Journal of Comparative Psychology
1987, Vol. 101, No. 2, 197-201

0735-7036/87/$00.75

The Spontaneous Interconnection of Four Repertoires of Behavior in a Pigeon (*Columba livia*)

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A pigeon was trained (a) to peck a small facsimile of a banana placed within its reach, (b) to climb onto a box, (c) to open a door, and (d) to push a box toward targets. When confronted with a new situation—the banana was placed out of reach, and the box was placed behind the door—the four repertoires came together rapidly to produce a humanlike solution to the problem. A tentative account of the performance is offered in terms of empirically validated principles.

Epstein, Kirshnit, Lanza, and Rubin (1984) reported that pigeons with appropriate training histories can solve the classic box-and-banana problem in an insightful, humanlike fashion. They assessed the contributions of different experiences by varying the training histories of different birds. Three birds had learned (a) to push a box toward a small green spot placed at random positions around the base of a large cylindrical chamber, (b) to climb onto a box and peck a small facsimile of a banana suspended overhead, and (c) not to jump or fly toward the banana when it was suspended out of reach in the absence of the box; all 3 solved the problem in what has traditionally been called an "insightful" manner (Koffka, 1924; Köhler, 1925; Yerkes, 1929): Each bird first appeared to be confused; it stretched toward the banana, motioned toward the box, looked back at the banana, and so on. Then, in a continuous series of movements, it pushed the box toward the banana, sighting the banana and realigning the box as it pushed, stopped pushing when the box was near the banana, climbed, and pecked. The performances lasted roughly 1–2 min.

Birds that had learned to peck but not to climb did not successfully climb when the banana was suspended above the box. Birds that had learned to climb and peck but not to push did not push in the test situation. Birds that had learned to push but never to push toward targets pushed aimlessly during the test; one bird managed to solve the problem after 14 min in a manner that one might call trial and error. Another procedure produced behavior suggestive of the classic performance of Sultan, one of Köhler's (1925) chimpanzees: A bird whose jumping and flying had not been eliminated jumped and flew toward the banana for several minutes and then, after a total of about 7 min, solved the problem in the insightful manner described earlier.

Epstein et al. (1984) also offered a running account of the successful performances in terms of relatively simple principles. The solution can be understood as the interconnection of two repertoires of behavior which had been established separately and which were controlled by separate stimuli. The two repertoires were made to occur in close temporal proximity by the new arrangement of box and banana, which contained approximations of the stimuli that controlled each of the repertoires separately. The period of apparent confusion was probably the result of the competition between these repertoires (Cumming & Eckerman, 1965; Epstein, 1985a; Epstein et al., 1984; Migler, 1964). The sequence that emerged seems to have been determined by several processes, one of which is *automatic chaining:* As the bird pushed the box closer to the banana, it arranged for itself an increasingly close approximation of the stimulus—box under banana—that controlled climbing and pecking; hence it stopped pushing, climbed, and pecked.

Other investigations have also identified *resurgence* as a phenomenon that makes multiple repertoires available in problem-solving situations (Epstein, 1985b; Epstein & Medalie, 1983): When, in a given situation, recently successful behavior is no longer successful, other behaviors that were successful under similar conditions in the past tend to recur (Barker, Dembo, & Lewin, 1941; Epstein, 1983; Epstein & Skinner, 1980; Estes, 1955; Freud, 1920; Hull, 1934, 1952; Leitenberg, Rawson, & Bath, 1970; Maltzman, 1955; Masserman, 1943; Mowrer, 1940; Notterman, 1970; Pryor, Haag, & O'Reilly, 1969; Sears, 1943; Staddon & Simmelhag, 1971; Yates, 1970). Resurgence seems to be the principal phenomenon that allowed pigeons to solve a problem by using a box as a tool to extend their reach (Epstein & Medalie, 1983), and it also seems to have been involved in a more complicated performance in which a rapid, though not especially insightful, solution to the box-and-banana problem was generated by the spontaneous interconnection of three repertoires (Epstein, 1985a).

In this experiment, a pigeon was provided with four separate repertoires appropriate to the solution of a still more complicated problem.

