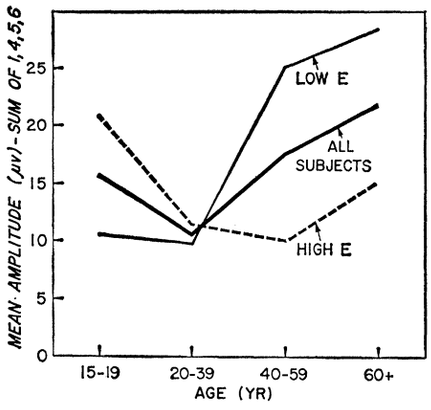

Fig. 3. Mean amplitudes by age group of peaks 1, 4, 5, and 6, summed without regard to sign, in subjects with high and with low "extraversion" scores, and in both together ($N = 58$).

with respect to the score for E. The data suggest that, if it were extrapolated to infancy, the overall curve relating age to amplitude would probably be U-shaped. The ascending limb of the U is demonstrated by our older subjects. The descending limb is shown only by those subjects which had high E scores in the youngest group; they had significantly higher amplitudes than the 20-to-39 group. Should the true curve be U-shaped, decreasing amplitude in early years would be associated with maturation and increasing amplitude in late life with neuronal degeneration (*7*). A further implication would be that neurophysiological maturation and aging both tend to occur later in more "extraverted" individuals. However, it is uncertain that the E score remains stable over many years, or that it has the same meaning at different ages. In our subjects, E decreased significantly with age ($p < .01$). The questions providing the score deal mainly with sociability, for example, "Do you like to have many social engagements?" The low E teenager could be unusually serious and mature, whereas the high E 70-year-old could be unusually lively and well-adjusted. The score may reflect a different kind of adjustment factor at each age. Further studies, with additional tests, will be required to delineate the relevant personality variables.

The results emphasize the need for the use of controls for age and sex in studies of cerebral evoked responses and draw attention to the importance of experimental designs that permit demonstration of interactions with these variables.

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Sequential Behavior Induced Repeatedly by Stimulation of the Red Nucleus in Free Monkeys

Abstract. *Rhesus monkeys in a colony were stimulated by means of intracerebral electrodes controlled by radio, for 5 seconds every minute, day and night, for periods up to 14 days. Stimulations of the red nucleus evoked a reliable sequence of behavior including bipedal locomotion, climbing, vocalization, and social interactions. During periods of spontaneous sleep, stimulations produced only a small head movement, but the whole behavioral sequence reappeared as soon as the animal awoke. In monkeys injected with chlorpromazine, the evoked behavior was inhibited in the same way as during spontaneous sleep, while the administration of atropine, Regitine, and Indurol which blocked both sympathetic and parasympathetic systems, produced only minor modifications of the sequential response.*

Excitation of the brain for long periods of time has obvious scientific and therapeutic importance which has been little explored experimentally. We know that rats may learn to stimulate their own brains repeatedly for many hours (*1*), and in previous studies with cats and monkeys I showed that intracerebral electrodes may be used for over 4 years with reliable results (*2*), while if stimulations were repeated 1 hour daily for several days, lasting electroencephalographic disturbances appeared in the amygdala and thalamus (*3*). It is conceivable that repeated stimulation of other cerebral areas less involved in epileptogenic activity would evoke reliable behavioral results without functional or electrical disturbances. In the experiments described here we have explored this possibility.

A colony was permanently established in a cage measuring 1 by 1 by 2 m, with four normal monkeys which served as controls and another animal equipped with intracerebral electrodes which was introduced into the colony for several weeks. Four monkeys with electrodes were tested in this way. Group behavior was recorded day and night by 16-mm time-lapse photography, with plus-X and infrared films. Analysis of the motion pictures permitted a practical and systematic qualification and quantification of spontaneous and evoked behavior as described elsewhere (*4*, *5*). The animals were stimulated while completely free within the colony by means of intracerebral electrodes connected through subcutaneous leads to small radio-activated stimulators strapped on their backs, as shown in Fig. 1 (*6*). The stimulations were monopolar, cathodal, exponentially falling pulses of 0.5 msec duration, 100 cy/sec and 1 to 2 ma, applied for 5 seconds every minute for 1 hour or longer. In addition, the animals were studied under restraint for oscilloscopic monitoring of the excitations and for recording of the intracerebral electrical activity. After 5 to 12 months of experimentation, the monkeys were killed under anesthesia for histological study of the brain, so that electrode placement could be verified and neuronal morphology after the long-term stimulations could be analyzed.

Electrical stimulations of the rostromedial part of the left red nucleus evoked a similar effect in each of the four monkeys studied. The effect was characterized by an immediate interruption of the animal's spontaneous activities, change in facial expression, head turning to the right, standing up on two feet, circling to the right, walking on two feet with excellent preservation of equilibrium (Fig. 1*A*), climbing the pole on the cage wall, and descend-

Table 1. Evoked behavior in monkey "Ludi" during 100 consecutive stimulations.

