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Skinner's Early Research

From Reflexology to Operant Conditioning

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The facts of Skinner's research in the 1930s on the acquisition of operant behavior are combined with his own later comments. Skinner discovered that a single reinforcement is enough for conditioning of an arbitrary response. The combination of successive extinction curves after single reinforcements within one session led to the first schedule of intermittent reinforcement. Operant conditioning also could be arranged to generate new forms of behavior by shaping by successive approximation. Skinner was first influenced by the then dominant terminology of reflexology, but he soon rejected this stimulus–response tradition by demonstrating that eliciting stimuli play no role in operant conditioning. Theoretical implications of Skinner's early research are compared and contrasted with other theories of conditioning at the time.

Some great scientists have donated to posterity either their brains or some genetic material presumably under the assumption that similar brains and genes may perhaps produce great scientists in the future. Subscribing to a different philosophy of life, Skinner donated to posterity detailed descriptions of his environment from his childhood, through his active career, and to his retirement (Skinner, 1956, 1967, 1976, 1978, 1979, 1983, 1989). From this source of information one can glimpse some of the conditions that initiated and kept a young scientist at work.

The monumental influence of Skinner's first book, *The Behavior of Organisms: An Experimental Analysis* (1938), is well established (e.g., Thompson, 1988). Less well recognized is Skinner's very early research that led to the formulation in his book. The purpose of this article is to highlight what Skinner himself considered the crucial first steps that carried him from reflexology to operant conditioning. The early research is placed in a historical perspective, and Skinner's accounts later in his career are interwoven with details from the original research. The article describes Skinner's discovery that a single reinforcement is sufficient for operant conditioning, the role of extinction in the discovery of intermittent schedules, the development of the method of shaping by successive approximation, and Skinner's break with and rejection of stimulus–response psychology.

A Search for Orderly Data

Through his writings, Skinner described the conditions that prevailed when he entered graduate school at Harvard University in the fall of 1928. Even though he had not had any psychology as an undergraduate, he had read Pavlov's *Conditioned Reflexes* (1927) and Watson's *Behaviorism* (1924) as well as Bertrand Russell's *Philosophy* (1927). Skinner (1979) stated that these books "prepared me for a career in psychology" (p. 4) and that Russell's works had converted him to behaviorism. In particular an article by Russell (1926) in the *Dial* had introduced Skinner to Watson's work (Skinner, 1979, p. 10).

As a graduate student, Skinner followed developments in philosophy of science in general and made contact with Bridgman's *The Logic of Modern Physics* (1927) as well as Mach's *The Science of Mechanics* (1883/1960), both of which emphasized the scientific value of an objective and empirical analysis (see also Marr, 1985, and Smith, 1986). A college teacher had earlier showed Skinner Loeb's *Comparative Physiology of the Brain and Comparative Psychology* (1900), which had suggested that an independent science of the "organism as a whole" might be possible. Even though Skinner was a student of psychology, he did most of his research at the Department of General Physiology. The head of that department, W. J. Crozier, had worked with Loeb and was therefore a splendid supporter of Skinner's early ideas.

Thus inspired to conduct an objective study of the behavior of the whole organism, Skinner began by looking for lawful processes in the behavior of the intact organism (see Skinner, 1956). He studied rats' adaptation to a startling sound, their forward motion when their tails were suspended, and how a sudden sound disrupted walking on a long runway. To make the rat go down the runway, Skinner placed food at the end, and the slight vibration of the runway as the rat walked on it was the main datum. However, he did not quite know what to do with all the data, and the rat's movement on the runway was not as easy to quantify as was Pavlov's counting of drops of saliva. Following Pavlov's general lead of "control your conditions and you will see order" (Skinner, 1956, p. 223), Skinner simplified his experiment by adding a back alley. Once placed on the runway, the rat would run to the food dish, eat, wait a bit, and then run back to the start position along the back alley. It would then repeat the sequence. Skinner did not interrupt the rat by taking it out for each run, and he thereby embarked on his first element of an account of voluntary behavior. Often the rats waited after

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having eaten before running back to the start position. By quantifying these delays with a stopwatch and plotting them on a graph, Skinner saw that they grew longer as the session progressed. Here were the orderly data that he had been looking for all along.

Because orderliness of data was the main impetus for his research, he simplified the bulky rectangular runway in several steps and arrived at a small box, wherein the rat simply had to open a door that covered a food bin. An electric switch placed on the door recorded when the rat entered the food bin. The behavior was thus reduced from walking several feet on the runway to opening a door. In turn, Skinner obtained even more smooth and orderly curves. When plotted on logarithmic paper, the delays between entries to the food bin formed straight lines. Skinner soon realized the implications of the results and wrote to his parents

> In a word, I have demonstrated that the rate in which a rat eats food, over a period of two hours, is a square function of the time. In other words, what heretofore was supposed to be "free" behavior on the part of the rat is now shown to be just as much subject to natural laws as, for example, the rate of his pulse. (Skinner, 1979, p. 59)

Skinner's immediate academic environment proved supportive of his early work. In particular Crozier was probably partly responsible for the continuation of Skinner's early research. Thus, of the reactions to the orderly eating curves, Skinner (1979) related that

> Crozier was indeed worked up. Orderly processes in the organism as a whole composed the field of General Physiology, and I had turned up a reproducible example. He was soon to give a talk at Rutgers and took a slide or two of my records with him, and later I reported to my parents that "what Crozier said about me at Rutgers stirred up a lot of comment." I also reported that he was sending me notes almost every day about things to be done, and that he wanted a couple of articles before summer. (p. 60)

In comparison with today's publication bureaucracy, one cannot help envying Skinner the immediate gratification he must have experienced in submitting the paper in April and having it published in June of the same year (Skinner, 1930). So, merely 26 years old, and even before he had stuck a lever in his box, Skinner had contributed to an independent science of behavior and articulated the implications of orderly and reproducible behavior for the cherished notion of the "free" organism.