Portions of this article were presented at the 26th annual meeting of the Psychonomic Society, Boston, November 1985. The work was supported in part by National Institutes of Health Grant MH32628 to the Foundation for Research on the Nervous System.

I am grateful to E. Scott for training the bird, to K. Greene, F. Lopez, and J. Miller for technical support, to M. Marsted for help in manuscript preparation, and to J. Cerella for suggestions.

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Method

Subject and Apparatus

The subject was an adult, male, White Carneaux pigeon (289WP) that had been previously used in a variety of laboratory experiments, including a problem-solving experiment in which it had been trained in directional pushing (see *Procedure* section). It was maintained at roughly 80% of the weight that it would normally attain if given free access to food. Training sessions were conducted daily in a cylindrical, wire-mesh chamber, 76 cm in diameter. A cardboard box, 8 cm high and with a base 10 cm^2, was used in some conditions, as was a small, yellow, cloth-covered facsimile of a banana, 7 cm in length. A portable enclosure, shaped like half a cylinder, was placed in the chamber under some conditions. The enclosure was 12 cm deep at its center, and it had a wire-mesh back and, in front, a door that could be opened. The door itself was made of clear Plexiglas and measured 18 cm high by 27 cm wide; its outer edge was covered with opaque black tape. It did not swing freely; its movement rotated a metal gear, the teeth of which caught a piece of metal that was fixed to the door frame. Moving the door thus produced audible clicks. A standard grain dispenser was attached to the base of the chamber.

Procedure

There were five parts to the training, which was accomplished in twenty-four sessions over a period of 9 weeks. The bird received a total of about 16 hr of training during this period and had previously received about 12 hr of training in directional pushing.[1] The major steps in establishing directional pushing were as follows: At first, aimless pushes were reinforced (with 3-s operations of the grain dispenser); then pecks to a green spot (4 cm in diameter) were reinforced; then the box was mounted on a thin wire that constrained its movement, the spot was placed at one end, and sighting the spot and then pushing the box toward it was reinforced; then the wire was removed, the box was placed close to the spot, and the sight-and-push sequence was reinforced; then the distance between the spot and the box was gradually increased.

When directional pushing was well established, a few minutes were spent each day on one or more of each of the four other aspects of training: In the absence of the box, the banana, and the spot, opening the enclosure door was shaped and maintained with intermittent food presentations. In the absence of the enclosure, the box, and the spot, the banana was placed within reach of the bird, and pecking it was shaped and maintained with intermittent food presentations. In the absence of the banana, the enclosure, and the spot, the box was fixed in place on the floor of the chamber, and stepping onto it and standing in place was shaped (by means of a series of increasingly taller boxes) and maintained with intermittent food presentations. Finally, in the absence of the other objects, the banana was placed out of the bird's reach, and the bird was placed alone with it until the bird neither flew nor jumped toward it. All of the objects were moved repeatedly to different positions in the chamber during all phases of training.

The following test situation was arranged: The banana was suspended out of the pigeon's reach (41 cm from the floor) at a point (determined by a random number) 5 cm from an edge of the chamber. The portable enclosure was placed opposite this point at the other side of the chamber, the box was placed in the center rear of the enclosure, and the enclosure door was closed. A video camera recorded the test session from a position about 1.5 m from the chamber. The pigeon was placed in the chamber, and the chamber door was immediately closed. The session was timed from the moment the chamber door was closed.

Results

The results are shown in Figure 1. At first the bird stretched toward the banana, then it oriented toward the enclosure door and box. After about 10 s, it approached the enclosure door and pecked it open. Pecks on the door persisted even after it was fully open. From 50 to 100 s into the session, the bird oriented and stretched toward the banana several times, pecked the box briefly at 88 s (not shown), and again pecked the open enclosure door. Finally, at 107 s, it began to push the box out of the enclosure. It sighted the banana several times as it pushed, stopped pushing about halfway across the chamber, climbed, and stretched toward the banana (142 s). Then it dismounted, pecked weakly at the enclosure door (150 s), climbed onto the box again, and stretched again toward the banana (160 s), after which it dismounted and pushed the box along the path indicated in Figure 2 (164–230 s). It oriented toward the banana at 221 s (not shown) and again at 231 s, after which it immediately climbed and pecked the banana (237 s).

