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Representation of Masticatory Movement in the Amygdala, Hypothalamus, and Midbrain

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Chewing as a reaction to stimulation of amygdala has been noted by several investigators[1,2,3,4] in the course of their search for the functional organization of this nuclear complex. All these observations are, however, rather fragmentary as regards the masticatory movement. The present study is, therefore, intended systematically to examine the possible predilection in the distribution of masticatory sites in the amygdala, to explore the hypothalamus and midbrain for masticatory responses, and to infer the courses of amygdalar masticatory efferents through the diencephalon and midbrain.

Materials and Methods

Thirteen cats of both sexes weighing between 1.9 and 3.5kg. were subjected to the experiment. Under intraperitoneal Nembutal anesthesia (30mg/kg body weight), the skull was opened with a rongeur. A concentric needle electrode insulated except at the very tip was implanted stereotaxically into the brain and bipolar stimulation was carried out, watching the occurence of rhythmical masticatory movement of the mandible. A train of 3 cycle/second square waves was applied for about 10 seconds, the usual duration of each wave being three milliseconds.

Electrode positions in each brain were marked with a small direct current, and subsequently identified on histological sections. Responses were plotted in the stereotaxic atlas of cat's brain published by Jasper and Ajmone-Marsan.[5]

Results

The results are summarized in Fig. 1 and Table 1. In calculating Table 1, high threshold atypical and dubious responses were omitted. Masticatory sites distributed throughout the amygdaloid nuclear complex with the exception of the anterior amygdaloid area (Fig. 1). The most consistent masticatory responses were obtained by stimulation of the medial and cortical amygdaloid nuclei, where chewing was seen every time following stimulation in all animals studied (Table 1). The second most responsive area was the basal nucleus, and the third the central nucleus. The olfactory tubercle was not studied in any sizable extent, but seemed quite responsive. The lateral amygdaloid nucleus made only inconsistent masticatory responses and the anterior amygdaloid area no response.

The readiness of the response seemed to be influenced by the depth of anesthesia. Only the medial and cortical amygdaloid nuclei responded in deep anesthesia, but in light one almost all the nuclei of the amygdala tended to show the masticatory response. The threshold for masticatory response varied widely among animals and conditions, but the lowest threshold was observed in the basal amygdaloid nucleus, and the next lowest in the medial and cortical amygdaloid nuclei (Table 1). The central and lateral amygdaloid nuclei had higher threshold.

In the preoptic region, the hypothalamus proper, and the midbrain, there was no point where the masticatory response was invariabley obtained upon stimulation. In the preoptic region, however, masticatory responses could be evoked in more than half of the ocasions stimulated. In the hypothalamus proper, the response was most frequently elicited in the ventromedial nucleus and in the medial forebrain bundle, the latter having lower threshold than the former (Table 1). The lateral hypothalamic area also responded in almost half the cases, but the zona incerta gave only inconsistent results, and the posterior and the dorsal hypothalamic areas did not

