SHAPING BY AUTOMATED TRACKING OF AN ARBITRARY OPERANT RESPONSE

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Although shaping is a widely accepted operant-conditioning procedure for establishing new responses, technological problems involved in specifying and recording precise approximations to the target response have hindered experimental analysis of the shaping process. The present study used a computer-controlled system that allows relatively precise procedural specification by continuous tracking of a pigeon's head and reinforcing successively closer approximations to contact of the head with an arbitrary fixed spherical region of 3-cm diameter. The procedure was demonstrated to be effective, in that shaping of the target response occurred rapidly for each of the 3 birds in the study.

Key words: shaping, successive approximations, reinforcement, operant behavior, automated technology, key peck, pigeons

A commonly used method for establishing new operant responses is the process of shaping, whereby successively closer approximations to the target response are reinforced while previous approximations are extinguished (Catania, 1984, pp. 108-109; Skinner, 1953, pp. 91-98; Staddon, 1983, pp. 456-458). Typically, new approximations to reinforce are selected on the basis of continuously observed variations in response topography. For example, in the case of shaping a pigeon's key pecking, reinforcement may be made contingent on a movement of the beak discriminably closer to the key relative to the position of the beak before the previous reinforcement. Spatially continuous observations (visual discriminations on the part of the experimenter) of the position of the beak are required in order for this to be accomplished.

There probably are very few who doubt the effectiveness of shaping. However, precise examinations of the process have been lacking because of technical difficulties involved in accurately adhering to specific parameters of shaping procedures and in recording the close-

ness of specific behavior patterns to a given target response. Hence, little is known about the relative effectiveness of various shaping parameter values, or even about which specific parameters are effective and which are ineffective. As it is typically carried out, the procedure is highly intuitive, and is often characterized as involving more "art" than science. The present article provides a demonstration of the effectiveness of specific shaping parameter values in establishing an arbitrary operant response, and describes a methodology for studying shaping as a spatially continuous process. In this way it may be possible to begin to move shaping from the realm of art to that of science.

Previous research in which shaping parameter values have been specified and successive approximations recorded often has not dealt with shaping as a spatially continuous process. For example, studies on shaping the duration of a response (e.g., Kuch, 1974; Lane, Kopp, Sheppard, Anderson, & Carlson, 1967) or the length of interresponse times (e.g., Platt, 1973, 1979) have focused on the temporal properties of behavior. Closer to the present research is work by Eckerman, Hienz, Stern, and Kowlowitz (1980) in which the location of a pigeon's pecking on a long key was shaped. However, the technology used in that study did not permit monitoring of movements that failed to activate the key. The present study used a computer to track continuously the position of a pigeon's head in the experimental chamber and to shape contact of the head with

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a specific target location. The continuous tracking permitted the computer to reinforce very fine spatial approximations to the target response.

Although key pecking is the operant response usually studied in pigeons, the fact that this response can be established by merely pairing keylight presentations with food presentations has rendered it suspect as an arbitrary operant response (Brown & Jenkins, 1968; Gamzu & Schwartz, 1973; Jenkins & Moore, 1973; Williams & Williams, 1969). In particular, what is commonly assumed to be operant shaping of the key-peck response may be due to the pairing of the key with the feeder that occurs when feeder operations follow the bird's looking at or approaching the key (Hearst & Jenkins, 1974, p. 40; Moore, 1973, p. 176). The target response used in the experiment reported here precluded this possibility.

METHOD

Subjects

The subjects were 3 adult male White Carneaux pigeons maintained at approximately 80% of their free-feeding weights. Pigeon B6698 had an extensive history of key pecking reinforced on fixed-ratio schedules (every n th peck reinforced), or exposure to fixed-time 15-s and 1-min schedules (reinforcers delivered after fixed intervals of time independent of behavior), and of extinction (no reinforcement following a period of reinforcement). In addition, this bird had a history of shaping to several target locations different from the target location used in the present experiment. Pigeons B3116 and B3117 had extensive histories of exposure to fixed-time 15-s, fixed time 5-min, variable time (reinforcer delivery independent of behavior after intervals in time that vary in length) 15-s, variable time 15-min, and extinction. Thus, no explicit reinforcement contingency had been applied to behavior of the latter 2 birds. All 3 birds had been monitored frequently during the above sessions by closed-circuit television, and none had been observed to go into the back left quadrant of the chamber—the region from which the target location was selected.

