sulfur-bearing fungicides possessed higher inherent toxicity (*21*). Japanese workers (*22*) detected low concentrations of H_2S in rice soil incubated in the laboratory, and subsequent investigations have shown that Akiochi disease, a physiological disorder of rice in Japan, is caused by H_2S (*23*).

Our results provide the first instance of real biological control of nematode populations on a broad-scale field basis. They support a rationale for investigation of the role of H_2S in the control of soil-borne diseases and as an etiological agent in physiological diseases of rice and other crop plants.

RODRIGO RODRIGUEZ-KABANA
JOSE WALFREDO JORDAN
JOHN P. HOLLIS

Department of Plant Pathology, Louisiana State University, Baton Rouge 70803

References and Notes

1. J. P. Hollis and M. J. Fielding, *Bull. Louisiana Agr. Exp. Sta.* **515**, (1958).
2. J. P. Hollis and T. M. Johnston, *Phytopathology* **47**, 16 (1957).
3. T. M. Johnston, thesis, Louisiana State University (1959).
4. A. Walkley and I. A. Black, *Soil Sci.* **37**, 29 (1934).
5. C. W. Gehrke and J. S. Thornton, mimeographed report (February 1963).
6. M. Hemala, J. Marek, Z. Valcikova, *Prace Ustavu Naftovy Vyzkum Publ.* **C 4–8**, 111 (1955).
7. J. W. Seinhorst, *Nematologica* **1**, 249 (1956).
8. J. P. Hollis, *Nature* **193**, 798 (1962).
9. ———, *Phytopathology* **50**, 639 (1960).
10. J. Pochon and H. Barjac, *Traite de Microbiologie des Sols* (Dunod, Paris, 1958), p. 281.
11. R. Rodriguez-Kabana and J. W. Jordan, *Phytopathology* **54**, 897 (1964).
12. M. J. Fielding and J. P. Hollis, *Plant Disease Reptr.* **40**, 403 (1956).
13. E. C. LeClerg, W. H. Leonard, A. G. Clark, *Field Plot Technique* (Burgess, Minneapolis, 1964), pp. 144, 367–68.
14. F. N. Ponnamperuma, thesis, Cornell University (1955).
15. R. Rodriguez-Kabana and J. P. Hollis, in preparation.
16. J. P. Hollis, *Nematologica* **6**, 315 (1961).
17. T. Takai and T. Asami, *Soil Sci. Plant Nutr. Tokyo* **8**, 40 (1962).
18. M. H. van Raalte, *Ann. Botanic Garden Buitenzorg* **51**, 43 (1951); *ibid.* vol. hors serie May 1944, (1944), p. 15.
19. E. R. Lemon and A. E. Erickson, *Soil Sci.* **79**, 383 (1955).
20. R. Rodriguez-Kabana, J. W. Jordan, J. P. Hollis, *Phytopathology*, in press.
21. J. G. Horsfall, *Principles of Fungicidal Action* (Chronica Botanica, Waltham, Mass., 1956) pp. 162–65.
22. Y. Takai, T. Koyama, T. Kamura, *Soil Plant Food Tokyo* **2**, 63 (1956).
23. S. Mitsui, S. Aso, K. Kumazawa, *Nippon Dojo-Hiryogaku Zasshi* **22**, 46 (1951).
24. Supported in part by PHS grant EF-00252 to J.P.H. We thank M. Yates, MicroTek Instruments, Inc., for assistance in gas chromatography of fatty acid samples; J. E. Sedberry, Jr., and R. H. Brupbacher, L.S.U., for facilities and advice; M. de los Reyes, A. Contino, R. Espino, R. Valdes-Fonte, A. Rovira, and A. Lichea; and H. R. Caffey, S. P. Firmin, G. Martin, G. C. Meaux, and M. Veillon of L.S.U. for assistance in planning the field experiments.

18 February 1965

Signal Detection in Fixed-Ratio Schedules

Abstract. *A psychophysical choice technique can be used to measure discrimination of the stimuli produced by two fixed-ratio schedules. As the difference between the two ratios is reduced, the number of errors in discrimination increases. The analysis differentiates between discrimination and response bias, which are frequently confused in animal psychophysics.*

The theory of signal detectability was originally developed to specify the electronic detection of radar signals in noise. Psychophysical methods based on this theory have been applied in sensory psychology to measure detection of auditory signals in noise by human observers (*1*). Psychophysical methods are usually applied to exteroceptive stimuli whose properties can be physically specified. We demonstrate that an analysis adapted from the theory of signal detectability can also be applied to detection of stimuli resulting from different reinforcement schedules.