The obvious competition of repertoires that occurred throughout this session can be understood as the result of multiple controlling stimuli or *stimulus matching* (Cumming & Eckerman, 1965; Epstein, 1985a; Epstein et al., 1984; Migler, 1964). The bird was exposed to simultaneously presented approximations of stimuli that controlled four separate repertoires, and hence each of the behaviors appeared. The sequence of their appearance and reappearance was constrained by the changing arrangement of stimuli, the bird's training history, and behavioral processes such as automatic chaining and resurgence: The bird's first stretches toward the banana disappeared rapidly, both because they were not reinforced and because of the bird's history of nonreinforcement when the banana was alone and out of reach. Unsuccessful stretches should have produced, among other things, a resurgence of other behaviors that had been successful in the chamber; thus the bird oriented toward and then approached the enclosure door and box, but the physical setup at this point prevented contact with the box. The bird pecked the enclosure door open, and this behavior, too, went unreinforced, increasing the probability of alternative behaviors. For nearly 1 min pecking the enclosure door alternated with stretching toward the banana until, finally, the bird approached and pushed the box. With the box halfway across the chamber, other behavior interfered (the spot—the usual target—was absent, and pushing was also unreinforced): The bird climbed, faced the banana, and immediately stretched toward it (the banana was now more nearly in the orientation that had allowed the bird to peck it during training sessions), but food was still withheld, so the bird dismounted, again pecked weakly at the enclosure door, which was immediately in front of the bird, and then pushed the box closer to the banana. Previous experiments

[1] The bird had previously been a subject in a replication of the "tool use" experiment (Epstein & Medalie, 1983), for which it was trained to push two types of boxes toward the green spot. It had had no experience with the enclosure door or the banana in this experiment and had not been taught to climb.