Behavior	1st day	7th day	14th day	Atropine	Atropine, Regitine, Indurol	Chlorpromazine
			During stimulation			
Interruptions*	100	100	100	100	100	
Head to right	100	100	100	100	100	100
Circling to right	92	98	100	96	97	0
Walking on 2 feet	95	62	57	65	22	0
Climbing	22	15	18	20	4	0
			After stimulation			
Threatening	50	32	21	38	16	0
Walking	100	92	98	100	82	0
Approach others	95	80	71	84	64	0
Avoided by others	86	72	60	72	14	0
Mounted by "Jerry"	0	6	18	0	0	0

* Interruption of spontaneous activity. The red nucleus was stimulated for 5 seconds every minute for 14 days. Each value is for 100 consecutive stimulations on 3 different days. In the three experiments in which drugs were administered, data were obtained for 100 stimulations beginning 15 minutes after injections.

ing to the floor. Then, as after effects, the animal vocalized, adopted a threatening attitude directed toward subordinate monkeys (Fig. 1*B*), walked a few steps on all fours, and peacefully approached some other member of the colony, resuming activities like picking, grooming, or just sitting down. The entire behavioral sequence was recorded with each stimulation, and the effect was reliable on different days. In a few experiments, three monkeys were simultaneously excited inside the colony, and all of them performed the full sequence of effects without interfering with each other.

To test long-term modifications of behavior, stimulations for 5 seconds per minute were applied in one monkey for 24 hours, in two others for 48 hours, and in a fourth monkey named "Ludi" for 14 days. Results were comparable in the four monkeys and Table 1 shows the data for "Ludi," who was stimulated for the longest time. This animal was a dominant female who became boss of the colony, which included two males. With one of them, named "Jerry," she maintained friendly relations which included 0 to 2 mountings per hour in the absence of stimulation. This number was not modified when her red nucleus was stimulated for only 1 hour, but mounting increased considerably after several days of stimulation, as shown in Table 1. A similar increase in mounting of a female monkey stimulated in the nucleus medialis dorsalis of the thalamus was described in a previous paper (*5*). At the end of the 2 weeks, more than 20,000 stimulations had been administered to "Ludi," and the full sequence of evoked behavior remained reliable without any indication that the experiment could not have been prolonged, perhaps indefinitely. At this time, local excitability had not changed and spontaneous electrical activity was similar to that in recordings obtained before stimulation began. Histological study of the brain failed to reveal any signs of electrolysis or neuronal degeneration around the stimulated points.

Table 2. Infrared recordings of the behavior of a colony of five monkeys during a night when one of them, "Ludi," was stimulated once every minute. The last four columns are expressed in occurrences and represent the evoked responses which occurred only during general movement. Small head movements were recorded once a minute throughout the night but are not shown in the table.

Time of observation	Behavior (expressed in minutes)			Movements of "Ludi" during general movements (No. during period of observation)			
	Sleeping		General movement	Circling	Bipedal locomotion	Threatening	Mounted
	In 1 group	In 2 groups					
9 p.m.		15					
			2				
		2					
			5	4	4	1	1
		38					
	58						
11 p.m.							
	10						
			2	2	1	1	
	108						
1 a.m.							
			1	1			
	39						
			5	4	3	2	
		75					
3 a.m.							
		12					
			3	3	2		
		105					
5 a.m.							
		32					
			2	2			
		86					

Because of its simplicity, electrical stimulation of the brain could not be considered responsible for the perfect coordination of circling, the skills of bipedal locomotion, the strategies involved in aggressive acts, or for the sequential appearance of these effects. Electricity may be a nonspecific trigger of mechanisms preestablished in the corresponding anatomical structures, and as proposed in a previous paper (*7*), behavioral performance may be considered as a pattern of motor fragments organized in time and in space, with each fragment having anatomical and functional reality inside of the brain, which can be elicited by electrical excitation. In the present experiments, the artificial electrical trig-