Conditioning of an Arbitrary Response

Skinner realized that his rats obviously had learned to push the door to the food tray. Because of his early readings of Pavlov, he had always wanted to study learning per se. However, pushing the door was compounded with entry into the tray to retrieve the food. Skinner next attempted a separation of the learned component from the food retrieval component by adding a new response that was arbitrary with respect to eating. Later, Skinner (1979) remarked that

> I was studying what Pavlov would call unconditioned reflexes, or at best the physiological process of ingestion, but I was interested in learning. Running around that tilting rectangular track was learned, but, like behavior in a maze, it was composed of too many "reflexes." Pushing open the door of a bin was also learned, but it was not a sample of behavior that would be easy to study. I needed a simpler response. I bent a heavy wire into a square U and mounted it like a lever so that the crosspiece moved up and down. A spring held it up, but a rat could easily press it down. . . . The conditioned response I proposed to study was "pressing the lever." (p. 62)

Adding the lever-pressing response did not change the shape of the curve of the "eating reflex," which therefore became more general. However, Skinner still wanted to study how the rats learned to press the lever. Having already read Thorndike's *Animal Intelligence* (1911), Skinner saw a resemblance between his own lever apparatus and Thorndike's problem box, from which a cat could escape by turning a latch. But there was an important difference. In Thorndike's case, the cat was placed in the box over and over, and the time it took the cat to escape—the latency—was the main datum. In Skinner's case, the rat remained in the box for a long period of time (usually an hour). Skinner referred to his own apparatus as *the repeating problem box* because the trial of a lever press followed by food could be repeated by the rat itself. For Thorndike, the frequency of trials was determined by the experimenter, whereas for Skinner the frequency of trials was entirely an aspect of the rat's behavior. The difference between Thorndike's and Skinner's experimental arrangements therefore made an important difference in how the data were obtained, analyzed, and interpreted. Indeed, Skinner dropped the term *trial* altogether, and the title of his first learning article was simply "On the Rate of Formation of a Conditioned Reflex" (Skinner, 1932). Four rats first were carefully habituated to the chamber so that handling and the noise from the food pellet dispenser did not disturb their behavior. Next, Skinner presented food pellets at irregular intervals until the rat ate each pellet immediately on delivery. Even though the lever had been in the box continuously during preliminary training, it was fixed in the lower position so that the rat could not move it. Skinner next freed the lever and arranged for a pellet to be delivered each time the rat pressed the lever. Figure 1 shows the resulting cumulative curves. Each lever press advances the curve a small step vertically, and time passes continuously horizontally. Two rats, KI2 and P2, began responding at a high rate as soon as the first lever press produced a food pellet. For the other two rats, P1 and KI1, the high rate was reached after the second and fifth response, respectively.

Skinner's (1932) first article on conditioning is remarkable not only for the results but also for the theoretical issues involved. He argued that two types of conditioning must exist. In Pavlov's conditioning, two reflexes S–R and S′–R′ were elicited or paired simultaneously. S–R is a reflex that is observable before conditioning, where

S refers to stimuli emanating from food and R refers to some response involved in the ingestion of the food. S′–R′ is also a reflex but of an investigatory type, such as looking (R′) at a light that turns on (S′). Such investigatory reflexes ordinarily disappear through adaptation. Pavlov had found that when S′ is presented alone after many simultaneous pairings of S–R and S′–R′, R will occur without S. That is, S′ will come to elicit R. In Skinner's conditioning, two reflexes were chained together. He demonstrated that when the investigatory reflex (S′–R′), pressing the lever (R′) after seeing it (S′), immediately precedes the S–R reflex (food–eat), S′–R′ will be strengthened, as seen in the increased rate of R′. Skinner thus initially retained Pavlov's terminology by arguing that the lever (S′) elicited the response to the lever (R′) and that this *reflex* had gained strength by being followed by the S–R reflex. Another important theoretical emphasis in Skinner's first article on conditioning was that he described R′ not as a repetition of the same physical response but as a group of many similar responses. Similarly, S′ was a group of similar stimuli that elicited the elements of R′. Skinner reasoned that the submaximal rate of the S′–R′ reflex in the beginning of the curve for some rats (e.g., P1 and KI1 in Figure 1) could result because not all elements of S′ may be conditioned on each occasion. As more elements of S′ became conditioned, the rate of R′ would show a positive acceleration, as seen for those rats.

