shown in Fig. 1. Prior to their training on each stimulus pair all animals were given a single discrimination-reversal test. The stimulus pairs used for the three discrimination-reversal tests were also used for the training phases. The criterion for discrimination-reversal learning was 12 consecutive correct responses.

The results of the training phases are shown in Fig. 1, which plots the mean percentage of win-stay, lose-shift responses for both groups as a function of 100-trial blocks. These curves reflect the number of correct responses. Improvement is indicated by a rising curve for the discrimination-reversal group and a falling curve for the alternation group. The discrimination-reversal group did show progressive improvement with extremely efficient transfer from one training phase to another, whereas the alternation group showed no such improvement. The latter group failed to solve the object-alternation task. The differential effects of training were further demonstrated by performance on the test series. Mean numbers of errors to criterion for tests 1, 2, and 3 were 57.8, 6.5, and 3.5 for the discrimination-reversal group, and 44.3, 38.7, and 45.0 for the alternation group. Matched t tests between tests 1 and 2 and tests 2 and 3 revealed significant positive transfer effects for the discrimination-reversal group (p's $< .05$) and no transfer for the alternation group. The differences between the groups on tests 2 and 3 were also significant (p's $< .02$). These results show clearly that chimpanzees positively transfer the effects of successive discrimination-reversal training on a single stimulus pair to a new stimulus pair.

The second experiment was undertaken to test the transfer effects of successive discrimination-reversal training to a learning-set series of 180 discrimination problems. Upon completion of experiment 1 all subjects received a series of ten, 6-trial discrimination problems each day for 18 days. Figure 2 presents the percentage of correct responses on trial 2 for each group as a function of problem blocks. Throughout testing the discrimination-reversal group appeared to obtain all the information necessary for problem solutions on the first trial. The effect was immediate and persistent. The alternation group showed progressive improvement, attaining consistent one-trial learning only after 90 problems. In spite of extensive alternation training the learning-set function produced by this group was similar to those functions obtained by Hayes *et al.* (5) on naive chimpanzees. On the basis of the results obtained in these two experiments we may conclude that a win-shift, lose-stay strategy was not established in the alternation group.

A study by Riopelle (6) indicated that relatively naive rhesus monkeys who were trained on a series of 216 discrimination problems, constructed from all possible combinations of four stimulus objects, showed a consistently high efficiency of learning when shifted to an ordinary learning-set series. In view of my results and those of Riopelle, it is suggested that the learning-set phenomena may arise from any training technique producing a win-stay, lose-shift strategy which transcends the physical properties of the stimulus objects (7).

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2 April 1962

Inhibition and Facilitation of Afferent Information by the Caudate Nucleus

Abstract. Stimulation of the caudate nucleus modifies inputs to the visual system of the cat. The modification of such sensory information is similar to the modification seen on stimulation of the thalamus and brain stem reticular formation. Preliminary stimulation of the caudate nucleus at different intervals prior to the afferent input may have facilitatory or inhibitory effects on both evoked potentials and unitary responses of the visual cortex.

Recently a considerable number of experimental data have shown that there is a striking functional similarity between the caudate nucleus and the reticular formation of the brain stem. In the case of both the caudate nucleus and the reticular formation, stimulation has yielded modification of monosynaptic spinal reflexes (1), low-frequency stimulation has produced a sleeplike syndrome (2), and high-frequency or strong stimulation has produced arousal (3). Further, stimulation of the caudate nucleus produces widespread bilateral evoked potentials and recruiting responses in the specific systems (4). It has been shown in microelectrode studies (5) that a convergent organization similar to the brain stem exists within the caudate nucleus, with cells responding to a variety of sensory stimuli—olfactory, auditory, somatosensory vestibular, or visual. The recent work of Albe-Fessard (6) and her collaborators has clearly demonstrated the polysensory character of neurons within the caudate and, in both macro- and microelectrode studies, has shown evoked and single unit responses in the caudate to multimodal stimulation. Electrophysiologically, the existence of long multineuronal chains in the caudate similar to those described for the brain stem reticular formation has suggested sustained reverberatory activity (7).

There remain, however, demonstrated functions of the reticular formation which have not yet been established as functions of the caudate nucleus. Stimulation of the reticular formation or of the diffusely projecting thalamic nuclei has facilitatory or inhibitory effects upon cortical responses to afferent stimuli (8). In the series of investigations reported here an attempt was made to determine whether such modification of sensory afferents could be achieved by stimulation of the caudate nucleus.

