarchitectonically, the splenium may be divided into two parts, the first of which forms the upper part (the bending itself) and the second makes up the lower part which, ventrally, is slightly bent forwards. This division is in conformity with that of Déjérine (1895) who, in man, distinguished the following three parts of the splenium of the corpus callosum: (1) the posterior part, (2) the splenium proper (the upper part of the splenium in the present paper) and (3) the lower part.

The upper part contains perfectly stained fibers which form compact bundles running virtually laterodorsocaudally. Both systems of callosal fibers, described above, are represented in this region. Within the splenium, oblique fibers are shorter and, instead of narrow bands, form thick

bundles irregular in shape and running more laterally than those, in the previously described parts of the corpus callosum. They form a characteristic picture on the perimeter of the posterior bending where they are most numerous. They join the posterior part of the radiation of the corpus callosum and the upper part of the forceps major. A small part of them penetrates the cingulum.

In the anterior part of the splenium, the transverse fibers form fairly numerous bundles, jammed between the oblique fibers. Most of them are situated in the middle of the splenium volume. They run laterocaudally and somewhat dorsally. It is only in the lowermost bundles, on the boundary with the lower part, that the laterocaudoventral course of fibers is observed. These bundles enter the posterior part of the callosal radiation, as well as the upper and middle parts of the forceps major. They are mostly medium in thickness and well-stained (Figs. 2, 5, 6, 11).

The lower part of the splenium completely borders on the forceps major. No transverse bundle system is seen in this region. Instead, fibers with a more or less oblique trace may be seen which run dorsally or ventrally, forming an upper and lower fascicle. Both fascicles contain fibers medium in thickness and well-stained. The bundles are looser and contain a lesser number of fibers than those in the upper part of the lobe. The upper fascicle is rather small and its fibers, after crossing the middle line, run laterodorsocaudally to the central parts of the forceps major. The lower fascicle, occupying about 3/4 of the entire area of this region, contains fibers which strongly bend downwards and sidewards, entering the central and lower parts of the forceps major.

In addition to the callosal fibers, mentionned above, the splenium is joined ventrally by the fibers, coming from the upper part of the fornix and from the septum. These are the so-called "fibrae perforantes" (Kölliker 1896). In the dog, there are few of them and they do not form bundles but single fibers pierce the splenium of the corpus callosum. Mostly, they are visible in the gaps between the callosal fascicles and they are surrounded by the glia substance. They run dorsolaterally from the middle line and are finer than the callosal fibers. Some of them intersect in the lower part of the splenium (Figs. 6 and 10).

DISCUSSION

The corpus callosum, has been subject to many investigations. Numerous neuroanatomists were primarily interested in the phylo- and ontogenetic development of the corpus callosum (Elliot Smith 1895, Kölliker 1896, Ramon y Cajal 1904, Abbie 1939). Some of them tries to find cortical cells which originate the callosal fibers (Cur-

tis 1940, Garol 1942 and others), others studied the distribution of callosal fibers over particular portions of the brain. The following three investigation methods were used: the observation of sections, stained in different manners, the degeneration method and the electrophysiological method.

Electrophysiologists (Curtis 1940, Garol 1942 and others) primarily dealt with the intercortical connections which run through the corpus callosum and with the question whether or not these connections occur only between homonymous portions of the cortex. These investigations led to the discovery that connections exist between all homonymous cortical fields and that they run through the corpus callosum. In addition, the existence of heteronymous connections is very likely, at least for some cortical fields.

As to the myeloarchitecture of the corpus callosum, the literature contains only the details of the general, external morphology of the corpus callosum and few remarks about its internal structure (Kölliker 1896, Ramon y Cajal 1904, Mingazzini 1922, Ariëns Kappers et al. 1936, 1947, Ribet 1957, Clara 1959, Crosby et al. 1962). A general pattern of distribution of the callosal fibers in different cortical regions has been discovered in the degeneration studies, of Mingazzini (1922), Sunderland (1940), Berke (1960), Maršala and Lutenberg (1962), and Lutenberg and Maršala (1963).

It should be, however, stated so far none of the methods, mentioned above, led to an unequivocal answer to the question of the origin terminations and the course of the callosal fiber bundles. The most promising seem to be the degeneration methods invented by Marchi, Nauta and Gygax. However, in order to draw justified conclusions that certain degenerated fibers belong to this and not to that region, one ought to maintain maximal precision during both the surgery and determination of lesions. Unfortunately, the studies, based on degeneration methods, enable us to draw general conclusions only. The most accurate is Maršala and Lutenberg's study carried out on the cat but even this arouses some doubts. Lesions, labelled by Maršala and Lutenberg as temporal, occipital and parietal, slightly overlap and, despite of indubitable differences in the course of the degeneration that occurs in the corpus callosum, one cannot assign, with a sufficient degree of certainty, a given cortical to a corresponding portion of the corpus callosum. The same applies to lesions of the motor cortex. In this respect, the following four lesions have been described: (1) the lesion of the gyrus sigmoideus anterior, (2) the lesion of the gyrus sigmoideus posterior, (3) and (4) the lesions of both these areas, but one of them covers the region, situated more laterally and does not encroach the sulcus cruciatus, while the other

runs more medially and covers the sulcus cruciatus. In both lesions the gyrus sigmoideus anterior and posterior have been destroyed. The degenerations in the corpus callosum have shown that the gyrus sigmoideus anterior and posterior send their fibers to the genu of the corpus callosum, that is, one of these gyri — to its dorsal and the other to its ventral part. The degenerations, resulting from lesion 3 make up a sum of the two former ones. On the other hand, the degenerations, produced by lesion 4 by which, according to the figure the dorsomedial part and the fissura cruciata have also been destroyed, are different in character. They penetrate the trunk of the corpus callosum to a considerable depth, being much less numerous in the genu where they are widely scattered over its entire surface, while in former lesions the degenerations (also according to the figures) indicate a considerable concentration of fibers in the genu of the corpus collosum.

The attempts at a comparison of the results of the degeneration atudies, dealing with an identical problem but carried out on different animal species, encounter considerable difficulties. It seems that there are several causes of this. Firstly the homology of cortical fissures and gyri in different animals (as, for instance, in dog, macaque, etc.) has not been satisfactorily determined so far. Secondly, the lesions do not cover identical areas which may result either from individual investigators interests in different regions of the brain, or from an insufficient accuracy of the surgery. Thus, for instance, Berke (1960) whose studies of the macaque were primarily devoted to the trace of fibers, running through the claustrum, external capsule and extremal capsule, also pays much attention to the corpus callosum. Unfortunately, due to both a different character of lesions and the fact that they cover together two or three adjacent regions and even, in the case of Berke, reach the white substance, this study cannot be compared with that of Sunderland (1940) on the distribution of fibers in the corpus callosum in the macaque. Furthermore, when compared with Maršala's and Lutenberg's investigations of the cat, the two studies on macaque mentioned above display only a general convergence of their results. Altogether, we do not learn much more than it has been previously well known from Mingazzini's (1922) studies and even papers by Ramon y Cajal (1904), Köllicker (1896) and other authors who stated generally that the frontal and motor cortical areas send their fibers through the genu, the parietal areas through the trunk, whereas the occipital cortical areas send their fibers through the splenium.

Our studies on the myeloarchitectonics of the inner parts of the corpus callosum do not contradict the results mentioned above. The division of different parts of the corpus callosum into smaller sections is in confor-

mity with Maršala's and Lutenberg's study on the cat. Moreover, it seems to be very likely that callosal fibers, coming from the same region do not run as a compact bundle but they run separately or grouped in small bundles intermingled with fibers coming from adjacent regions. This causes a mutual interlacing of many callosal fibers which is perfectly visibile in the sections.

In addition to fibers, coming from the cortex, the corpus callosum contains also a small number of fibers which come from other regions of the brain such as, primarily, the bundles coming from the fornix and the septum. Many small fibers, coming from the latter structures, and passing through the corpus callosum as „fibrae perforantes" in rabbit, macaque and man have been described by several authors (Kölliker 1896, Zuckerhandl 1901, Ramon y Cajal 1904, Ariëns Kappers 1947, Clara 1959, Crosby et al. 1962). These fibers run to the striae longitudinales mediales et laterales Lancisii and, hereafter, together with them, to the hippocampus. In the dog, no such fibers have been found either in the genu, or in the trunk of the corpus callosum. On the other hand, fine fibers, coming from the fornix longus, i.e. from the part of fornix connected with septum (Miodoński 1967) enter, as "fibrae perforantes", the base of the callosal splenium. Some fibers from the dorsal part of the fornix enter the callosal splenium slightly more posterior to fibres from fornix longus.

SUMMARY

On the basis of the sections examined in this study it has been found that the fibers of the corpus callosum are very well stainable by the Weigert-Wolters method. They ae mostly medium in thickness, and run either single or in bundles, either parallel to each other or interlacing. Two fundamental fiber systems have been determined. The fibers of one of them run transversely in relation to the sagittal plane of the brain and, within the corpus callosum, display an only small oral and caudal deviation. The fibers of the other system, running at a certain angle to the former ones, keep a ventrodorsal direction with a larger or smaller lateral deviation. In different parts of the corpus callosum, there are different situations of these systems in relation to each other. These differences allowed me to determine the morphological boundaries between the macroscopically distinguishable parts of the corpus callosum (rostrum, genu, trunk and splenium). Each of these parts could be also divided into sections with different mutual proportions and different direction relationship of both systems.

In addition to fibers of the cortical origin, fibers coming from the

septum and the fornix have been also observed in the corpus callosum. These fibers (the so-called "fibrae perforantes") enter the corpus callosum at the base of the splenium where they form single fine fibrilis. In passing upwards and slightly posteriorly, they run to the other cerebral hemisphere. Most of them connect the septum with the hippocampus. On the other hand, no fibers have been found which would run from the pre- and postcommissural fornix to the striae longitudinales (laterales et mediales) Lancissi, penetrating through the anterior part of the callosal trunk and which have been described by other authors in rabbit, macaque and man.

It has been found that the tapetum, accompanying the corpus callosum on its lateroventral side, contains nerve fibers running in a quite different direction than the callosal fibers.

LIST OF ABBREVIATIONS

C — cingulum
C.r — corona radiata
Ca — nucleus caudatus
Cf — commissura hippocampi
Cr. — sulcus cruciatus
F — fornix
F.o. — fibra olfacto-septales
F.p. — "fibrae perforantes"
F.s.h — fibrae septo-hippocampales
Fi — fimbria
Fl — fissura longitudinalis
fcca — fasciculus callosalis anterior
fccp — fasciculus callosalis posterior
G — genu corporis callosi
g.c — gyrus cinguli
g.r — gyrus subproreus
g.sc — gyrus subcallosus
H — hippocampus
R — rostrum corporis callosi
R1, R2 — dorsal and ventral part of the rostrum
S — septum
Scc — sulcus corporis callosi
Sm — substantia medullaris
Sp — splenium corporis callosi
Sp I, Sp II — dorsal and ventral part of the splenium
Spl — sulcus splenialis
Str.m — stria longitudinalis medialis
T — tapetum
Th — thalamus
Tr — truncus corporis callosi
Tr I, Tr II, Tr III — three parts of truncus corporis callosi
V.l — ventriculus lateralis
W_1, W_2, W_3 — the layers of truncus corporis callosi
W.cc — commissural fibers running in the truncus corporis callosi to the cingulum
W.S.P — Fibers of the transversal system
W.S.S — Fibers of the oblique system

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QUALITATIVE VERSUS DIRECTIONAL CUES IN DIFFERENTIAL CONDITIONING

3. THE ROLE OF QUALITATIVE AND DIRECTIONAL CUES IN DIFFERENTIATION OF SALIVARY CONDITIONED REFLEXES

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In a previous paper of this series (S z w e j k o w s k a 1966) dogs were trained to place their right forelegs on the feeder to CS_1 and not to do so to CS_2 in a simple food-no food differentiation training. CS_1 and CS_2 differed both in quality and direction. When thereafter in test trials the site of the CSs was reversed, it appeared that in most cases the qualitative cues prevailed over the directional cues, however, in about 30% of trials the directional cues determined the animal's responses. As we know from another paper of this series (D o b r z e c k a and K o n o r s k i 1966) the directional cues clearly prevailed over the qualitative cues when instead of go-no go differentiation the right leg — left leg differentiation was trained. This fact was then interpreted by assuming that in the instrumental CR training the motor conditioned response becomes connected with the orienting motor response towards the source of the CS and not with the auditory aspect of that stimulus.

When comparing the results of these two series experiments it might be supposed that the dominance of directional cues over the qualitative cues in some instances of go-no go differentiation could be also attributed to the connections established between the orienting response to the CS and the instrumental response. If this assumption were true it might be expected that by using purely classical CRs in our tests the dominance of the qualitative cues would be complete.

The aim of the present paper was to test this hypothesis.

MATERIAL AND METHODS

The experiments were performed on eleven naive mongrel dogs in a regular sound-proof CR chamber. Group I consisted of seven dogs in which the sound of a buzzer (B) was the positive CS — always reinforced by presentation of food — and the beating of a metronome (M) was the negative CS — never reinforced by food. In four dogs the buzzer was situated in front of the animal, and the metronome behind, in three other dogs — vice versa. Group II consisted of four dogs in which a tone 900 cps (T_1) produced by a loudspeaker in front of the animal was the positive CS, and a tone 500 cps (T_2) from a loudspeaker behind the animal was the negative CS. The schedule of the training is represented in Table I.

Table I

Schedule of experiments

Dogs	$\overset{+}{CS}$	Its location	$\overset{-}{CS}$	Its location
1	B	In front	M	Behind
2	B	In front	M	Behind
3	B	In front	M	Behind
4	B	In front	M	Behind
5	B	Behind	M	In front
6	B	Behind	M	In front
7	B	Behind	M	In front
8	T_1	In front	T_2	Behind
9	T_1	In front	T_2	Behind
10	T_1	In front	T_2	Behind
11	T_1	In front	T_2	Behind

All the animals had salivary fistulae of the parotid gland ducts made according to the Sołtysik and Zbrożyna technique (1957). Salivation (in drops) was recorded with the electrical device described by Ellison and Konorski (1965). The food was presented by putting into position successive bowls containing small portions of dried breadcrumbs moistened with broth.

When the dogs had learnt to take food from the feeder, a positive CS was presented in overlapping sequence with food reinforcement. At the onset of a series of experiments the CS—US interval was 1 sec, and it was gradually lengthened until it reached twenty sec in group I and ten sec in group II.

After a few sessions in which only the positive CS was given, a negati-

ve CS was introduced, having duration equal to the CS—US interval in the positive trials. In each experimental session five positive and five negative trials were given in a random order, the first trial being always positive. The intertrial intervals varied from three to four minutes.

When the salivation to the positive and to the negative CSs reached a stable level during at least ten consecutive sessions, then a block of ten test sessions followed. The latter consisted of eight or nine regular trials (5 or 6 positive and 3 negative) and two test trials in which the directions of the CSs were reversed: the positive CS sounded from the site of the negative one, and vice versa. In each test session one test trial with the positive CS and one with the negative CS was given. In the test trials neither the positive nor the negative CSs were reinforced by food. The data of a typical test session is presented in Table II.