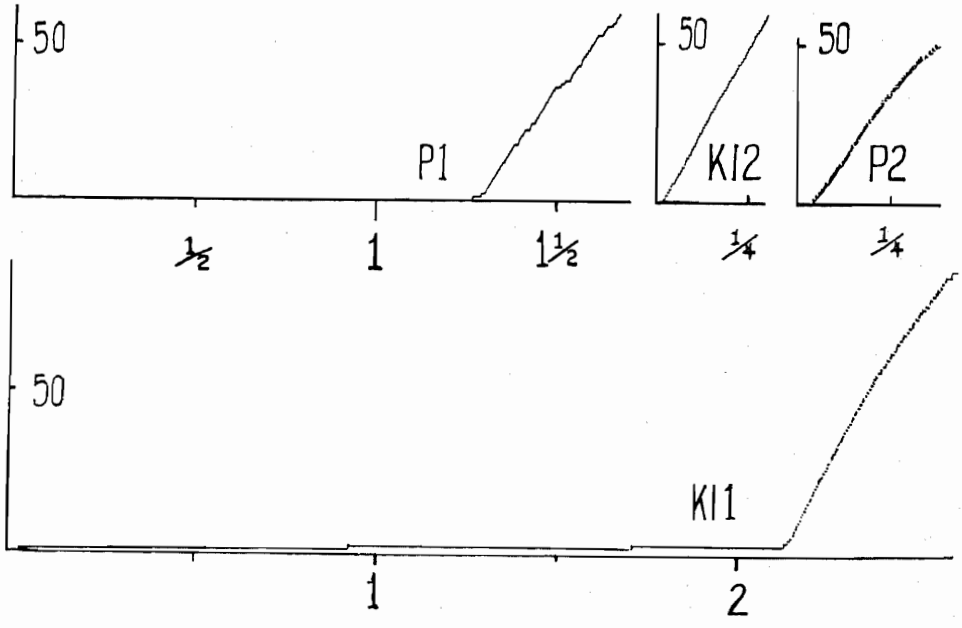
The First Extinction Curve

The reverse of conditioning, extinction, had been studied by Pavlov (1927) by repeatedly presenting the conditioned stimulus without the unconditioned stimulus, and the conditioned reflex slowly vanished. Skinner's first extinction curve turned up by accident. Skinner (1979) related that one day the pellet dispenser had jammed while he was absent:

> When I returned I found a beautiful curve. The rat had gone on pressing although no pellets were received, at first more rapidly than usual since no time was lost in eating, but then more and more slowly as time wore on. Some oscillation between high and low rates made the cumulative record wavelike. The change was more orderly than the extinction of a salivary reflex in Pavlov's setting, and I was terribly excited. It was a Friday afternoon and there was no one in the laboratory whom I could tell. All that weekend I crossed streets with particular care and avoided all unnecessary risks to protect my discovery from loss through my death. (p. 95)

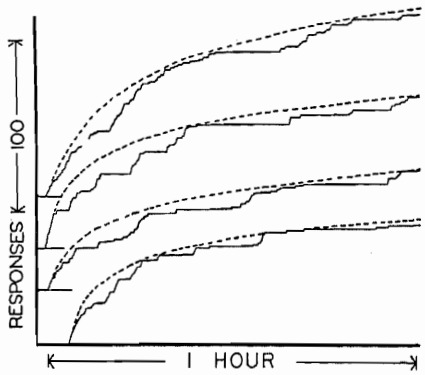
In his article "On the Rate of Extinction of a Conditioned Reflex" (Skinner, 1933a), lever pressing was first conditioned in four rats with 100 pellets in one day. On the next day the pellet dispenser was disconnected so that lever pressing did not produce food pellets. Figure 2 shows for each rat the resulting extinction curve over a period of one hour; each rat made more than 50 unreinforced responses to the lever. Skinner argued that the extinction

Figure 1
Conditioning of Lever Pressing



Note. Cumulative records of lever pressing from the first session where each press was reinforced with one food pellet. Four records show data for four rats. The abscissa shows the time in hours, and the ordinate shows the cumulated number of responses to the lever. From "On the Rate of Formation of a Conditioned Reflex" by B. F. Skinner, *Journal of General Psychology*, 7, p. 280, 1932. Reprinted with permission of the Helen Dwight Reid Educational Foundation. Published by Heldref Publications, 1319 18th Street, NW, Washington, DC 20036-1802. Copyright 1932.

Figure 2
Extinction of Conditioned Lever Pressing



Note. Cumulative records of lever pressing during an extinction session without delivery of food pellets for lever pressing. In the preceding session each of 100 lever presses was reinforced with one food pellet. Four records showing data for four rats are displaced along both axes to avoid overlapping. The abscissa shows time in hours, and the ordinate shows the cumulated number of responses to the lever. This graph is a simplified version of the original from Skinner (1933a), which appeared in Skinner (1938). The broken smooth curves are theoretical logarithmic curves drawn by Skinner. From *The Behavior of Organisms: An Experimental Analysis* (p. 75) by B. F. Skinner, 1938. New York: Appleton-Century-Crofts. Copyright 1938 by B. F. Skinner. Reprinted by permission of the B. F. Skinner Foundation.

curve was a case of "pure behavior" because no elicitation was directly involved. The behavior was entirely due to the past circumstances of having been reinforced in the previous session. Skinner noted that he now had a curve that made contact with Pavlov's work. Extinction apparently had not been attempted before with Thorndike's trial-and-error learning. So Skinner's extinction data extended Pavlov's by demonstrating that behavior can be controlled in the absence of any eliciting stimuli. These extinction data were a first step toward Skinner's later recognition that eliciting stimuli are not important in a scientific account of purposive or voluntary behavior. Instead, the past reinforcement history was the critical determinant of whether or not the response occurred.

A Single Reinforcement Is Enough for Conditioning

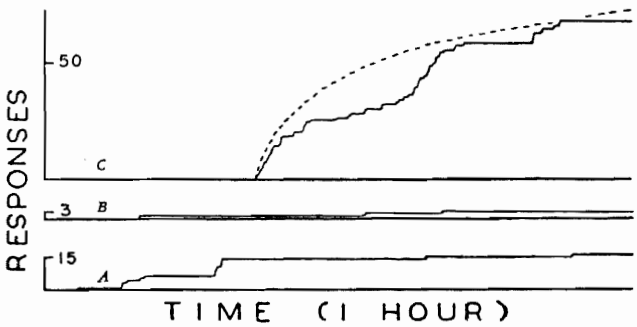
In his first conditioning experiment, where each lever press produced a food pellet, Skinner (1932) had argued that the strength of the reflex could reach the maximal value after only one reinforcement. However, the rate of lever pressing also reflected the effect of continued reinforcement. The slight positive curvature on the rate curve for some subjects suggested an effect of continued reinforcement. To study more directly the effect of a single reinforcement, Skinner (1933c) next isolated the effect of continuous reinforcement from the effect of the first reinforcement. Using new rats with the same apparatus and preliminary training as described above, Skinner arranged for only the first lever press to be reinforced.

