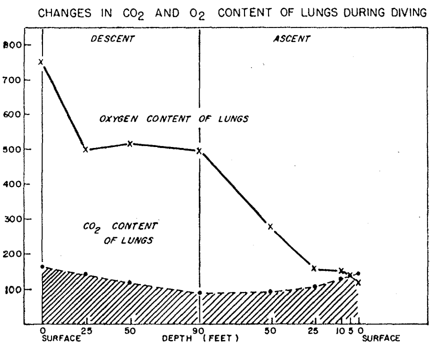

Fig. 2. CO_2 and O_2 content of lungs during diving (milliliters, STPD) calculated from measured gas tensions and volumes of mixed expired and alveolar air at various depths, the known residual volume and the total dry gas pressure in the lungs.

pCO_2 between 50 and 90 feet of depth because of the CO_2 uptake in the blood. During ascent alveolar pCO_2 falls less than would be predicted from the ambient pressure decrease because CO_2 is again entering the lungs from the blood. The influx of CO_2 into the lungs during ascent is regulated, at least in part, by the speed of ascent.

Figure 1 shows alveolar CO_2 and O_2 tensions measured after surfacing from dives in which three different rates of ascent were used. The highest alveolar CO_2 tensions were obtained in a group of six subjects (standard deviation of the mean indicated in box form) whose ascent rate averaged 1.9 ft/sec. The subject, for whom the whole alveolar pathways during diving were determined, had an ascent rate of 2.3 ft/sec and his end dive values were lower. In three cases the rate of ascent was increased to 3.5 ft/sec resulting in alveolar pCO_2 tensions as low as 30 mm-Hg.

Breath-holding experiments on the surface equal in time to the diving experiments were carried out on the same six subjects. The alveolar pCO_2 values at the breath-holding end points were significantly higher (7 mm-Hg) than the end dive CO_2 tensions (Fig. 1). Both sets of data (shown in the boxes) fall on the breath-holding point curve of Otis, Rahn, and Fenn (*6*). The diving breath-holding curve reaches a plateau at around 50 mm-Hg, which is 10 mm-Hg lower than the breath-holding breaking point curve and 10 mm-Hg higher than the normal alveolar air curve.

The lower alveolar pCO_2 values during breath-hold dives are caused by the CO_2 transfer from the lungs into the blood. A quantitative estimation of the CO_2 transfer is given in the changes in the CO_2 content of the lungs (Fig. 2). The CO_2 content decreased during descent to 90 feet linearly from 163 ml to 89 ml and remained approximately at this level during the first part of ascent to 50 feet. Only in the latter part of ascent was the normal CO_2 gradient re-established as the lungs started to refill with CO_2.

The O_2 content of the lungs does not change linearly. During the 15 seconds of effortless descent to 25 feet, 250 ml of O_2 are transferred from the lungs while the estimated O_2 consumption (based on O_2 uptake during resting) is 59 ml during this period. No further O_2 transfer occurs during descent from 25 to 90 feet. Climbing up the line during ascent results in another decrease in O_2 content which does not cover the O_2 cost during this period. Toward the end of the dive, the O_2 transfer is reduced to minimal values. These peculiar changes in O_2 content cannot be explained adequately at this time. It was speculated that the rapid decrease in O_2 tension during the last part of ascent might lead to a reversed O_2 gradient from the blood to the lungs (*5*). However, the measurements of expired and alveolar O_2 tensions obtained in breath-hold dives did not show any evidence for this hypothesis. The extremely low O_2 tension found after surfacing indicates the existing danger of hypoxia. One of our subjects became briefly unconscious upon reaching the surface, but recovered after the first deep breath.

In Table 1 the measured alveolar CO_2 and O_2 tensions are listed together with the gas tensions which should theoretically exist at various depths, based on alveolar gas tensions measured at the surface prior to the dive. The differences give an estimation of the changes in O_2 and CO_2 content of the lungs which compare reasonably well with the changes calculated from the measured expiratory and alveolar volumes and gas concentrations and the gas content of the known residual volume (*7*).

