fibers during this period, but at first the movement was intermittent. Within 2 or 3 days, however, cytoplasm in all of the elongated cells streamed at an even rate characteristic of more mature phloem fibers.

The stems of bean plants also developed immature phloem fibers with rotational cytoplasmic streaming at a very early stage in their growth. For example, cells adjacent to the endodermis had elongated and became relatively free of reserve materials by the time the first internode was approximately 1 mm long. Within 2 days of the plants' appearance above the soil surface, elongated immature phloem fibers with pointed ends had developed in the first internodes which were then approximately 2 mm long. At this stage of stem development, the cytoplasm in the elongated cells had assumed a steady rate of rotational streaming typical of that observed in more mature fibers.

The average phloem fiber in the hypocotyl of a relatively mature plant was approximately 2 mm in length—about 200 times the width of the fiber and approximately 25 times the length of the average phloem parenchyma cell in the same plants. An individual plastid was observed continuously for several minutes as it was carried by a longicellular current within a phloem fiber. This plastid traveled 1.84 mm before reaching the pointed end of the cell where it turned and the direction of movement was reversed.

Although emphasis was placed on the study of phloem fibers in stems of bean, rotational streaming was also observed in xylem fibers of this plant. In addition, rotational streaming was observed in cells which appeared to be fibers in stems of young cucumber, tomato, sunflower, and flax. The rate of streaming in all of these cells appeared to be similar to that observed in the phloem fibers of bean plants.

Cross sections through stems of relatively mature bean plants showed an average of about 1400 phloem fibers when counts were made by observing the cut surfaces of these sections. Secondary thickening in the walls of mature phloem fibers might be expected to reduce the volume of cytoplasmic streaming in this type of cell. At flowering, approximately half of these fibers in the lower third of bean stems appeared to be closed sufficiently, due to secondary thickening, to greatly reduce the volume of streaming cytoplasm compared with that which could be found in them at an earlier stage. The remaining fibers did not show enough thickening for the volume of streaming cytoplasm to be appreciably reduced.

Since molecules must enter living phloem fibers, and this is thought to take place partly through pits, counts were made which showed that there were about 280 of these pits in the average mature fiber. The width of the pit canals leading from the inner wall surfaces to the primary walls was approximately 0.7 to 1.0 μ. Pits of this type leading from fiber cells to parenchyma cells, as well as from fiber to fiber, were noted in the stems of bean plants.

In view of the rotational streaming in the form of longicellular currents of cytoplasm described here, it appears that, upon entering a fiber, molecules or other particles would be moved mainly in an upward and downward direction to other points within the fiber where some would be expected to leave the cell. The rate of transport within a cell would depend mainly upon the rate of rotational streaming in the fiber. It should be emphasized that the speed of movement of plastids observed in the longicellular cytoplasmic currents described here was not necessarily indicative of the speed of movement of the molecular or submicroscopic units that composed the longicellular currents themselves.

Evidently, an intracellular transport system develops in immature phloem fibers very early in the growth of the plants. The system appears to be capable of moving substances from one end of the cell to the other at a relatively slow but essentially constant rate. The fact that these elongated fiber cells are generally arranged as closely-packed columns, the cells being interconnected by many pits, suggests the possibility that substances may also move to some extent from cell to cell through these columns.

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6. Credit is given M. D. Montgillion for many freehand sections. Each section was mounted in tap water under a rectangular cover glass supported as a bridge 0.26 to 0.32 mm above a standard glass slide by one square cover glass at each end of the slide. Paraffin was used to seal the edges of the square cover glasses to the slide. It was necessary that longitudinal sections be sufficiently thick to include uninjured fiber cells in order to observe streaming.
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9 June 1964

Reinforcement as Input: Cyclic Variable-Interval Schedule

Abstract. *Daily exposure of pigeons to four cycles of a reinforcement schedule in which the density of reinforcements varied cyclically as a function of time induced a periodicity in their responding matching that of the schedule, but out of phase with it. The technique used of presenting the same sequence of interreinforcement intervals in every session may have useful application in determining animals' adjustment to more complex temporal patterns of reinforcement. Investigation of animals' response to cyclic schedules of different frequencies suggests links with engineering methods of frequency analysis.*

