

## THE SPONTANEOUS INTERCONNECTION OF THREE REPERTOIRES

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A previous study (Epstein, Kirshnit, Lanza, & Rubin, 1984) showed that pigeons that had acquired two relevant behaviors (pushing a box toward targets, and climbing onto a box and then pecking a small facsimile of a banana) could solve the classic box-and-banana problem. A human-like solution emerged as a result of the manner in which the two repertoires became interconnected moment-to-moment in time (Epstein et al., 1984; Epstein & Medalie, 1983). In the current experiment, a pigeon acquired three separate behaviors: (a) climbing, (b) pushing toward targets, and (c) pecking the banana. When the pigeon was confronted with the problem, a swift but erratic and not especially "insightful" solution emerged. Some simple principles shed light on the differences between the performances generated by the interconnection of two repertoires and the interconnection of three repertoires in this situation.

The emergence of novel behavior has long been a subject of speculation and debate, but, for the most part, it has defied rigorous scientific analysis. Epstein (in press) has described several sources of novel behavior which are amenable to such analysis. One, the spontaneous interconnection of repertoires, is probably responsible for the rather dramatic instances of novel behavior that lead people to speak of insight, creativity, reasoning, and so on. People are often unaware of the precise sequence of events that culminates in a "new idea," but when such sequences are observed, interconnection seems to be at work, and the process seems to be orderly.

Psychologists have long recognized interconnection as a possible source of novelty, but accounts have been speculative. For example, Maier (1929, 1932) arranged situations in which separately established behaviors in rats combined to produce simple novel performances. In one situation, a rat was trained to climb a pathway to reach food and, in the absence of the pathway, given the opportunity to explore a room. When the pathway was placed in the room, the rat approached it readily and climbed. Rats were able to do this in the dark, and rats that had not been given the opportunity to explore failed the task. Simple accounts of these results were offered by Dashiell (1930), but Maier (e.g., 1931) insisted that the "integration of past experiences" was a higher-order *Gestalt* phenomenon that is not reducible to simpler ones. The assertion has been echoed

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repeatedly since then (e.g., Duncker, 1945; Ellen, 1982). According to Maier (1931), integrations are produced by a "field of strain" set up by current stimulus conditions and the organism's motivational state.

Hull (1935, 1952) objected to Maier's analysis on the grounds that it was tautological. To explain sudden integrations of previously established behaviors in terms of unanalyzable Gestalts is, according to Hull, "merely [to] re-assert the fact of problem solution in a new terminology without in any sense deducing the outcome from any principles whatever" (Hull, 1935, p. 227). Hull (1935, 1952) suggested that current principles of learning and motivation could account for the problem-solving performances of Maier's (1929, 1932) rats and Köhler's (1925) chimpanzees. Unfortunately, his accounts were nearly as speculative as those offered by the Gestaltists. He did not offer new data, and his explanations depended heavily on speculations about internal motivational states, internal stimuli, "action tendencies," and "anticipatory goal reactions," none of which had been documented in the reports he was analyzing.

Epstein and Medalie (1983) and Epstein et al. (1984) have identified some simple, empirically validated phenomena that reliably produce a variety of novel performances (also see Epstein, 1983, 1984a, in press). These phenomena can be observed and studied directly, and their role in the emergence of problem-solving or other novel performances can be tested in detail.<sup>1</sup>

The approach may be summarized as follows: Interconnection is likely when multiple behaviors are made available, either through resurgence of previous reinforced behaviors during extinction (Epstein, 1983, 1985) or by multiple controlling stimuli (Cumming & Eckerman, 1965; Migler, 1964; cf. Epstein et al., 1984). Multiple behaviors may combine to produce new sequences (Epstein et al., 1984; Epstein & Medalie, 1983; Epstein & Skinner, 1981), behaviors that have new functions (Epstein & Skinner, 1981), or behaviors that have new topographies. Interconnections come about moment-to-moment in time through a variety of processes, any and all of which may be operating simultaneously. One important process is automatic chaining: One behavior changes the environment or the orientation of the organism and hence produces stimuli that make other behaviors more or less likely. When topographies are compatible, blends may appear, as one sees in verbal behavior or painting. The dynamics can be extremely complicated as behaviors are simultaneously waxing or waning in strength, resurging, producing new stimuli, and so on.