In a fixed-ratio schedule of reinforcement, a hungry animal is reinforced with food at the completion of a fixed number of responses counted from the preceding reinforcement. Ferster and Skinner (*2*) point out that either the number of responses in the fixed ratio or the time required to emit them could serve as a discriminative stimulus. The present study makes no attempt to specify the nature of such discriminative stimuli, but does attempt to demonstrate that the discrimination of these stimuli may be studied by means of psychophysical methods.

Two adult White Carneaux pigeons were maintained at 80 percent of their "free feeding" weights. The pigeons were tested in a chamber containing three plexiglass keys mounted on one wall. Each key was illuminated from behind by a light bulb, each of the three bulbs being of a different color. A food magazine located below the center key was raised to permit access to grain as reinforcement.

There were two steps in the procedure. In the first step the bird pecked the center key the number of times specified by a fixed-ratio schedule. In the second step the bird pecked one of the two side keys. During the first step, the center key was illuminated with white light and one of two fixed-ratio requirements was in effect. The schedule for each trial was selected by a pseudorandom series (*3*). We will refer to the shorter fixed ratio as the "signal" and the longer fixed ratio as the "noise." The fixed ratio required under the signal schedule was varied during the experiment, while the noise schedule remained constant at fixed ratio 50.

When the bird had pecked the center key the required number of times, the light for the center key went off and the two side keys were illuminated. Reinforcement of a peck on the side key was contingent upon discriminating which schedule had been in effect on the center key. If the bird had just pecked the center key the number of times specified by the signal schedule, a peck on the left key was reinforced while a peck on the right key darkened the box and delayed reinforcement for 60 seconds. If the bird had just pecked the center key the number of times specified by the noise schedule, the reinforcement contingencies were reversed. Each animal was given 100 trials a day, 50 with a signal schedule on the center key and 50 with a noise schedule.

Training began with fixed ratio 5 as the signal and fixed ratio 50 as the noise. The signal-noise difference was gradually reduced as the discrimination improved. Both birds met a criterion of 90 percent responses for two consecutive days with fixed ratio 35 as the signal, and a signal-noise difference of 15. The discrimination was established in about 120 sessions. After the criterion was met, the psychophysical function for the discrimination of ratios was obtained by daily increasing the signal ratio in increments of 2 until the percentage of correct responses fell below 60 percent. Four determinations were made at each of the signal ratios in the following series: ascending, descending, ascending, descending.

Figure 1 presents the results for bird 5488. Each datum point is the percentage of the correct responses for each of the four determinations at each signal condition. The percentage decreases as the signal ratio approaches the noise ratio. The results for bird 4800 are similar. The percentage of correct responses for both birds falls

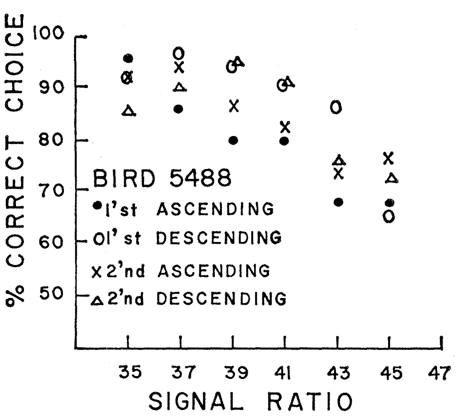

Fig. 1. Percentage of correct-choice responses for bird 5488 for each determination at each signal ratio.

below 60 percent at a signal value of fixed ratio 47. Since there are no systematic differences between the two series, we may conclude that the discrimination is not influenced by the signal ratio of the previous condition. The lack of improvement over the four sessions indicates that the data points represent asymptotic behavior.

The data were analyzed for detectability of the signals (see Fig. 2). The coordinates are the conditional probabilities of pecking the left key given the signal ratio, P (L|S), and of pecking the left key given the noise ratio, P (L|N). A peck on the left key was reinforced if the animal had just completed pecking the center key the number of times specified by the signal schedule. The positive diagonal is the locus of points at which the probability of pecking the left key is the same for either stimulus, that is, chance discrimination.