Figure 3 shows cumulative records of lever pressing under three conditions for one rat. In C the first response occurred after 20 minutes. This single response was followed immediately by a single reinforcement (the delivery of three food pellets in rapid succession). Even though only one response instance was reinforced, the rat began to respond immediately. The ensuing extinction curve showed that a single reinforcement was sufficient for conditioning of that response. Records B and A were obtained earlier during preliminary training and show the low rate of responding before conditioning. Skinner also controlled for the possible facilitating effects of food presentations on lever pressing by delivering food pellets after periods without lever pressing, but he found no comparable increase in the response rate. Skinner replicated this result in a number of rats using only a single food pellet in some cases (Skinner, 1938) and water reinforcement in other cases (Skinner, 1936). By demonstrating that the change in behavior could be practically instantaneous, Skinner had distanced himself considerably from Pavlov's work. Later Skinner (1979) wrote

> The speed with which the behavior changed was surprising. Pavlov's "all-time record holder" was said to have needed seven reinforcements before making a conditioned response, and Pavlovian conditioning had been criticized as too slow to explain most learning in daily life. My rats learned to press the lever in one trial, and no learning could be faster than that. . . . I had apparently found a process of conditioning that was different from Pavlov's and much more like most learning in daily life. (pp. 88–89)

Skinner's results obviously also had implications for the customary interpretation of Thorndike's trial-and-error learning. Thorndike's latencies plotted over a series of trials formed a "learning curve" as the cat escaped more and more quickly. The shortening latency reflected the gradual disappearance of movements that were unsuccessful in escaping from the box. In Thorndike's Law

Figure 3
Conditioning by a Single Reinforcement



Note. Cumulative records of lever pressing for one rat during three sessions. In record C a single press on the lever is reinforced once (using three food pellets delivered in rapid succession); the following presses on the lever were unreinforced. A and B are control records from sessions before conditioning. From " 'Resistance to Extinction' in the Process of Conditioning" by B. F. Skinner, *Journal of General Psychology, 9,* p. 422, 1933. Reprinted with permission of the Helen Dwight Reid Educational Foundation. Published by Heldref Publications, 1319 18th Street, NW, Washington, DC 20036-1802. Copyright 1933.

of Effect, successful behavior was "stamped in" and unsuccessful behavior was "stamped out," hence the term *trial-and-error learning*. But Skinner's method of conditioning was different and produced different results.

> In carefully controlling my conditions I had eliminated almost all the unsuccessful behavior in Thorndike's "learning curve" *before conditioning took place*. There was nothing to be "stamped out." The successful response did not merely survive; it was conspicuously strengthened. So was the successful response in Thorndike's experiment, but the evidence was not to be found in his "learning curve." (Skinner, 1979, p. 88)

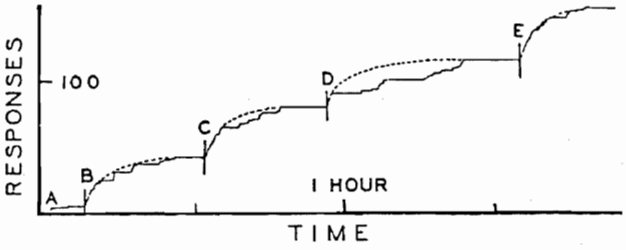
Skinner's rapid and instantaneous single-reinforcement conditioning was therefore a step closer to being a fundamental mechanism of conditioning than was Thorndike's Law of Effect and Pavlov's classical conditioning.

From Acquisition by a Single Reinforcement to Schedules of Reinforcement

Skinner (1933a) also had demonstrated that a previously conditioned and subsequently extinctioned response easily could be reconditioned. By combining the methods of reconditioning and single-reinforcement conditioning, Skinner arrived at his next breakthrough. Skinner (1979, p. 97) mentioned that a low supply of food pellets (which he made himself) also played a role in the decision to reinforce the response only now and then because the supply thereby would last longer. Skinner simply reconditioned the response with a single reinforcement on a periodic basis several times within one session. Figure 4 shows data for one rat from a two-hour session that followed a previous session of continuous conditioning and a subsequent extinction session. At B, C, D, and E, a single food pellet was presented dependent on a single press on the lever; the pellet dispenser was disconnected at all other times. Each reinforcement was followed by an extinction curve that was practically complete when the next reinforcement occurred (Skinner, 1933b). With these data in hand, Skinner surmised that if reconditioning by the second reinforcement would occur before extinction after the first reinforcement was nearly complete, the remainder of the first extinction curve might sum with the second to produce a higher rate, and so on for the third and fourth reinforcement. Figure 5 shows cumulative records of lever pressing for two rats. In previous sessions, the rats had the usual preliminary training, one session of continuous reinforcement, and a subsequent session of extinction. During the session shown in Figure 5, one response was reinforced at B for one rat and at B′ for the other rat; lever pressing then went unreinforced for five minutes until C (or C′), when the next lever press was reinforced, and so on for each vertical mark. When reconditioning was repeated periodically at an interval shorter than the time for complete extinction, the successive curves indeed continued to sum until the response strength remained at a near constant value.