Apparatus

The apparatus recorded the position of the bird's head every 1/30th s as the bird moved

about freely in the experimental chamber, the inner dimensions of which were 57 by 57 by 38 cm. Because descriptions of the apparatus have been published elsewhere (Pear, 1985; Pear & Eldridge, 1984), only a brief description will be given here. Two walls of the chamber consisted of clear glass, one wall consisted of white opaque Plexiglas, and one wall was composed of white opaque Plexiglas and metal painted white. Reinforcement was 5-s presentation of an electronically raised food hopper containing commercial pigeon food. The food aperture, located near the center of the opaque Plexiglas and metal "front" wall, was continuously illuminated. The intensity of this illumination increased when the feeder operated. A translucent plastic response key, located on the front wall 26 cm from the aluminum mesh floor and 21 cm from the left wall, was transilluminated continuously with white light for B6698 and was dark and covered with a white paper shield for the other 2 birds.

Two TV cameras connected to a video-acquisition module were oriented perpendicularly to the two adjacent glass walls. Each bird's head was painted with black shoe polish and, because completely white birds were used and the chamber was well illuminated, the head was the only dark region in the chamber. The video-acquisition module scanned down the image from each camera every 1/30th s until it encountered a dark region of a critical width, and computed the 3 spatial coordinates of the point at the center of this region. This point was defined as the position of the pigeon's head. The video-acquisition module was connected to a Cromemco Z-2D microcomputer that stored the position data for later analysis. The microcomputer also controlled the experiment, including presenting food on the basis of position data. An Epson dot-matrix printer was used for graphing the data. Data obtained during feeder operations were excluded from the graphs.

Procedure

The target response that was selected was one that none of the birds had been observed to make during their extensive histories in the chamber. The computer program defined a virtual target sphere of 3-cm diameter with its center located 2.5 cm from the left wall, 8.5 cm from the back wall, and 15 cm from the aluminum mesh floor of the chamber. Because

Fig. 1. Radius of the shaping sphere (top graphs) and distance from the center of the target sphere (bottom graphs) over sessions. Each data point is an average of three data points sampled at 1/30-s intervals. All shaping sessions and the session immediately following shaping are shown for each bird. The dashed vertical lines show the termination of each of the indicated shaping sessions. The vertical marks in the top band below each graph indicate target responses; those in the bottom band indicate reinforcements. The long excursions seen in the bottom graphs typically are trips from the feeder. The horizontal bars above the bottom set of graphs indicate 10-min periods of data shown expanded in Figure 2. Note that the time scales are different for the 3 subjects.

this was below the standing heights of the birds, each bird could "contact" the target only by lowering its head. Concentric with the target sphere was a shaping sphere whose radius could be programmed to expand at a specified rate and to contract a specified amount when contact was made between it and the bird's head. Food delivery was programmed to occur whenever contact occurred between the bird's head and the virtual target or shaping spheres. Thus, the reinforced response consisted of moving the head into the sphere, unless the sphere expanded past the head, in which case food was delivered irrespective of head movement.

Prior to the shaping sessions, each bird was given at least three 1-hr sessions during which the radius of the shaping sphere was set equal to that of the target and did not expand. No bird contacted the target during these sessions. Thus no food deliveries occurred, and activity declined to a low level. To determine whether increased activity would induce contact with the target sphere, the radius of the shaping sphere was programmed to expand within one sampling period (i.e., 1/30th s) to the position of the bird's head every 60 s for B6698 and every 15 s for B3116 and B3117, and to contract instantly to the radius of the target sphere upon contact with the bird's head. This program was in effect for a minimum of four sessions for each bird, during which no bird

contacted the target sphere. These and the following sessions each terminated after 70 food deliveries for B6698 and after 60 food deliveries for the other 2 birds.

