EFFECT OF BILATERAL SUPRASYLVIAN ABLATION ON FEAR BEHAVIOR ELICITED BY HIPPOCAMPAL STIMULATION IN CATS

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Abstract. Fear responses elicited by electrical stimulation in the dorsal and ventral hippocampus of cats, and the conditioned fear behavior established by pairing this stimulation with a neutral stimulus disappeared after bilateral ablation of the suprasylvian gyrus. The same reactions were not affected when the ectosylvian gyri were removed. The suprasylvian ablation did not impair conditioned classical defence reflexes when a noxious stimulation of the hind limb was used as an unconditioned stimulus. It is suggested that the suprasylvian association area plays an important role in fear produced by hippocampal stimulation but not in pain responses elicited by a noxious peripheral stimulus.

INTRODUCTION

In a previous publication one of us (10) discussed the substantial difference between emotional behavior and effects of electrical brain stimulation which were termed pseudo-emotional responses. After reviewing the recent literature and interpreting data obtained from stimulation of discrete areas of the rabbit brain it was concluded that emotional behavior of gyrencephalic mammals cannot occur without participation of the neocortex (11).

Emotional responses are easily induced by direct neocortical stimulation in cats (14, 20, 23, 36). Low-intensity stimulation of the anterior suprasylvian gyrus was found to elicit attention and searching behavior while more intense stimulation produced a fear response (36). Fear
behavior elicited by medial suprasylvian stimulation was observed by Fangel and Kaada (14).

Taking these data into account we decided to study the role of the neocortical association areas in subcortically induced emotional behavior. The present experiments were designed to study the role of the suprasylvian gyrus in aversive behavior elicited by hippocampal stimulation in cats.

MATERIAL AND METHODS

Eleven adult cats of either sex weighing between 2.3–4.1 kg were used. All surgery was performed under Nembutal (pentobarbital sodium) anesthesia (35 mg/kg) under aseptic conditions. Eight stainless steel monopolar 0.2 mm diameter electrodes insulated except at the tip were implanted into the dorsal and/or ventral hippocampus of each animal. The loci where stimulation elicited overt aversive behavior were selected for further study. Stimulating and reference electrodes were attached to the skull with acrylic resin. Care was taken to leave enough space for subsequent cortical ablations without electrode displacement.

The stereotaxic coordinates for hippocampal stimulation were taken from Jasper and Ajmone-Marsan’s atlas (21) as follows: for the dorsal hippocampus, A4, L5, H+7; for the ventral hippocampus, A7, L11, H-4 or A7.5, L9, H-5.5; or A8.5, L10, H-5. The actual hippocampal sites stimulated are shown in Fig. 1.

The experimentals were carried out in a chamber (160 cm X 100 cm X 80 cm) where cats were allowed to move freely. Behavior was observed through a small glass window.

In nine cats the classical defence conditioning procedure consisted of pairing a 500 Hz tone (conditioned stimulus — CS) lasting 5s with hippocampal stimulation (unconditioned stimulus — US). Both stimuli were turned off as the animal displayed a flight response. The hippocampus was stimulated with rectangular 0.2 ms pulses at a frequency of 150–200 Hz. The current varied from 300 to 1,000 μA. Intertrial intervals during acquisition lasted 1.5–2 min. Five or 6 trials were made daily, to stabilize the conditioned response. In four cats 10/s clicks were paired with electrical stimulation of the hindlimb. In two of these animals the conditioned flight response with hippocampal stimulation as an US was previously established, whereas two others were naive at the time of training.

In eight cats the suprasylvian gyri were removed bilaterally, and in two other animals ectosylvian gyri were ablated. In the eleventh cat
Fig. 1. The hippocampal sites generating the emotional fear response. The upper drawing shows different sites of the dorsal hippocampus, the lower drawing — the ventral hippocampus. Summarized results obtained on 11 cats. For abbreviations see Jasper and Ajmone-Marsan (21)
both suprasylvian and ectosylvian gyri were removed. Neocortical abla-
tions were performed with utmost care to be sure that only gray matter 
was removed. The size of the cortical ablations is shown schematically in 
Figs. 3–5.

After completion of the experiments the cats were sacrificed with an 
overdose of ether. The brains were removed, fixed in 10% formalin 
solution and sectioned after 4–7 days.