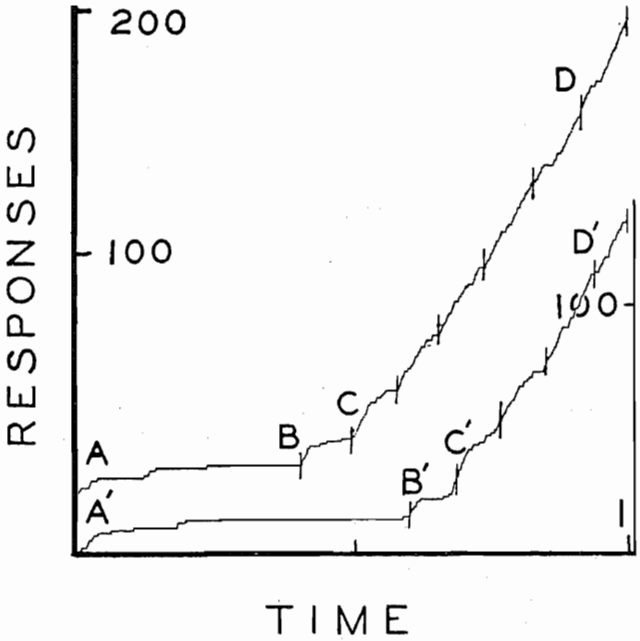
Again, Skinner's results added a significant empirical as well as theoretical distance to both Pavlov's and Thorndike's conditioning models. Pavlov had, unbe-

Figure 4
Repeated Reconditioning by Single-Pellet Reinforcement Within One Session



Note. Cumulative record of lever pressing for one rat. A single lever press was reinforced with one food pellet at B, C, D, and E. All other lever presses were unreinforced. The abscissa shows time in hours, and the ordinate shows the cumulated number of presses on the lever. The broken smooth theoretical curve was drawn by Skinner. From "The Rate of Establishment of a Discrimination" by B. F. Skinner, *Journal of General Psychology, 9,* p. 306, 1933. Reprinted with permission of the Helen Dwight Reid Educational Foundation. Published by Heldref Publications, 1319 18th Street, NW, Washington, DC 20036-1802. Copyright 1933.

Figure 5
Periodic Reconditioning



Note. Cumulative records of lever pressing for two rats. A single lever press was reinforced with one food pellet at each vertical mark beginning at B and B′; the minimum time between the marks is five minutes. All other lever presses were unreinforced. The abscissa corresponds to one hour, and the ordinate shows the cumulated number of presses on the lever; note the different ordinates for the two rats. From "The Rate of Establishment of a Discrimination" by B. F. Skinner, *Journal of General Psychology, 9,* p. 307, 1933. Reprinted with permission of the Helen Dwight Reid Educational Foundation. Published by Heldref Publications, 1319 18th Street, NW, Washington, DC 20036-1802. Copyright 1933.

known to Skinner, experimented with periodic reconditioning by arranging for the unconditioned stimulus to follow the conditioned stimulus only on some trials. However, the conditioned response was difficult to acquire and maintain under such conditions (see Kimmel, 1977). Periodic reconditioning also generated a new paradigm compared with Thorndike's Law of Effect where reinforcement occurred on every trial. Besides, Thorndike's experimental setup would have proven unsuitable for studies involving high-rate emission of behavior. Skinner had not explicitly looked for a paradigm that would maintain conditioned behavior.

> I was not immediately aware of the significance of these results. Up to that time the study of learning had been concerned almost exclusively with acquisition and forgetting, but I had stumbled onto the *maintenance of behavior in strength.* (Skinner, 1979, p. 99)

So what is now better known as the fixed-interval schedule was the first intermittent schedule of reinforcement that Skinner designed. An important element in Skinner's immediate success with intermittent reinforcement was that his previously established method of recording conditioned behavior as response rate was ideally suited for an analysis of how schedules of reinforcement maintain a high response rate over time.

Shaping New Behavior by Successive Approximation

In the experiments with continuous and intermittent reinforcement, Skinner had waited for lever pressing to occur before he presented the first reinforcement. Some years later, at the University of Minnesota, Skinner explored the generation of new and complex behavior that did not occur before conditioning. Other psychologists earlier had taught chimpanzees to first earn and then later spend poker chips in exchange for food (see Boakes, 1984). Inspired by this work, Skinner designed an environment for a single rat, Pliny, who was to release a marble by pulling a chain, grasp the marble and carry it across the cage to deposit it in a slot that would release a food pellet. This complex chain of behavior would never occur by itself. Instead, Skinner slowly built up the final performance through small changes in the apparatus (see Skinner, 1979, pp. 196–197). The news about this "smart" rat spread from local newspapers to *Life* magazine. Figure 6 shows pictures of Pliny at work, as they appeared in *Life* in 1937.

Clark Hull from Yale, who visited Skinner's laboratory, was impressed with Skinner's demonstration. Later he wrote

> As an example of the remarkable lengths to which training may be carried through the progressive shifting of response intensities by means of judicious reinforcement of small oscillatory variations in a favorable direction, we have a striking experiment performed a few years ago by Skinner. (Hull, 1952, pp. 210–211)

Several years were to pass before Skinner shaped new behavior not through small changes in the apparatus but through small changes in the contingency of reinforcement by the method of hand shaping (see Skinner, 1951, 1953, 1958). The first experiment of this sort took place while Skinner worked at General Mills during World War II. Regarding the first episode of hand shaping, Skinner (1979) later wrote

> We had shaped a very complex topography of behavior through successive approximation in a matter of minutes, and we "gazed at one another in a wild surmise." I remember that day as one of great illumination. We had discovered how much easier it was to shape behavior by hand than by changing a mechanical device. (p. 268)

Curiously, years earlier, in his exchange with Konorski and Miller (see below), Skinner (1937) had written a clear account of what amounts to hand shaping of lever pressing in rats:

> Elaborate and peculiar forms of response may be generated from undifferentiated operant behavior through successive approximation to a final form. This is sometimes true of the example of pressing the lever. A rat may be found (very infrequently) not to press the lever spontaneously during a prolonged period of observation. The response in its final form may be obtained by basing the reinforcement upon the following steps in succession: approach to the site of the lever, lifting the nose into the air toward the lever, lifting fore-part of body into the air, touching lever with feet, and pressing lever downward. When one step has been conditioned, the reinforcement is withdrawn and made contingent upon the next. With a similar method any value of a single property of the response may be obtained. (p. 277)