Operations were performed on 20 cats under ether anesthesia; these were followed by curarization and respiration. The exposed tissue margins were treated with procaine and the eyes were treated with atropine at regular intervals, and the experiments were begun after 3 to 5 hours, when the effects of the anesthesia had dissipated. Two types of afferent stimuli were used—a physiological stimulus (presentation in the dark of brief flashes of light from a photostimulator) and a nonphysiological stimulus [brief pulses (0.1 msec, 6 v) delivered to the nucleus center median of the thalamus]. Potentials were always recorded in the visual cortex, from either bipolar insulated stainless-steel electrodes or tungsten microelectrodes; the gross and the single-unit responses were recorded from the same electrode, the slow and the fast components being fed through two separate amplifiers with appropriate frequency settings. The thalamocortical stimulation or the light flash was preceded by a single brief pulse, or train of brief pulses, to the head of the caudate nucleus at differing periods before the afferent stimulation.

Stimulation of the caudate prior to an afferent input clearly modifies the resulting cortical response to the afferent stimulation (Fig. 1). It may be seen that the facilitatory effect of caudate stimulation prior to an afferent input is striking, both for the direct-light stimulation (Fig. 1*a*) and for the thalamocortical stimulation (Fig. 1*b*). It may also be seen (Fig. 1*c*) that, while the most striking effect is on the grossly recorded cortical response, single-unit bursting in response to light stimulation is also enhanced.

As emphasized by other investigators (*6*), separation of the conditioning and the test stimulations is very important for facilitation or inhibition of afferent activity. An interval of 80 to 100 msec between the conditioning and the test stimulations appears to be optimal for facilitation, whereas an interval of 20 to 50 msec regularly produced inhibition. As shown in Fig. 1*d*, an interval of 50 msec between the conditioning and the test stimulations produced a distinct inhibition, although the caudate electrode was in the same place for both the facilitating and the inhibiting stimulations and the same stimulation parameters were used. Related studies in our laboratory showed that stimulation of this area also has striking inhibitory and facilitatory effects upon respiration, spontaneous motor activity, and suprasegmental reflexes accompanied by arousal (*9*).