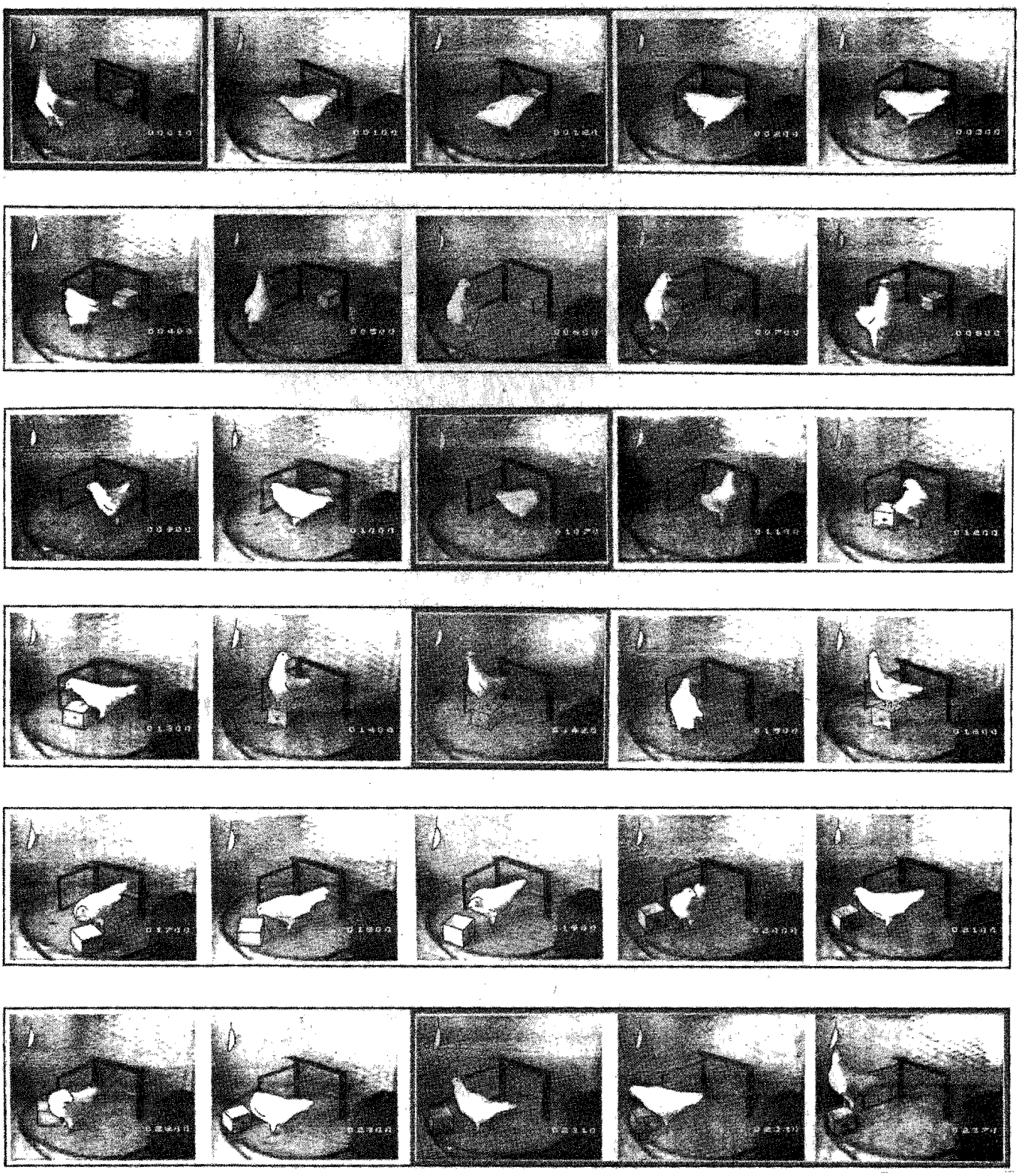

Figure 1. Videotape frames showing the bird's performance at 10-s intervals. [Photos outlined in grey show the performance at other times. The figure was constructed as follows: A dub of the original videotape was made, onto which a digital timer added running time to the lower right of the picture, with a 0.1-s resolution. Then a Tektronix 4632 raster-scan printer was used to print frames at the intervals shown. The bird, box, banana, and enclosure door were outlined in black to make them easier to identify. During the first few seconds of the performance, the bird stretched toward the banana. At about 10 s into the performance (00100 in the figure), the bird began to open the enclosure door. After it approached the banana again and pecked again at the open door, the bird pecked weakly at the box (88 s, not shown), stretched again toward the banana, and then began to push the box out of the enclosure (107 s). It climbed and stretched toward the banana at 142 s and did so again at 160 s. Finally, it brought the box to rest near the banana, began to climb (233 s), and pecked the banana (237 s).]

(Epstein, 1985a; Epstein et al., 1984; Epstein & Medalie, 1983) have shown that pigeons that have learned both to push a box toward the training target and to peck the banana will push the box toward the banana, a phenomenon suggestive of what some call *functional generalization* (Bruner, Goodnow, & Austin, 1956; Stemmer, 1972). Because the bird had never seen box-under-banana (cf. Epstein et al., 1984), it pushed somewhat beyond the banana but then, because the banana was still the target, pushed back toward the banana, and so on, until pushing extinguished in roughly a damped oscillatory pattern of pushes in the area of the banana (Figure 2). With pushing and pecking the enclosure door greatly weakened, the bird climbed and, orienting toward the banana, immediately pecked.

Discussion

This test was my first and only attempt at obtaining the interconnection of four repertoires of behavior in a pigeon, and I believe that a positive result is significant even if attempts with other pigeons fail. If my analysis of the performance is correct, however, additional attempts will succeed, although individual differences among subjects should affect both the rapidity and smoothness of the process of interconnection. As noted earlier, when another pigeon was confronted with a simpler problem, three repertoires came together to produce a solution in less than 1 min (Epstein, 1985a).