RESULTS

Stimulation of only one or two placements in each animal produced 
a conspicuous flight response accompanied by vocalization, mydriasis, 
urination and defecation. Loci where stimulation elicited single somatic 
effects without an emotional component were eliminated from further 
study.

The first signs of conditioning were seen after 2–9 pairings of the 
CS with stimulation of the hippocampus. The CS produced a flight re-
sponse and restlessness which outlasted each trial by 1–2 min. The 
animals also displayed aversive behavior when presented with the exper-
imental situation. They actively opposed being placed in the experi-
mental chamber, and urinated and defecated at that time.

After consolidation of the conditioned fear response, the suprasylvian 
gyri were bilaterally ablated in four cats (C1, C4, C5 and C9). The medial 
part of the gyrus was totally removed (area 7) as well as part of the 
anterior (area 5) and posterior (area 21) areas. The size of the suprasyl-
vian ablations is shown in Figs. 2 and 3.

As shown in Table I, the suprasylvian ablation abolished all beha-
vioral and vegetative components of the emotional response to the hip-
pocampal (unconditioned) as well to the conditioned stimulus. The stimu-
lation of the hippocampus which previously produced a prolonged cessa-
tion of eating, now evoked this effect only during the action of the sti-
mulus itself. Stimulation of the hippocampal sites which prior to the 
suprasylvian ablation had a dramatic effect on the animal's behavior 
now provoked only separate purposeless motor responses without after-
effect. The preoperative restlessness and negative attitude towards the 
experimental environment disappeared entirely.

In the next series of experiments a “reverse” order of investigation 
was applied. In two experimentally naive cats (C2 and C8) the suprasyl-
vian gyri were removed bilaterally and an attempt was made to elabo-
rate conditioned response on the basis of hippocampal stimulation. In 
cat C2 the dorsal hippocampus and in cat C8 the ventral hippocampus
were stimulated. Although the same stereotaxic coordinates were used as in the previously described animals, no emotional responses to the hippocampal stimulation were observed. Instead only "automatic" motor activity was obtained. We tried to elaborate conditioning on the basis of these movements. In spite of over 40 reinforcements in each case the CS evoked no response. The medial part of the ectosylvian gyrus was removed in three cats (C3, C6 and C7). The size of ablation is shown in Fig. 4.

As shown in Table II, the aversive effects of hippocampal stimulation were not affected, nor was the conditioned aversive response, which was established prior to the surgery, impaired.

In C7 a second operation was performed. The suprasylvian gyri were removed after ectosylvian ablation (see Fig. 5). This second ablation abolished both the flight response evoked by the hippocampal stimulation and the conditioned stimulus.

Bilateral suprasylvian ablation in two cats (C10 and C11) did not
Fig. 3. Size of the suprasylvian ablations in C1, C2, C4, C5 and C8.

TABLE I

Effect of bilateral ablation of the suprasylvian gyrus on hippocampally elicited behavioral (BR) and vegetative (VR) responses

<table>
<thead>
<tr>
<th>Cat</th>
<th>Structure stimulated</th>
<th>Responses Before ablation</th>
<th></th>
<th></th>
<th>Responses After ablation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CS</td>
<td>US</td>
<td>CS</td>
<td>US</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BR</td>
<td>VR</td>
<td>BR</td>
<td>VR</td>
</tr>
<tr>
<td>C1</td>
<td>dorsal hippocampus</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>C4</td>
<td>ventral hippocampus</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>C5</td>
<td>ventral hippocampus</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>C9</td>
<td>ventral hippocampus</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>+</td>
</tr>
</tbody>
</table>

Symbols for behavioral responses: ++++, jumping, vocalization, flight; ++, vocalization, flight; +, startle; -, none.
Symbols for vegetative responses: ++++, mydriasis, urination, defecation; ++, mydriasis, urination; +, mydriasis; -, none.
CS, conditioned stimulus; US, unconditioned stimulus.

affect the classical conditioned defence reflex reinforced by a noxious stimulation of the hind leg. The same conditioning was easily acquired by two other cats (C7 and C8) in which the suprasylvian ablation had abolished the hippocampally elicited flight and the conditioned aversive response reinforced by hippocampal stimulation.
Fig. 4. Size of ectosylvian ablations in C3 and C6.

