the sexual behavior of the mouse as a function of experience. *Psychological Reports*, 1962, 10, 284.

RABEDEAU, R. G., & WHALEN, R. F. Effects of copulatory experience on mating behavior of the male rat. *Journal of Comparative & Physiological Psychology*, 1959, 52, 482-484.

ROSIENBLATT, J. S. Effects of experience on sexual behavior in male cats. In I. A. Beach (Ed.) *Sex and behavior*. New York: Wiley, 1965. Pp. 413-439.

STONE, C. P. The retention of copulatory ability in male rats following castration. *Journal of Comparative Psychology*, 1927, 7, 269-287.

1970) and consisted of 1-arterenol bitartrate (noradrenaline) (40 micrograms/microliter), ethobutanol (13.5 micrograms/microliter), carbamylcholine chloride (carbachol) (8 micrograms/microliter), and atropine sulfate (50 micrograms/microliter). Each was dissolved in Locke-Ringer solution and each injection was 2 microliters.

Injectons of neurohumors in the cat thalamus and visual discrimination performance

DAVID D. AVERY, Colorado State University, Fort Collins, Colo. 80521
and
DWIGHT M. NANCE, University of Houston, Houston, Tex. 77004*

The influences of central applications of adrenergic and cholinergic stimulating and blocking agents to the cat thalamus on successive visual discrimination performance were investigated. Applications of both noradrenaline and the adrenergic blocking agent ethobutanol improved discrimination performance by reducing nonreinforced responding. Conversely, injections of both the cholinergic stimulator and blocker disrupted visual discrimination. Carbachol reduced responses to the discriminative stimulus without affecting nonreinforced response rate, and atropine sulfate increased nonreinforced responses without changing the rate of reinforced responding.

The center median nucleus of the thalamus is one of the nonspecific thalamic nuclei that provide a thalamocortical extension of the brainstem reticular system in the cat. The thalamic-brainstem continuum appears to supply certain integrative or motivational functions that are essential for acquisition, retention, and performance of new behavioral patterns. Support for this notion derives from studies showing changes in performance measures as a result of altering reticular function by electrical stimulation, ablation, or, more importantly for the present investigation, chemical stimulation (Zuckerman, 1959; Warren & Ackert, 1960; Grossman et al., 1965). Grossman and his colleagues (1965, 1966, 1968), in a series of experiments, have demonstrated that cholinergic stimulation or blockage of both thalamic midline and reticular nuclei in the rat can greatly affect acquisition and asymptotic performance in both appetitive and aversive test situations. In addition, Avery & Nance (1970) found that injections of adrenergic, as well as cholinergic, substances into the center median nucleus of the cat thalamus can selectively inhibit or facilitate simple appetitive operant responding. Adrenergic stimulation and cholinergic blockage increased response rate, whereas cholinergic stimulation and adrenergic blockage had an opposite inhibitory influence.

*Presently a postdoctoral fellow at the Worcester Foundation for Experimental Biology, 222 Maple Avenue, Shrewsbury, Mass. 01545.

Since ascending cholinergic and aminergic pathways through the brainstem have been identified in the cat, as well as the rat, and in view of the previous findings in both species with thalamic injections of neurohumors, the investigation to be reported was an attempt to unravel the functional significance of these chemical circuits in the performance of newly acquired, complex behavioral patterns. More specifically, the experiments were concerned with the effects of direct injections of adrenergic and cholinergic stimulating and blocking agents in the cat thalamus on complex visual discrimination.

METHOD

A double-wall cannula was directed at the center median nucleus of the thalamus in each of 13 mature mongrel cats, weighing between 6 and 9 lbs. The implant was secured to the skull and anchor screws with dental cement, following standard procedures. Each animal was housed individually in a constantly illuminated, temperature-controlled room ($22.0^{\circ} \pm 1.0^{\circ}\text{C}$). Injections were made with the aid of a micromanipulator and a Hamilton microsyringe, which was attached to the internal cannula via polyethylene tubing. A dummy cannula, constructed from stainless steel wire, was in place except during injections. The injection cannula was of the same length and diameter as the dummy cannula.