Epstein et al. (1984) reported that pigeons that had acquired relevant behaviors could solve one of the box-and-banana problems with which Köhler (1925) had confronted his chimpanzees.<sup>2</sup> The solutions were rapid and remarkably human-like. An account of their emergence was offered in the terms described herein. By varying the training histories of different animals, the authors were also able to offer reasonable guesses about the contributions that several different histories make to success in the problem.

"Insightful," human-like performances were produced when pigeons had

<sup>1</sup>They can also be represented formally. The author has recently presented equations and a computer model which predict the emergence of novel performances moment-to-moment in time. The model has been validated with humans (Epstein, 1984b).

<sup>2</sup>A preliminary report appeared in Epstein (1981).

acquired two repertoires: First, in the absence of the banana, they were trained to push a small box toward a green spot placed at random positions around the base of a chamber. Second, in the absence of the spot and with the box fixed in position beneath the banana, they were trained to climb onto the box and peck the banana. Finally, in the absence of both the box and the spot, the banana was placed out of reach, and jumping and flying toward it were extinguished.

In the test situation, the banana was placed out of reach near an edge of the chamber at a position determined by a random number, and the box was placed in the center of the chamber. Each pigeon was thus confronted with a stimulus configuration it had never seen before, one which was identical to the one with which Köhler (1925) had confronted his chimpanzees. Each of three pigeons that had had all of the training herein described behaved in a similar fashion. At first, the bird appeared to be "confused": It stretched toward the banana, turned back and forth from the banana to the box, and so on. Then, rather suddenly, it began to push the box toward the banana, sighting the banana and readjusting the path of the box as it pushed. Finally, it stopped pushing when the box was near the banana, climbed onto the box, and pecked the banana. The performances lasted 49, 67, and 101 seconds, respectively.

The problem would be more difficult if a bird were trained separately (a) to peck the banana when it was within reach and (b) to climb onto the box (that is, to climb but not to peck anything overhead). Would a solution still emerge if the climbing and pecking repertoires were separated? The question has theoretical significance, since the moment-to-moment account of the performance reported by Epstein et al. (1984) would apply only partially to this case. The principles they invoked predict the period of confusion and pushes toward the banana, but at that point the account breaks down. These issues will be discussed later. At the moment, an empirical question is posed: Can a solution to the box-and-banana problem emerge from the interconnection of the three separate repertoires?

## Method

### *Subject and Apparatus*

One adult male White Carneaux pigeon (159WP) served in this experiment. He had previously been used in a variety of experiments but had never been used in a problem-solving experiment.<sup>3</sup> He was maintained at roughly 90% of his free-feeding weight. All sessions were conducted in a cylindrical wire-mesh chamber 76 cm in diameter. A small cardboard box, 8 cm high and 10 cm square, was employed in some conditions, as was a facsimile of a banana, 7 cm in length and made of yellow cloth mounted on a wire frame. A round piece of cardboard, which was 4 cm in diameter and painted fluorescent green, served as the target during training.

### *Training Procedure*

Thirty-nine training sessions were conducted over an 11-week period. The total training time was 28 hrs. The three repertoires were established using

<sup>3</sup>This was in fact "Jack" in Epstein, Lanza, & Skinner (1980) and Epstein & Skinner (1981).

methods similar to those described by Epstein and Medalie (1983) and Epstein et al. (1984):

*Session 1.* Adaptation.

*Session 2.* Hopper training.