A hungry animal will learn to peck a key or press a lever in order to receive food. Animals will do this even if food (the reinforcer) does not follow every response, but is only made available intermittently. When the rule specifying which response is reinforced depends in some way on time, the procedure is termed a temporal schedule of reinforcement. Such schedules make the reinforcer available at intervals determined solely by the time elapsed since the preceding reinforcement; the simplest temporal schedule is the fixed-interval schedule (FI)—minimum (*1*) interreinforcement interval is fixed from reinforcement to reinforcement. All other temporal schedules—in which time between reinforcements is not fixed but varies in some specified way—are termed variable-interval (VI) schedules. Historically, such schedules (with the interval between reinforcements varying irregularly or randomly) were devised in order to generate a constant rate of responding suitable as a baseline sensitive to the effects of other independent variables. The fairly steady responding produced by such schedules is apparently related to the unpredictability of successive interreinforcement intervals.

Any VI schedule may be specified by a series of numbers representing successive minimum interreinforcement intervals. As usually programmed this series is irregular and, because programming is usually accomplished by means of a punched loop of film or tape, repeats after a finite number of reinforcements. Moreover, the point in the series at which each experimental session begins varies irregularly from session to session. The properties of temporal reinforcement schedules may therefore be simply expressed in terms of three characteristics: namely, the sequence of interreinforcement intervals available, the position in this sequence at the beginning of each session, and the position at the end of each session.

In the case of fixed-interval schedules, the sequence of interreinforcement intervals is single-valued, and therefore the position at the beginning —and usually at the end—is constant. In irregular variable-interval schedules, on the other hand, the sequence of interreinforcement intervals has many values, and both starting and finishing positions in the sequence vary from session to session, usually only the number of interreinforcement intervals (reinforcements per session) remaining the same in each session. This polarity is reflected in the performances usually obtained by these two procedures. After prolonged exposure to irregular variable-interval schedules, pigeons—and most other organisms—typically develop a fairly steady rate of responding, showing little systematic variation with time from the beginning of the session (*2*). Fixed-interval schedules, on the other hand, generate a characteristic temporal pattern of responding consisting of a pause after each reinforcement, followed by responding at a progressively higher rate as the time elapsed since the preceding reinforcement approaches the fixed-interval duration ("scalloping") (*2*).

Some of the properties of a schedule intermediate between the fixed and the irregular variable-interval are here reported; the series of interreinforcement intervals, although not single-valued, varies systematically (rather than irregularly) in a way simply related to a sinusoidal function, and each experimental session starts and finishes at a fixed point in the series. The expectation, which is borne out by the results of the experiment, is that the behavior resulting from prolonged exposure to this schedule will show a degree of differentiation, with respect to time, intermediate between that produced by fixed and irregular variable-interval schedules. The form of the relation between the temporal pattern of reinforcements, as input, and the temporal pattern of responding, as output, may shed light on the mechanism controlling responding on temporal schedules in general.

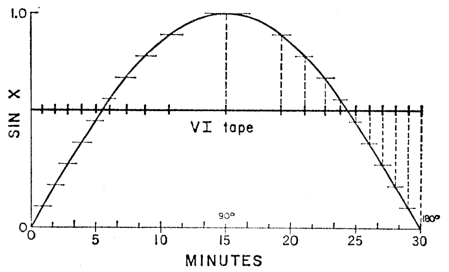

Fig. 1. The variable-interval tape. The ordinate from 0 to 1 is divided into ten equal segments and ten lines parallel to the abscissa are drawn. The 20 perpendiculars dropped from the points of intersection of these lines with the ascending and descending halves of the function $y = \sin x$ give the spacing of the holes in the variable-interval (VI) tape. In this experiment the tape, with holes for 20 reinforcements, took 30 minutes to complete one cycle (180 deg). Because this tape is actually a loop, the points of 0 deg and 180 deg are the same.

Figure 1 shows the method used to determine the spacing of reinforcements on the variable-interval tape; the caption describes the construction used. This procedure provides a simple and direct way of specifying any desired temporal pattern of reinforcements.