Table 1. Pulmonary CO_2 and O_2 exchange during breath-hold dives to 90 feet. The number of experiments is shown in parentheses.

Depth (ft)	Alveolar partial pressure (mm-Hg)		Change in gas (%)	
	Measured	Theoretical	Tension	Content
	CO_2 exchange			
0	30 (3) 1			
25	46 (7) 2	52	-11	-12
50	50 (3) 1	74	-32	-27
90	52 (2)	110	-52	-45
	O_2 exchange			
0	118 (3) 1			
25	153 (7) 13	206	-26	-33
50	227 (3) 6	295	-23	-32
90	344 (2)	437	-28	-34

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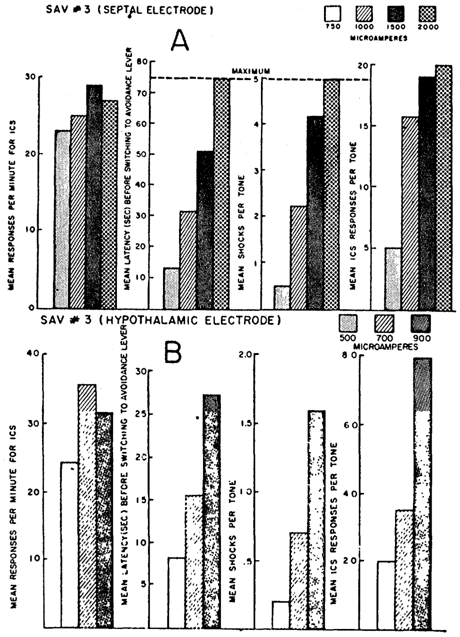
Reinforcing Brain Stimulation in Competition with Water Reward and Shock Avoidance

Abstract. Employing response rate as the index of reinforcing strength in self-stimulation experiments is questioned. With water reward or shock avoidance placed in competition with brain stimulation, self-stimulation rate does not reflect relative reinforcement value. The results agree with preference tests which show that, for a given electrode site, stimulus intensity, not rate, is directly related to reward strength.

An assumption underlying most self-stimulation studies is that performance rate reflects the strength of the reward. However, it has recently been demonstrated that with rewarding, intracranial stimulation (ICS) rate may be a misleading index (*1*). When provided with a choice, animals often exhibit a preference for either an electrode placement or a stimulus intensity which supports a significantly lower rate than



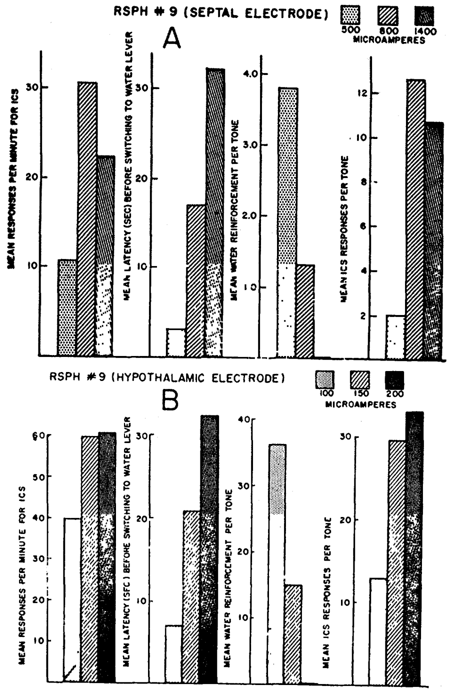


Fig. 1 (left). Response to avoidance-warning tone when working for different intensities of (*A*) septal and (*B*) hypothalamic stimulation. Fig. 2 (right). Response to tone signaling availability of water when working for different intensities of (*A*) septal and (*B*) hypothalamic stimulation. [Walter Reed Army Institute of Research]

the alternative. It would appear that conclusions based upon the explicit or implicit assumption that self-stimulation rates provide even a comparative measure of the motivational effects of intracranial stimulation need to be qualified. Similarly, curves illustrating performance rate as a function of stimulus intensity do not accurately reveal the dispersion of rewarding neural elements around the electrode tip (*2*) since various side effects of stimulation at high intensities may interfere with responding and may conceal further increases in strength of reward.