Table II

Experimental session No. 54, dog No. 1, 23. 1. 65

Successive trials	CS	Direction of CS	Isolated period of CS	Salivary CR in drops	Reinforcement
1	Buzzer	In front	20	12	+
2	Metronome	Behind	20	5	−
3	Buzzer	In front	20	21	+
4	Buzzer	In front	20	25	+
5	Buzzer	Behind	20	18	−
6	Buzzer	In front	20	24	+
7	Metronome	Behind	20	6	−
8	Metronome	Behind	20	4	−
9	Buzzer	In front	20	23	+
10	Metronome	In front	20	5	−
11	Buzzer	In front	20	28	+

RESULTS

The main features of the differentiation training before the test sessions are presented in Table III. It is seen from this table that differentiation in group II took a somewhat longer time than that in group I, and that the ultimate level of salivary responses in negative trials amounted to about 10 to 20 per cent of the positive trials. Only in one dog (No. 4) was this level higher, amounting to 30 per cent.

The results of the test trials are represented in Table IV for the salivary responses to the negative CSs transferred to the "positive" site, and

Table III

The course of training before the test sessions

Dogs	Location of CS		Number of trials		$\frac{-}{CR}$ in % of $\frac{+}{CR}$ in last 10 trials
	$\frac{+}{CS}$	$\frac{-}{CS}$	Positive	Negative	
Group I					
1	BA	MP	125	100	17
2	BA	MP	50	30	10
3	BA	MP	100	85	18
4	BA	MP	80	80	31
5	BP	MA	85	75	14
6	BP	MA	100	85	7
7	BP	MA	100	85	20
Group II					
8	T_1A	T_2P	225	200	11
9	T_1A	T_2P	190	100	12
10	T_1A	T_2P	140	90	16
11	T_1A	T_2P	120	100	20

Table IV

The results of test trials with negative CSs

Dogs	$\frac{-}{CS}$		$\frac{\frac{+}{cCR}-\frac{-}{tCR}}{\frac{+}{cCR}-\frac{-}{cCR}} \cdot 100$										Means
	Original location	Reverse location	Successive test sessions										
			1	2	3	4	5	6	7	8	9	10	
1	MP	MA	78	100	100	100	94	94	91	96	104	113	97
1	MP	MA	90	105	100	100	109	106	107	100	94		114
3	MP	MA	136	94	122	75	90	100	63	108	78		96
4	MP	MA	125	128	90	112	133	125	127	121			120
5	MA	MP	95	100	108	83	112	100	114	100			101
6	MA	MP	95	104	104	120	104	105	105	95			104
7	MA	MP	133	100	75	110	123	93	105	111	106	105	115
8	T_2P	T_2A	90	100	104	90	100	110	92	90	80	114	96
9	T_2P	T_2A	55	87	66	100	86	108	110				87
10	T_2P	T_2A	71	120	100	120							103
11	T_2P	T_2A	122	91	80	100	105	106					101

in Table V for the salivary responses to the positive CSs transferred to the "negative" site. The responses were calculated in the following way: the means of the conditioned responses (except for the first one) were taken for all the positive trials ($\overset{+}{cCR}$) and all the negative trials ($\overset{-}{cCR}$) in each test session. The values of the test CRs ($\overset{+}{tCR}$ and $\overset{-}{tCR}$) for each session were calculated according to the formula $\frac{\overset{+}{tCR}-\overset{-}{cCR}}{\overset{+}{cCR}-\overset{-}{cCR}} \cdot 100$ for the positive trials and $\frac{\overset{+}{cCR}-\overset{-}{tCR}}{\overset{+}{cCR}-\overset{-}{cCR}} \cdot 100$ for the negative trials. In other words, in positive test trials the difference between the test positive response and the control negative response was expressed as the percentage of the difference between the control positive and control negative response. In negative test trials the "degree of inhibition" was measured, i.e. the difference between the control positive response and test negative response as percentage of the difference between the control positive response and control negative response. It follows that the more the test positive response approaches 100% the more it approximates the normal positive response; the more the test negative response approches 100%, the more it approximates normal negative response.

To illustrate this, in the protocol of the test session presented in Table II the value of $\overset{+}{tCR}$ equals $\frac{18-5}{25-5} \cdot 100 = 85$ and the value of $\overset{-}{tCR}$ equals $\frac{25-5}{25-5} 100 = 100$.

Comparing the data presented in Table IV and V it may be seen that the salivary responses to the negative and positive CSs in the test trials behaved in a different way. As far as the response to the negative CSs are concerned all of them in all the dogs were almost exactly the same in the test trials as in the regular trials, the statistical difference between the corresponding data was insignificant. This means that the negative CSs located in the reverse position preserved their negative character. This was not true of the responses to the positive CSs in the test trials. As seen in Table V only in 26 per cent of trials amounted these reponses to more than 2/3 of regular positive responses. In other trials (20%) the responses were between 1/3 and 2/3 of regular positive responses and in 54% they did not exceed 1/3.

As indicated in our previous paper (Szwejkowska 1966) there may be at least two reasons for this diminution of the positive responses to the CSs placed in the reverse position. For one thing the orientation reaction elicited by the change of the site of the stimulus could inhibit the positive CR. For another, since the CS in the test trials was never reinforced by food, the response to it could gradually extinguish. In the first

Table V

The results of test trials with positive CSs

Dogs	CS		$\frac{+ \quad -}{tCR - cCR} \cdot 100$											
			First five test sessions					Means	Second five test sessions					Means
	Original location	Reverse location	Successive test sessions						Successive test sessions					
			1	2	3	4	5		1	2	3	4	5	
1	BA	BP	100	100	100	72	89	92	50	73	0	0	30	31
2	BA	BP	60	5	10	10	9	19	13	0	8	6	0	5
3	BA	BP	22	6	11	17	0	11	83	11	25	58	22	40
4	BA	BP	0	0	0	0	90	18	90	33	9	7	31	34
5	BP	BA	47	91	75	17	9	48	0	0	43	20		16
6	BP	BA	23	22	9	0		13	15	53	4	43		29
7	BP	BA	33	55	50	10	15	33	7	0	27	0	15	10
8	T_1A	T_1B	100	90	93	91	90	93	100	75	55	100	57	77
9	T_1A	T_1B	55	50	44	33		45	0	14	0	8		6
10	T_1A	T_1B	70	60	90	100	87	81						
11	T_1A	T_1B	58	38	64	100	17	55	96	41	91	43		68

instance, the responses in the later trials should be higher than in the first trials, in the second, on the contrary, they would be lower.

It may be seen from Table V that both these phenomena are found. For instance, in dog No. 1 in the first three test trials the conditioned responses were of the full-size value and then gradually diminished. On the contrary, in dogs Nos. 5, 10 and 11 the full-size conditioned response to the tested stimulus was reached only in the second or fourth test trials. If we take into account the first five positive test trials, i.e. the period when the extinction of the CR to the test CS did not yet develop we can divide the animals into the following groups:

Dogs Nos. 1, 8 and 10 displayed practically full-sized positive responses to the positive test CSs, i.e. they reacted exclusively to the quality of the CS while neglecting its direction.

Dogs Nos. 5, 7, 9 and 11 displayed highly irregular responses oscillating around 50% of positive responses.

Dogs Nos. 2, 3, 4 and 6 displayed usually very low responses, however from time to time the high, and even nearly normal, responses were observed. This sudden increase of responses occurred either in the first five test trials or even in the second five (see, for instance the data for dogs Nos. 3 and 4).

DISCUSSION

As far as the negative test trials were concerned the results obtained were identical to those found in our previous study in which instrumental CRs were used (Szwejkowska 1966). The animals considered a negative CS as purely negative irrespectively of the site from which it sounded. In other words the directional cue did not participate in determining the response.

More complex, and again analogous to that of our previous study was the situation in respect to the positive test trials. Only a few dogs did consistently utilise the qualitative cue neglecting the directional cue. The responses of the remaining dogs were mixed: in some trials there was a total neglect of the qualitative cue and the test CS gave nearly the same response as the negative CS, in others the response was positive but strongly diminished. The lack of consistency and unpredictability of the responses was seen here.

It seems reasonable to assume that in the positive test trials the animals based their responses on both qualitative and directional cues, these two cues not beeing antagonistic to each other. The more the qualitative cue was taken into account, the stronger response was manifested, the smaller was the response, the more the directional cue prevailed.

It is not clear what is the cause of the discrepancy between the cues utilized in positive and inhibitory CRs. The most probable explanation seems to be the following: There is a large body of evidence to show that a positive LS produces a strong arousal and ipso facto elicits a strong orienting reaction directed to the source of the stimulus (cf. Rowland 1957). In consequence, the proprioceptive feedback of this reaction may easily become a CS pari-passu with the auditory stimulus itself. Since the arousal produced by the negative CS is much less significant, this may explain why the appropriate orienting reaction does not participate in the inhibitory CR, and in consequence the quality of the stimulus prevails over its direction in that reflex.

SUMMARY

1. In eleven dogs the food-no food differentiation to auditory stimuli differing both in quality and direction was established, and then, by transferring the positive CS to the site of the negative one and vice versa the relative significance of both cues was tested.

2. The negative CSs transferred to the site of the positive CSs produced always the negative response. On the other hand the positive CSs

transferred to the site of the negative CSs either preserved their positive responses, or produced more or less diminished responses or gave negative effects.

3. It was assumed that the positive CSs produced a stronger orienting responses than the negative CSs and therefore the directional cue plays more important role in their operation than in the operation of the negative CSs.

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REVERSAL LEARNING IN RELATION TO THE PATTERN MAZE ALTERATIONS IN FRONTAL RATS

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Previous experiments have shown that normal rats considerably improve in their ability to learn successive reversals in a complex maze (Dąbrowska 1959). Rats with frontal lesions, however, showed no improvement in their ability to learn successive problems when the number of runs to criterion was considered and only a slight improvement when the number of errors was used as the measure (Dąbrowska 1964). Rats which were operated on after much experience in the maze showed as great a deficit as naive rats with frontal lesions (Dąbrowska 1964b).

The aim of this paper is to elucidate why frontal lesions impair the ability of rats to improve on successive maze reversals.

MATERIAL AND EXPERIMENTAL PROCEDURE

Experiments were performed on 20 white rats, 2.5 months old. During the training period the animals were deprived of food for 22 hours before testing. The four-unit-quadruple-choice apparatus together with details of preliminary and main training has been described in the previous papers (Dąbrowska 1963, 1964a).

After the preliminary training had been terminated the animals were divided into four groups: Group I and III (normal groups), consisting of 5 animals each, were subjected to a sham operation in which the bone covering the frontal area was removed. Groups II and IV (frontal groups), consisting of 5 animals each, were subjected to an operation in which the

rostro-dorsal parts of the cortex in front of the motor area were bilateraly removed.

The operation was performed one month before the main training. The cortex was removed by suction under nembutal anesthesia. Recovery of animals was uneventful.

The first task was the same for all animals. When this task was mastered to criterion (6 consecutive runs without errors), they started to learn the second task.

The second task for group I (control) and II (experimental) was the same as the first task except for a change in the first choice point, while the second task for group III (control) and IV (experimental) was changed only in the last (fourth) choice point.

When the animals reached criterion in the second task, the third was given which was the same for all groups, and which involved a change in every choice point.

After the series of experiments were completed, the animals were killed, their brains were removed, fixed in 10 per cent formaline, embedded in parafin and cut serially. The sections were stained by Nissl technique. Cortical lesions were reconstructed according to the Lashley (1931) method. Black areas in Fig. 1 denote the parts of brain from which grey and white substance were removed. Parts from which only grey substance was removed, or in which white substance was slightly damaged, are represented by striped areas.

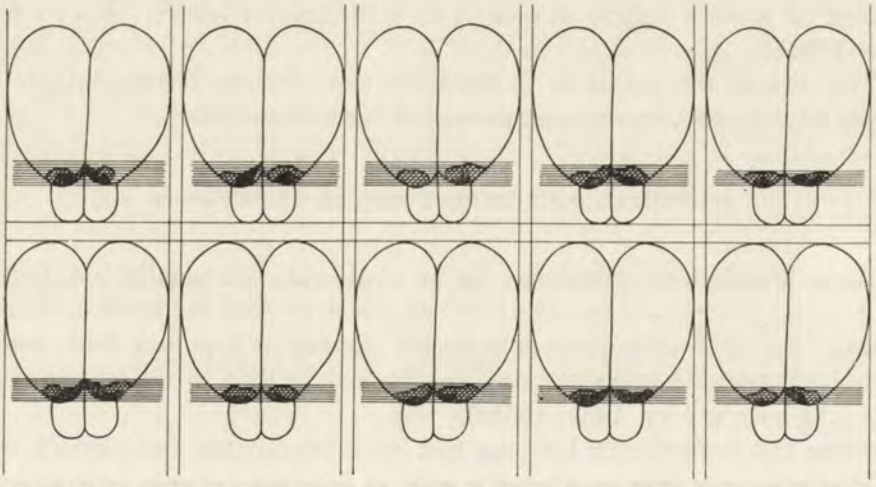

Fig. 1. Brains of the rats with lesions of the frontal cortex. Black areas denote the parts of brains in which both grey and white matter were removed. Striped parts show the parts in which grey matter was removed with or without a slight damage to the white matter

RESULTS

Table I gives the number of runs needed to mater three consecutive tasks for Groups I (normal) and II (experimental). The rats with frontal lesions mastered the first task after a greater number of runs than normal rats, and this difference was statistically significant (frontal rats 68.8 runs, control rats: 53.6 runs). The second task in which the maze was changed in the first choice point was mastered by normal rats more quickly than the first task, but the the frontal group solved this task even faster than the normal group (Group I — 25 runs, Group II — 18 runs). For the third task the maze was changed in all choice points for both groups. The frontal group solved this task slowly and made as many runs to criterion as in the first task (68.6 runs) but the normal group mastered this task very quickly (20.4 runs).

Table I

Number of runs needed to master three consecutive tasks in frontal and normal animals, the second task being changed in the first choice point, the third task being changed in all points

	number of animal	task 1	task 2	task 3
frontals	1	64	15	69
	2	78	21	71
	3	69	19	69
	4	68	18	66
	5	65	17	68
mean		68.8	18.0	68.6
normals	6	54	23	20
	7	55	24	21
	8	52	27	23
	9	53	25	18
	10	54	26	20
mean		53.6	25.0	20.4

Table II shows the number of errors at each wall of the maze made by the normal and frontal rats in three consecutive tasks. The rats with frontal lesions made more errors than the normal rats in the original learning and especially in the last reversal learning in which all choice points

were changed. However, the frontal animals made fewer errors than the normal animals in the reversal learning in which only one, the first choice point was changed. The distribution of errors in maze was quite different between frontal and normal animals in the reversal learning in which the first choice point was changed. The frontal animals made most of their errors at the first wall oh the maze and in the other walls there were only few errors (at the first wall — 102 errors, at the second wall — 6, at the third — 1, and at the fourth wall — 0). The normal animals made many errors at the second and third walls as well as at the first wall, the difficulty of a wall being related to its closeness to the point of change (at the first wall — 170 errors, at the second wall — 71, at the third — 30, and at the fourth wall — 4 errors). The total number of errors in this task was much greater in the normal rats than in the frontal ones.