*Sessions 2 to 5.* Pushing the box was shaped and maintained on a rich variable-ratio schedule of access to grain. The feeder was operated by hand, and each reinforcement lasted approximately 3 seconds. The schedule was gradually thinned, and reinforcement was made contingent on sequences of pushes which covered a large area of the floor. Not all pushes were reinforced. Since head-on thrusts allow poor control, they were never reinforced. Appropriate pushes hook the box at one of its corners near an upper edge and thus rotate it slightly. The bird's head must be tilted to one side or the other while pushing in this manner (Figure 1).

*Session 6.* Pecking the green spot was shaped and maintained on a rich variable-ratio schedule. The spot was moved to different locations along the base of the chamber wall.

*Sessions 6 to 20.* The box was mounted on a wire that was stretched taut from one side of the chamber to the other. The wire allowed the box to move freely in a straight line. The spot was placed at one end and the box was placed near it. A two-response sequence was established: The feeder was operated when the bird pecked the spot and then moved its head behind the box and pushed the box toward the spot. The sequence was altered as rapidly as possible in a number of ways: First, we replaced the peck with a mere head movement in the direction of the spot—a conspicuous observing response. Second, the distance between the box and the spot was gradually increased, and food was gradually made contingent on multiple pushes toward the spot. In all sessions, the spot was repeatedly moved from one end of the string to the other, and the wire was repeatedly repositioned.

*Sessions 20 to 21.* Pecking the box was extinguished in the absence of the green spot.

*Sessions 21 to 25.* During the first part of each session, the training was continued with the box mounted on the wire, as previously. Then, for only a few minutes at first and for increasingly longer periods thereafter, the training was continued with the wire removed. The box was placed close to the spot at first and gradually moved farther away. The wire was reintroduced and the box was moved closer to the spot from time to time when the performance deteriorated. To correct a tendency to peck from only one side (that is, leaning left), the wire was suspended close to the wall in a way that forced the bird to peck from the other side.

*Sessions 26 to 29.* The training was continued without the wire. The position of the spot was moved repeatedly, and the

distance between the spot and the box was varied until the bird could reliably sight the spot and push the box from the center of



*Figure 1.* Videotape frames showing the bird's performance during the test at 2-s intervals, from 2.0 s to 60.0 s. Thus each row of the figure shows 10-s intervals of the performance. The figure was constructed as follows: A dub of the original tape was made, onto which a digital timer added running time to the lower left of the picture, with a 0.1-s resolution. Then a Tektronix raster-scan printer was used to print frames at the intervals shown. The bird, box, and banana were outlined in black ink to make them easier to identify. A period of "confusion" is evident during the first 20 s. The bird pushes the box and brings it to rest near the banana during the next 30 s. It begins to climb at 50.0 s and ultimately pecks the banana about 10 s later. A white triangle in the first frame marks the spot on the floor beneath the banana (the triangle was added to the photograph; there was no such mark on the chamber floor). See the text for a detailed analysis of the emergence of the performance.

the chamber to the spot in a continuous series of pushes. The feeder was operated when the box made contact with the spot. By Session 29, the pigeon performed this task reliably.

*Sessions 30 to 31.* The banana was suspended from the ceiling of the chamber within reach of the bird. Pecking the banana was shaped and maintained on a rich variable-ratio schedule. The position of the banana was changed repeatedly. In the absence of the banana and in the presence of the spot, we continued to reinforce directional pushes for a few minutes each day, as described previously.

*Sessions 32 to 39.* In the absence of both the banana and the spot, a small box, roughly 3 cm high and 4 cm square at its base, was fixed into position on the floor of the chamber, and stepping onto it and standing was reinforced. Taller boxes were immediately substituted until the bird reliably climbed onto the test box, which was 8 cm high. Pecking the boxes was extinguished. For a few minutes each day, with the box removed and banana within reach, pecking the banana was reinforced as described. With the banana removed and the box and spot present, directional training also proceeded as described. The positions of the box, spot, and banana were changed repeatedly.