At the beginning of each shaping session, the computer expanded the radius of the shaping sphere within 1/30th s to the position of the bird's head. On this and each succeeding contact of the bird's head with the shaping sphere, the radius of the shaping sphere contracted by 1 cm from the position of the bird's head when contact was detected by the computer. For every 10-s period in which contact did not occur, excluding reinforcement time, the radius expanded 0.25 cm. In the session immediately following the session in which the bird first contacted the target sphere (regardless of when during the session this contact occurred), the radius of the shaping sphere was set equal to that of the target sphere and programmed not to expand. Thus, after the completion of shaping, reinforcement occurred only when the target response was emitted.

RESULTS

The top set of graphs in Figure 1 shows the radius of the shaping sphere over all shaping sessions and the first maintenance session. Note that the radius of the shaping sphere reached its largest value early in the first

shaping session for each bird, and then was quickly driven down near the radius of the target sphere. Although the radius of the shaping sphere subsequently never reached a maximum as large as that obtained early in the first session, B6698 and B3116 did not contact the target sphere until their third and fourth sessions, respectively. Subject B3117 contacted the target sphere near the end of the first session. For all 3 birds, two distinct stages in the shaping process can be seen. The shaping sphere was (1) contracted to a region close to the target sphere where it remained for a period of time before it was (2) contracted to the target sphere. Video monitoring of the birds indicated that these two stages corresponded to two topographically different features of the target response: (1) walking toward the region of the target sphere, and (2) lowering the head, thus making contact with the target sphere. Thus, for all 3 birds the walking response developed before the head-lowering response did. None of the birds pecked at the floor or wall of the chamber at any time during the shaping procedure.

The bottom set of graphs in Figure 1 shows the distance of each bird's head from the center of the target plotted over the same time periods as for the top set of graphs. The first stage (walking) can be seen as an abrupt drop (beneath a horizontal bar representing a 10-min period) in the minimum distance. This "ramp" effect is not as evident for the second stage (head lowering), possibly because of the much shorter distances involved in that stage. Nevertheless, the head-lowering response also appears to have begun abruptly. Note, however, that rate of contacting the target sphere increased gradually during the last shaping session, and increased to a high steady level after the shaping program was terminated. The long excursions in the figure generally indicate trips from the feeder after eating; they are of unequal lengths because data during the feeder cycle are not shown and the birds frequently left the feeder prior to the completion of the feeder cycle. The probable reason for the birds' leaving the feeder before the completion of the feeder cycle is that they ate most or all the food at the top of the hopper prior to the completion of the cycle, and reactivating the feeder restored food to the top where it was more accessible. The continuous-reinforcement schedule for contacting the shaping sphere apparently favored moving

quickly back to the target area and reactivating the feeder sooner than would be the case if the bird remained at the feeder until the end of the cycle.

To permit comparison of the three ramps related to the first "stage" of shaping on the same time scale, Figure 2 shows portions of the distance-versus-time graphs taken from the 10-min regions indicated by the horizontal bars above the bottom set of graphs in Figure 1. Note that the ramps for B3116 and B3117 occupy about the same amount of time, whereas that for B6698 occurs over a longer time period and has a "hump" in it. A possible reason for this difference is B6698's former history of shaping to several other regions of the chamber.

Figure 3 shows a sequence of photographs taken of a pigeon whose behavior had been shaped by the system. The two topographies that were shaped in this study (walking and head lowering) can be seen in this figure. After the completion of shaping, the target response was maintained for at least six sessions for all 3 birds, thus indicating that an arbitrary response that has been shaped in this manner can be maintained. Figure 4 shows cumulative records of responding by each of the 3 birds during its sixth session after the completion of shaping.