Table II

Number of errors in each point made by frontal and normal rats, the second task being changed in the first choice point, the third task being changed in all points

walls	task 1		task 2		task 3	
	frontals	normals	frontals	normals	frontals	normals
I	126	223	102	170	207	56
II	288	165	6	71	295	31
III	156	167	1	30	154	42
IV	172	116	0	4	20	40
sum	742	671	109	275	676	169

Table III

Distribution of errors at the separate walls throughout training in normal and frontal rats in the second task, which was changed in the first choice point

runs 1—6			7—12		13—18		19—24		25—30	
walls	F	N	F	N	F	N	F	N	F	N
I	73	77	18	77	0	11	—	5	—	0
II	6	26	0	23	0	18	—	4	—	0
III	1	10	0	12	0	7	—	1	—	0
IV	0	2	0	0	0	2	—	0	—	0
sum	80	145	18	112	0	38	—	10	—	0

Table III shows, for the second task in which only the first choice point was changed, the distribution of errors at each wall throughout training. The normal animals made a maximum number of errors at all walls at the begining and the number of errors gradually diminished at all walls as the training progressed.

Table IV gives the number of runs made by Group III and IV in three consecutive tasks. In the second task only one, the fourth point of choice was changed, and in the third task every choice point was changed. The number of runs in the first task was greater in the frontal rats than in the normal rats and this difference was statistically significant. The frontal rats mastered the second task quicker than normal rats (frontal group — 17 runs, normal group — 56.6 runs). The third task in which all choice points were changed was mastered quicker by normal rats (22.4 runs) than by frontal animals (67.4 runs) and this difference was statistically significant.

Table IV

Number of runs needed to master three consecutive tasks by frontal and normal rats, the second task being changed in the fourth choice point, the third task being changed in all points

	number of animal	task 1	task 2	task 3
frontals	1	72	15	71
	2	63	19	65
	3	69	14	67
	4	77	29	69
	5	66	17	67
mean		69.4	17.0	67.4
normals	6	53	61	24
	7	55	56	20
	8	52	59	21
	9	50	50	23
	10	51	57	26
mean		52.2	56.6	22.4

Table V shows the number of errors made by frontal and normal rats at each wall in three consecutive tasks. As before, the animals with frontal lesions made errors than the normal animals in the original learning and especially in the reversal learning in which all choice points were

changed. However, the frontal animals made fewer errors than normal animals in the reversal learning in which only one, the fourth choice point was changed. Again the frontal group made the greatest number of errors at the wall in which the choice point was changed (126 errors at the fourth wall) and at the other walls these rats made only few errors (7). The normal rats made many errors at each wall. The distribution of these errors is similar as in our previous work (D ą b r o w s k a 1964a). At the first wall — 84 errors, at the second wall — 56 errors and at the fourth — 83 errors.

Table V

Number of errors in each choice point made by frontal and normal rats, the second task being changed in the fourth choice point and third task being changed in all points

walls	task 1		task 2		task 3	
	frontals	normals	frontals	normals	frontals	normals
I	115	159	5	84	162	36
II	323	173	0	56	303	26
III	96	157	2	76	105	35
IV	162	105	126	83	73	40
sum	696	594	133	299	643	137

Table VI shows, for the second task in which only the fourth choice point was changed, the distribution of errors at each wall throughout training. For the normal animals at the begining of reversal learning most errors were made in the changed choice point. When the errors were diminished at this wall there was an increase of errors at the third wall, and as these third-wall errors were diminished, the maximum number of errors were observed at the first and second walls.

Table VI

Distribution of errors at the separate walls throughout training in normal and frontal rats in the second task which was changed in the fourth choice point

runs 1—6			7—12		13—18		19—24		25—30		31—36	37—42	43—48	40—53
walls	F	N	F	N	F	N	F	N	F	N	N	N	N	N
I	3	8	2	10	0	8	—	6	—	14	14	10	9	5
II	0	4	0	13	0	6	—	3	—	5	13	6	5	1
III	2	5	0	15	0	24	—	10	—	6	9	3	3	1
IV	119	44	7	12	0	14	—	6	—	1	3	2	1	0
sum	124	61	9	50	0	52		25		26	39	21	18	7

A similar distribution of errors was not observed in the frontal animals, which made almost all errors in the changed choice point, and at the other walls errors appeared only sporadically.

DISCUSSION

The results of the present experiments indicate that rats with frontal lesions do not synthesize the separate elements of the maze into a whole but rather solve each segment of the maze separately. When only one choice point is changed, performances in the others are not impaired and reversal learning in this case is easy. When all choice points are changed, performance is very difficult.

For normal rats, on the other hand, the solution at one choice point is dependent upon the performance at both the previous and succeeding choice points. Thus changing the correct door at only one wall produces errors at all the walls and such a task may be even more difficult than one in which all doors are changed.

A possible explanation for this difference in methods of solution is that normal animals use primarily kinesthetic cues while frontal animals use primarily visual cues. If the normal animal learns the maze as a zigzag pattern (kinesthetic cues), then a change of response at any wall would be expected to disrupt the whole pattern. However, if the frontal animal is biased against the use of kinesthetic cues but rather solves the problem on the basis of visual cues, his solution at the different walls might be expected to be independent of each other.

From this point of view, the general improvement in reversal learning ability with succeeding reversals in normal animals is due to their ability to kinesthetically synthesize maze habits. The lack of such ability would explain why rats with frontal lesions show little general improvement in succeeding reversals. This hypothesis is supported by the demonstration that rats with frontal lesions show no deficit in the reversal of a brightness discrimination — a task in which normal as well frontal animals are forced to use visual cues (B o u r k e 1954).

SUMMARY

1. The present paper is concerned with the course of reversal learning in which the change of a single choice point was made in a four-unit-quadruple-choice apparatus in rats with frontal lesions.

2. Original learning was longer (more runs) in rats with frontal lesions than in the normal ones.

3. When the first choice point was changed, both groups made fewer runs than in original learning but frontal rats were better than the normal rast.

4. When the fourth choice point was changed the normal animals made more runs than in original learning while the frontal animal made much fewer.

5. The normal rats made errors in each choice point in spite of only one choice point being changed while the frontal animals made most errors in the changed choice point and only few errors in others.

6. When all choice points were changed in the second reversal learning, the normal animals solved this task very quickly, while the frontal animals learned as slowly as in the original learning.

7. The results of these experiments seem to indicate that normal rats use kinaesthetic cues while frontal rats use visual cues in solving the maze problem.

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PREFRONTAL CORTEX AND FEAR-MOTIVATED BEHAVIOUR

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Removal of the prefrontal cortex is known to produce a definite change of behaviour in laboratory mammals. Changes interpreted as a deficit in "immediate memory" (Jacobsen 1935, 1936), loss of "attention" (Wade 1947), "distractibility" (Klüver 1933), "behavioural instability" (Pribram et al. 1964, 1966), "Hyperreactivity" (Konorski and Ławicka 1964), impairment of "internal inhibition" (Konorski et al. 1952, Brutkowski 1964), "drive disinhibition" (Brutkowski 1964), "perseverative tendencies" (Stanley and Jaynes 1949, Konorski 1957, Mishkin 1964), and other symptoms have been pointed out as sequelae of total or partial ablation of the non-motor frontal cortex. Functional significance of prefrontal cortex and possible localization of functions in particular areas within the prefrontal region has been thoroughly discussed in the recent review by Brutkowski (Brutkowski 1965).

Most of the experimental data have been obtained from animals trained by the food reward technique. No conflicting results have been reported, despite the different training procedures, surgical techniques and theoretical backgrounds. However, the situation is more controversial with the defensive reflexes and the fear-motivated behaviour.

The paper of Auleytner and Brutkowski (1960) brought in an evidence that classical conditioned reflexes, based on the injection of acid into mouth or the electrical stimulation of animal's leg as the unconditioned stimulus (US) undergo a similar change after prefrontal lobectomy as do the conditioned reflexes (CR) established by food reinforcement. The authors observed both an increase in the positive CRs and a disinhibition of the conditioned inhibitory responses. Such changes were seen

in the salivary responses, as well as in the leg flexion CRs and in licking movements. Similar results have been earlier reported by Afanasev (1913), and Allen (1949).

On the other hand, a number of authors have recently observed that there was a decrease in aversive reactions in the prefrontal animals (Lichtenstein 1950, Streb and Smith 1955, Pribram and Weiskrantz 1957, Waterhouse 1957, Maher and McIntire 1960. Also in humans the corresponding lesions produce a reduction of fear and anxiety (Moore et al. 1948, Heath 1949, Landis 1949).

Our experiments started a few years ago and first results have been presented at the Congress in Leyden (Zieliński, Sołtysik and Rougeul 1962). In a group of cats positive and inhibitory avoidance CRs have been established. Pressing a bar to a tone was the positive response; it terminated the conditioned stimulus CS) and prevented the electric shock through a floor-grid. The inhibitory task consisted in presenting the CS together with the click stimulus in two combinations described as the "easy" and "difficult" conditioned inhibition (Sołtysik and Zieliński 1962). The details of these inhibitory tasks will be described below in the experimental procedure of the Experiment I. In this experiment a prefrontal lobectomy, i.e. a total removal of the cortex and white matter rostrally to the presylvian sulcus did no affect the inhibitory responses, but produced a transient though significant ($p < 0.002$) decrease in the positive responses (Zieliński et al. 1962).

There are several possible explanations of this result. First, it is conceivable to assume that in cats, whose prefrontal cortex is relatively underdeveloped, as compared with large frontal poles in dogs and still larger in primates, this minute ablation may not effect in any gross disturbance of inhibitory faculties. Secondly, it may simply be that the ablation of the prefrontal cortex possibly involving the premotor area produces some damage in the neural apparatus of the instrumental movement. Thirdly, it is possible that prefrontal cortex does not play the same role in fear-motivated behaviour as it does in the classical and instrumental food conditioning. The decrease of fear reflexes in the prefrontal animals would be the simplest explanation.

In order to find out, which one of these hypotheses may account for on apparent decrease of drive in the avoidance cats and for the lack of disinhibition, two separate experiments were carried out. The first experiment repeated the study of Zieliński et al., using the same subjects (cats), the same positive and inhibitory CSs and similar procedure, but different motivation: the avoidance conditioning was replaced by the food reward training. This experiment was expected to elucidate which one if any of the first two hypotheses is correct.

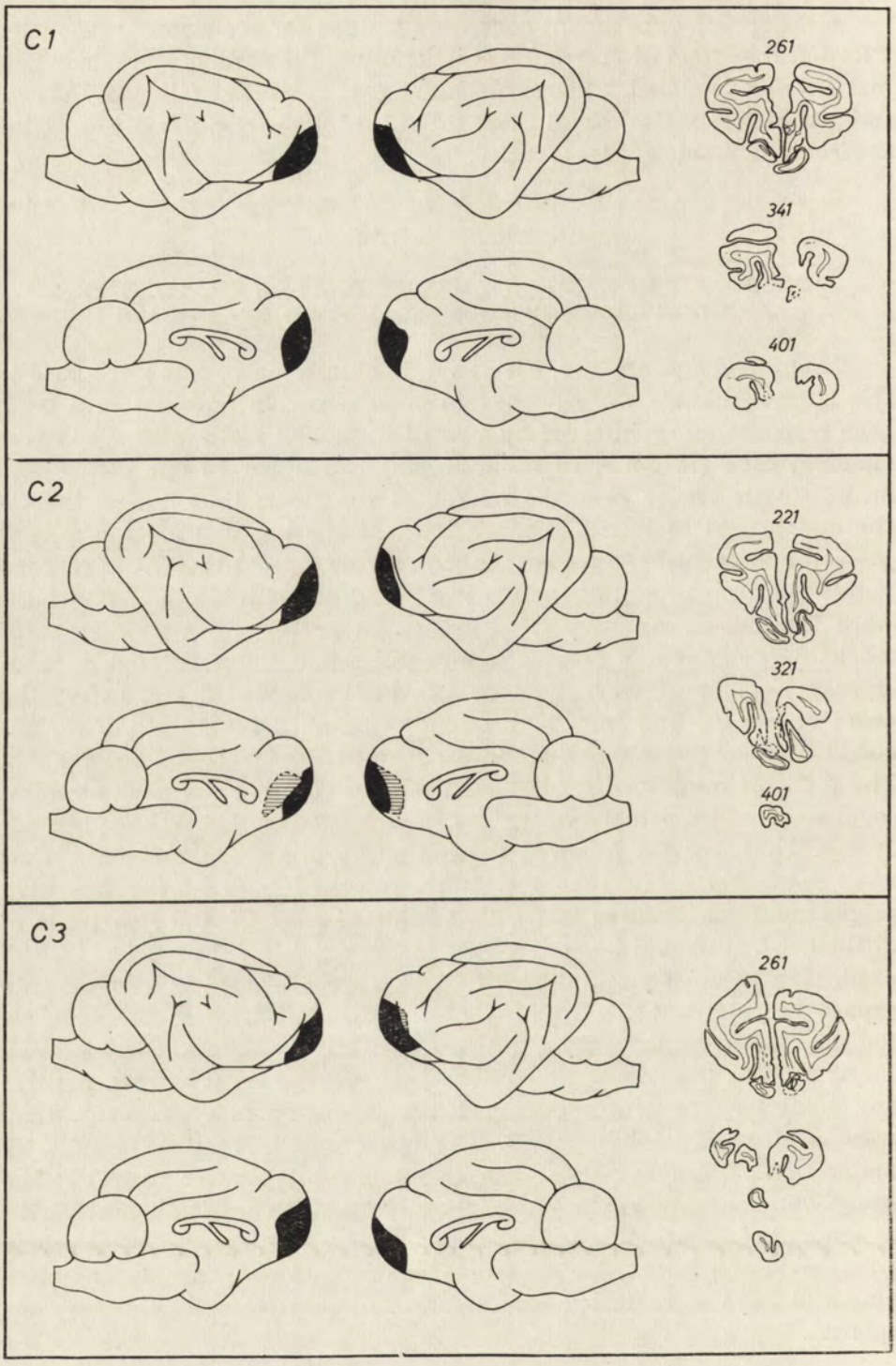
In the second experiment dogs were trained for the classical defensive CRs and the effect of prefrontal ablation upon the cardiac and motor CRs and URs was studied. Changes in heart rate responses (allegedly concomitants of fear states) should test the third hypothesis: namely, that the prefrontal animals are less fearful.

EXPERIMENT I

THE EFFECT OF PREFRONTAL LOBECTOMY ON THE POSITIVE AND INHIBITORY INSTRUMENTAL FOOD CRs IN CATS

Experimental procedure. Five experimentally naive cats were used in this study. Animals were trained to press a bar in response to a tone; each response was reinforced by a small portion of fresh meat. The experimental cage (70 cm × 70 cm × 50 cm) had a bar in one corner and an automatic feeder near the middle of the floor; thus during the CS the animal had to turn and move towards the bar and after having it pressed approached the feeder. As soon as the cats had learnt to respond within the first 10 sec. of the CS two "conditioned inhibition" (CI) tasks were introduced. An easy CI consisted in presenting a new stimulus (clicks 5 cps delivered from a square pulse stimulator through a loud-speaker) combined with the tone CS. Clicks started 5 sec. before the onset of the CS and then both stimuli continued for 10 sec. Thus the conditioned inhibitor (click stimulus) formed a background for the CS. The difficult inhibitory trial started with presenting the click stimulus for 5 sec. and immediately after its termination the CS was applied for 10 sec. Thus, the CS followed the inhibitory stimulus. Inhibitory trials were randomly intermingled with the positive ones in the following proportions: ten positive trials, five trials of easy CI and five trials of difficult CI. It should be added, that in the experiment of Zieliński et al. (1962) the easy and difficult CI task were trained in two separate groups of cats; but the training of the difficult CI was preceded by the acquisition of the easy CI.