*Sessions 38 to 39.* For a few minutes each day, in the absence of the box and the spot, the banana was suspended out of reach, 41 cm from the floor, and reinforcement was withheld. The purpose of this procedure was to extinguish jumping and flying toward the banana, but we observed little jumping and no flying. The position of the banana was changed repeatedly.

During the 39th session: (a) In the absence of the spot and the banana, the pigeon repeatedly climbed onto the box. (b) In the absence of the spot and the box and with the banana suspended within reach, the pigeon pecked the banana readily. (c) In the absence of the banana, the pigeon pushed the box rapidly and in reasonably straight lines from the center of the chamber to various locations in which the spot was placed around the base of the chamber wall. (d) In the absence of the spot and the box and with the banana suspended out of reach, the pigeon stretched toward the banana but neither jumped nor flew toward it.

#### Test

The box was placed in the center of the chamber, and the banana was suspended out of the bird's reach, 41 cm from the floor, at a location about 3.5 cm from the edge of the chamber on a radius selected by a random number (84 degrees clockwise from the feeder). The trainer placed the bird in the chamber and then sat in a chair beside it, as she had during training. The performance was videotaped.

#### Results and Analysis

The bird's performance during the test is shown in Figure 1 in frames from

the videotape. The overall performance was similar to successful performances reported by Epstein et al. (1984). A period of apparent confusion was evident, during which the bird stretched toward the banana and looked back and forth repeatedly from the box to the banana (Frames 2.0 s to 20.0 s). Then the bird pushed the box in a manner that brought the box to rest beneath the banana (Frames 22.0 s to 48.0 s). It began to climb at 50.0 s and finally pecked the banana at 59.5 s (Figure 2).

This performance is unlike those reported by Epstein et al. (1984) in two critical respects. First, in the earlier study the pigeons sighted the banana repeatedly as they pushed, especially when the box was near the banana. The pushes were not only directional; they appeared to be "directed." In the current performance, there was little evidence of sighting, even when the box was beneath the banana. Second, in the earlier study the birds climbed as soon as the box reached the banana; indeed, two of them climbed and stretched toward the banana even before the box reached it. In the current study the box approached the banana at about 34 s, at which point the bird pecked it back and forth weakly for nearly 18 s before climbing. Finally, in the previous study all three of the birds pecked the banana immediately after climbing. In the current performance, nearly 10 s elapsed between the time the bird began to mount the box (50.0 s) and the time it pecked the banana (59.5 s).

All in all, the performance did not seem to be especially "insightful," which

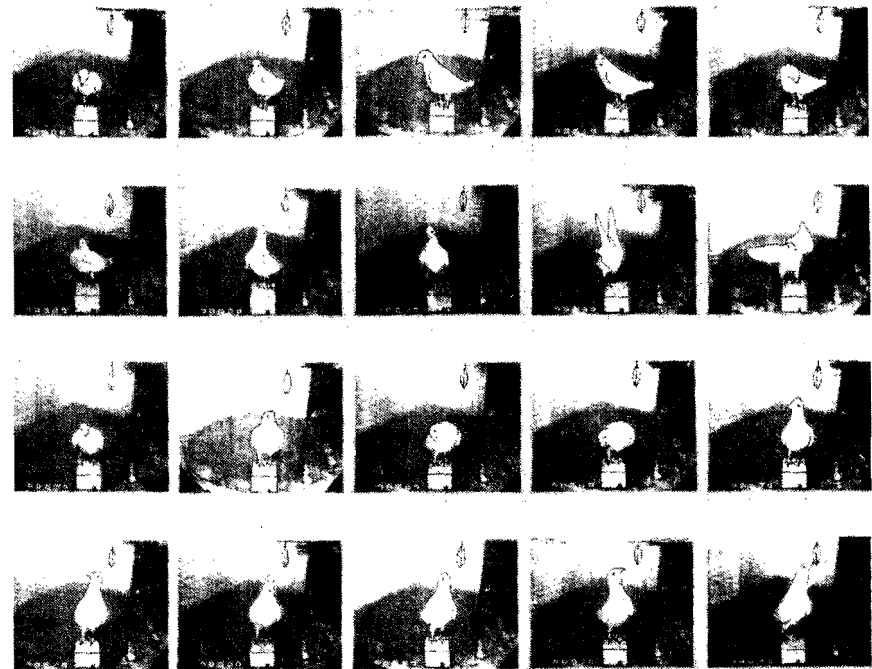


Figure 2. Videotape frames showing the bird's performance during the final 10 s of the test, from 50.0 s to 59.5 s, in 0.5-s intervals. See the text for an analysis of the performance.