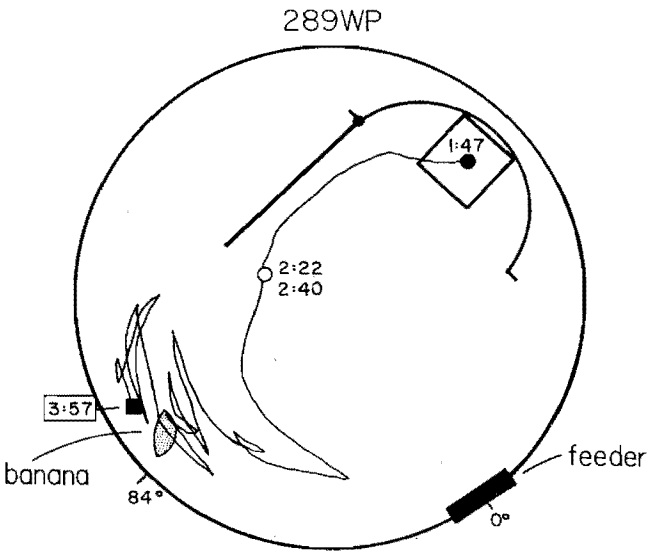

Figure 2. Floor diagram of the chamber. (The bird pushed the box fairly directly toward the banana but did not stop pushing when the box first approached the banana. Rather, it pushed somewhat beyond, pushed back toward the banana and then somewhat beyond, and so on, in roughly a damped oscillatory pattern. In so doing, the bird kept the box within a few centimeters from the position on the floor beneath the banana for more than 50 s before it finally climbed. The open circle marks the position at which the bird twice climbed and stretched toward the banana before bringing the box to rest near the banana. Times are shown in minutes and seconds.)

A large number of repertoires can undoubtedly be made to compete with each other in a novel situation, but that does not guarantee that they will combine successfully to produce adaptive behavior. Trivial factors can have profound effects: A turn of the head radically changes the visual field and hence may increase the probability of inappropriate behaviors; critical behaviors that persist too early in the performance may weaken to such an extent that they are unavailable at appropriate points later in the performance; the problem may be structured so that a slight variant of an appropriate behavior leads to a cul-de-sac (the box could easily have become trapped behind the open door of the enclosure, for example).

I have described elsewhere a general approach to understanding and predicting ongoing, novel performances in both human and nonhuman animals (Epstein, 1985c, 1986).[2] Previously established behavior manifests itself in new situations in orderly ways as a function of the genes and ontogenic history of the individual, as well as of the current stimuli and the manner in which they are changed over time by the organism or other agents. Researchers will further an understanding of ongoing behavior by varying species and individuals, by varying training histories, and by further elaborating the principles that predict the transformation of previously established behavior under new circumstances.

This approach to understanding ongoing behavior has been helpful in two ways: It has allowed the engineering of increasingly complex, novel performances in relatively simple organisms (Epstein, 1985a; Epstein et al., 1984; Epstein, Lanza, & Skinner, 1981; Epstein & Medalie, 1983; Epstein & Skinner, 1981), and it has led to the development of a formal theory, called *generativity theory*, which has proved useful in predicting ongoing behavior in human subjects under laboratory conditions (Epstein, 1985c). The approach might also prove helpful in the design of problem-solving software for artificial intelligence systems.

[2] The interconnection of repertoires has often been suggested as a source of novelty in behavior. Consider Hull (1935), Koestler (1964), Maier (1929), Maier and Schneirla (1935), Poincaré (1946), and Rothenberg (1971).

References

Barker, R. G., Dembo, T., & Lewin, K. (1941). *Studies in topological and vector psychology: No. 2. Experiments on regression and frustration.* Iowa City: Iowa University.

Bruner, J. S., Goodnow, J. J., & Austin, G. A. (1956). *A study of thinking.* New York: Wiley.

Cumming, W. W., & Eckerman, D. A. (1965). Stimulus control of a differentiated operant. *Psychonomic Science, 3,* 313–314.

Epstein, R. (1983). Resurgence of previously reinforced behavior during extinction. *Behaviour Analysis Letters, 3,* 391–397.

Epstein, R. (1985a). The spontaneous interconnection of three repertoires. *The Psychological Record, 35,* 131–141.

Epstein, R. (1985b). Extinction-induced resurgence: Preliminary investigations and possible applications. *The Psychological Record, 35,* 143–153.

Epstein, R. (1985c). Animal cognition as the praxist views it. *Neuroscience and Biobehavioral Reviews, 9,* 623–630.