Three pigeons, kept throughout at 80 percent of their "free-feeding" weights, were exposed to this procedure for about 60 daily sessions. Each session consisted of four cycles (80 reinforcements) of the tape and lasted about 2 hours. Reinforcement was 3 seconds access to grain (*3*). Two of the birds had been used in a variety of other experiments; the third had no previous experimental history.

The averaged results of the last seven sessions for bird 116, and for all three birds, are summarized in Fig. 2. It is apparent that the cyclic variation in reinforcement density shown in the top panel produces a corresponding variation in the pigeons' responding. This cyclicity is easily discernible in the data for individual sessions and in individual cumulative records. A peculiarity of the particular cyclic reinforcement schedule used is shown in Fig. 1. Because of the linearity of the sine function over most of its range, the distribution of reinforcements resembles a short fixed interval much of the time. The birds responded to this by showing "scalloping" from reinforcement to reinforcement during the shorter intervals. The overall cyclic pattern did not appear to be reducible to any property of these local rate variations (*4*). Examination of the details of responding showed great uniformity among the three animals. In each case the amplitude of the oscillation was approximately 75 responses for each 5-minute period, and the phase lag was about 12.5 minutes (150 degrees with

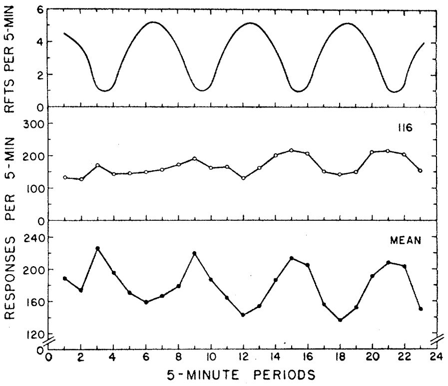

Fig. 2. The top panel shows a smooth, nonsinusoidal curve drawn through points representing the rate of reinforcement in successive 5-minute intervals throughout the session. The center panel shows rate of responding of one of the pigeons throughout the session, and the last panel shows the mean rate of responding of all three birds.

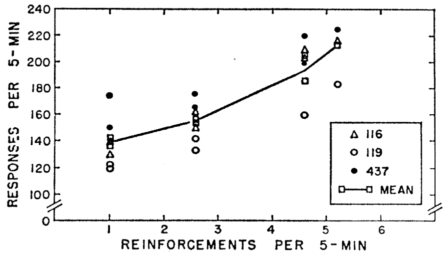

Fig. 3. Response rate as a function of reinforcement rate; obtained by displacing the response function along the abscissa as described.

respect to the reinforcement rate cycle) (*5*). The overall response rates for the three birds, 116, 119, and 437, also showed good agreement at 33.6, 33.6, and 39.4 responses per minute, respectively.

While it might be expected that both phase lag and amplitude of oscillation will be functions of variables such as cycle length, length of training, and so on, later experiments suggest that the lag, at least, is little affected by a change in cycle length from 30 to 60 minutes. Skinner's experiment (*4*), which can be considered as a 10-minute cycle, also shows a phase lag close to 180 degrees. The general pattern of responding shown in Fig. 2 emerged quite early in training, and later sessions served mainly to reduce day-to-day variation; the phase lag was always close to 150 degrees, with the birds tending to peck most rapidly when reinforcements came least frequently. The similar phase lag shown by the third and fourth cycles in Fig. 2, together with the results of later experiments, suggest that lag is likewise not a function of the number of cycles per session. Given that the cyclic pattern is established, therefore, it seems always to show a lag near 180 degrees.

Figure 3 depicts the relation between response rate and reinforcement rate implicit in the results shown in Fig. 2. These points were derived by displacing for each animal the response rate functions along the abscissa until they were in phase with the reinforcement function, and then plotting corresponding values as shown (*5*). There is reasonable agreement among the three animals on the form of the function, and the line drawn in Fig. 3 (which represents the mean of both ascending and descending parts of the function for all three birds) is quite representative. The relation is clearly not a linear one, although these data do not afford a decision between concave-upward and sigmoid alternatives.