As soon as the cats attained 90% performance level in both positive and inhibitory responses during ten consecutive daily sessions, they were prefrontally lobectomized. The operations were done aseptically under Nembutal anaesthesia. The grey and white matter rostral to the presylvian sulcus was removed bilaterally by suction. Histological verification and reconstruction of the lesions is shown on Fig. 1. The olfactory tracts were left intact. All the animals recovered uneventfully and after about 10 days were tested for retention of positive and inhibitory responses.



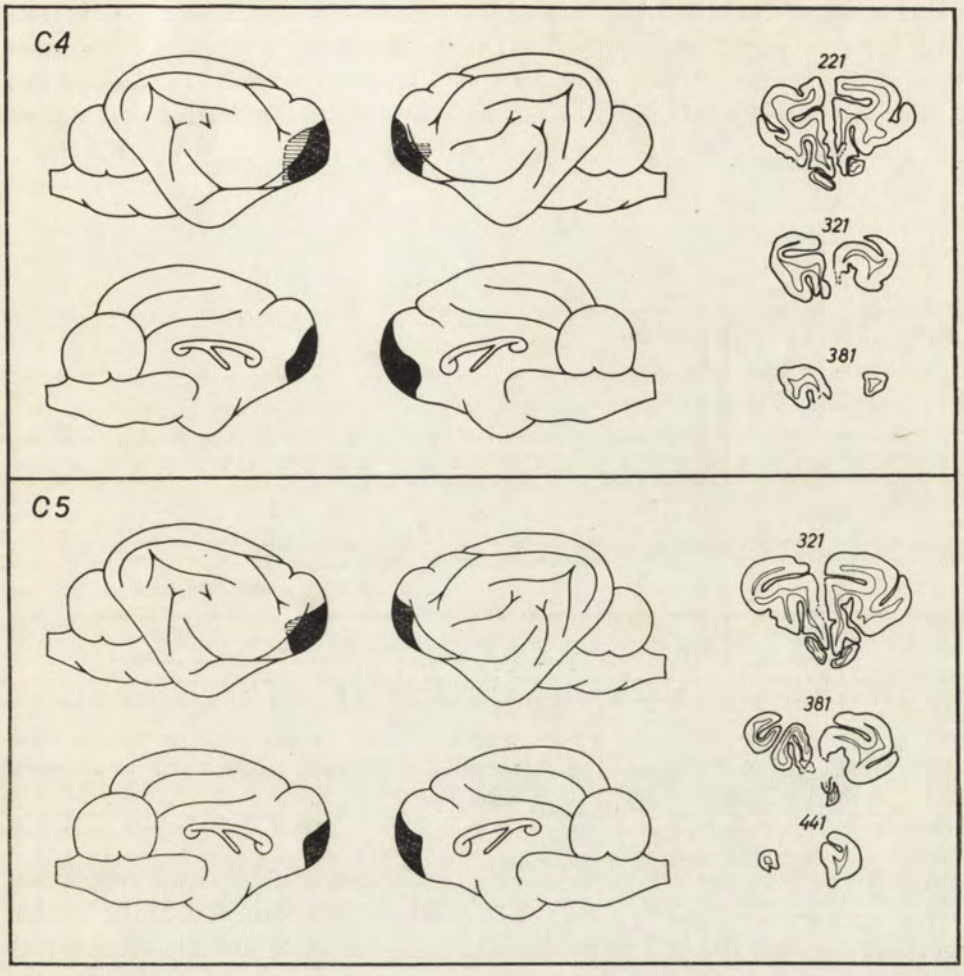


Fig. 1. Reconstruction of the lesions and cross sections through the lesions in 5 cats. Blackened areas indicate extent of lesions

Results

A. Positive CRs and general behaviour. In the first two or three postoperative sessions the cats had diminished appetite, longer latency of the CRs and sometimes failed to react to the CS. Fig. 2 shows a progressive decrease of the latencies of the CRs during 50 postoperative sessions. The "secondary" increase of the latencies during 20th—25th sessions coincided with the recovery of the inhibitory responses. The

main cause of the initial increase of latencies of the instrumental CRs (except for the very first two sessions) was apparently a marked augmentation of the consummatory activity and a strong tendency to stay by the feeder. Cats were reluctant to mowe away from the feeder and either

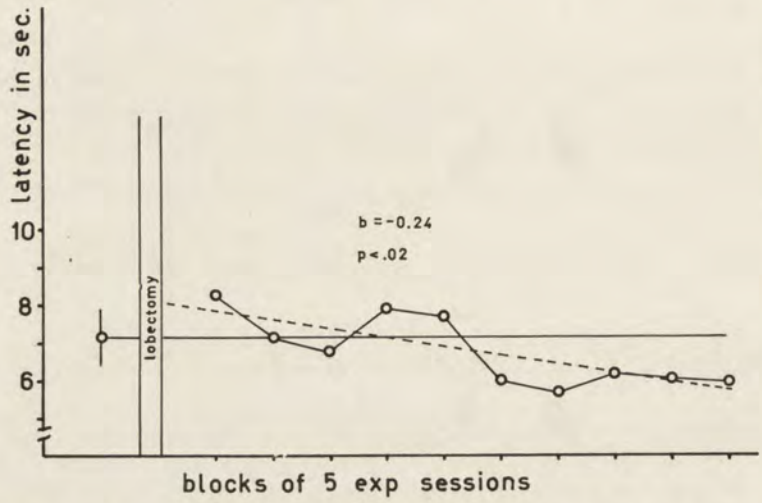


Fig. 2. Gradual shortening of latencies of bar press to CS after operation. First circle with vertical line shows the preoperational average latency and its standard error

did not react to the CS or performed abortive instrumental responses, e.g. they moved a little toward the bar but swiftly returned to the feeder without pressing the bar, or performed bar-presses in the air, often without approaching the bar. Eventually the animals moved hesitantly towards the bar and pressed it. Sometimes, instead of instrumental CRs, the cats miaowed and scratched the feeder's bowl. Interesting is the fact that they behaved in he same way even after they have been fed before the session. One of them used to eat so much before the session that he vomited in the experimental cage, but, in spite of that, in response to the CS, he would rush promptly to the feeder and voraciously eat the meat. All the cats exhibited this increased appetite also in their home cages. In two animals unusually copious conditioned salivation during carrying them from the home cages to the experimental room was observed; experimenters had to wear gloves to avoid wetting their hands. The same phenomenon though of much lesser degree was also observed in other cats. No such conditioned salivation was seen before the operation.

B. Inhibitory conditioned responses. In all operated cats a marked impairment of inhibitory CRs was found. Performance in both easy and difficult CI tasks during the first 20—30 sessions was significantly poorer as compared with the preoperational level (Mann-Whitney U test, White's modification, two tailed). Fig. 3 shows the results. The performance in the difficult inhibitory task was significantly worse than both responding to the positive CSs and the performance in the easy CI task during second through fifth 5-session blocks postoperatively. The easy inhibitory task was significantly impaired during the first 20 postoperative sessions.

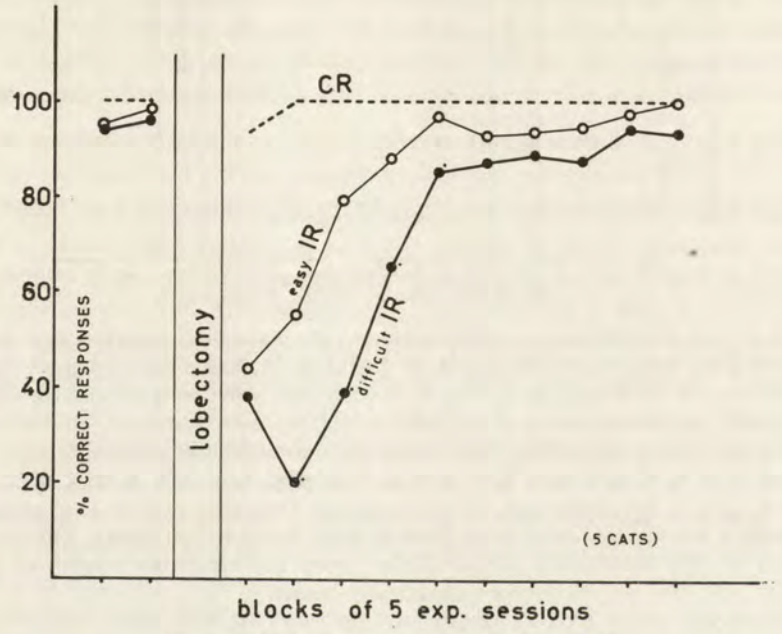


Fig. 3. Disinhibition in lobectomized cats

As it was stated before, this experiment is a replica of our earlier study on the effect of prefrontal lobectomy upon positive and inhibitory avoidance CRs in cats (Z i e l i ń s k i et al. 1962). Fig. 4 is presented to show how different are the results in these two studies. It can be seen that lobectomy had no effect upon the inhibitory avoidance responses, in spite of the fact that they were even more difficult to elaborate than in the present experiment, and some animals did not even reach the criterion of 90% correct responses. The easy and difficult CI tasks are illustrated separately since they were trained in two groups of animals. Only the first ten sessions after lobectomy are shown because no changes have been observed during consecutive training.

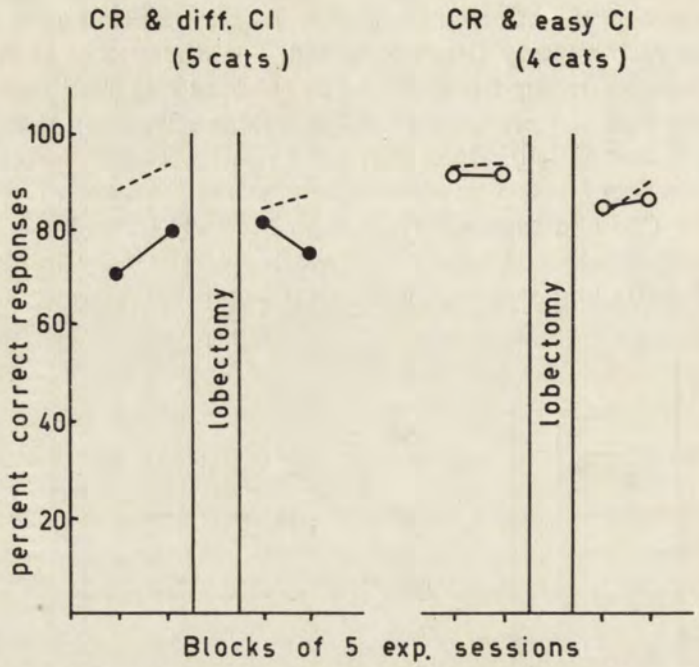


Fig. 4. Lack of disinhibition in lobectomized cats trained in positive and inhibitory avoidance CRs. Data from the study of Zieliński, Sołtysik and Rougeul (1962) are presented in the same way as in Fig. 3. Broken line represents avoidance CR. Filled circles show the preformance of difficult inhibitory task and open circles show the performance of easy inhibitory task. After the operation the avoidance CRs were in many animals (with difficult CI) seriously disturbed and the testing of inhibitory responses had to be postponed till the positive CRs returned to the preoperative level; such a retraining lasted from several days up to a few weeks. The postoperative level of CRs thus refers to that period when the inhibitory responses could be systematically tested

Discussion

The present experiment has confirmed the previously reported investigations on dogs (Konorski et al. 1952, Brutkowski et al. 1956, Brutkowski 1957, 1959a, 1959b, Ławicka 1957, Brutkowski and Dąbrowska 1963), monkeys (Fulton et al. 1932, Watts and Fulton 1934, Brutkowski et al. 1963), and rats (Richter and Hawkes 1939). Cats, likewise, show an increased food intake, augmentation of the conditioned consummatory activity and the disinhibition syndrome. The failure to obtain disinhibition the lobectomized cats in avoidance situation (Zieliński, Sołtysik and Rougeul 1962) cannot be thus attributed to the relative underdevelopment of prefrontal cortex in this species. Also the impairment of the positive avo-

idance responses found in lobectomized cats (Zieliński et al. 1962, Zieliński 1966) cannot be explained as an effect of the destruction of the neural apparatus necessary for the bar pressing movement.

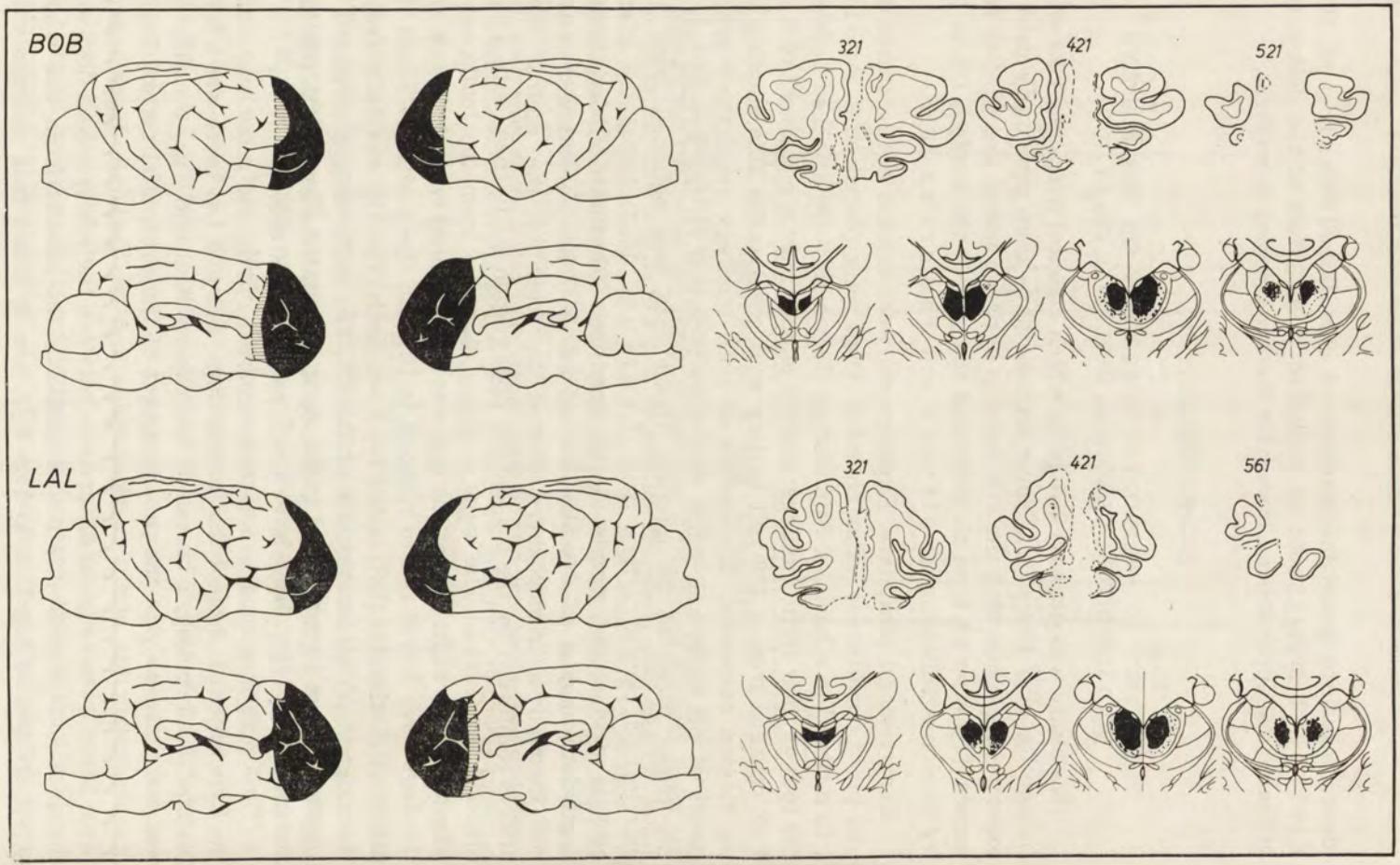
EXPERIMENT II

THE EFFECT OF PREFRONTAL LOBECTOMY ON THE POSITIVE AND INHIBITORY CLASSICAL DEFENSIVE CRs IN DOGS

This study was done on 4 dogs in which classical defensive CRs were trained for over two years. These animals have been previously used in experiments concerning the relationship between motor and cardiac responses (Jaworska et al. 1962) and the role of the noxious US in the leg flexion conditioning (Sołtysik and Jaworska 1962).