Yet, Skinner mentioned (1979, p. 268) that this earlier account of shaping was actually an account of Thorndike's method of hand shaping. So, according to Skinner, Thorndike evidently is to be credited for having been the first to use the method of hand shaping. Unfortunately Skinner did not mention where Thorndike described this method. Possibly Skinner might have been referring to Thorndike's (1911) brief indications that he had managed to train a monkey to jump on top of a cage, cats and monkeys to lick or scratch their fur, and chickens to go through chains of different behavior to obtain food. These training procedures must have involved some form of hand shaping because no operanda were used. However, Thorndike's account of how behavior can be modified in this manner is far less complete than Skinner's. Also, from a theoretical perspective, Thorndike's trial-and-error learning does not address how one form of behavior can be changed to another; trial-and-error learning involves the strengthening of behavior that already exists full blown in the animal's repertoire. Thorndike did, however, describe a principle of "associative shifting" as "the shifting of a response from one situation to another by gradually changing a situation without disturbing the response to it" (Thorndike, 1913/1970, p. 16). This principle appears to be very similar to what is now known as stimulus shaping (e.g., Cooper, Heron, & Heward, 1987). Note that Skinner changed both the situation and the response form in his initial demonstration of shaping by successive approximation. In any event, by systematically imple-

THIS SMART UNIVERSITY OF MINNESOTA RAT WORKS A SLOT MACHINE FOR A LIVING

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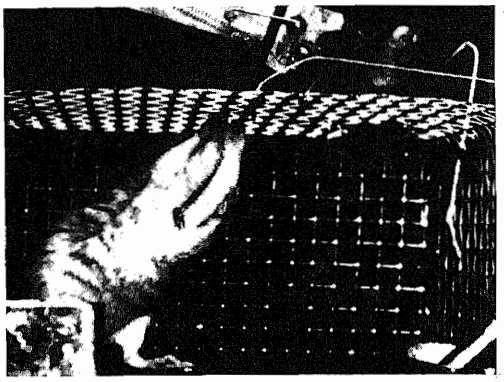

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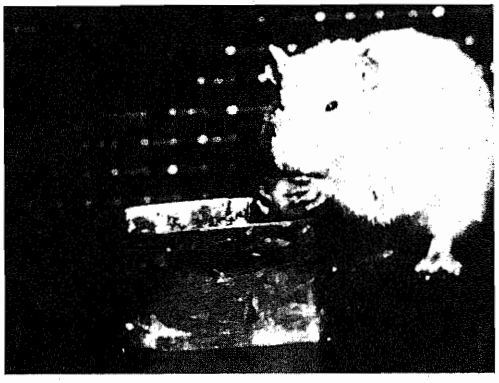

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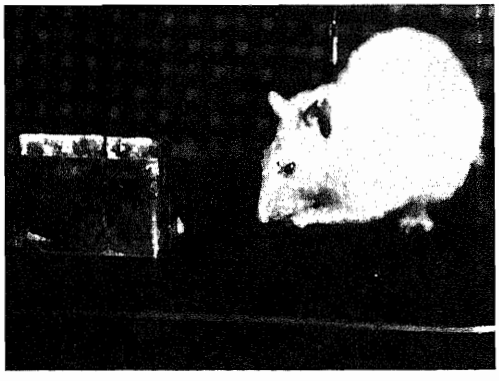

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Figure 6. A series of photographs of the rat, Pliny, who was trained by the method of differential reinforcement of successive approximations. The following captions appeared beneath each figure in the original version but were deleted here because of difficulty in reproducing them with sufficient clarity: 1. This is Pliny, the smart white rat who lives in a wire cage in the University of Minnesota's psychology department. He must work or starve. He is a very willing worker. 2. Pliny gets up on his hind legs to take hold of a hanging chain with his sharp teeth. When he pulls, an agate marble falls to the floor of the cage from the trough above. 3. The marble is what Pliny uses as a coin for his slot machine. Soon as it bounces into the cage, Pliny pounces on top of it. He picks it up with his small white forepaws. 4. Pliny carries the marble to the slot. When he first learned the trick, the slot was simply a hole in the floor. The raised portion was added to make things harder for him. 6. As the marble falls in the slot, it closes an electric circuit which causes food to drop down into Pliny's feeding tray. Pliny reaches the tray even before the food does. 7. Pliny's reward is 1/20th of a gram of dog biscuit. This meagre meal is gobbled in five seconds. But with a little industry, Pliny manages to eke out a comfortable living. From "Rat Works Slot Machine for a Living," *Life,* 1937, May 31, p. 80. Two additional photographs (5 and 8) on an adjacent page showed Pliny between the slot and the feeding tray (5) and pulling the chain when the slot was covered (8).

menting and refining the method of shaping by successive approximation, Skinner soon served as a great promulgator of this useful technique to generate new or complex behavior from existing behavior.

Contemporary Work on Related Problems

While Skinner was developing what is now known more broadly as operant conditioning, scientists in other countries were working on related problems. In Russia, Ivanov-Smolensky (1927) had trained children to squeeze a rubber ball to obtain chocolate. In Poland, Miller and Konorski (1928) had worked for years on a related paradigm, but their work was not well known in the English-speaking countries at that time. In 1937 Konorski and Miller commented on Skinner's work in the *Journal of General Psychology,* where Skinner had published most of his work. In what may have been the first critique of Skinner's method, they argued that Skinner's experimental situation was not appropriate for his analysis of a new form of conditioning. Konorski and Miller had demonstrated experimentally with dogs that when one reflex S_0–R_0 (S_0 = shock to a leg, R_0 = lifting the leg) was followed by a second reflex S–R (S = food, R = consuming the food), something happened between trials that was unexpected from the perspective of Pavlovian conditioning. After several pairings, the dogs began lifting the leg *before* the shock was applied. In other words, lifting the leg became conditioned by the food as lever pressing did in Skinner's experiments. However, the initiation of the response was different. According to Konorski and Miller, lifting the leg between trials was a new reflex, S_G–R_0, in which S_G represents the general experimental situation, and it is this reflex that gains strength, not S_0–R_0. In their view, the new conditioning represented a shift of the eliciting stimulus from S_0 to S_G. Skinner had argued that in his situation the investigatory reflex (S_0–R_0) gained strength when followed by S–R, and the eliciting stimulus remained S_0. (Between 1932 and 1935 Skinner had changed the terminology for the investigatory reflex from S′–R′ to S_0–R_0.) Konorski and Miller (1937) stated their point of view as follows:

> The lever in [Skinner's] experiments plays a double role. On one hand, it is S_0, as far as it elicits an investigatory response R_0 (pressing). On the other hand, it is also a prominent component of the whole experimental situation, S_G. Since the true mechanism of the new type of conditioned reflex consists, as we have shown, in the replacement of S_0 by S_G, this substitution in Skinner's experiments could not have been noticed, since S_0 and S_G were represented by the same object. (p. 267)

In Pavlovian conditioning, R_0 is unimportant and disappears; R is the important response. In the new type of conditioning, on the other hand, R_0 increases in frequency whereas R is unimportant. In some sense Konorski and Miller as well as Skinner had been trapped by the reflex terminology. The exchange with Konorski and Miller made Skinner examine more carefully the role of the hypothetical eliciting stimuli. Impelled by the argumentation over unseen entities (S_0 vs. S_G), Skinner (1937) replied that the eliciting stimuli for R_0 are not important and that this terminology should be dropped. In his reply, he introduced the terms *respondent* and *operant* for the first time and clarified that operant conditioning does not require a stimulus that elicits the operant; the only important property of operant conditioning is the contingency between response and reinforcement. He also noted that an important difference between his method and that of Konorski and Miller was that operant conditioning may be established with a single reinforcement, whereas several reinforcements were required for their method, as for Pavlov's. In addition, Skinner suggested that ignoring the eliciting stimuli in operant conditioning

> eliminates the implausible assumption that all reflexes ultimately conditioned according to Type R [operant conditioning] may be spoken of as existing as identifiable units in unconditioned behavior and substitutes the simpler assumption that all operant responses are generated out of undifferentiated material. (Skinner, 1937, p. 276)

This statement clearly separates Skinner's type of conditioning from those of Pavlov, Thorndike, and Konorski and Miller. Operant conditioning is not restricted to fully formed behavior, and in his reply Skinner also for the first time described the method of shaping by successive approximation, as indicated above. (Miller and Konorski's original article in French from 1928 was later translated by Skinner and supplemented with a brief postscript by Konorski; see Miller and Konorski, 1969.)

Apparently independent of Skinner, Grindley (1932) in England had developed a position very similar to Skinner's both experimentally and conceptually. He trained guinea pigs to push a lever with the head to obtain food. Grindley's experimental design and data description are impressive, even by modern standards; however, his use of a restrained animal and somewhat cumbersome methods of recording and reinforcer delivery rendered his technique less practical than Skinner's freely moving rat in a fully automated apparatus. Nonetheless, Grindley's work seems worthy of a better recognition than it has had. Like Skinner, Grindley too emphasized the need to downplay the role of unknown stimuli in trial-and-error learning.

Skinner's Rejection of Stimulus–Response Psychology

In 1924 Watson proposed that "behavioristic psychology has as its goal to be able, given the stimulus, to predict the response—or, seeing the reaction take place to state what the stimulus is that has called out the reaction" (p. 18). This stimulus–response (S–R) psychology was soon to be overthrown by Skinner's work. Even though he at first called lever pressing an investigatory reflex and referred to unmeasured eliciting stimuli, Skinner later shifted away from the S–R tradition because he discovered that in operant conditioning, what happens immediately after the response is more important than what happens right before. Also, he considered his extinction curves to be cases of pure behavior in which eliciting stimuli played

no role. Most important, the final form of a conditioned response did not have to exist prior to conditioning and therefore could not stem from elicitation. The method of shaping by successive approximation could generate forms of behavior that had not previously been seen in a subject's behavior repertoire. So, all in all, Skinner's early work completely contradicted Watson's "no stimulus—no response" rule.

The basic problem for Skinner was that historically a reflex had comprised both the eliciting stimulus and the resulting response (e.g., Keller, 1973). Consistent with this early influence while still a student, Skinner first spoke of hypothetical stimuli that elicited lever pressing. However, as his experimental techniques became more effective, these unmeasureable stimuli became less important because they were of no use to control behavior. The exchange with Konorski and Miller provided the final push that made Skinner reformulate his terminology from reflexology to operant conditioning. For Skinner, the essence of operant conditioning was that behavior is not triggered by the environment but selected by it. Skinner (1978) later noted about his reply to Konorski and Miller that

> It would have been the right time to abandon "reflex," but I was still strongly under the control of Sherrington, Magnus, and Pavlov, and I continued to hold to the term doggedly when I wrote *The Behavior of Organisms* (1938). It took me several years to break free of my own stimulus control in the field of operant behavior. From this point on, however, I was clearly no longer a stimulus–response psychologist. (p. 119–120)

Obviously, the common practice of labeling Skinner as a stimulus–response psychologist has no bearing on Skinner's position and is a misrepresentation of his work.

