JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1991, 55, 213-231 NUMBER 2 (MARCH)

EFFECTS OF REINFORCING PRESELECTED APPROXIMATIONS ON THE TOPOGRAPHY OF THE RAT'S BAR PRESS

PATRICIA D. STOKES AND PETER D. BALSAM

COLUMBIA UNIVERSITY AND
BARNARD COLLEGE OF COLUMBIA UNIVERSITY

The effects of different shaping approximations on the topography of the rat's bar press were investigated in two experiments. Behavior was classified into discrete components, and changes in components and their sequential organization were analyzed. Experiment 1 examined response form early in training and found that specific components reinforced during shaping were incorporated into press sequences. Experiment 2 investigated how response form changed when a shaping contingency was relaxed later in training. Two topographies were selected for reinforcement, and both appeared in the press sequences of all subjects by the end of shaping. Subsequently, all variations of bar pressing were reinforced, and neither topography was necessary to satisfy the contingency. Although the frequency of the topographies reinforced during shaping declined for 3 of 4 subjects during this phase, the most frequent press sequence for 2 rats at the end of training included both unnecessary topographies. Variability in press topographies declined when all emitted variants were reinforced. However, all subjects emitted novel response forms throughout training. The results demonstrate that specific response-reinforcer contingencies influence response form by modulating component availability and organization.

Key words: shaping, response topography, response form, response variability, bar press, rats

The primary dependent variable in studies of instrumental learning has been some quantitative property of a response, such as its rate, latency, or duration. The form of the response—its topography—has been largely ignored. As a result, we know a great deal about how organisms learn when and where a particular response should be made (Balsam, 1988) but relatively little about how new response forms are acquired. Despite the paucity of empirical work on this problem, several very different theoretical analyses have been offered to account for the acquisition of new response topographies.

Skinner (1938, 1953) claimed that shaping by successive approximations molds behavior along continuous dimensions into novel forms. Shaping proceeds via the combined effects of reinforcement and extinction. Extinction increases variability, facilitating induction of a response that more closely approximates the target response, which may then be strengthened by subsequent differential reinforcement. Support for Skinner's model comes from experiments showing that variability along different response dimensions increases in extinction and that response form is sensitive to contingencies placed on form. Evidence that variability increases as reinforcer frequency decreases comes from studies of response location (e.g., Antonitis, 1951; Eckerman & Lanson, 1969), duration (e.g., Margulies, 1961; Millenson & Hurwitz, 1961; Millenson, Hurwitz, & Nixon, 1961), displacement (e.g., Herrick, 1965; Herrick & Bromberger, 1965), latency (e.g., Stebbins & Lanson, 1962), and force (e.g., Notterman, 1959). Furthermore, if reinforcement requires a sequence of responses (e.g., respond three times on the left and three on the right), such sequences are more variable during extinction than during continuous reinforcement (e.g., Schwartz, 1980, 1982; Vogel & Annau, 1973). Evidence for selection of response forms by specific contingencies comes from successful demonstrations of the shaping of responses directed at particular locations (e.g., Davis & Platt, 1983; Eckerman, Hienz, Stern, & Kowlowitz, 1980; Galbicka & Platt, 1989; Midgley, Lea, & Kirby, 1989; Pear & Legris, 1987; Scott & Platt, 1985), lasting for

We thank Bruce Moore, James Deich, Evalyn Segal, and William Timberlake for their comments and reactions to earlier drafts of this paper. We also thank Christina Benedetto, James Deich, Christine Kozma, Amy Lazev, and Octavia Wong for help with various other aspects of this project. Correspondence should be addressed to P. Balsam, Psychology Department, Barnard College, Columbia University, New York, New York 10027.

designated durations (e.g., Lane, Kopp, Sheppard, Anderson, & Carlson, 1967), having specific spatial qualities (e.g., Deich, Allan & Zeigler, 1988), or following particular interresponse times (e.g., Alleman & Platt, 1973; Galbicka & Platt, 1986).

An alternative concept of shaping follows from Hull's (1932, 1934, 1935) analysis of how new responses are induced. Hull hypothesized that all stimuli present when an instrumental response is reinforced are paired with the reinforcer and come to elicit fractions of the goal response. These "fractional anticipatory goal responses" (r_g) produce sensory feedback (s_g) to which all overt responses are then conditioned. Because responses closer to the goal are more strongly conditioned than those farther away, alternative response sequences leading to a common reinforcer (a habit family) will be organized hierarchically. The shortest path—the one most strongly conditioned to the s_g—will be the most probable. Should this path be blocked or unavailable, the s_g directs responding along alternative sequences or sub-sequences drawn from the hierarchy, chaining these segments into novel combinations to reach the goal. Evidence supporting this kind of chaining model is provided by experiments requiring the novel combination of previously learned responses to solve a problem (e.g., Birch, 1945; Köhler, 1925; Maier, 1929, 1931).