DISCUSSION

Inasmuch as the target response that was shaped in the present study was one that none of the birds had emitted during extensive histories in the experimental chamber, this study demonstrates the effectiveness of shaping in establishing an arbitrary operant response. Moreover, because of the computer procedure that was used, precise specification of effective shaping parameter values is possible. Our current knowledge of what happens during shaping is primarily qualitative and not easily communicated (hence the term "art of shaping"). The data presented here show what happens moment-to-moment during shaping under certain quantitatively specified parameter values. It therefore appears that the present technique may provide the technology needed for an experimental analysis of shaping.

Several questions arise from the data produced in this study. One question of interest is why walking toward the target (the first

Fig. 2. Expansion of 10-min periods of distance-from-target data indicated by the horizontal bars above the distance graphs shown in Figure 1. (The short "ticks" in the upper part of the lower band indicate instances in which one of the cameras failed to detect a dark region or the system detected a movement greater than 10 cm/s; typically the latter was the case as a result of the bird leaving the area of the feeder prior to the completion of the feeder cycle, during which the system did not track the bird.)

stage of the shaping process) appeared before head lowering (the second stage). This result seems to be dictated by the contingencies used in the study. If the bird was close to the shap-

ing sphere early in the shaping procedure, either walking or lowering the head would bring the head into contact with the sphere. However, if the bird was far from the shaping

Fig. 3. A bird (B3117) whose "contact" with the target sphere had been shaped. The sequence shown is as follows: (a) bird leaves feeder, (b) turns toward target, (c) approaches target, (d) contacts target (feeder light brightens), (e) turns toward feeder, (f) eats from feeder. Negative image shows view of bird's head from the second camera. Intersecting white lines indicate two of the spatial coordinates of the bird's head as tracked by the system from data received from the two cameras.

sphere, lowering the head would have been unlikely to bring the head into contact with the sphere, whereas walking would have done so. Thus, early in the shaping procedure, the contingencies probably favored walking over head lowering.

Another question is why the shaping process seemed to occur abruptly, as indicated by the ramp effect seen in Figures 1 and 2. This effect is consistent with speculation that the conditioning of simple or unit responses occurs instantaneously (Sidman, 1960, pp. 295-297; Skinner, 1938, pp. 69-72). For example, Sidman suggested that instantaneous learning might be observed if the animal is thoroughly habituated to the chamber and well trained to eat from the feeder, and if a suitably simple and topographically consistent response is utilized. The first two conditions clearly were met in this experiment. Moreover, it seems reasonable to postulate that walking in the direction of the target satisfied the third condition, thus perhaps explaining the strikingly sudden appearance and continuous mainte-

nance of this response after a lengthy period during which it was absent.

A third question concerns the pauses seen at the beginning of the sessions illustrated in the cumulative records in Figure 4. This effect was fairly consistent across all maintenance sessions, especially for Birds B6698 and B3117. Although the birds occasionally approached the target without contacting it during these pauses, most of this pause time was spent standing still or engaging in motions that appeared to be unrelated to the target response (e.g., preening). In addition, the first response of each maintenance session usually occurred with a direct approach to and contact with the target; that is, there was little or no apparent searching for the target at the beginning of a session. Thus, there is no indication that the pauses at the beginning of maintenance sessions represented any significant forgetting of the target location, despite the fact that there was no localized marker correlated with the target. It is possible, however, that the pauses were due in part to a resurgence of responses that had been conditioned earlier in the shaping procedure (cf. Epstein, 1985).

Although the technique described here provides the potential for precise shaping, limitations on its precision should be noted. One limitation concerns the size of the area on the subject that must be darkened to ensure reliable tracking. It can be seen in Figure 3 that the entire head of the pigeon was darkened so that no matter how the pigeon moved in the chamber, some part of the head region was likely to be visible to both cameras. If, for example, a smaller area such as just the beak were darkened in order to shape key pecking, there probably would be times when the dark region was not accessible to both cameras. This problem could be solved by using more than two cameras suitably positioned so that the dark region would be accessible to at least two cameras at any given time, or by using a much smaller chamber or restraining the animal so that it could not move the dark area out of the range of either camera. Another limitation of the system is that it does not detect the orientation of the subject. Thus, for example, in the present study, reinforcement occurred whether or not the bird was facing the target, even though behavior that occurred when the bird was facing away from the target was