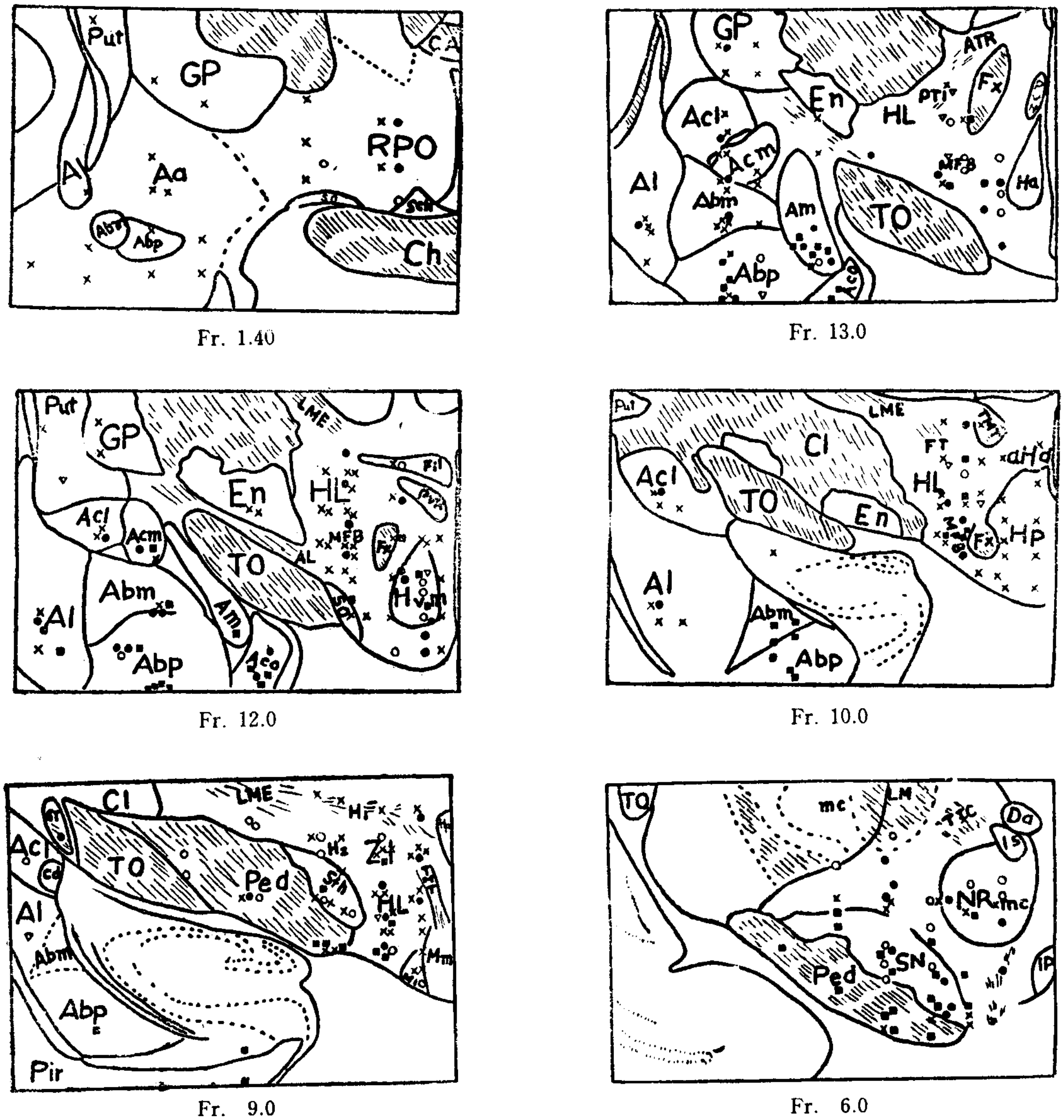

Fig. 1. Representation of masticatory movement in selected frontal sections of cat's brain. Filled squares, sites making low threshold (less than 50 volts) response; filled circles, masticatory sites the threshold of which is moderate (less than 100 volts); open circles, sites making atypical or high threshold masticatory response (over 100 volts); open triangles, sites with dubious response; crosses, sites making no masticatory response. For explanation of abbreviations refer to 'Abbreviations' at the end of the text.

show any response. The subthalamic nucleus, on the other hand, responded in slightly more than half the cases.

In the midbrain, stimulation of the substantia nigra and the cerebral peduncle evoked masticatory responses in most cases. The red nucleus also made positive responses very often, but the mesencephalic reticular substance responded rather poorly. Caudally, there seemed to exist some tendency for the positive points in the cerebral peduncle to move lateralwards. The cerebral peduncle had the lowest threshold for masticatory response among sites explored in this study (Table 1). The threshold became increasingly higher in the order of the substantia nigra, the red nucleus, and the mesencephalic reticular substance.

No other structures were investigated intentionally,

Table 1. Threshold and Percentage Positive Masticatory Response of Sites in the Amygdala, Hypothalamus, and Midbrain

Site stimulated[1]	% positive response[2]	Threshold(volt)	
		minimum	mean[2]
Am	100	30	44.5
Aco	100	30	46.6
Acm	40	50	55.0
Acl	33	65	78.7
Aa	0	—	—
Abp	80	15	43.1
Abm	60	15	46.1
Al	39	45	62.1
RPO	67	60	65.0
Hvm	63	35	84.5
MFB	59	8	54.4
HL	46	30	75.5
ZI	31	35	69.0
Sth	57	25	51.2
SN	87	10	50.2
Ped	80	3.5	37.0
NR	79	35	89.2
Ret. Mes.	29	80	97.5

[1]For explanation of abbreviations refer to 'Abbreviations' at the end of the text.

[2]Mostly more than 10 observations were made for each value. The stimulus threshold values were generally high due to the anesthesia and the high resistance of the concentric needle electrode employed.

but among the basal telencephalic structures stimulated in passing, the pyriform cortex seemed to posses active points, and the nucleus acumbens also responded positively. The head of the caudate nucleus and the globus pallidus responded poorly. In the thalamus the medial lemniscus and the paralemniscal nucleus seemed to contain positive points, and the external medullary lamina also responded occasionally. The stria terminalis between the caudate and the thalamus responded well.