Chaining is also involved in Skinnerian discussions of shaping, where it appears to have a less restricted role than that described by Hull. That is, insofar as one response component produces "the eliciting or discriminative stimulus for another" (Skinner, 1938, p. 52), chaining can induce response forms that are closer approximations to the target, including components that belong to a response class different from the response that initiated the chain (Segal, 1972). By extension, novel problems can be solved if each response component produces the discriminative stimulus for the requisite next step in the sequence (Epstein, Kirshnit, Lanza & Rubin, 1984). Although Hull does not specifically preclude chaining between components or segments of different habit families, he discusses only novel combinations within a single habit family.

Bindra (1972, 1974, 1976) proposed a very different view of the mechanism underlying response shaping. In his model, response form is determined by the current motivational state and the response-evoking properties of specific conditioned stimuli (CS) rather than any response–reinforcer contingencies. Shaping response location and form follow from the fact that stimuli acquire different conditioned incentive properties proportional to their association with the reinforcer. During shaping, those stimuli that evoke the required response will be more closely and reliably followed by the reinforcer, thus acquiring stronger conditioned incentive properties than other stimuli. Consequently, the animal will become more and more attracted to these *response-evoking* stimuli and the target response will become more frequent. Bindra argued that operantly shaped responses resemble autoshaped ones (Jenkins & Moore, 1973; Wolin, 1948/1968) because both procedures guarantee that the subject will notice the critical stimulus features that evoke the requisite responses. In autoshaping, the lit key that is paired with food acquires conditioned incentive properties. As a result, the bird will be attracted to the *peck-evoking* stimulus, the lit key. Thus, the same responses will emerge from either a shaping or autoshaping procedure if the stimulus features that evoke those particular responses become more effective elicitors than other stimuli in the training situation.

Moore (1973) has also argued that instrumental topographies may be determined by implicit Pavlovian associations. Reinforcing successive approximations results in cues closer to the manipulandum being more frequently paired with the reinforcer than more remote cues. As a result of these pairings, subjects will approach and contact the manipulandum. Thus, as in Bindra's model, instrumental topographies are effectively arrived at via stimulus–reinforcer rather than response–reinforcer contingencies. Moore parts from Bindra in attributing Pavlovian response form to a larger number of factors, including the nature of the unconditioned stimulus (US) rather than the CS alone. He bases this view on evidence from autoshaping in pigeons. First, autoshaped pecks emerge via a series of gross stages similar to those seen in operant conditioning (i.e., increased activity during a trial, gradual centering of movement around the lit key, and finally pecking movements in the direction of the key). Secónd, the form of autoshaped pecks, like that of operant pecks reported earlier by Wolin (1948/1968), is determined by the nature of the reinforcer (Jenkins & Moore, 1973).

Finally, Moore presents data showing that the form of the peck is relatively insensitive to modification by operant contingencies (but see Deich et al., 1988). Although Moore explicitly confines his conclusions to the analysis of the pigeon's key peck, it is worthwhile to consider this view as a viable model of shaping in general. We shall refer to it as the Pavlovian account.

A final class of shaping models can be derived from the literature involving constraints on learning (Bolles, 1970; Breland & Breland, 1961; Hinde & Stevenson-Hinde, 1973; Shettleworth, 1972; Timberlake, 1983). The core idea is that response forms strengthened by reinforcement will be appropriate to a biologically organized behavior system. The specific behavior that can be strengthened by a given reinforcer will come from a limited set of preorganized behavior patterns, constrained by motivational state, stimulus, and reinforcer type. For example, Shettleworth (1973, 1975) has shown that only those action patterns that increase in frequency when hamsters are hungry (i.e., anticipatory food responses) increase in frequency with food reinforcement; maintenance activities (e.g., face washing, scratching, and scent marking) are not easily conditioned with a food reinforcer. In a similar vein, Timberlake (1983; Timberlake, Wahl, & King, 1982) has demonstrated that responses with similar topographies are generated by both Pavlovian and operant procedures so long as they employ the same reinforcer and manipulandum. Because similar behavior patterns occur when the manipulandum predicts delivery of food and when contact is explicitly required to obtain food, responding is assumed to reflect species-typical foraging and food-handling behavior. Although discussions of these behavioral systems models frequently imply strong constraints on the nature of learned behavior, one recent formulation of this position (Timberlake & Lucas, 1989) explicitly allows for considerable flexibility in the form of learned behavior. However, even this flexible view of a behavior system suggests that species-typical behavior will be very likely to emerge in the usual conditioning experiment. "In behavior system terms, shaping activates the food system, instigates a combination of general and focal search modes primarily focused on the area of the food tray, and links modules related to food capture or handling to the movement of the lever" (Timberlake & Lucas, p. 262).