The substances applied intracranially and their respective dosages were the same as in a previous study (Avery & Nance,

1970) and consisted of 1-arterenol bitartrate (noradrenaline) (40 micrograms/microliter), ethobutanol (13.5 micrograms/microliter), carbamylcholine chloride (carbachol) (8 micrograms/microliter), and atropine sulfate (50 micrograms/microliter). Each was dissolved in Locke-Ringer solution and each injection was 2 microliters.

The apparatus for behavioral measures was an operant chamber constructed from Formica, with inside dimensions of 48 in. long x 30 in. wide x 36 in. high. A bar, milk-delivery device, and photic-stimulation bulb were located in close proximity on one wall of the chamber. Preliminary training included shaping of barpressing for milk reinforcement and a shift to an FR-5 schedule, which was maintained for three 30-min daily sessions prior to visual discrimination training. The visual discrimination task was of the "go/no-go" variety. Each trial consisted of a 10-sec reinforcement period indicated by a Grass photic stimulator flashing at 7 Hz. During this period each barpress was reinforced with .3 cc of milk. Reinforcement periods were separated on a variable-interval schedule ranging from 27.5 to 33.5 sec, with a mean of 30 sec. If three responses occurred during the 10 sec prior to the onset of the reinforcement period, the intertrial interval was extended an additional 10 sec. Ss received 50 trials per day, and records were made of total responses (TR), reinforced responses (SDR), and intertrial responses (ITR). After each daily session the ratio of intertrial responses to reinforced responses (ITR/SDR) was calculated for the 50 trials, and this ratio was utilized as an index of visual discrimination performance. Injections did not occur until an animal averaged two or less as many nonreinforced as reinforced responses (ITR/SDR ratio < 2.0) for 3 consecutive days. The substances were applied in a random order and there were at least 48 h between injection sessions. Before a baseline session qualified as a control day, the original performance criterion of ITR/SDR ratio < 2.0 had to be met.

RESULTS

Histology

At the end of the experiment each animal was sacrificed and perfused according to standard procedures. Photomicrographs were made of each placement and the accuracy of the implant was evaluated. The tips of all cannulae were within ± 1.0 mm in the anterior-posterior and lateral planes and ± 0.5 mm in the horizontal plane of the intended Horsley-Clark stereotaxic

Fig. 1. Mean percent increase or decrease during visual discrimination in reinforced (SD) and nonreinforced (IT) responses from the preinjection, baseline session for each injection condition.

coordinates for the center median nucleus of the thalamus.

Discrimination Performance

The statistical test used for all analyses was the matched-pairs signed-ranks test. Mean percent increases or decreases in reinforced (SD) or intertrial (IT) responses, in comparison with baseline measures, for each stimulation condition are shown in Fig. 1. The effects of the response rate changes on discrimination performance, as reflected in ratio scores (ITR/SDR), are listed in Table 1.

Injections of noradrenaline tended to decrease IT responding ($p < 1.0$) without affecting SD responding, thus resulting in better discrimination performance ($p < .10$). Applications of ethobutanol had similar effects. Visual discrimination improved ($p < .05$) and intertrial responding decreased ($p < .05$) without a change in SD responding.

Both carbachol and atropine injections resulted in poorer discrimination performance ($p < .05$). However, the deficits occurred for different reasons with each substance. Applications of carbachol decreased SD responding ($p < .05$) without affecting IT responding; atropine increased IT responding ($p < .05$) and had no effect on SD responses.

Table 1
Mean ITR/SDR Scores for 50 Trials in Both Preinjection Baseline Sessions and Injection Sessions for Each Injection Condition. A Lower Ratio Score Indicates Improved Discrimination Performance and a Higher Score, Poorer Performance.