Epstein, R. (1986). Bringing cognition and creativity into the behavioral laboratory. In T. J. Knapp & L. Robertson (Eds.), *Approaches to cognition: Contrasts and controversies* (pp. 91–109). Hillsdale, NJ: Erlbaum.

Epstein, R., Kirshnit, C., Lanza, R. P., & Rubin, L. (1984). "Insight" in the pigeon: Antecedents and determinants of an intelligent performance. *Nature, 308*, 61–62.

Epstein, R., Lanza, R. P., & Skinner, B. F. (1981). "Self-awareness" in the pigeon. *Science, 212*, 695–696.

Epstein, R., & Medalie, S. D. (1983). The spontaneous use of a tool by a pigeon. *Behaviour Analysis Letters, 3*, 241–247.

Epstein, R., & Skinner, B. F. (1980). Resurgence of responding after the cessation of response-independent reinforcement. *Proceedings of the National Academy of Sciences, U.S.A., 77*, 6251–6253.

Epstein, R., & Skinner, B. F. (1981). The spontaneous use of memoranda by pigeons. *Behaviour Analysis Letters, 1*, 241–246.

Estes, W. K. (1955). Statistical theory of spontaneous recovery and regression. *Psychological Review, 62*, 145–154.

Freud, S. (1920). *A general introduction to psychoanalysis*. New York: Boni & Liveright.

Hull, C. L. (1934). The rat's speed-of-locomotion gradient in the approach to food. *Journal of Comparative Psychology, 17*, 393–422.

Hull, C. L. (1935). The mechanism of the assembly of behavior segments in novel combinations suitable for problem solving. *Psychological Review, 42*, 219–245.

Hull, C. L. (1952). *A behavior system*. New York: Wiley.

Koestler, A. (1964). *The act of creation*. New York: Macmillan.

Koffka, K. (1924). *The growth of the mind*. London: Kegan Paul.

Köhler, W. (1925). *The mentality of apes*. London: Routledge and Kegan Paul.

Leitenberg, H., Rawson, R. A., & Bath, K. (1970). Reinforcement of competing behavior during extinction. *Science, 169*, 301–303.

Maier, N. R. F. (1929). Reasoning in white rats. *Comparative Psychology Monographs, 6*.

Maier, N. R. F., & Schneirla, T. C. (1935). *Principles of animal behavior*. New York: McGraw-Hill.

Maltzman, I. (1955). Thinking: From a behavioristic point of view. *Psychological Review, 62*, 275–286.

Masserman, J. H. (1943). *Behavior and neurosis*. Chicago: University of Chicago Press.

Migler, B. (1964). Effects of averaging data during stimulus generalization. *Journal of the Experimental Analysis of Behavior, 7*, 303–307.

Mowrer, O. H. (1940). An experimental analogue of "regression" with incidental observations on "reaction-formation." *Journal of Abnormal and Social Psychology, 35*, 56–87.

Notterman, M. (1970). *Behavior: A systematic approach*. New York: Random House.

Poincaré, H. (1946). *The foundations of science*. Lancaster, PA: Science Press.

Pryor, K. W., Haag, R., & O'Reilly, J. (1969). The creative porpoise: Training for novel behavior. *Journal of the Experimental Analysis of Behavior, 12*, 653–661.

Rothenberg, A. (1971). The process of Janusian thinking in creativity. *Archives of General Psychiatry, 24*, 195–205.

Sears, R. R. (1943). *Survey of objective studies of psychoanalytic concepts*. New York: Social Science Research Council.

Staddon, J. E. R., & Simmelhag, V. L. (1971). The "superstition" experiment: A reexamination of its implications for the principles of adaptive behavior. *Psychological Review, 78*, 3–43.

Stemmer, N. (1972). Concepts and abstractions. *Communication and Cognition, 5*, 45–54.

Yates, A. J. (1970). *Behavior therapy*. New York: Wiley.

Yerkes, R. M. (1929). *The great apes*. New Haven, CT: Yale University Press.

Received April 2, 1986
Revision received December 31, 1986
Accepted December 31, 1986 ■