The procedure described here has two essentially independent properties: (i) the cyclic change in reinforcement density over time, and (ii) the identity of the temporal pattern of reinforcements in successive sessions. The second property may, in the long run, prove to be the more useful as a tool, since it permits reliable estimation of an organism's adjustment to any desired sequence of interreinforcement intervals. The results of this particular experiment, which follow from the cyclic property of the procedure, suggest links with established analytical methods of systems engineering (*6*) and emphasize once more the usefulness of response rate as a dependent variable in the analysis of behavior (*7*).

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1. The programming tape can only specify the *minimum* interreinforcement interval; the *actual* interval is determined by the organism since reinforcement is always conditional upon a response. In practice the minimum value is closely approached because response rates are ordinarily high by comparison with the interreinforcement interval.
2. C. B. Ferster and B. F. Skinner, *Schedules of Reinforcement* (Appleton-Century-Crofts, New York, 1957).
3. All timing equipment was halted during the three-second reinforcement cycle.
4. The only other example I have discovered of the kind of cyclicity discussed here (apart from fixed-interval responding) is mentioned by B. F. Skinner in ***The Behavior of Organisms*** (Appleton Century, New York, 1938), p. 272; this example shows no "scalloping" despite the use of only two interreinforcement intervals.
5. These values were computed for the penultimate cycle, between the 12th and 18th 5-minute periods.
6. In particular the methods of sinusoidal frequency analysis, see J-C. Gille, M. J. Pélegrin, P. Decaulne, *Feedback Control Systems* (McGraw-Hill, New York, 1959), for modern techniques; H. von Foerster, in *Homeostatic Mechanisms* (Brookhaven Symposia in Biology No. 10, 1957), gives a short introduction to control theory for biologists.
7. The significance both of response and reinforcement rates is widely documented; see B. F. Skinner, *Am. Psychol.* **18**, 503 (1963); R. J. Herrnstein, *J. Exptl. Anal. Behavior* **7**, 27 (1964); D. Premack, *Psychol. Rev.* **66**, 219 (1959).
8. Supported by grants from NSF to Harvard University. I thank Dr. R. Herrnstein for advice and criticism. Thanks are also due to Mrs. Antoinette Papp and W. Brown, Jr., for assistance.

8 June 1964

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Visual Hallucinations during Sensory Deprivation: A Problem of Criteria

Abstract. *Attempts to elicit visual hallucinations in sensory deprivation indicate the desirability of adopting a set of criteria for identifying hallucinations as distinct from reported visual sensations in general.*

Although the frequent occurrence of visual hallucinations was one of the most dramatic reports of early workers in sensory deprivation, later experimenters have obtained less consistent results. In a recent review (*1*), Zuckerman and Cohen indicated the tremendous variety of procedures and results in this area, and attempted to identify the factors which lead to the appearance of visual imagery in sensory deprivation. Because of the lack of standardized terminology among experimental reports, the review passes lightly over what we consider to be an important problem. This is the question of differentiating between hallucinations and "reported visual sensations" (*2*) in general. As has been pointed out, the question of criteria must be answered before results can be adequately evaluated: hypnagogic imagery, daydreams, fantasies, and other sensations can be extremely vivid in sensory deprivation, and "If . . . criteria [for hallucinations] could be applied to the earlier studies, fewer hallucinations would probably be noted" (*3*, p. 39).

Table 1. Summary of the hallucination studies conducted at Princeton University.

Experimental conditions						No. of subjects reporting:	
No. of study	Duration (hr)	Visual stimulation	Motility	Other	No. of subjects	Visual hallucinations	Visual sensations
1	48	Red lamp*	Extensive		4	0	
2	72	Light leaks*	Extensive		9	6	
3	96	None	Moderate		9	1	
4	48	Diffuse†	Moderate		10	2	
5	48	Diffuse†	Moderate	Thermal noise†	11	0	
6	48	Amorphous*	Moderate		10	1	7
7	48	Geometrical figures*	Moderate		5	1?	4
8	48	Rorschach*	Moderate		5	1?	3
9	24	None	Restricted		7	0	
10	24	None	Restricted	Anxiety arousal	8	1	
11	24	Rorschach*	Restricted	‡	7	0	7
12	48	Light leaks*	Extensive		4	0	2

* Intermittent. † Constant. ‡ Experience with, expectation of, and encouragement to report unusual visual sensations.