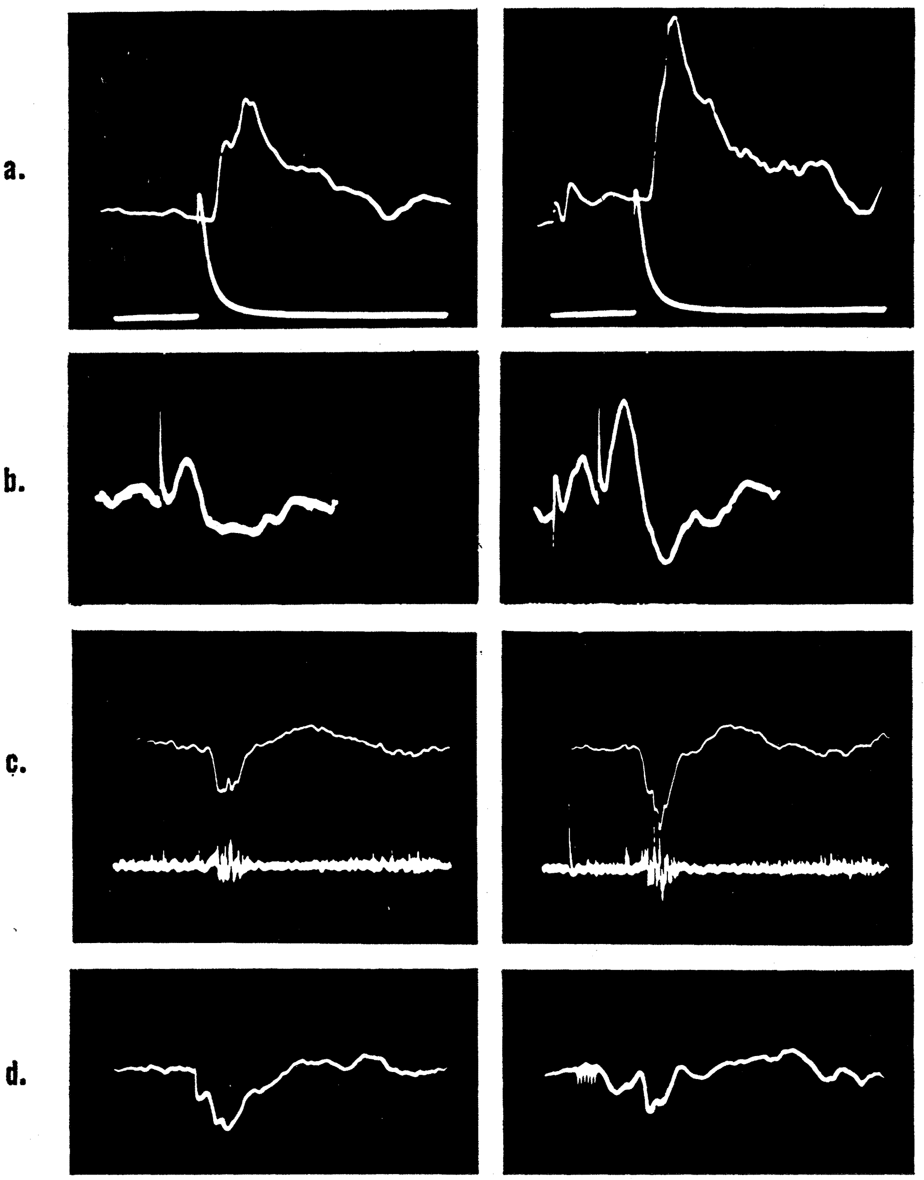

Fig. 1. Facilitation and inhibition of visual cortical responses through stimulation of the caudate nucleus. Evoked potentials, recorded from the visual cortex of the cat, are shown as controls in the column at left, in response (*a, c, d*) to light stimulation and (*b*) to thalamic stimulation. Effects of conditioning stimulation of the caudate appear in the column at right: (*a, b, c*) interstimulation interval, 80 msec; (*d*) interstimulation interval, 50 msec. Photocell response appears on the lower trace of *a*, and unit response appears on the lower trace of *c*.

Trains of pulses (100 to 300/sec) of from 20- to 50-msec duration also had profound facilitatory or inhibitory effects upon cortical evoked potentials; this was often the case even when the stimulating electrode was located at a point where single pulses had no modifying effect upon the visual cortical response. While the effectiveness of such trains may simply be a matter of increased intensity of stimulation, other data suggest that temporal summation may also be involved. Often on the first two or three occasions on which the conditioning caudate stimulus preceded the test stimulus (light), little or no facilitation was seen. By the third pairing of the conditioning and test stimulations, facilitation occurred, sometimes even when the repetition rate was only 1 pulse/sec. The similarity of outcome suggests, however, that more than one pulse to the caudate is necessary before the conditioning stimulus becomes effective in modifying the afferent response.

These findings, in addition to supporting the suggested functional parallel between the caudate nucleus and the reticular formation of the brain stem in terms of integrative activity, also throw light on questions raised by earlier studies. The modifications of sensory input observed suggest a function for the extensive convergence of afferents in the striatum (*5*). Since lesions of the caudate have not as yet been shown to cause any obvious sensory deficit, a more integrative role for the caudate appears quite possible. Clearly, the caudate, functioning in an integrative capacity, could make use of such polysensory information from the various modalities. The combination of motor and reflex coordination and sensory integration suggests a sensory-somatomotor-readiness role (*10*) for the caudate nucleus.

It is important, however, to avoid the conclusion that, with the exception of the reticular formation, only the caudate is capable of modifying sensory input at the cortex. Preliminary studies have shown that other areas of the brain, in particular the hippocampus, may have modifying influences; the effects so far demonstrated have been primarily inhibitory.

From findings collected by such classical double-shock methods as were used in the studies reported, interpretations regarding a final role for the caudate are necessarily limited. Answers to such questions of function must await more extensive behavioral studies under conditions in which complex interactions of excitatory and inhibitory responses can take place and give a natural modulation of afferent information (*11*).

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Occurrence of Whitlockite in Chondritic Meteorites

Abstract. The first reported occurrence of the tricalcium phosphate mineral, whitlockite, in several chondrites is described. The identification of this mineral and previously reported chlorapatite were made by x-ray diffraction; the results do not confirm the postulated existence of meteoritic merrillite. Some other remarks pertaining to the existence of merrillite are presented.

Specific identification of phosphate minerals in stony meteorites has been neglected, since they usually occur in concentrations of less than 1 percent. The names apatite, chlorapatite, and merrillite have been assigned to material having optical properties approximately characteristic of these minerals, but apparently no x-ray diffraction patterns have been reported.

The meteoritic mineral, merrillite, was reported by Shannon and Larsen to have the formula $3CaO \cdot Na_2O \cdot P_2O_5$ (*1*). Their identification was made from chemical analyses on concentrates of the phosphate mineral obtained from kilogram amounts of the New Concord and Allegan chondrites. Since the reported optical properties of merrillite are similar to those of whitlockite, I suspected that these two minerals could be the same.