Chemical	Baseline	Injection
Noradrenaline	.72	.56*
Ethobutanol	.75	.58**
Carbachol	.44	1.22**
Atropine Sulfate	.50	.78**

* $p < .10$

** $p < .05$

DISCUSSION

It is apparent from the results that both adrenergic and cholinergic mechanisms in the cat thalamus are involved in the execution of behavioral responses of a complex nature. The observations that both cholinergic stimulation and blockage result in poorer discrimination performance and that adrenergic blockage leads to better performance, along with a similar tendency with adrenergic stimulation, were, however, quite unexpected. In the case of cholinergic mechanisms, a more detailed analysis of stimulation and blockage effects on specific response components of discrimination performance clarifies to some extent the perplexing findings. Injections of carbachol greatly reduced the SD responses, thus reflecting improved performance, as indicated in the ITR/SDR index. This finding is consistent with the observation reported previously of a reduction in simple operant response rate with cholinergic stimulation (Avery & Nance, 1970), and thus poorer discrimination performance may reflect a general motivational influence. Discrimination performance deficits with central applications of atropine sulfate were directly dependent upon a large increase in responding during the intertrial interval. The effect may again be due to a disruption of motivational processes or perhaps is a function of a breakdown in inhibitory mechanisms. Similar effects on associative and memory process with atropine-induced blockage in the rat thalamic reticular system have been observed (Grossman & Peters, 1966).

With adrenergic stimulation and blockage, an analysis of the response categories does not lead to a conclusion of differential effects. Injections of both noradrenaline and ethobutanol improved performance by reducing

intertrial responses. If one accepts that mechanisms subserving motivation are influenced by these injections, then the noradrenaline effect is consistent with the disruptive effect of carbachol on discrimination performance and the previous finding of improved performance after intrathalamic adrenergic injections in a simple appetitive situation (Avery & Nance, 1970). However, ethobutanol inhibited operant responding in the earlier experiment, and thus the present finding of better discrimination performance does not easily lend itself to an explanation in terms of motivational changes. Perhaps a more adequate explanation is that adrenergic blockage enhances inhibitory mechanisms.

In summary, the observation that applications of cholinergic and adrenergic substances to the cat thalamus influence complex visual discrimination behavior cannot be denied in light of the experiments reported. However, the present findings cannot be adequately accounted for on the basis of either motivational or associative processes exclusively. Perhaps a more salient explanation is that both processes are subserved by mechanisms involving both modes of neurohumoral action in the thalamus. In order fully to understand the role of adrenergic and cholinergic thalamic systems in the cat for the mediation of behavior, the effects of intracranial injections on a wide variety of behaviors, including active and passive avoidance as well as other appetitive tasks, must be investigated.

REFERENCES

- AVERY, D. D., & NANCE, D. M. Behavioral correlates of chemical stimulation in the cat thalamus. *Psychonomic Science*, 1970, 19, 7-8.
- GROSSMAN, S. P. Acquisition and performance of avoidance responses during chemical stimulation of the midbrain reticular formation. *Journal of Comparative & Physiological Psychology*, 1966, 61, 42-49.
- GROSSMAN, S. P. Behavioral and electroencephalographic effects of microinjections of neurohumors into the midbrain reticular formation. *Physiology & Behavior*, 1968, 3, 777-786.
- GROSSMAN, S. P., & PETERS, R. H. Acquisition of appetitive and avoidance habits following atropine-induced blocking of the thalamic reticular formation. *Journal of Comparative & Physiological Psychology*, 1966, 61, 325-332.
- GROSSMAN, S. P., PETERS, R. H., FREEDMAN, P. E., & WILLER, H. I. Behavioral effects of cholinergic stimulation of the thalamic reticular formation. *Journal of Comparative & Physiological Psychology*, 1965, 59, 57-65.
- WARREN, J. M., & AKERT, K. Impaired problem solving in cats with thalamic lesions. *Journal of Comparative & Physiological Psychology*, 1960, 53, 207-211.
- ZUCKERMANN, E. Effect of cortical and reticular stimulation on conditioned reflex activity. *Journal of Neurophysiology*, 1959, 22, 633-643.