One technique of measurement involves placing different rewards in a competitive relationship. Our paper reports the results of a study in which either water reward or the avoidance of a painful foot shock (1.5 ma for 0.5 sec) competed with reinforcing intracranial stimulation for an animal's responses.

The subjects were two albino rats, each with bipolar electrodes (*3*) stereotaxically implanted in the posterior hypothalamus and medial septal nucleus. (At the completion of the experiment the electrode placements were confirmed histologically.) One animal was trained to press a lever to obtain water and the other was trained to avoid shock delivered through the grid floor. With the shock avoidance procedure the warning tone was sounded for 15 seconds and was terminated either by deliverance of the shock or by the rat's pressing of the avoidance lever during the tone period. With the water reward procedure, the animal was deprived of water for 48 hours, and lever pressing was reinforced by a 0.2-ml cup of water; lever pressing was rewarded only in the presence of a tone.

When 90 percent of total lever-pressing for water occurred during the tone period and the animal trained on the avoidance schedule successfully avoided over 95 percent of the shocks, a second lever was introduced into the testing chamber. The pressing of the second lever was reinforced with intracranial stimulation consisting of a ½-second train of biphasic rectangular waves (frequency, 100 pulses per second; duration, 0.2 msec). Response rates with both electrodes at three or four stimulus intensities were obtained from averages of five 20-minute periods. During test trials, the warning tone signaling the forthcoming grid shock and the tone indicating the availability of water were presented at random time intervals during the lever-pressing for ICS. Both tones were presented for a maximum of 1.25 minutes. Water reward was available throughout this period; with avoidance trials the shock was presented every 15 seconds (maximum of five shocks) unless the animal terminated the tone by pressing the avoidance lever. Thus, the response to the tone provided an index of the relative reinforcing strength of the ICS compared with either shock avoidance or water.

Results are presented in the two figures. Calculations were based on 35 tone presentations at each stimulus intensity. Figure 1 shows that response rate exhibits the commonly observed (*1, 4*) decline at high intensities, but response latency to the warning tone, number of shocks per tone, and responses on the ICS-reinforced lever during the tone period progressively increase with higher amplitudes of stimulation. Data obtained from septal and hypothalamic electrodes were essentially identical. The results with water reward justify the same conclusion (Fig. 2). It is particularly striking that response rate does not differentiate between middle and high stimulation intensities (Fig. 2*B*), but both the latency and the number of responses on the water reinforced lever demonstrate clearly different reinforcement strengths. It can be seen that with higher intensities of intracranial stimulation, self-stimulation rate does not increase and may even decline, but reinforcement strength as measured by resistance to competing rewards may continue to increase.

The animals' ability to perceive the signal tones may be questioned. In a previous study (*5*), however, we demonstrated that animals, while stimulated at comparable intensities, were capable of making more difficult auditory discriminations than those required by the present experiment. Also, in an experiment not previously reported, seven rats with electrodes implanted in the posterior hypothalamus were given similar tests with ICS- and food-reinforced levers. All animals left the ICS lever and responded for food at intermediate intensities; but with high intensities of intracranial stimulation the animals did not respond to the food tone. However, when the value of the food reward was increased by lengthening the period of food deprivation, they did respond.

Similar findings have been reported with other rewards. Animals can ingest only small amounts of 30 percent glucose, for example, but in preference tests they select this concentration over more dilute solutions which are ingested in large amounts (*6*). Likewise, high intensity intracranial stimulation cannot be "ingested" as rapidly as lower intensities, but as judged by either preference tests or ability to compete with other rewards it is the more potent reinforcer of behavior. It is unlikely that any single measure will adequately describe all that is implied by the concept of reward strength, but in self-stimulation experiments it is necessary to be particularly cautious about conclusions based only on response rate. It is evident that the relative reinforcement strength of brain stimulation and other reinforcers must be stated with reference to the intensity parameter of the intracranial stimulation.

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Incidence of Color in Immediately Recalled Dreams

Abstract. With careful interrogation close to the time of dreaming, color was found to be present in 82.7 percent of the dreams. This figure is substantially higher than figures reported by previous investigators using questionnaire and other methods.