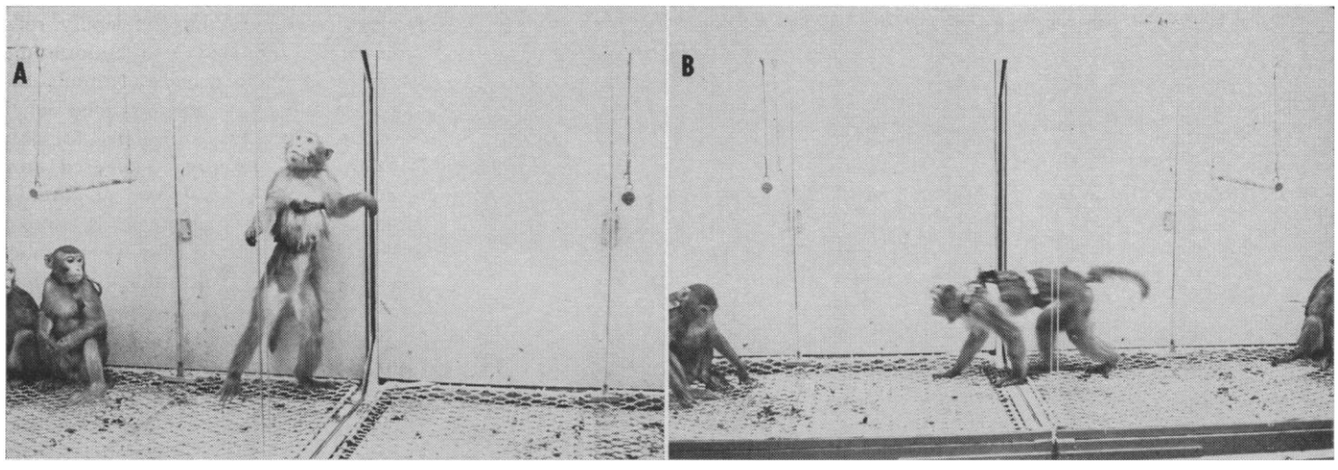

Fig. 1. Sequential behavior evoked by radio stimulation of the rostro-medial part of the left red nucleus in monkey "Ludi" included turning to the right and bipedal locomotion (*A*), and threatening (*B*).

ger was comparable to physiological triggers; both were harmless for the anatomical structure and were reliable through time, and the two competed and mixed with each other.

Adaptation of evoked responses to physiological changes in the brain was clearly demonstrated during spontaneous sleep. The monkeys usually engaged in a variety of activities during the day which were interrupted by naps occupying 10 to 30 percent of the time, and they spent the nights sleeping together in one or two clusters (Table 2) broken by several 1- to 5-minute periods of general activity to change their positions or partners. Since stimulations of the red nucleus were repeated once every minute, it was possible to analyze the influence of normal wakefulness and sleep upon the effects evoked by cerebral stimulations. Results demonstrated that in contrast with the sequential pattern of behavior evoked in the awake monkey, during sleep there was only a small turning of the head. Infrared recordings showed discrete but evident movements of the heads of the monkeys in the cluster, which were repeated every minute. Apparently the head-turning of the stimulated animal induced a chain reaction in the others, for all heads moved nearly simultaneously, although the animals remained clustered and resting. The complete sequence of evoked behavior returned as soon as the animal awoke and disappeared as soon as it fell asleep. A relation between depth of sleep and inhibition of the evoked response was observed while the animals fell asleep and the evoked response progressively diminished. Threatening and mounting (see Table 2) which were evoked during the brief periods of nocturnal activity, were never recorded on control nights.

The fact that during sleep the evoked turning of the head persisted although the rest of the sequential pattern disappeared, suggested that sleep did not change the local excitability of the red nucleus but blocked neuronal recruiting and spread of effects. In normal conditions, local excitatory states may require the cooperation of other cerebral areas (perhaps thalamic or reticular unspecific systems) for the performance of sequential behavior. This working hypothesis was supported by the results of stimulation of the red nucleus while the animal was under chlorpromazine (1 mg per kilogram of body weight injected intraperitoneally), a substance which is known to block the reticular formation. After injection of the drug, the evoked sequential behavior progressively diminished in the same way as when the monkey fell asleep, and after 10 to 15 minutes, the only response was head-turning (see Table 1). This dose of chlorpromazine certainly made the animal sleepy, but the inhibition of evoked responses continued for at least 10 hours whether or not the animal moved around the cage and its eyes were opened or closed. The following day, when the effects of the chlorpromazine had worn off, the evoked sequential behavior reappeared with all its complexity.

Blocking of the parasympathetic system with atropine sulfate (1 mg/kg, i.p.) produced obvious dilatation of the pupils but did not modify the evoked sequential pattern (Table 1). A simultaneous blocking of both parasympathetic and alpha and gamma endings of the sympathetic systems by administration of atropine sulfate (1 mg/kg), Regitine (1 mg/kg, i.p.), and Indurol (0.5 mg/kg, intravenously) (*8*), did not modify the pupil size, reduced the heart rate by about 20 percent, and increased the time the animal spent lying down, without abolishing any part of the evoked sequential response, while diminishing the frequency of some categories of behavior, as shown in Table 1. The fact that threatening was evoked 16 percent of the time, in spite of autonomic blocking, indicated that for this type of emotional reaction autonomic activation did not seem to be essential, and this is a controversial issue which deserves further investigation.

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