Different predictions about the effects of shaping can be derived from these models based on the extent to which each attributes response form to response–reinforcer contingencies. The behavioral systems and Pavlovian models are similar in predicting that the response forms induced by shaping will be restricted to a preorganized set of species-specific topographies, which may be "somewhat modifiable (but) more often highly resistant to differentiation" (Moore, 1973, p. 169). Thus, these views anticipate little individual variation in response form as well as little influence of the specific approximations selected for reinforcement in operant shaping relative to the views of Skinner (1938, 1953), Hull (1932, 1934, 1935), and Bindra (1972, 1974, 1976).

The models proposed by Skinner, Hull, and Bindra all predict that final response form will crucially depend on the approximations reinforced during training. According to Skinner (1938, 1953), the reinforced approximations increase in frequency to a greater degree than all other response forms. As training proceeds, the former will be replaced by even closer approximations to the target response. These approximations might include components that are topographically related to earlier ones. If such components become necessary precursors to the terminal response and/or become chained to effective press components, they would remain in the target response sequence even though they are not strictly necessary (Midgley et al., 1989). According to Hull (1932, 1934, 1935), the reinforced approximations would initially be strongly conditioned to the goal stimulus. Because they remain in the habit family, they might easily be combined via chaining with effective press topographies. Finally, according to Bindra (1972, 1974, 1976), a specific response–reinforcer contingency ensures that subjects are attracted to the requisite response-producing stimuli. Because the stimuli that generate the approximations will be highly associated with the reinforcer, the animal will initially be attracted to them. If the animal continues to come in contact with these stimuli as shaping progresses, the approximations may be maintained in the terminal performance. Thus, these three views allow for a substantial influence of specific response–reinforcer contingencies on response form.

The main purpose of the present experiments was to contrast these accounts of the shaping process in the acquisition of bar press-

ing by rats. Experiment 1 examined whether the specific approximations used in shaping had an influence on the form of the rat's press just after acquisition of the target response. Experiment 2 analyzed whether the specific topographies reinforced during shaping persisted with extended training, during which they were no longer a critical aspect of the contingency.

EXPERIMENT 1

The first experiment examined whether reinforcing different sets of approximations would lead to differences in bar-press topography. If either stimulus substitution or a behavioral systems account is correct, there ought to be little effect of the selected approximations on response form. Alternatively, if Skinner's (1938, 1953), Bindra's (1972, 1974, 1976), or Hull's (1932, 1934, 1935) model is correct, subjects' behavior might well reflect the specific history of reinforced approximations.

The current study differs from prior studies of shaping in that behavior was not analyzed as a continuous variable changing in time and space. Rather a coding scheme was devised to classify behavior into discrete categories. This approach was chosen because independent evidence suggests that behavior is organized in discrete units. Support for this point of view comes from developmental and neurophysiological analyses of many types of motor behavior (Fentress, 1983; Gallistel, 1980; Golani & Fentress, 1985) including operants (Teitelbaum, 1977). Additionally, studies of shaping and response induction show that reinforcement or extinction of one response may increase the frequency of topographically unrelated responses. For example, reinforcing novel behavior can result in the production of responses that are topographically unrelated to previously reinforced responses (Goetz & Baer, 1973; Holman, Goetz, & Baer, 1977; Pryor, Haag, & O'Reilly, 1969). Similarly, reinforcing one member of a positively covarying set of responses may increase the frequency of other members with quite different topographies, whereas extinction of one member of a set of negatively covarying responses may increase the frequency of topographically dissimilar behavior (Kara & Wahler, 1977; Kazdin, 1982; Russo, Cataldo, & Cushing, 1981; Wahler & Fox, 1982).

In the current study, behavior was classified into four general categories: those directed at the bar, at the light above the bar, at the dipper, and at anything other than the bar, light, or dipper. Separate components in each category were defined by topography, location, and, in one case (press), by function. Changes in the frequencies of these components and their sequential organization were analyzed to assess the effects of reinforcing different approximations on the form of the bar press. This type of sequential analysis has already proved useful in characterizing the molar response structure of learned behavior (Iversen, 1976, 1986; Staddon & Simmelhag, 1971) and in the more molecular structure of species-typical action patterns (Fentress, 1983; Golani & Fentress, 1985).

To ensure that presses resulted from the reinforcement contingency, the analysis began at the ninth rather than at the first press. To see the greatest influence of specific approximations on press topography, only four press sequences were analyzed. There were two reasons for adopting this strategy. First, because approximations are no longer reinforced once those closer to the target have been selected for reinforcement, the effects of the specified approximations on response form might be relatively transient. Second, response form may drift with extended training (Muenzinger, 1928; Muenzinger, Koerner, & Irey, 1929; Notterman & Mintz, 1965; Skinner, 1938). Thus, the first experiment looked at the form of the ninth through 12th presses in two groups of rats shaped with different sets of approximations.