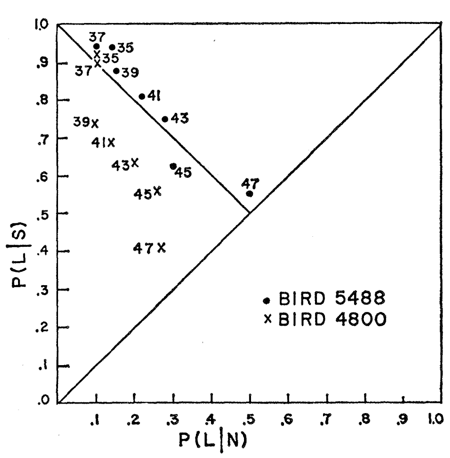

Fig. 2. Signal detectability functions. The ordinate is the probability of pecking the left key given completion of the signal ratio on the center key. The abscissa is the probability of pecking the left key given completion of the noise ratio. The number beside each point is the signal ratio with 50 as the noise ratio.

Points above the positive diagonal represent more correct responses than would be expected by chance. Points on the negative diagonal represent equal probabilities of correct choice or isobias toward either key, with the assumption of a signal a priori probability of $P = .50$. Proximity to the upper left corner is an index of the efficiency of the discrimination. Response bias increases, the greater the distance from the negative diagonal. Position habits on the right and left keys would have the coordinates 0,0 and 1,1, respectively. A point in the upper left corner would indicate errorless discrimination.

The decrease in the discrimination observed in Fig. 1 is reflected in Fig. 2, which shows that the points approach the chance line as the signal schedule increases. Response bias is slight for signal ratios 35 and 37, where the signal schedule primarily controls the choice behavior. Bird 5488 is not biased toward either key, while bird 4800 becomes more biased toward the right key. As control of the choice behavior by the stimuli from the ratios decreases, it is more likely that other stimuli, for example, the position of the choice key for bird 4800, will gradually acquire control of the choice behavior.

The choice behavior in the second step of the procedure provides a sensitive index of the discrimination between the two schedules which the animal completes in the first step. The procedure is sensitive to small signal-ratio increments. The gradual decrease in the percentage of correct discriminations suggests that the ability to discriminate ratios is a continuous, not an all or none, process.

This experiment demonstrates the usefulness of choice behavior as a dependent variable in the experimental analysis of behavior. The theory of signal detectability differentiates between response bias and discrimination, which are often confused in threshold measures obtained from animals. This procedure could also be used to investigate variables which influence response bias, for example, the a priori signal probability or the values and costs of the reinforcement matrix. The procedure may also provide a base line to investigate those variables, such as drugs, which influence the stimuli that control behavior on reinforcement schedules (*4*).

MARK RILLING

Department of Psychology, Indiana University, Bloomington

COLIN MCDIARMID

Department of Psychology, Stanford University, Palo Alto, California

References and Notes

1. J. A. Swets, Ed., *Signal Detection and Recognition by Human Observers* (Wiley, New York, 1964).
2. C. B. Ferster and B. F. Skinner, *Schedules of Reinforcement* (Appleton-Century-Crofts, New York, 1957), pp. 39–41.
3. S. S. Stevens, Ed., *Handbook of Experimental Psychology* (Wiley, New York, 1951), p. 533.
4. R. Berryman, W. W. Wagman, F. S. Keller, in *Drugs and Behavior*, L. Uhr and J. C. Miller, Eds. (Wiley, New York, 1960), pp. 243–249.

5. Supported in part by NIH grant MH-07323-01 to the University of Texas.

18 February 1965

Preferential Settling of the Sea Anemone Stomphia coccinea on the Mussel Modiolus modiolus

Abstract. *In resettling after its "swimming" response,* Stomphia *shows a special behavior pattern when in contact with bivalve shells. Movements of the tentacles, oral disc and column, and huge swellings of the pedal disc are the chief features in a coordinated purposive sequence, which settles the anemone on the shell in a few minutes.*

The sea anemone *Stomphia coccinea* is well known for the swimming response it shows on contact with certain starfishes (*1, 2*) and with a nudibranch (*3*) and to electrical stimuli (*4*). By this response, unique among sea anemones, *Stomphia* detaches its basal disc quickly and, once free, "swims" away by flexing its body repeatedly.

I have recently observed a second complex behavior pattern in this animal in response to the shell of the mussel, *Modiolus modiolus*. *Stomphia coccinea* (the so-called "small" *Stomphia*) collected by dredging in San Juan Channel of Puget Sound usually comes up on the shells of *Modiolus*. This suggests preferential settling on these shells. In a trial experiment, 18 *Stomphia* were induced to swim by contact with the starfish *Dermasterias imbricata* (*1, 2*). After swimming ceased, each anemone was placed in a separate bowl contain-