Fig. 4. Cumulative response records for each of the 3 birds during the sixth session after the completion of shaping. A response was defined as contact of the head with the target sphere. The records were plotted by the computer.

probably not a reasonable approximation to the target response. One approach to this problem might be to rewrite the shaping program so that the shaping sphere expands only when the bird moves in the general direction of the target. However, this solution would not be entirely satisfactory because, as presently designed, the system would be unable to detect whether the bird was moving forward, backward, or sideways. In order for the apparatus to detect directionality in the sense of the subject's orientation in the chamber, a minimum of two points would have to be located on the subject. This might be done by using color cameras and painting two differently colored areas on the subject. In short, it should be technically possible to overcome many of the limitations of the tracking-and-shaping system described here.

REFERENCES

- Brown, P. L., & Jenkins, H. M. (1968). Auto-shaping of the pigeon's key-peck. *Journal of the Experimental Analysis of Behavior*, **11**, 1-8.
- Catania, A. C. (1984). *Learning* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.
- Eckerman, D. A., Hienz, R. D., Stern, S., & Kowlowitz, V. (1980). Shaping the location of a pigeon's peck: Effect of rate and size of shaping steps. *Journal of the Experimental Analysis of Behavior*, **33**, 299-310.
- Epstein, R. (1985). Extinction-induced resurgence: Preliminary investigations and possible applications. *Psychological Record*, **35**, 143-153.
- Gamzu, E., & Schwartz, B. (1973). The maintenance of key pecking by stimulus-contingent and response-independent food presentation. *Journal of the Experimental Analysis of Behavior*, **19**, 65-72.
- Hearst, E., & Jenkins, H. M. (1974). *Sign-tracking: The stimulus-reinforcer relation and directed action*. Austin, TX: Psychonomic Society.
- Jenkins, H. M., & Moore, B. R. (1973). The form of the auto-shaped response with food or water reinforcers. *Journal of the Experimental Analysis of Behavior*, **20**, 163-181.
- Kuch, D. O. (1974). Differentiation of press durations with upper and lower limits on reinforced values. *Journal of the Experimental Analysis of Behavior*, **22**, 275-283.
- Lane, H., Kopp, J., Sheppard, W., Anderson, T., & Carlson, D. (1967). Acquisition, maintenance, and retention in the differential reinforcement of vocal duration. *Journal of Experimental Psychology*, **74**(2, Pt. 2), 1-16.
- Moore, B. R. (1973). The role of directed Pavlovian reactions in simple instrumental learning in the pigeon. In R. A. Hinde & J. Stevenson-Hinde (Eds.), *Constraints on learning* (pp. 159-188). New York: Academic Press.
- Pear, J. J. (1985). Spatiotemporal patterns of behavior produced by variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, **44**, 217-231.
- Pear, J. J., & Eldridge, G. D. (1984). The operant-responder distinction: Future directions. *Journal of the Experimental Analysis of Behavior*, **42**, 453-467.
- Platt, J. R. (1973). Percentile reinforcement: Paradigms for experimental analysis of response shaping. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 7, pp. 271-296). New York: Academic Press.
- Platt, J. R. (1979). Interresponse-time shaping by variable-interval-like interresponse-time reinforcement contingencies. *Journal of the Experimental Analysis of Behavior*, **31**, 3-14.
- Sidman, M. (1960). *Tactics of scientific research: Evaluating experimental data in psychology*. New York: Basic Books.
- Skinner, B. F. (1938). *The behavior of organisms: An experimental analysis*. New York: Appleton-Century.
- Skinner, B. F. (1953). *Science and human behavior*. New York: Macmillan.
- Staddon, B. F. (1983). *Adaptive behavior and learning*. Cambridge: Cambridge University Press.
- Williams, D. R., & Williams, H. (1969). Auto-maintenance in the pigeon: Sustained pecking despite contingent non-reinforcement. *Journal of the Experimental Analysis of Behavior*, **12**, 511-520.

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