Theoretical Implications of Skinner's Early Work

Compared with Pavlov's, Skinner's method showed very rapid conditioning of a response that was not elicited by the reinforcer. When a response was intermittently reinforced, the strength of the response increased further in contrast to Pavlov's method in which intermittent reinforcement weakened the conditioned response. Skinner's method could be applied (at least in principle) to any response, whereas Pavlov's was limited to responses elicited by the reinforcer. Skinner mentioned several times (e.g., Skinner, 1978) that he saw Thorndike's work as the first clear demonstration that consequences select behavior. Yet, Skinner had developed a method that was far superior. With Thorndike's method, frequency of behavior was clearly confounded by the opportunity to respond offered by the experimenter, whereas with Skinner's method, the subject could respond at any time. Nonetheless, Thorndike and Skinner agreed that the important stimuli in conditioning of spontaneous behavior were those that followed the behavior.

Skinner's work now is commonly considered an extension of Thorndike's Law of Effect. Yet, in the 1930s the Law of Effect was not generally accepted and was opposed by some leading experimental psychologists. For example, Watson (1924) believed that the frequency of a response was unaffected by its previous consequences, and he considered Thorndike's satisfiers to be "kind fairies" devoid of scientific analysis. Tolman (1932) also did not consider the Law of Effect important because consequences were unimportant in his own learning paradigm; Tolman did acknowledge the role of consequences for performance, however. Guthrie (1934, 1935) too was opposed to the Law of Effect because he did not consider learning to be a strengthening of behavior. However, Guthrie was closer to Skinner's position in emphasizing one-trial learning and contiguity. Kohler also had attacked Thorndike's Law of Effect several times, arguing that simple effect could not explain the complex problem-solving behavior that he studied (e.g., Kohler, 1917/1927).

In contrast to other leading learning theorists, Hull had developed a strong belief in Thorndike's Law of Effect, and he quickly adopted Skinner's methodology. Several of Hull's graduate students began to conduct experiments using lever-pressing equipment built after Skinner's model (e.g., Bugelski, 1938; Ellson, 1938; Youtz, 1938). Hull's (1943) *Principles of Behavior: An Introduction to Behavior Theory* referred to this general equipment variously as the Skinner–Bugelski, Skinner–Ellson, or Skinner–Youtz apparatus. Hull simply tagged on his students' names to Skinner's. The term *Skinner box* appeared on p. 139 in Hull's *Principles* and has been popular ever since, much to Skinner's disliking (e.g., Skinner, 1983, p. 164). But Hull's group had adopted Skinner's technique, not his science of a functional analysis. Skinner (1944) reviewed Hull's *Principles* and did not like it, in spite of its many references to his own work, because "the postulates described an internal mediating system in which stimuli entered the organism, underwent various changes, and emerged as responses" (Skinner, 1979, p. 269; see also Wearden, 1989). Although Skinner initially was disturbed by Hull's lack of coverage of his functional analysis, he later wrote that

> I could scarcely complain, because I myself never made any use of the work of Hull or his students. . . . My results did not fit their theories nor their results mine. It was not, I think, a self-centered isolation on the part of anyone; the science had not yet found a generally accepted formulation" (Skinner, 1979, p. 270).

Nonetheless, both Hull and Skinner had expanded on Thorndike's Law of Effect. Beginning in the 1940s, Hull and Skinner parted ways. Hull remained closer to the S–R tradition and focused on the measurement of intervening variables. Skinner had already abandoned the S–R tradition and was now beginning to focus on the effective, practical implementation of operant conditioning in education, society, and therapy.

Conclusion

Skinner's early work should be seen in the light of some theoretical confusion about the nature of the fundamental learning processes. The basic fact that Pavlov's and Thorndike's methods were different and produced different results took time to become generally accepted. Only by the end of the 1930s was it evident that two types of

conditioning rather than one existed. Thus, Hilgard and Marquis' (1940) influential textbook *Conditioning and Learning* summarized the collective evidence, including Skinner's work, and concluded that two processes existed. Skinner's (1937) terms *respondent* and *operant conditioning* were soon to become common in psychology.

In his early articles, Skinner had already indicated that a conditioned response should be given a generic definition as a class of movements so that each response instance could vary slightly from one occasion to the next. This definition solved the theoretical problem of what was reinforced in both operant conditioning and trial-and-error learning. Reinforcement does not strengthen the response instance that produces the reinforcer. That response has already occurred and cannot be changed. Instead, reinforcement increases the probability that a similar response will occur in the future. Skinner early rejected Tolman's (1932) notion that behavior is goal directed. According to Skinner, a response does not occur because of what will follow it. That is, behavior is not caused by something that has not yet happened. Rather, in operant conditioning, the emission of a response reflects past conditioning. The response occurs because similar responses were reinforced earlier, not because it will be reinforced later. As far as Skinner was concerned, the initial high response rate seen in extinction sessions exemplified this important aspect of operant conditioning. Of equal importance was the fact that a single reinforcement may be sufficient for strengthening of a response. Skinner often referred to this finding as an essential aspect of operant conditioning (e.g., 1971, p. 176; 1978, p. 116; 1979, p. 88; 1983, p. 368; 1987, p. 168; 1988, p. 466; 1989, p. 126).

Skinner has emphasized that his research quite literally was shaped by the contingencies of finding "orderly data." Skinner did not develop his methods to test a theory or to prove a hypothesis but to start an independent science of the voluntary behavior of the individual organism. As Skinner often emphasized, "Operant behavior is the very field of purpose and intention" (Skinner, 1974, p. 55). By continuously refining his methods so that his data became more and more orderly, instead of making theoretical allowances for empirical deviations, he established a standard, pragmatic method. Skinner's general method is thus no less than the Petri dish of experimental psychology because one can analyze the effects of a variety of variables on a standard model of conditioned behavior (see Iversen & Lattal, 1991, for an overview of basic techniques in operant conditioning). Both historical and contemporary analyses of learning illustrate that Skinner's scientific method of experimental analysis of behavior can be used for diverse purposes that transcend different theoretical issues.

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