In a few experiments the amygdala was stimulated following extensive bilateral electrolysis of both the ventromedial hypothalamic nucleus and the medial forebrain bundle. These bilateral lesions in the hypothalamus abolished amygdalar masticatory responses, but lesions confined to one side did not abolish the response. Similar bilateral lesions in the substantia nigra, the red nucleus, or the cerebral peduncle failed to abolish the response. The lesions were not extensive enough to cover all or most of these structures.

Discussion

Opinions seem to be divided as to the functional localization in the amygdala. Reviewing the literature, Gloor[6)] obtained the impression that there was no distinct topographical representation of patterns of activity within the amygdala. Maclean and Delgado[2)], for example, had reported that responses involving the structures related to the oral end of the digestive tract had multiple representation and were obtained from points throughout the greater part of the amygdala. Kaada et al.[3)], on the hand, reported that the autonomic and immediate somato-motor effects tended to group medially in the amygdala. In waking cats they produced chewing movements only by stimulation of points in the anteromedial group of nuclei. In subsequent experiment, Ursin and Kaada[4)] evoked the most marked masticatory responses from the rostral part of the amygdala. They found positive sites throughout the basal nucleus,and several active points in the periamygdaloid cortex. However, they also located scattered points within the lateral nucleus and in the region of the central nucleus.

From the present study it seems certain that almost all regions of the amygdala including the lateral nucleus contain active sites for masticatory response. Working with waking cats, Kim[7)] also located positive points in the lateral amygdaloid nucleus. However, it seems equally certain that there is some predilection in the distribution of masticatory sites, the cortical, medial, and basal nuclei being more ready to respond than the other nuclei. In conjunction with the experience that the readiness of the response increased with lighter anesthesia, these results may be suggesting that the cortical, medial, and basal nuclei have more direct paths with only a few synapses to the masticatory nucleus in the medulla than the others, which may discharge masticatory impulse through multisynaptic connections with the former nuclei or with some other paths.

Anatomically the amygdaloid nuclear complex has been divided into two subgroups: the phylogenetically older corticomedial group of nuclei including the cortical, medial, central, anterior nuclei, as well as the nucleus of lateral olfactory tract, and the phylogenetically newer basolateral group of nuclei including the basal and lateral nuclei.[8] With the above anatomical subdivisions in mind, the present data seem to show that the predilection for the masticatory response is not confined to either of the two anatomical subgroups.

In the hypothalamus the ventromedial nucleus, the medial forebrain bundle, and the lateral hypothalamic area made masticatory responses most frequently. The positive sites in the ventromedial hypothalamic nucleus may have two explanations. The one is that this structure by itself actively integrates mastication; this explanation might be in line with the known implication of the ventromedial nucleus in the regulation of the food intake. The other is that the masticatory efferents from the amygdala take their path through or make synapse in this structure. In this connection, Fox[9] states that in the cat the corticomedial group of nuclei and the posterior part of the basal nuclei feed the stria terminalis, which, according to Adey and Meyer[10], reach as far caudal as the infundibular region, where it seems to end especially in the ventromedial hypothalamic nucleus. Besides, Johnston[8] describes other fibers running in a more or less diffuse way from the amygdala towards the hypothalamus and possibly joining the medial forebrain bundle. The masticatory responses observed in and around the medial forebrain bundle and the lateral hypothalamic area in this study might be the result of stimulating these diffuse fibers. The absence of amygdalar masticatory responses following extensive bilateral destruction of the hypothalamus also suggests that the chief efferent path from the amygdala courses through this part of the brain.

It is not clear how the masticatory impulses running through or originating in the hypothalamus reach midbrain, but it might be that they finally get to the subthalamus, red nucleus, and particularly the substantia nigra, judging from the high rate of positive masticatory response these nuclei make. However, here also the possibility remains that these midbrain stures are by themselves active integrators of masticatory activity and not mere relay stations of amygdalar or other efferent paths. The midbrain reticular formation responded poorly, probably due to the anesthetic blockage of multisynaptic paths in it. The fact that electrolytic lesions of circumscribed areas in the midbrain did not abolish the amygdalar masticatory responses seems to indicate that the masticatory representation in the midbrain is more diffuse than in the hypothalamus.