Experimental procedure. Experiments were carried out in a semi-sound-proof conditioned reflex chamber. Dogs were placed on a Pavlovian stand in a harness. Stimulating electrodes were attached between the toes of their right hindlegs; electric shocks from a condenser of 2 or 4 μF charged from a 120-volt battery were used as the USs eliciting the leg flexion responses. Movements of both hindlegs, respiratory movements of the chest and pulse rate were recorded on the kymograph at the paper speed of 20 mm/sec. Heart rate was obtained from the exteriorized carotid artery (van Leersum 1911) using the piezoelectric device and simple A. C. amplifier. Rhythmic clicks (10/sec) applied through a loudspeaker served as the CSs. The stimuli delivered through a loudspeaker situated in front of the animal were always reinforced by the US and the dogs responded to them with a conditioned leg flexion. The same auditory stimulus from the loudspeaker situated at the right side of the dog was never paired with the shock and the dogs have learnt not to respond to it. Both the positive CS and the differential stimulus (DS) lasted for 3 sec. each. The US was delivered at the moment of the termination of the CS. The daily session consisted of 10 positive and 10 inhibitory trials. As it was stated above, both positive and inhibitory responses have been well overtrained.

The operations on the dogs were carried out in the same way as in the Experiment I., except that in two dogs, Bob and Lal there was a total prefrontal lobectomy, whereas in two others, Ami and Tuz, the ablation was restricted only to the medial aspect of the prefrontal cortex. Fig. 5 is a reconstruction of the cortical lesion and the thalamic degeneration. Since there were no gross differences between the lobectomized dogs and the dogs with medial prefrontal ablation, the results from the whole group are pooled together in Figs 6, 7, and 8. Heart rate changes were



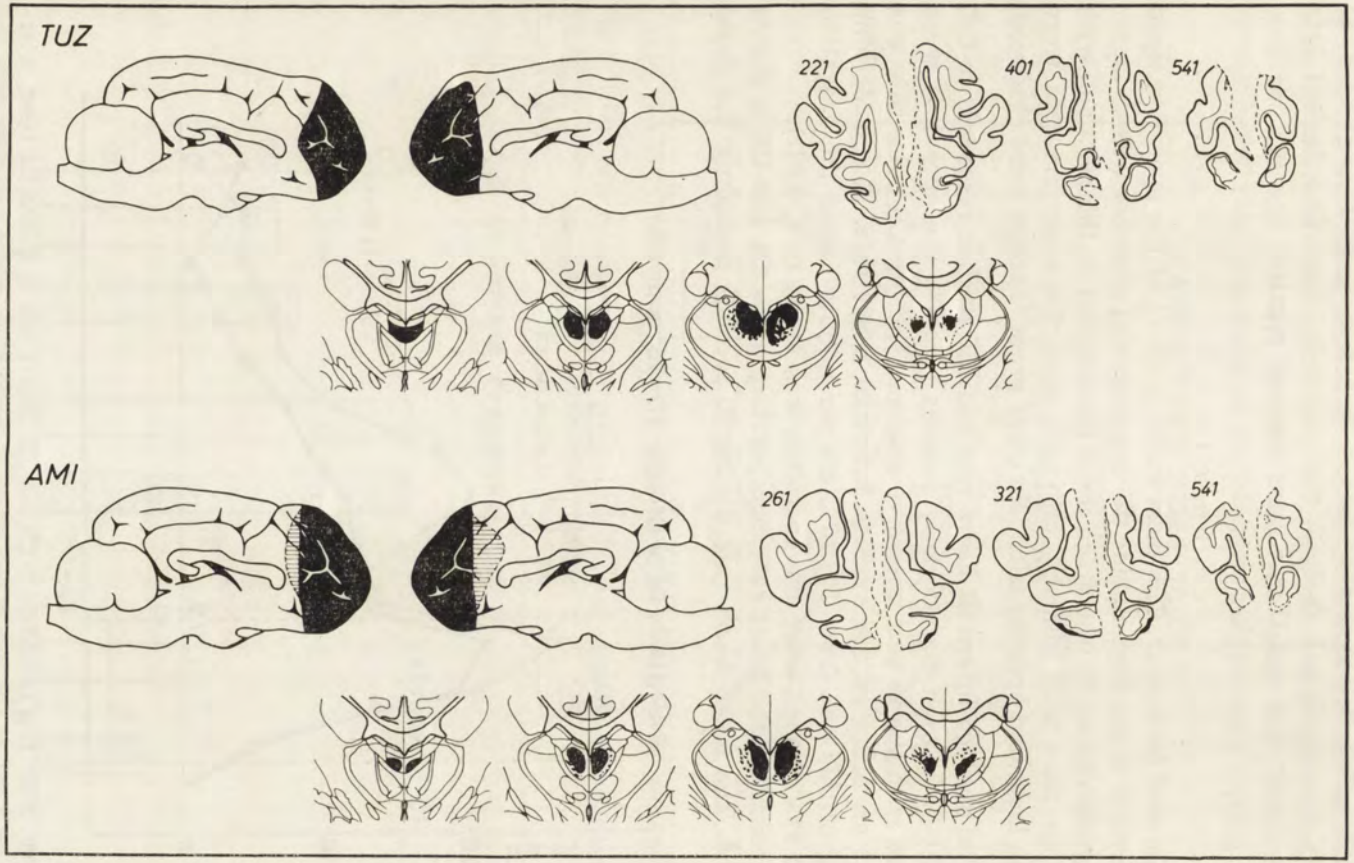


Fig. 5. Reconstruction of the lesions and cross sections through the lesions and through the thalamus. Blackened areas indicate extent of lesions and of thalamic degeneration

calculated using the second-by-second technique (cf. Jaworska et al. 1962). For statistical analysis the raw data were transformed into z-scores. Both t-test and U-test gave identical results.

Results

A. General behaviour. The most striking effect of the operation upon the behaviour of the dogs outside the experimental chamber was an increased aggressiveness. It was much more pronounced in the relations with other dogs than with humans, although even the experimenters were met with increased apprehension. No other gross changes were observed.

B. The average intertrial heart rate and the cardiac responses to CS, DS and US. In each dog 15 daily sessions prior to the operation were compared with the 15 post-operative sessions. The pre-CS pulse rate was taken as an index of the average intertrial heart rate. A considerable lowering of this rate from 107.20 beats per minute before the operation down to 92.07 b.p.m. after the operation was found ($p < 0.001$).

The course of the heart rate changes during the CS and US is shown on Fig. 6. The mean heart rate during 10 seconds preceding the onset

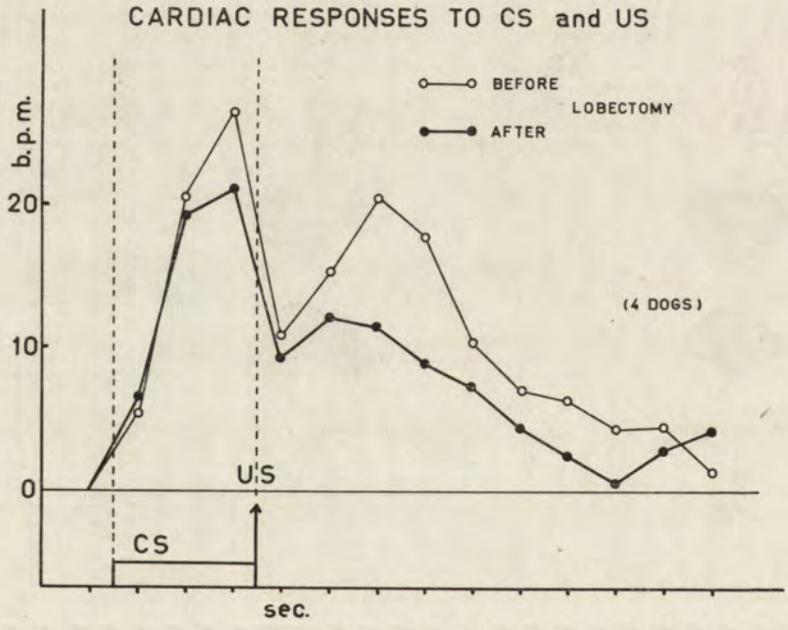


Fig. 6. Mean heart rate responses to CS and US. Heart rate is shown (in 1-sec. intervals) during 3 sec. of CS and 10 sec. after its termination which coincides with the application of US. Pre-CS heart level (during 10 sec.) is taken as 0 level. Note the decrease of cardiac CR and UR after the operation

of the CS was taken as the zero level for the responses obtained both prior to and after the operation. It is seen that the peak amplitude of both the CR and the UR decreased after the operation. This reduction of the heart rate responses is statistically insignificant during the CS

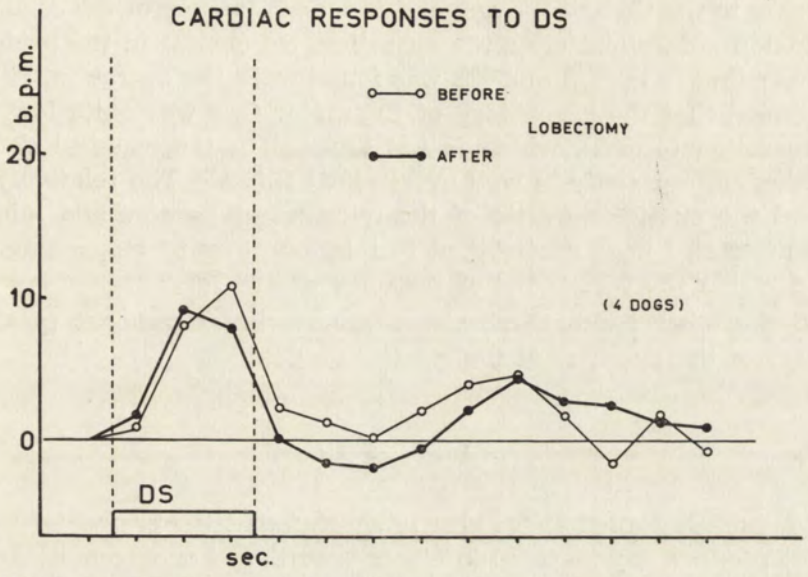


Fig. 7. Heart rate responses to differential conditioned stimulus do not change after prefrontal ablation

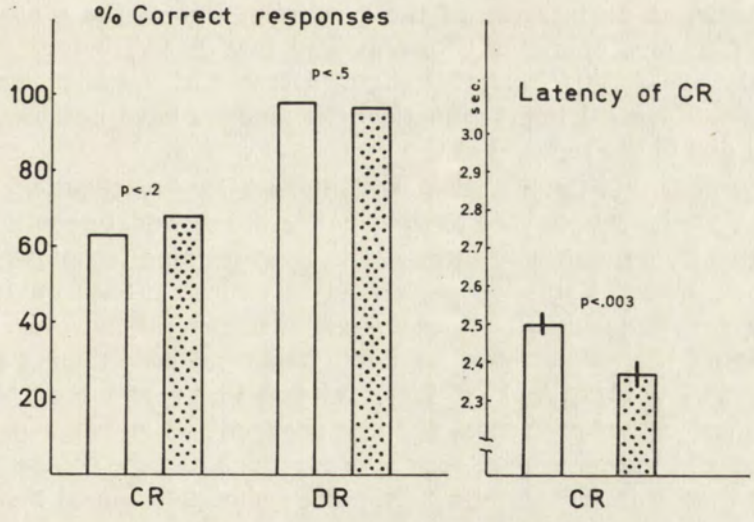


Fig. 8. Leg flexion CRs before (white collumns) and after (dotted collumns) the operation

but reaches a 0.05 level during the 3rd and 4th second after the application of the shock US. No change was observed in the heart rate responses to the DS (see Fig. 7).

C. The leg flexion responses. Fig. 8 shows the percentage of correct responses to the CS and the DS, and the mean latency of the conditioned leg flexion before and after the operation. No change in the probability of responding to the CS and DS was found after the operation. It should be stressed that the percentage of the motor CRs was quite low before the operation (63.0%), which is not unusual in the classical defensive conditioning, especially in well overtrained animals. The relatively weak US and the one-to-one ratio of the numbers of positive and inhibitory trials must also have contributed to this low level of responding. After the operation the percentage of respones was 68.3%.

On the other hand, there was a minute but significant ($p < 0.003$) decrease of the latencies of the leg flexion CR.

DISCUSSION

The data presented above clearly showed that the prefrontal ablation did not produce any increase in either conditioned or unconditioned cardiac responses to noxious stimuli in dogs. On the contrary, there was a decrease in the intertrial heart rate and in the amplitude of cardiac responses to the CSs and USs. The shortening of the latencies of motor CRs may be interpreted as an increase of the reactivity. But at the same time the relative amount of motor CRs remained low (63.0% before and 68.3% after the operation). Thus, this slight, decrease of the latencies does not change the general impression that the animals have not become more fearful due to the removal of the prefrontal cortex.

How does this finding fit in with the earlier investigations? First of all, there is no simple way to systematize the seemingly conflicting data presented by a number of authors. Different training techniques, varying sizes of prefrontal ablation performed in various species render all the comparisons and generalizations uncertain. In general, however, the experiments on the animals trained by the classical conditioning procedure (Afanasev 1913, Allen 1949, Auleytner and Brutkowski 1960) showed that prefrontal ablation produced an increase in both conditioned and unconditioned defensive reactions. On the contrary, experimenters using instrumental conditioning technique claimed that prefrontal animals showed behavioural alteration which they interpereted as a decrease of fear (Streb and Smith 1955, Lichtenstein 1950,

Waterhouse 1957, Pribram and Weiskrantz 1957, Zieliński et al. 1962). In other studies the deficit in conditioned avoidance responses was interpreted in terms of interference due to the release of aggressive and defensive emotional reactions (Brutkowski and Wojtczak-Jaroszowa 1963, Brutkowski 1965, Brutkowski 1966).

Zieliński (1966) in a recent study confirmed our earlier observation (Zieliński et al. 1962) that prefrontal cats perform more poorly in avoidance CRs. He also found that at the same time the latencies of escape responses become shorter, and this led him to the conclusion that none of existing explanations could satisfactorily cope with the data available.

Let us reconsider the problem, taking into account the results of our present experiments. First of all, there is no doubt that prefrontal cats do not differ from prefrontal dogs with respect to either classical (e.g. salivation) or instrumental food CRs. Our animals showed all the symptoms of disinhibition and an increase in food intake. Thus, the consistent though slight impairment of the avoidance CRs, observed in our earlier study (Zieliński et al. 1962), cannot be explained by any damage of the neural effector mechanism of the bar-press movement.