is to say that it did not fulfill one of Köhler's requirements for genuine insight, namely that once the performance begins, it occurs in a smooth, continuous fashion until it is complete. In this case, the pushing, climbing, and pecking were somewhat disjointed from each other; they appeared to be three "unrelated" acts, as opposed to a single response unit. The final peck seemed to be "accidental" (Figure 2).

The differences between the performances can be understood in terms of some simple principles. For convenience, the performance will be divided into six parts:

*Period of apparent confusion.* In the previous study, the behavior that suggested confusion appeared to be the result of competition between behaviors set up by the new arrangement of the box and the banana. Because of the bird's training, banana-over-box controlled behavior with respect to the banana, and box-with-spot controlled behavior with respect to the box. In the test, the bird was faced with a stimulus that was approximately intermediate between these two: The banana was shifted away from the box, and the spot was shifted outside of the field of vision. Hence, one would expect behavior with respect to each stimulus to occur (consider Cumming & Eckerman, 1965; Migler, 1964).

In the current study, four controlling stimuli were established—box alone, box-and-spot, banana-within-reach, and banana out-of-reach. The test configuration was not a clear intermediate; rather, it was a compound whose elements were similar or identical to three of the training stimuli. The compound produced multiple, incompatible behaviors with respect to both the banana and the box.

*Starting to push.* In both studies, the competition that was set up initially was unstable, since reinforcement was withheld. Behavior with respect to the banana weakened rapidly relative to behavior with respect to the box because of the recent history of extinction of jumping and flying when the banana was out of reach (compare the performance of bird 110YP in Epstein et al. [1984]). In the previous study, as behavior with respect to the box increased in relative frequency, the bird faced it more directly; it thus faced a close approximation to the stimulus that controlled pushing, and, indeed, it began to push.

In the current study, as the bird came to face the box more directly, it should have been inclined both to push and to climb, since box-and-spot controlled pushing and box-alone controlled climbing. No climbing occurred, but we would expect to see climbing in replications of this experiment. Note that climbing would rapidly extinguish, and we would then expect to see a resurgence of pushing (Epstein, 1983, 1985),<sup>4</sup> at which point the performance should continue more or less as it does below (with the possible exception that the bird might fail to climb again when the box reached the banana).

*Pushing toward the banana.* Why the birds pushed the box toward the banana is still under investigation. Epstein et al. (1984) described a simple pilot study which is suggestive: Two birds, trained to push toward the spot but never to

<sup>4</sup>The principle of resurgence may be stated as follows: When, under given stimulus conditions, a response that was recently reinforced is no longer reinforced, behavior that was reinforced in the past under similar stimulus conditions tends to recur. The principle has, in various guises, enjoyed a long and distinguished history in both clinical and experimental psychology. For further discussion and a review of empirical support for this principle, see Epstein (1985).

peck the banana, did not push toward the banana in the test situation. Subsequent to this test, pecking the banana was reinforced, and then the test was repeated. Now each bird sighted the banana and pushed the box toward it (each test consisted of three 2-min extinction trials with the banana in three different locations). Each bird stopped pushing near the banana and neither climbed. This suggests that the spread of effect between the target spot and the banana does not occur because of common physical characteristics ("stimulus generalization") but rather because of a common reinforcement history ("functional generalization") (Epstein, 1984a; Epstein et al., 1984). In other words, in both the current and the previous performances, the birds push toward the banana apparently because of (a) a history of reinforcement for pushing toward the spot and (b) a history of reinforcement for pecking the banana.