**Table II**

Effect of bilateral ablation of the ectosylvian gyrus on hippocampally elicited behavioral and vegetative responses. Abbreviations and symbols as in Table I

<table>
<thead>
<tr>
<th>Cat</th>
<th>Structure stimulated</th>
<th>Responses Before ectosylvian ablation</th>
<th>Responses After ectosylvian ablation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CS (BR VR)</td>
<td>US (BR VR)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CS (BR VR)</td>
<td>US (BR VR)</td>
</tr>
<tr>
<td>C3</td>
<td>dorsal hippocampus</td>
<td>+++ + + +</td>
<td>+ + + + +</td>
</tr>
<tr>
<td>C6</td>
<td>ventral hippocampus</td>
<td>+ + + + + +</td>
<td>+ + + + + +</td>
</tr>
<tr>
<td>C7</td>
<td>ventral hippocampus</td>
<td>+ + + + + + + +</td>
<td>+ + + + + + + +</td>
</tr>
</tbody>
</table>

Fig. 5. Size of the suprasylvian and ectosylvian ablations in C7.

**DISCUSSION**

Stimulation in the majority of hippocampal sites produced various somatic and visceral responses which did not reflect activation of neural structures subserving a coordinated pattern of emotional behavior. These responses appeared in a form of "automatic" or "chaotic" reactions (10, 11) and were similar to the effects described in the macaque monkey.
Some authors concluded that the hippocampus plays no essential role in the control of biologically motivated emotional behavior (for review, see 45). However, the data obtained in our laboratory showed that stimulation of discrete areas in the dorsal and ventral hippocampus produced a clear-cut defence response in the cat (44). This finding was confirmed in the present study where stimulation in about one tenth of the hippocampal sites explored elicited well expressed defence responses. These responses appeared behaviorally similar to natural fear: initial flight was accompanied by long-lasting mydriasis, restlessness, urination and defecation. Even in the absence of an overt flight the animals permanently miaowed and rejected food even if hungry. Therefore, we assume that the hippocampal stimulations may activate the neural mechanism subserving fear. The fact that only about 10% of all hippocampal sites tested yielded fear responses indicates that functionally the hippocampus is a heterogenous structure. The involvement of the hippocampus in the central mechanism of fear is further supported by the ease to establish a classical defence reflex reinforced by hippocampal stimulation.

The present study demonstrated an important role of the suprasylvian gyrus in the development of the hippocampally produced emotional reaction. No such role can be ascribed to the ectosylvian gyrus.

Pertinent to our results is the finding of clear cut defence reactions produced by stimulation of the parietal cortex (14, 36), and of behavioral suppression following ablation at the same area (15, 16, 48). It was also shown that the parietal lesions do not cause ataxic disorders (13) as suggested by some authors (32, 34). Bates and Ettlinger (5) emphasized that “disorientation” rather than ataxia was observed after parietal ablations in rhesus monkeys and that the animals displayed a motionless state sitting “...hunched up, with chin resting on the chest”.

The same motionless state was observed in our cats. The animals’ restlessness in the experimental chamber was no longer seen after suprasylvian ablation, and placid behavior persisted for several months. Our results corroborate the data demonstrating an involvement of the parietal association area in the analysis of exteroceptive stimuli (1, 3, 8, 41–43) and in the mechanisms of conditioning and learning (2, 6, 7, 25, 37–39).

A fear response always begins with attentive behavior and electroencephalographic arousal. It has been suggested that neocortical sites responsible for these components are located in the association areas (14).

Our results are also consistent with the electrophysiological studies which demonstrated connections of the hippocampus with different parts of the suprasylvian gyrus (4, 17, 22, 24, 26). Elul (12) suggested that
there is a wide network of hippocampal projections to the parietal association area.

The fact that the noxious stimulation at the periphery continued to produce defence behavior after cortical ablations indicates that the parietal association areas are not essential for the sensation of pain. **Pain** is obviously realized through the phylogenetically older brain structures. Motor defence reactions to noxious stimuli may appear even on the spinal level (28, 29). The mesencephalic structures are also known to be responsible for pain reactions (9, 19, 30, 31, 38, 40). The thalamus is recognized as the highest level where the pain responses are formed (18, 27, 29, 33, 35). Hence when the thalamic and mesencephalic structures are intact, pain responses can be induced even after the suprasylvian ablations.

Therefore, we assume that motivation which subserves the flight elicited by hippocampal stimulation was more related to natural fear than to pain. We further claim that this aversive behavior and corresponding emotion may be controlled by the suprasylvian association area.

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