Recognition of a phosphate mineral in meteorites is ordinarily based on examination of prepared thin rock sections under the petrographic microscope; this limits any additional work on the few grains that may be present. I have found it possible to recognize phosphate grains in etched polished sections of meteorites. Powders scraped from these grains can then be identified by x-ray methods (*2*). Powder patterns of whitlockite have been obtained from the following chondrites: Pantar, Plainview, Allegan, Waconda, Harrisonville, Holbrook, Harleton, New Concord, and Arriba. Chlorapatite patterns have also been obtained from the last three stones and only chlorapatite from the Ness County chondrite.

The terrestrial occurrence of whitlockite was first described by Frondel (*3*) as a late hydrothermal mineral in granite pegmatites from the Palermo quarry in New Hampshire. The analyzed material was essentially $Ca_3(PO_4)_2$ with some magnesium and iron replacing the calcium. The x-ray pattern was distinctly different from that of apatite and was shown to be identical to the low-temperature polymorph of artificial anhydrous tricalcium phosphate, $\beta\,Ca_3(PO_4)_2$.

Powder data (Table 1) for whitlockite from the Palermo pegmatite quarry in New Hampshire (*4*) and from the Allegan chondrite are compared with synthetic $\beta\,Ca_3(PO_4)_2$. The main difference between the natural-occurring mineral and the pure compound is in the interplanar spacings, which undoubtedly reflect the substitution of sodium, magnesium, and iron for calcium. Ando has observed this effect when magnesium substitutes for calcium in synthetic preparations (*5*). A powder pattern from a preparation of composition $0.3\ MgO \cdot 2.6\ CaO \cdot 0.1\ Na_2O \cdot P_2O_5$ sintered in air at 1350°C is identical to that of whitlockite. It should be noted that special x-ray techniques are required because the amount of material available from the meteorites is small. Consequently, the relative line intensities, rather than the absolute intensities, should be compared. In this respect the agreement is good, as indicated. The patterns of whitlockite from all meteorites studied are identical in spacings and relative intensities and most probably indicate a uniformity of composition. The chlorapatite patterns from all the meteorites are alike. Calculated cell constants for the New Concord chlorapatite are $a_0 = 9.55 \pm 0.02$ A, $c_0 = 6.81 \pm 0.01$ A, in agreement with results reported for a terrestrial sample (*6*).

The results of a semiquantitative spectroscopic analysis, made with the copper spark method, for microgram amounts of whitlockite from the Allegan, Waconda, and Holbrook chondrites are presented in Table 2. Although phosphorus was detected microchemically, it was not possible to detect it spectroscopically. A blank of reagent grade tricalcium phosphate

Table 1. X-ray powder diffraction data, Norelco powder camera (diameter 11.45 cm), CuK$\alpha_1\alpha_2$, Ni filter. Abbreviations: I, intensity; S, strong; W, weak; F, faint; V, very; M, moderate(ly).

Whitlockite				Synthetic $\beta\,Ca_3(PO_4)_2$*	
Palermo quarry		Allegan chondrite			
d (A)	I	d (A)	I	d (A)	I
8.05	W	8.02	VVW	8.19	M
6.45	MW	6.45	VW	6.51	MS
5.155	M	5.18	W	5.25	S
4.33	VVW	4.355	F	4.40	W
4.04	MW	4.04	VVW	4.11	MS
3.505	VVW			3.83	VW
3.418	M	3.43	W	3.47	S
3.33	VW	3.34	F		
3.175	MS	3.185	W	3.22	VS
3.08	F				
2.98	W	2.99	VVW	3.03	W
2.858	S	2.852	M	2.90	VS
2.73	MW	2.732	VVW	2.83	W
2.688	F	2.688	F	2.73	
2.646	F				
2.583	MS	2.583	W	2.61	VS
2.54	VW	2.525	F	2.54	MW
2.495	VW	2.502	F		
2.383	W	2.392	F	2.42	MW
2.358	F	2.358	F		
2.24	W	2.24	F	2.27	M
2.18	VW	2.178	VVW	2.21	M
2.14	W	2.141	VW	2.17	M
2.082	F			2.09	M
2.04	F	2.048	F		
2.018	W	2.012	F	2.04	M
1.98	VW	1.996	F	2.01	M
1.916	MW	1.917	VW	1.95	S
1.88	W	1.877	dbl.	1.93	S
1.862	W		F		
1.815	F	1.813	F	1.85	M
1.795	F			1.82	M
1.78	F				
1.758	W	1.762	F	1.79	M
1.712	MW	1.710	VW	1.74	VS
1.692	VW	1.695	F	1.70	W
1.67	VW	1.67	F		
1.65	VVW				
1.622	VVW			1.65	MW
1.61	VVW	1.610	F		
1.588	VVW	1.590	F	1.61	M
1.54	MW	1.539	VVW	1.56	S

* Spacings calculated from θ values of Bredig *et al.* (*9*).