*Stopping.* From this point on, the previous performances and the current one differ considerably. In the previous study, we attributed the cessation of pushing to automatic chaining: As the bird pushed, it set up increasingly closer approximations to a stimulus that controlled other behavior—box-under-banana, which controlled climbing and pecking. The tendency to stop should have increased as the box approached the banana.

But in the current study, *the pigeon had never seen box-under-banana*. The bird should have been no more inclined to stop pushing when the box was beneath the banana than when the box was far away. Indeed, the bird did not stop pushing when the box reached the banana (Figure 1, Frame 36.0 s); it pushed somewhat beyond (Frames 36.0 s to 48.0 s). How did the bird manage to keep the box in the right area for so long, and why did it eventually stop pushing? As in the pilot study described, the banana seemed to have acquired some of the controlling characteristics of the green spot. Thus when the bird pushed the box beyond the banana, it should then have tended to push the box back toward the banana again, in a damped oscillatory pattern. Since reinforcement was withheld, pushing should have tended to disappear with the box still near the banana, and indeed that is what occurred.

*Climbing.* The principle of resurgence seems useful again at this point: With pushing and reaching toward the banana reasonably well extinguished, other previously reinforced behaviors, such as climbing, should have appeared. Thus, finally, the bird climbed.

*Pecking the banana.* The last 10 s of the performance are shown in 0.5-s intervals in Figure 2. Perched on the box, the bird at first faced away from the banana (that is, faced left in the figure), made a preening movement (52.0 s), stumbled briefly and flapped its wings (53.5 s to 54.5 s), faced down (56.5 s), faced slightly left (57.5 s), faced forward (58.0 s), faced right (59.0 s), and finally pecked the banana (59.5 s). Automatic chaining would seem to be responsible for the peck: The bird's own behavior (orienting to the right) produced a visual stimulus (banana within reach) that controlled other behavior (pecking). Because this process is orderly, it would be inaccurate to call the peck "accidental," but the bird clearly did not climb onto the box "in order to" peck; which is to say, it did not climb because climbing had previously produced an opportunity to peck. Climbing and pecking were indeed disjointed.

Various behaviors have been described herein as if they were discrete, but

in fact they are probably best described by smooth, continuous curves. The behaviors may appear to be discrete only because at any one moment we see only the most probable one, but at that same moment another behavior might be highly probable, a third less probable, and so on. The behaviors and their interactions may prove to be describable by continuous functions.

### Conclusions

The present performance was not especially "insightful," but neither was it "trial and error." These terms have occasionally been used as if they encompassed all problem-solving performances, but in fact they describe only rather extreme cases, each of which is relatively rare. "Insightful" performances are characterized by periods of confusion or inactivity followed by the sudden and continuous emergence of the solution (Koffka, 1924; Köhler, 1925; Yerkes, 1929). "Trial and error" solutions are characterized by the appearance of a great deal of behavior that is irrelevant to the problem; they are clumsy and slow. But virtually none of Köhler's (1925) chimpanzees performed in either fashion on any occasion, and the same may be said for human subjects (consider Duncker, 1945).

A more effective way to understand problem-solving performances and indeed all novel behavior is to identify the principles according to which new behavior is continuously generated under new circumstances. The same set of functions should presumably predict a wide range of possible performances in a problem-solving situation, including non-solutions, absurd and awkward solutions, insightful solutions, and so on. Indeed, all behavior—no matter what post hoc labels we may apply—should be predictable according to such principles. The principles should predict *different* performances as a function of relevant parameters: the genes and history of the individual, current stimuli and the manner in which such stimuli are changed over time as a result of the organism's behavior, and so on. If one knows the transformation functions and the relevant parameters, one should be able to predict where in this range the performance will fall and to provide a detailed probability profile of the succession of behaviors that will appear.

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