Previous studies indicate that color is present in a minor portion of dreams. These studies have sought to determine either the percentage of dreams that were colored, the percentage of individuals who experience colored dreams, or the percentage of color that was present in each dream. For studies of the percentage of colored dreams, the following investigators arrived at the percentages indicated: Hall, 29 (*1*); Monroe, 21 (*2*); and Knapp, 14 (*3*). For the percentage of individuals who experience colored dreams, Husband reported 40 (*4*); Middleton, 29 (*5*); DeMartino, 17 (*6*); Lovett Doust, 13 (*7*); and Tapia, Werboff, and Winokur, 14 (*8*). For the percentage of color reported in each dream, Bentley reported 19 (*9*).

Table 1. Summary of dream recalls when subjects were awakened during periods of eye movement.

Awakenings of single subjects	Subjects	Total No. of awakenings	Dreams (No.)				
			Recalled	Colored	Vaguely colored	Not colored	Vague or no recall
1	14	14	13	11	—	2	1
2	8	16	12	12	—	—	4
3	7	21	20	10	5	5	1
4	3	12	11	6	2	3	1
5	1	5	5	2	2	1	—
6	3	18	14	11	—	3	4
7	2	14	12	9	2	1	2
Totals	38	100	87	61	11	15	13

In comparison with the low values reported by these investigators, Tauber and Green (*10*) observed with patients in analysis and with others that although color was not a prominent characteristic of dream reports, when attention was focused on color, reference to it increased substantially. This study, while nonquantitative, encouraged support for the hypothesis that color is commonly experienced but is underreported for a variety of reasons. Specifically, we hypothesized that dream reports obtained close to the time of dreaming and after careful interrogation would reveal a substantially higher incidence of color than is reflected in the current literature.

In order to reduce the time interval between dreaming and reporting, the technique of Aserinsky and Kleitman (*11*) was used. This technique utilizes the electroencephalogram and eye movements as indicators of dreaming, and has been extensively described elsewhere (*12–14*). Subjects were awakened during periods of eye movement and asked to report any dreams that were in progress prior to their awakening. They then narrated the dream material into a tape recorder. After the uninterrupted description of the dream, the experimenters attempted to elicit additional information about specific items of content in order to determine the nature and color of the objects reported. To minimize suggestion, questions about color were imbedded randomly among other questions dealing with size, shape, location, and so on.

The dreams reported by the subjects were scored as *Colored* (the dream or part of it was colored); *Vaguely Colored* (the dream or part of it appeared in vague, dull, light, or tinted colors); or *Not Colored* (the dream description contained no mention of color). We also classified the dreams into the categories of *Vague Recall* (the recall of the dream was vague or hazy or foreshortened) and *No Recall* (no dream content was recalled). The colored dreams were further subdivided into those in which color was mentioned *spontaneously* in the initial dream narrative and those in which it was *elicited* during the questioning period.

To illustrate the procedure, two excerpts from typical dream reports are presented along with the type of questions that were asked after the narrative description was given. One subject mentioned that she saw "a bar of soap in the bathtub with the baby." After completion of the narrative, in which no reference was made to color, the experimenter asked, "What did the soap look like?" The subject replied, "Like any bar of soap looks. It was round, it was *pink*, and the baby was playing with it in the bathtub." This was scored as an *elicited* color response. Another subject stated in part of his dream narrative, "I saw all the girls come in and they were wearing bright *red* bathing suits." During the questioning period the experimenter asked, "What kinds of bathing suits were they?" The subject answered, "Well, they were ordinary one-piece bathing suits, not bikinis." Then the experimenter asked, "You say the bathing suits were red; how did you know?" The subject answered, "How did I know? I saw them. They were red." This report was scored as a *spontaneous* color response.

A total of 100 awakenings were made on 38 subjects (28 males and 10 females) who ranged in age from 18 to 33. These subjects were college students and other persons available to the experimenters. They had indicated before the study that they usually recalled dreaming. None of the subjects slept in the laboratory more than two nights. From these 100 awakenings,