Our Experiment II on dogs seems to be crucial in verifying the "diminution of fear" hypothesis. Fear is not a directly observable response but a "central motivational state" (Morgan 1940) or better a "drive reflex" (Konorski 1967), and we infer about its intensity either by the behaviour which is motivated or "driven" by it (e. g. avoidance CR), or by the responses such as the heart rate increase, which are thought to be correlated with the fear state. The data obtained in the Experiment II perfectly conform with the thesis of a diminished fear in prefrontal animals. Our dogs showed a decreased intertrial level of the heart rate. This may have been an indication of the reduced anxiety in the experimental chamber. But, even if we assume that it was some other, for instance, metabolic effect of the operation on the basal pulse rate, then the conditioned and unconditioned heart rate responses should increase according to the "law of initial values". In fact, they should have increased even if the operation would not have altered the fear reactivity of the dogs. However, the cardiac responses were smaller after the operation. Thus, we cannot avoid the conclusion that the fear responses were attenuated in operated animals trained in classical defensive CR situation. This seemingly contradicts the evidence from several other studies. That contradiction may be explained in the following way. Unconditioned (and classically conditioned) activities may be categorized as either drive or consummatory reflexes (Sołtysik and Konorski 1966). In the defensive conditioning fear

is a drive reflex and the particular withdrawal or protective patterns (e.g. eye blinking, leg flexion, salivation in acid conditioning) represent the consummatory reflexes. There need not be a parallelism in drive and consummatory reflexes. Miller et al. found an increase of food intake in rats after hypothalamic ventromedial lesions with concomitant decrease in hunger drive (M i l l e r et al. 1950). Similarly, J a w o r s k a et al. (1962) observed that the motor defensive (i.e. "consummatory") and cardiac defensive (i.e. "drive") CRs show little or no parallelism during either acquisition or acute extinction in dogs. Therefore one may be skeptic on the justifiability to infer about the drive from the consummatory behaviour. However, the earlier experiments on the classical defensive CRs in prefrontal animals were restricted, as a rule, to the consummatory activities. Incidently, also in our dogs there was a slight decrease in latencies of leg flexion CR. This dissociation of drive (lowering of heart rate CRs and URs) and consummatory (shortening of latency of leg flexion CRs) responses in our dogs seems to support our explanation. It should be added that the clinical data also strongly favor the notion of the diminution of fear and anxiety after severing the connections between frontal poles and subcortical neural structures (M o o r e et al. 1948, H e a t h 1949, L a n d i s 1949) although the same lesions may enhance the appetite and sexual reactivity (M o o r e et al. 1948, M e t t l e r 1949).

Why then Z i e l i ń s k i 's prefrontal cats (Z i e l i ń s k i 1966) responded faster to the US by pressing the bar with shorter latencies? It may be that pain is a separate drive and that it does not undergo the some reduction as fear. Another possibility is that prefrontal animals showing general hypermotility (cf. M a h e r and M c I n t i r e 1960) respond faster because their "freezing" responses are diminished. Therefore the escape CRs in Zieliński's cats and leg flexion CRs in our dogs had shorter latencies after the prefrontal ablations. Similar conclusions could be drawn from a recent study of W o l f (1967).

Another hypothesis put forward to explain the decrement in avoidance performance of the prefrontal animals assumed an interference of the released aggressive reactions *. There are quite a few facts supporting this view. First, it is known that lesions made more posteriorly and involving genual portion of the rostral cingulate area produce in dogs the "angry behaviour" along with the increased sensibility to tactual stimuli (B r u t k o w s k i et al. 1961). Similar symptoms were observed in cingulectomized monkeys (M i r s k y et al. 1957, P e c h t e l et al. 1958) and cats (K e n n a r d 1955). We have also observed that in March when cats

* Sometimes this release was misinterpreted as a drive (suggesting "fear-drive") disinhibition although no direct evidence has been presented to justify such a term.

are sexually aroused, avoidance CRs are poorer and often replaced by rage and aggressive reactions. Thus any operation which releases aggresive behaviour may cause an impairment of avoidance responses. The dogs described in the present paper did show increased aggressiveness, but it was never seen while they were left alone in the experimental chamber. Therefore it seems to us that the primary cause of impaired avoidance responses in the prefrontal animals is the decreased fear drive. However, it must be reminded that our dogs were well overtrained and stoically accepted the US. We plan to set up another experiment in which the effect of prefrontal lobectomy will be tested in a group of dogs with newly acquired defensive leg flexion reflexes.

The last problem for discussion is the lack of any trace of disinhibition in our dogs. It is plausible to assume that both the long training and the relatively easy inhibitory task (non responding to the DS which has never been paired with the US) are responsible for the lack of any discernible impairment of the inhibition after operation. Ł a w i c k a (pers. comm.) has long ago observed a similar lack of any effect of the prefrontal lobectomy upon a difficult inhibitory task (conditioned trace inhibition) in one dog trained in the classical defensive CR situation. It is then possible that the disinhibition in prefrontal animals is a secondary effect accompanying the release of drive (as in the case of food conditioning). When, however, there is no drive release, as in defensive conditioning, inhibitory responses remain unaffected. This may be the explanation of the results of our first study (Z i e l i ń s k i et al. 1962) presented in Fig. 4, where the prefrontal cats showed perfect retention of conditioned inhibitory responses. The same inhibitory task in food reward situation (see Fig. 3) was severely impaired.

SUMMARY

Two experiments were carried out in an attempt to test some hypotheses concerning the functional significance of the prefrontal cortex in the fear-motivated behaviour.

In the first experiment cats were trained to press a bar in response to a CS for food reward; consecutively, these animals were taught two conditioned inhibitory tasks. After bilateral prefrontal lobectomy the cats showed a perfect retention of the positive CRs, an enhanced consummatory activity and a severe impairment in the inhibitory task.

The second experiment was done on dogs in which positive and differential defensive classical CRs were well overtrained. No disinhibition was found after bilateral total or medial prefrontal ablations. There was, however, a detectable reduction of the latencies of the leg flexion CRs. Both the intertrial heart rate and the cardiac responses to the US were

significantly diminished. The cardiac CRs were also slightly reduced but the difference did not reach the 0.05 significance level.

These results support the hypothesis that prefrontal ablation reduces the fear drive, although it may facilitate the consummatory defensive responses.

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PREFRONTAL LOBECTOMY AND THE MULTIPLE INSTRUMENTAL CONDITIONED REFLEX IN DOGS

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In the preceding paper (W o l f 1963) the properties of the multiple instrumental conditioned reflex (MICR) were studied in dogs. The animals were first trained to perform an instrumental movement in response to a CS to obtain food reward; thereafter, the number of the motor responses required for obtaining food was gradually increased by the experimenter. It has been found that three different stages of the development of the MICR could be discerend. In the first stage (when the number of required movements did not exceed ten, on the average) the animals began to work for food immediately at the onset of a CS and performed the trained movement with maximal speed. In the second stage, when the number of required movements was further increased, the latency of the first movement increased and the initial motor responses occurred at a low rate which increased near the end of the CS—US interval. Finally, in the third stage, when about 30 or more motor responses were required, the animals gave up and stopped to perform the trained movement at all. The salivary conditioned response followed faithfully the motor performance being proportional, within limits, to the frequency of instrumental responses.

The explanation of this deteriorating effect of the increase of the number of required movements upon the MICR performance was that the longer is the CS—US interval, the more pronounced must be the inhibition of delay. As a consequence, the animal started to perform the trained movement with more and more prolonged delay, which led obviously to the still greater prolongation of the CS—US interval. In effect inhibitory CR took an upper hand over the excitatory CR and the animal refused to work altogether.

In a series of papers from the Nencki Institute it was shown that prefrontal lobectomy in dogs produces a dramatic impairment of inhibitory alimentary CRs both instrumental (Brutkowski et al. 1955, 1956, cf. also Brutkowski 1964, 1965) and classical (Brutkowski 1957). Therefore, the problem arose as to which would be the effect of these lesions upon the MICR task in that stage when the inhibition of delay takes an upper hand. The present study is concerned with this problem. Its preliminary report was given elsewhere (Wolf 1964).

MATERIAL AND METHOD

Six adult mongrel male dogs were used for experiments. The animals were trained in a Pavlovian stand situated in a sound-proof CR chamber. The details of the MICR training procedure were described elsewhere (Wolf 1963). Basically, the procedure consisted of a progressive increase of instrumental movements per trial in successive experimental series. In experimental series No. 1, dogs were trained to perform a single movement to the sound of a bell. The conditioned response was the placing of the right forelimb on the feeder situated in front of the animal. In each consecutive experimental series composed of six experimental sessions 2, 3, 4, 5, 6, 8, 10, 13, 16, 20, 25, 30, 35 conditioned movements per trial were required. The number of a given series denotes the number of movements required in each trial. Nine trials separated by three-minute intervals were given daily. As soon as the animal had performed the required number of movements a bowl containing bread crumbs moistened with broth was presented to him. Insufficient MICR performances were not reinforced.

The animals had fistulae of the right parotid gland ducts (shortened) made according to Sołtysik and Zbrożyna's method (1957). The salivary secretion was recorded on a kymograph by the recording technique of Kozak (1950). The animals were tested until a full suppression of the MICR activity ensued. This was determined by the failure to restore the performance by means of "gratis" food presentations in a few trials.

Subsequently, the animals No 1, No 2 and No 3 (experimental group) were lobectomized bilaterally, anterior to the presylvian and genual sulci on the lateral and medial brain aspects, respectively. The surgical procedure used was identical to that of Brutkowski et al. (1956). The animals were tested for retention 7 days after the surgery. Other three dogs, No 4, No 5 and No 6 (control group) were left unmolested. Following the MICR depression, they were allowed a rest of 1 month, after which they were re-tested.

RESULTS

1. Motor performance

According to the results of the previous paper (Wolf 1963), as the number of motor responses required in each trial increased, the latency of the first movement became more and more prolonged; the trials in which the required number of movements appeared, were interspersed with trials in which the animal gave up after performing a smaller number of movements; finally, he refused to work altogether.

After the prefrontal ablation, the experiments were resumed at the stage, when the animals refused to work. It was found that the dogs had improved only slightly. Thus, the dog No 1, which before the operation stopped performing the trained movements in series No. 25, after the operation performed only seven movements in a single trial. Dog No 2 performed in the first postoperative trial 25 movements (instead of 35 required movements) and in the next trials stopped making movements at all. Dog No 3 did not perform any movement in the first postoperative trial. Three control animals after one month interval did not perform any movements.

In view of this situation, in both experimental and control groups the training of the MICR was resumed from the very begining, exactly as it was carried out before the surgery. Accordingly, the two trainings, the preoperative and the postoperative one, could be compared in the experimental group and the first and second training could be compared in the control group.

The mean latencies in each series (taking into account only those trials in which the whole amount of movements was executed) are presented in Fig. 1. It is clearly seen that these latencies significantly decreased after operation. Even in the original training, in series from No 2 to No 8, in which the latencies were in general very short, they were almost always shorter in the postoperative period than in the preoperative period. This difference was much more pronounced in the later series. In fact, wheares in dogs No 1 and No 2 in the preoperative period the sudden prolongation of the latencies occurred in series No 13, in the postoperative period it occurred only in series No 20.

As it was noted above, before the full breakdown of the MICR activity there is a period in which in some trials the animal does perform the whole amount of movements required, and in others he does not. The comparison of the amount of such "ineffective" trials (i.e. trials in which the animal did not perform the whole number of movements required) before and after the operation is presented in Fig. 2. As seen from this

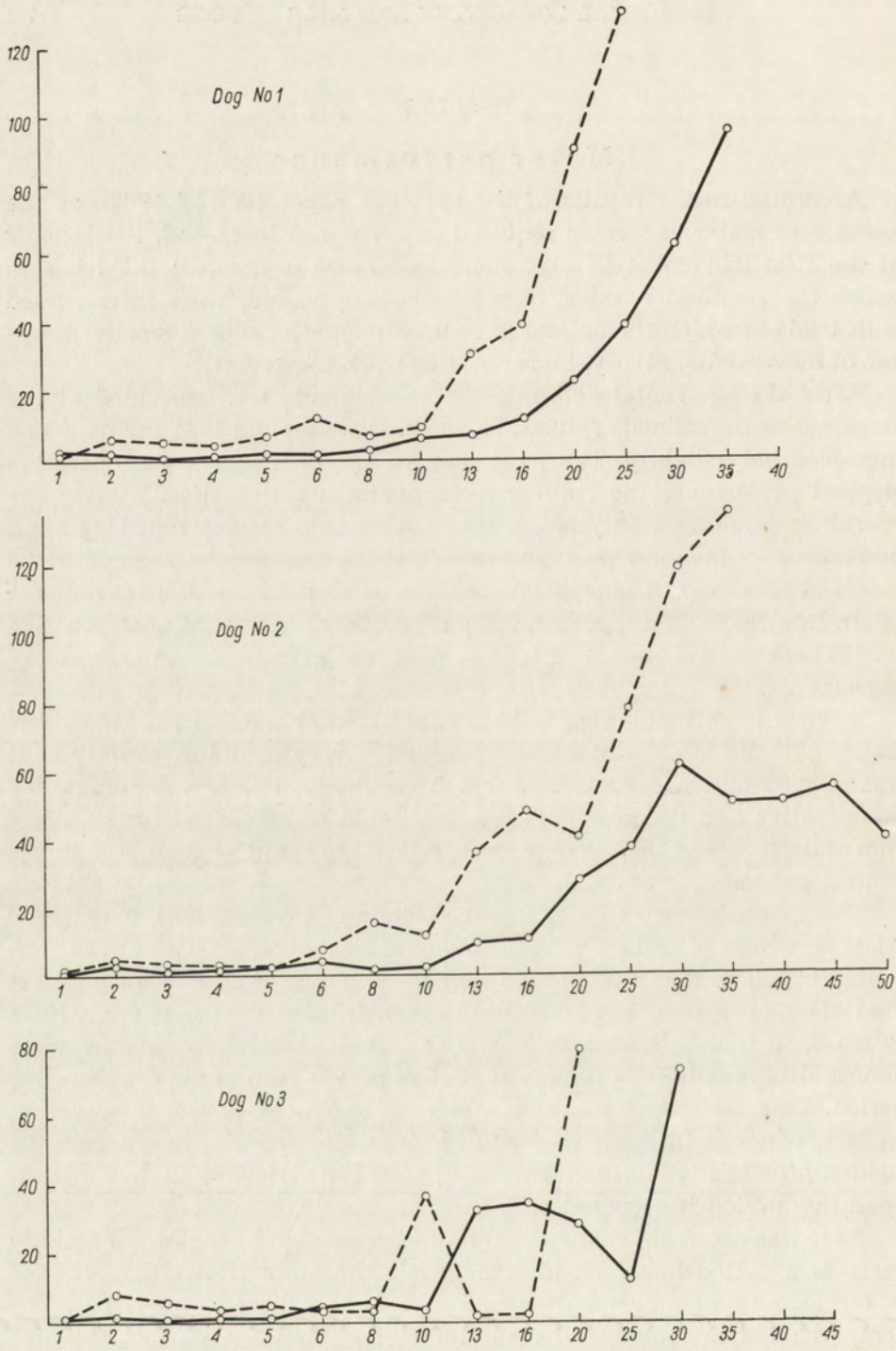

Fig. 1. Mean latencies of instrumental responses in successive series of sessions

Abscissae — successive series; Ordinates — latencies in sec. Interrupted line — before operation; continuous line — after operation

figure the inefective trials appeared before the operation in earlier series than after the operation, and their total amount was after the operation much smaller.