The cerebral peduncle responded very well to the stimulus and the threshold for masticatory response was lowest among structures investigated. Stimulating the amygdala, Gloor[6] obtained positive electrical responses in this efferent fiber bundle. While some masticatory impulses from the amygdala probably course through this fiber bundle, it may be that most of the responses from this bundle represent stimulation of fibers coming from the neocortex and feeding the cortico-bulbar tract.

Summing up the data, the present study does not tell if the amygdala is actively engaged in the integration of mastication by itself, or if it is participating in this activity only in a facilitatory capacity. It is equally uncertain whether other masticatory sites such as the ventromedial hypothalamic nucleus and the substantia nigra are capable of integrating mastication independently or they are mere efferent relay stations. As to the amygdalar masticatory pathway, however, it can be inferred from the present data that the masticatory impulses may be relayed in the ventromedial hypothalamic nucleus or may course through the medial forebrain bundle and lateral hypothalamic area and finally reach subthalamus, substantia nigra, or red nucleus, where they are relayed to the extrapyramidal motor paths.

Summary

In thirteen anesthetized cats, the amygdala, hypothalamus, and midbrain structures were stimulated electrically through stereotaxically implanted electrodes and the sites making masticatory responses were explored.

Active masticatory sites were found almost everywhere in the amygdaloid nuclear complex, but with the predilection of distribution in the medial, cortical, and basal nuclei.

Among hypothalamic structures investigated, the ventromedial nucleus and the medial forebrain bundle made masticatory responses most frequently.

Positive points were also found in the subthalamus, substantia nigra, and less frequently also in the red nucleus.

An inference is drawn as to a possible path of efferent masticatory impulses from the amygdala.

Acknowledgement: The auther wishes to express his appreciation to Professor Chul Kim for his Kind directions in this study.

Abbreviations

Aa	Area amydaloidea anterior
Abm	N. amygdaloideus basalis(pars magnocellularis)
Abp	N. amygdaloideus basalis(pars parvocellularis)
Acl	N. amygdaloideus centralis(pars lateralis)
Acm	N. amygdaloideus centralis(part medialis)
Aco	N. amygdaloideus corticalis
aHd	Area hypothalamica dorsalis
AL	Ansa lenticularis
Al	N. amygdaloideus lateralis
Am	N. amygdaloideus medialis
ATR	Anterior thalamic radiation
CA	Commissura anterior
Cd	N. caudatus
Ch	Chiasma opticum
CI	Capsula interna
Da	N. of Darkschewitsch
En	N. entopeduncularis
Fil	N. filiformis
FT	Fasciculus thalamicus
FX	Fornix
GP	Globus pallidus
H_1, H_2	Forel's fields
Ha	Hypothalamus anterior
HL	Hypothalamus lateralis
Hp	Hypothalamus posterior
Hvm	Hypothalamus ventromedialis
IP	N. interpeduncularis
Is	N. interstitialis
LM	Lemniscus medialis
LME	Lamina medullaris externa
mc	pars magnocellularis
MFB	Medial forebrain bundle
Mm	Corpus mammillare
NR	N. ruber
Ped	Pedunculus cerebralis
Pir	Lobus piriformis
PTI	Pedunculus thalamicus inferior
Put	Putamen
PVH	N. Periventricularis hypothalami
RPO	Regio praeoptica
Sch	N. suprachiasmaticus
SN	Substantia nigra
SO	N. supraopticus
Sth	N. subthalamicus
TMT	Tractus mammillo-thalamicus
TO	Tractus opticus
TTC	Tractus tegmentalis centralis
ZI	Zona incerta

국 문 초 록

편두핵, 시상하부 및 중뇌에 있어서의 저작운동의 표시

서울대학교 의과대학 생리학교실
<지도 김 철 교수>
김 창 욱

열세 마리의 마취된 고양이에서 편두핵, 시상하부, 및 중뇌 구조들을 전기로 자극하면서 저작반응의 유무를 조사하였다.

편두핵 속에서는 거의 어디서나 저작반응을 볼수있었는데 그중에서도 반응은 medial nucleus, cortical nucleus 및 basal nucleus에서 제일 잘 나타났다.

시상하부에 있는 구조들 중에서는 ventromedial nucleus와 medial forebrain bundle에서 자주 저작반응을 보았다.

저작반응은 subthalamus와 substantia nigra, 또 좀 덜하기는 하나 red nucleus에서도 볼 수 있었다.

위의 성적을 토대로 삼아, 편두핵에서 시작하여 저작에 관여하는 원심로의 경로에 관하여 추측하였다.

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