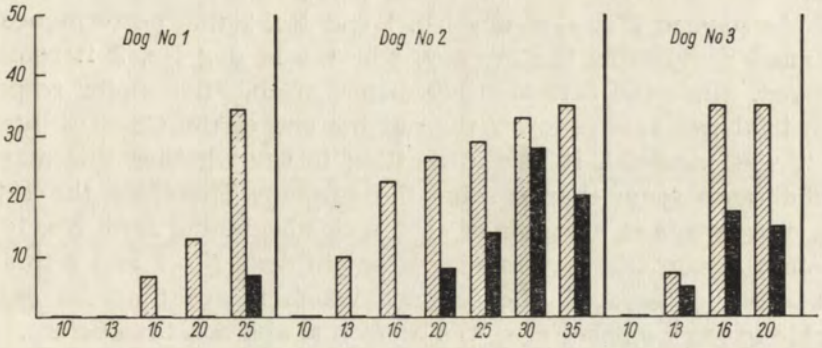

Fig. 2. Numbers of ineffective trials before and after operation

Abscissae — successive series, Ordinates the number of ineffective trials in each series. Hatched columns — before operation — black columns after operation

Finally, in all three dogs the total breakdown occurred after the operation in the series requiring more responses than before operation (cf. Fig. 1): in the dog No 1 it was in series No 35 instead of series No 25, in dog No 3 in series No 40 instead of series No 30, and in dog No 2, there

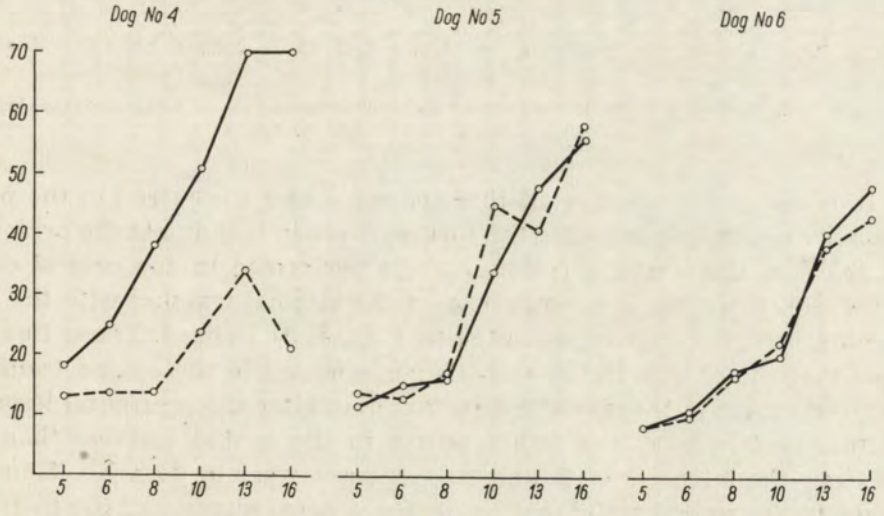

Fig. 3. Time required for the performance of full number of responses in each series

Abscissae — successive series, Ordinates — the mean time (in sec) required for the performance of the MICR. Interrupted lines — before operation, continuous lines — after operation

was no full breakdown in the postoperative period even when 60 movements were required for each reinforcement.

The next question which had to be answered was whether the motor performance of the dogs after the frontal ablations was more rapid than before. As seen in Fig. 3, in dog No. 1 and No. 2 this performance was much more rapid after the surgery, whereas in dog No. 3 it remained unchanged. Since the rate of performance of the first motor responses in each trial was always lower than at the end of the CS—US interval, when it was maximal, it was interesting to see whether this maximal rate undergoes some change after the surgery. Therefore the rate of 10 last movements in all trials of each series beginning from No. 10 was calculated. Again it is seen in Fig. 4 that in dogs No. 1 and 2 this rate was indeed greater after the surgery, which means that the animals were able to work quicker after the prefrontal ablation than before.

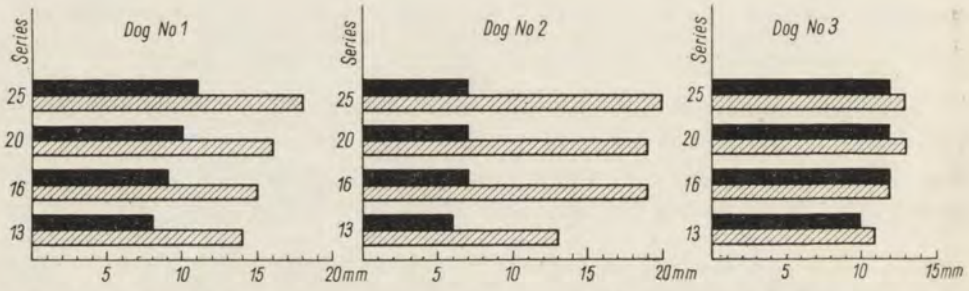

Fig. 4. The rate of the performance of the last 10 responses before and after operation

Abscissae — the rate of performance in mm of the kymographic record. Hatched bars — before operation; black bars — after operation

In order to see whether all these changes which occurred in the performance of our animals after the surgery were in fact due to the prefrontal ablation, the identical retraining was performed in our control dogs (No. 4, No. 5, No. 6). The comparison of the original training with the retraining in these dogs is presented in Figs. 5, 6, 7 and 8. These figures show that the change in the animals performance in the second training occurred rather in the opposite direction than after the prefrontal lesions, i.e. this performance was rather poorer in the second training than in the first: the latencies of the motor responses were in dogs No. 4 and 6 longer in the second training (Fig. 5), the general number of the ineffective trials was greater in all dogs (Fig. 6), and the rate of motor responses was either the same (dogs No. 5 and 6) or lower (dog No. 4) than in the first training (Fig. 7 and 8).

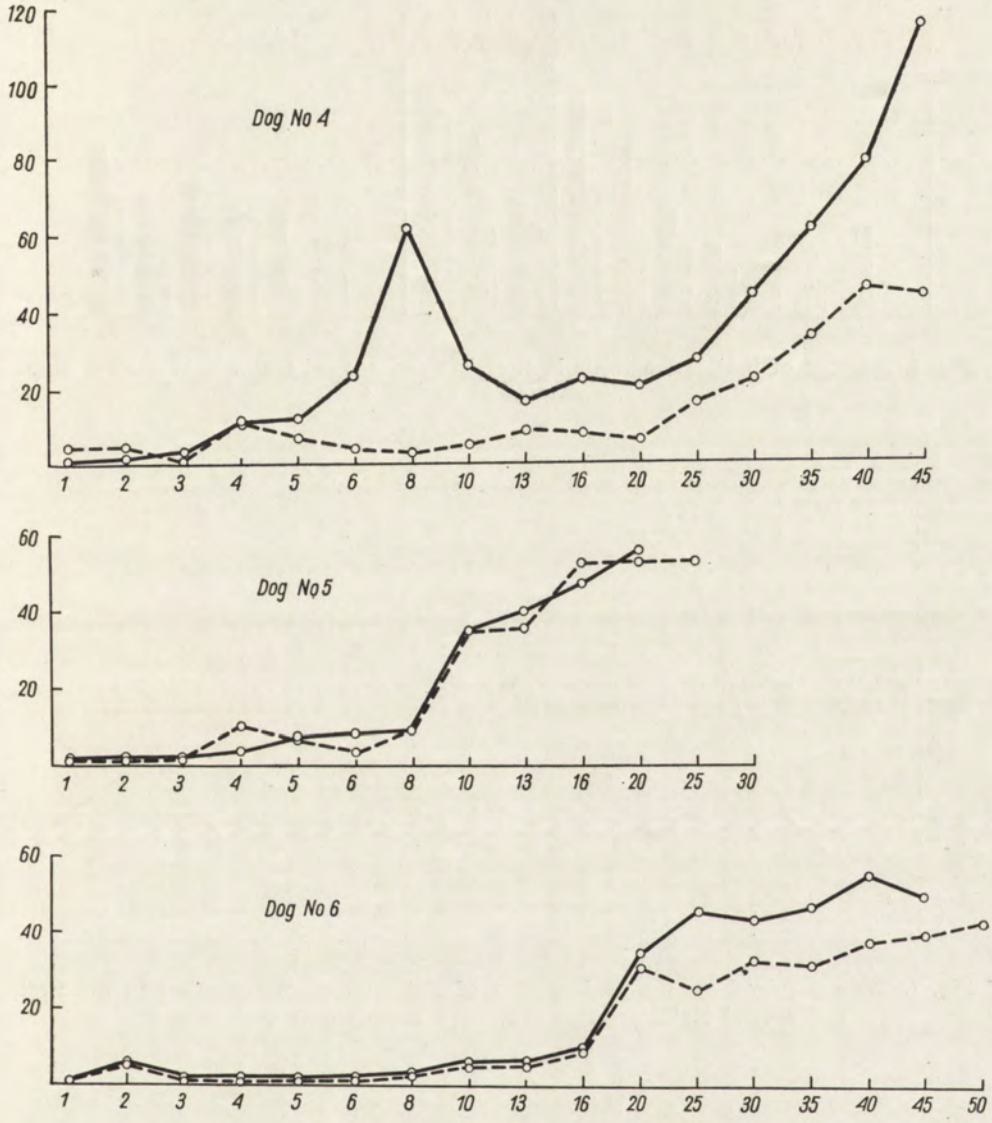

Fig. 5. Mean latencies of instrumental responses in the first and second training in control dogs. Denotations as in Fig. 1

2. Salivary conditioned response

The general amount of salivation per trial in each series before and after the operation is presented in Fig. 9. It may be seen that whereas in dogs No. 1 and No. 2 the general amount of salivation is slightly increased, in dog No. 3 it is rather decreased. If we compare the rate of sali-

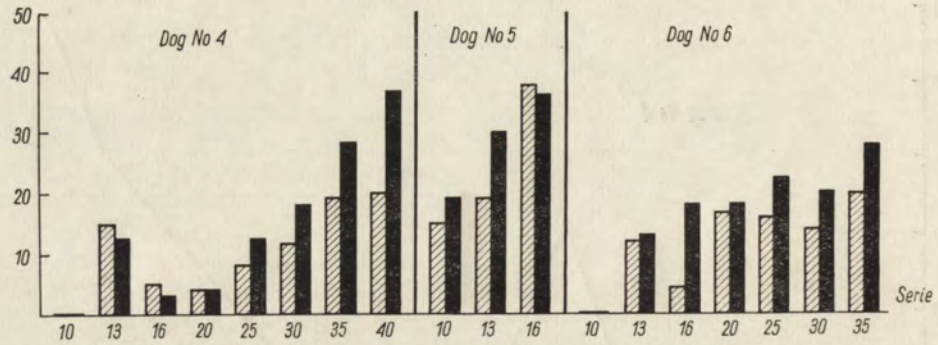

Fig. 6. Number of ineffective trials in the first and second training in control dogs. Denotations as in Fig. 2

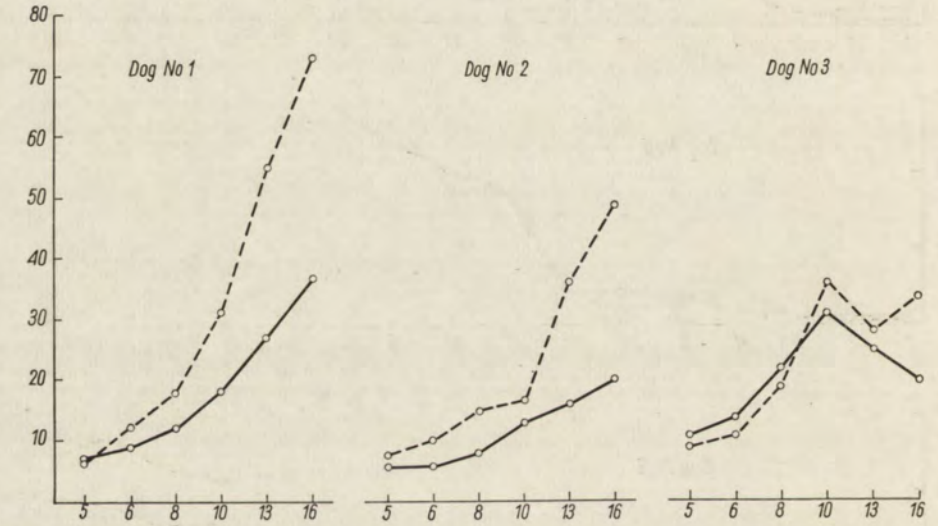

Fig. 7. Time required for the performance of full number of responses in the first and second training in control dogs. Denotations as in Fig. 3

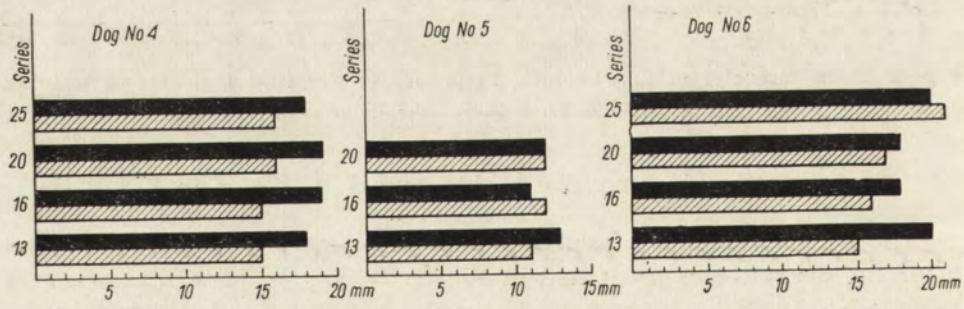

Fig. 8. The rate of the performance of last 10 responses in the first and second training in control dogs. Denotations as in Fig. 4

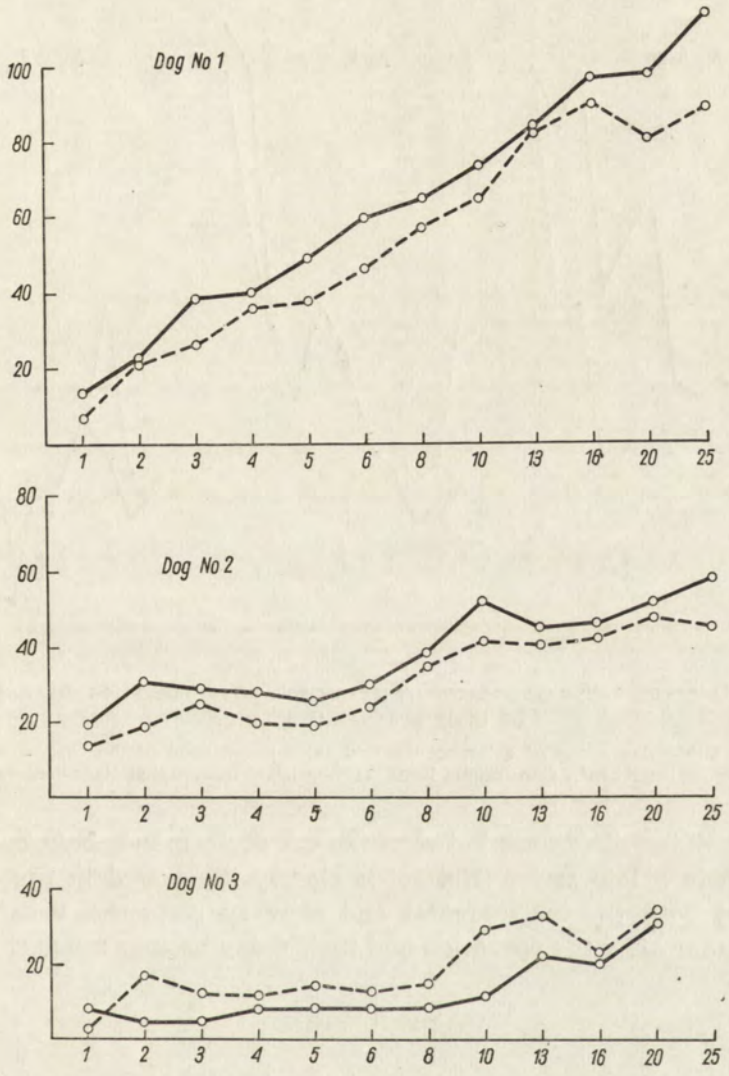

Fig. 9. The mean amounts of salivary conditioned responses in each series before and after operation

Abscissae — successive series, Ordinates — salivation in arbitrary units. Interrupted lines — before operation, continuous lines — after operation

vation per sec. with the rate of instrumental responses per sec. we may observe that there is a strict parallelism between the corresponding curves (Fig. 10). In fact, in dog No. 1 and No. 2 the general rate of motor performance was increased after the surgery (which was particularly clear in later series), and pari passu, the rate of salivation was increased. In dog No. 3 there was neither any increase of the rate of motor performance or of salivation.

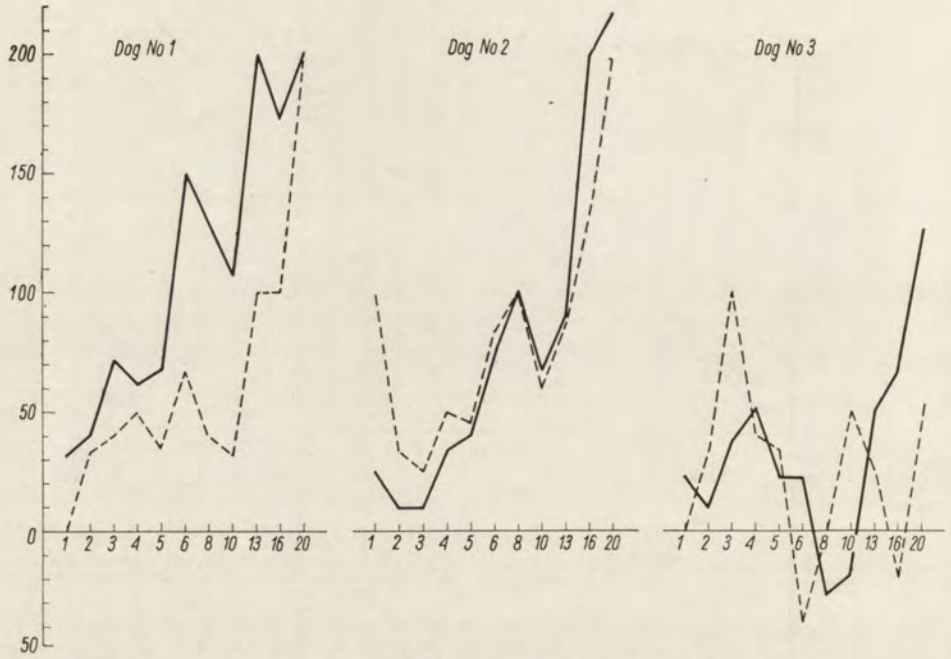

Fig. 10. Rates of salivary and motor responses after operation as a percentage of their preoperative values

Abscissae — successive series of experiments, Ordinates the change of the rate of salivary and motor responses (per cent). Continuous lines — salivation — interrupted lines — motor responses

The striking difference between the CR performance before and after operation in a late series (No. 20) is clearly illustrated in Fig. 11. It is seen that both the instrumental and salivary responses became much more regular after the operation and their delay became much shorter.

DISCUSSION

As seen from our experimental data the MICR became much improved after the prefrontal lesion: the animals were able to perform more instrumental responses per reinforcement, the latencies of the responses were much shorter, and, in two dogs, the maximal rate of motor performance was clearly increased.

As it was shown in our previous paper (W o l f 1963), the deterioration of the MICR with increasing number of responses was due to the development of inhibition of delay and the feedback effect produced by it: the longer the delay of the first response, the longer the CS—US interval. Since the frontal ablation is assumed to produce "drive disinhibition" (cf. B r u t k o w s k i 1964, 1965), it removes the inhibition of

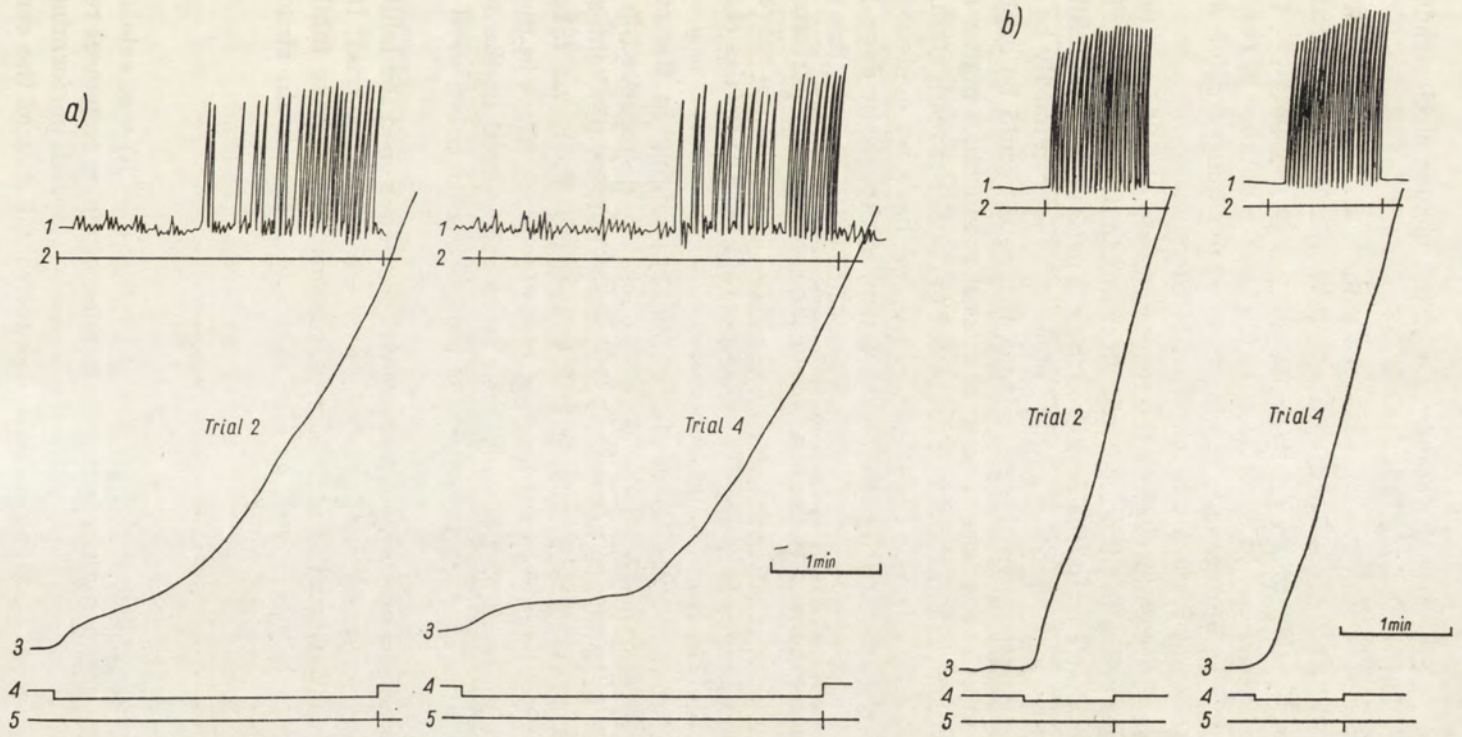

Fig. 11. Comparison of animal's performance before (a) and after (b) operation

Dog No. 1, series No. 20, session 4. 1, motor responses; 2, CS-UE interval; 3, voluminogram of food. Note the long latency of the MICR and its irregularity before operation, and prompt and rebular performance after operation

delay and thus prevents the occurrence of the vicious circle leading to the deterioration of the MICR.

Our experiments demonstrate clearly that drive disinhibition is a quite different phenomenon than a simple increase of drive produced, for instance, by starvation. As it was indicated in our previous paper, when an animal refuses to work because too large a number of responses is required per reinforcement, the increase of the hunger drive due to starvation does not restore the inhibited MICR.

It is more difficult to explain the increased rate of instrumental responses closely preceding the food reinforcement in dogs No. 1 and No. 2. For, it seems that during this period of the CR performance no inhibition is present in normal condition and therefore this fact can hardly be attributed to disinhibition. On the other hand, this result could be explained by reference to the increase of general arousal producing a higher motor efficiency. This problem should be subjected to further investigation.

As far as the salivary CR is concerned, we have no evidence that it was directly affected by prefrontal lesion. Although in dogs No. 1 and No. 2 the rate of salivation was increased after the surgery, this increase closely corresponded to the increase of the rate of motor performance. Since in our experimental procedure the performance of the movement (or rather the proprioceptive stimulus generated by it) was the classical CS this parallelism is easily understood.

As seen from the results of the secondary training in the control group, the performance of the animals was not only unimproved in comparison with that during the primary training, but, on the contrary, it deteriorated even earlier. This fact is understandable if we take into account that the inhibitory CR leading to the feedback effect in the first training left its trace and became even more pronounced in the second training. This fact makes the effect of the prefrontal lesion even more manifested.

Finally, one can ask, why our prefrontal dogs developed the inhibition of delay when too many motor responses were required per trial? It may be thought that either the cortical area responsible for drive inhibition was not completely removed, or else that some other brain structures took over the impaired function.

SUMMARY

The multiple instrumental conditioned reflex (MICR) was established in six dogs by gradually increasing the number of motor responses required for each reinforcement, until the animals stopped performing the trained movement. In three animals, the prefrontal area of the cerebral

cortex was ablated and the training was then resumed. In three other (control) animals the second training was given without any surgery. During the post-operative training, the latencies of the MICR were significantly reduced and the maximal numbers of movements performed by the animals were increased. In two dogs the frequency of motor responses was also increased. These changes were not manifested in the control dogs. The salivary responses were not directly affected by the prefrontal lesion and they followed closely the motor performance. These results are explained by reference to the reduction of drive inhibition after the prefrontal lesions.

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Book Review

Günter Siegel, *Die biologischen Wirkungen kleiner Dosen ionisierender Strahlung (Biological Effects of Low-level Ionizing Radiation).* Jena, VEB Gustav Fischer Verlag, 1966, 88 pp.

Günter Siegel's book makes up a concise review of literature, concerning the effects of low-level ionizing radiation on living organisms. This problem, which has recently acquired a special importance, claims attention not only on account of a rapid development of radiobiology, but also, and mostly, due to the fact that it provides a possibility to work out an effective protection against radiation. It is a well-known fact that, for several years now, the application of the ionizing radiation has exceeded the range of medicine, and served not only the therapy and diagnostics but also the industry, construction and all kinds of scientific research. The problems, related to the examination of biological effects of a low-level ionizing radiation are concisely discussed by the author who provided his book with 774 bibliographical items. The first two chapters (an introduction and general remarks) are devoted to the discussion of the main problems which ensued from the studies on the effects of the ionizing radiation on living organisms, carried out so far. Question whether or not there exists a lowest-level, threshold ionizing radiation in relation to somatic and genetic lesions, question whether or not the organism is capable to develop a certain resistance to the radiation and, finally, the question of againg caused by the ionizing radiation, are among the discussed problems. Specific effects of the ionizing radiation, as well as delayed lesions, occurring as an aftereffect of the radiation are most extensively discussed by the author in chapter 3. This chapter is divided into 15 subchapters, containing a review of literature which concerns the effects of low-level ionizing radiation leading to the formation of tumors and lesions of particular tissues, glands, organs, single cells, embryos, skin, to changes in blood, etc. In this review, the author discusses mostly the studies on the effects of radiation acting externally and pays much less attention to those occurring after the incorporation of labelled compounds. He describes the present state of studies in this field but does not formulate his own theses which could be of a general importance.

Irena Kąkol, Warszawa

Acta Biol. Exper. (Warsaw), Vol. 27, No. 4, p. 465, 1967

SECOND COMMUNICATION

XXIV INTERNATIONAL CONGRESS OF PHYSIOLOGICAL SCIENCES

August 25—31, 1968 ... Washington, D.C., U.S.A.

International Congress of Physiological Sciences will be held at the Sheraton-Park and Shorcham Hotels in Washington, D. C., August 25—31, 1968. This represents one of the oldest international congresses in the biomedical field, and has been held every three years since 1888, with a few exceptions during the two world wars. The 1965 Congress was held in Tokyo, Japan. The last Congress held in the United States was in 1929 in Boston, Massachusetts. It has met only one other time in North America in Montreal, Canada in 1953.

This Congress is sponsored by the International Union of Physiological Sciences (IUPS). The adhering member of that Union in the U.S.A. is the National Academy of Sciences, which will sponsor the Congress with the support of the American Physiological Society and the Society of General Physiologists. The management of the Congress has been entrusted to a Secretariat in the offices of the Federation of American Societies for Experimental Biology.

The program will open with a plenary session on Sunday afternoon or evening, August 25, 1968. Scientific sessions will be scheduled on Monday through Friday, August 26—30, with the closing plenary session on Saturday morning, August 31. A daily series of short invited lectures on "Recent Advances in Physiology" will be an innovation on the program. From many suggestions for symposia received from Member Countries, the Program Committee will select, perhaps 20 for half-day programs. There will also be the usual invited lecturers and many sessions of contributed papers on all aspects of physiology and allied sciences. Rooms for informal discusion will be provided in close proximity to session rooms.

Physiologists and other scientists working in allied fields may become active members of the Congress by payment of the registration fee of $ 35.00. Members of the families of active members, who are not themselves scientists, may register for $ 15.00 as affiliate members entitled to participate in the social events of the Congress.

Plans are being made for a number of additional symposia, before and after the Congress, in various locations. The Visiting Physiologists Committee will do everything possible to arrange lecture tours or visits to American laboratories and points of interest on the American continent. Correspondence on that subject may be addressed to the chairman of that Committee, Dr. Chandler McC. Brooks, via the Secretariat.

The scientific program will be augmented by tours of laboratories in the Washington area. Exhibits of pertinent laboratory equipment, apparatus, books and journals, and pertinent pharmaceuticals will be on display throughout the week of the Congress.

Limited funds for travel and subsistence expenses in Washington may be available to some registrants from abroad. It will be necessary, however, for most registrants to obtain funds for travel from sources other than the Congress.

The social program of the Congress will open with a mixer on Sunday, August 25. Other social events will include dinners in private homes for registrants from outside the United States, sightseeing tours in Washington, a special opening of the National Gallery of Arts, and a Congress Reception. Additional events are planned for affiliate members.

A definitive announcement of the Congress will be distributed in October 1967. This will provide the necessary forms and detailed information with regard to submission of abstracts, travel or subsistence allowances, advance registration and fees, hotel reservations, and plans for scientific and social programs.

The officers and committee chairmen for the Congress are as follows:

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