METHOD

Subjects

The subjects were 10 experimentally naive male Sprague-Dawley albino rats, approximately 10 to 12 weeks old at the start of the experiment. Subjects were housed individually with food continuously available in their home cages. All were deprived of water for 48 hr prior to each experimental session.

Apparatus

The apparatus consisted of 10 identical Lehigh Valley Electronics conditioning chambers (23.3 cm long, 20.3 cm wide, and 19.5 cm high). Each had clear Plexiglas sides (0.6 cm

wide) and tops (0.3 cm wide) and aluminum front and rear walls. The grid floor was made of stainless steel rods, 0.4 cm in diameter and spaced 1.1 cm center to center, and was located 4 cm above the base. All chambers contained a recess (7.5 cm by 5.5 cm by 1 cm) in which a dipper presented 0.016 mL of water. The recess was centered on the intelligence panel 1.5 cm above the grid floor. A metal level (2.5 cm by 2.0 cm by 0.7 cm) with rounded sides was mounted 2.5 cm above the floor and 2.5 cm to the right of the dipper recess. The lever protruded from a hole (1.5 cm by 3 cm). A minimum force of 0.05 N was needed to close the microswitch. Centered 2.5 cm above the bar was an unlit light (1.8 cm diameter), which protruded 1.25 cm into the chamber. Equipment was housed in individual rooms, approximately 1.5 m by 3 m each illuminated by two 100-W bulbs directed away from the experimental chamber. A Minolta® Chroma-Meter CL-100 held 1 in. from the end of the bar at bar height produced a surface illumination reading of 14.8 lux. Videocameras recorded each subject's behavior. The cameras were positioned at approximately bar height, perpendicular to the Plexiglas wall and parallel to the bar. Each camera was approximately 1 m from the wall; the size of the field that was recorded was adjusted so that the interior of the chamber filled the entire picture frame. A microcomputer controlled reinforcer delivery and recorded lever presses.

Procedure

All rats were first trained to drink from the dipper. Water was delivered on a variable-time 30-s (VT 30) schedule for approximately 1 hr. By the end of training, all subjects reliably and promptly drank from the dipper. One week after dipper training, subjects were randomly assigned to one of two experimental groups ($n = 5$). The groups differed in the approximations reinforced during shaping. Approximations for the rear group specified reinforcement for rearing anywhere in the chamber, then for rearing over the bar, and finally only for pressing the bar (rearing was no longer necessary). For the nose group, snout proximity to the bar, then snout contact, and finally only bar depression (not necessarily preceded by snout contact) was reinforced.

Observations. The 9th through 12th presses for each subject were videotaped. Subjects' behavior was sequentially coded by two independent observers into 41 topographically defined categories, described in Table 1. Several categories were modifications of existing classification schemes for rodent behavior (Davey & Cleland, 1982; Shettleworth, 1975); most were developed and refined during pilot coding of taped segments from several subjects. Observer agreement (calculated by dividing total agreements by total agreements plus total disagreements) averaged .87. Reliabilities for individual categories are shown in Table 1. Two of the three observers were unfamiliar with the hypotheses being tested.

Results

Figure 1 depicts the mean frequency of bar-directed components for each group. Nine components occurred in both groups, including one ingestive response, mouthing. One subject in the rear group and 2 in the nose group mouthed the bar. The only category in which the groups differed significantly was rearing: rats shaped to rear emitted significantly more bar rears, $t(4) = 2.32$, $p < .05$, than subjects shaped to nose. Two subjects in the rear group and 1 in the nose group also reared at the dipper. Two categories occurred only in the nose group; 1 subject contacted the bar with both paws simultaneously (both), and another waved his forepaws in the air (flail).

To determine whether components were organized differently in the two groups of subjects, response sequences for each subject were analyzed according to transition probabilities from each component to each other component. Separate analyses were conducted for the sequences that occurred between drinking and the next bar press and for those intervening between a press and subsequent contact with the dipper. The top panel in Figure 2 shows conditional probabilities for each component (R_n) following each other component (R_{n-1}) for 1 subject in the rear group. This set of transitions represents the forward flow of behavior: the probability of a response (R_n) conditional on the response (R_{n-1}) preceding it. For example, when Rat 1 was at the dipper, the probability of putting its snout in the hole at the back of the bar was 80%. Once at the hole, the probability of rearing over the bar (bar rear) was 36%. Given a bar rear, the probability of placing its left paw on the bar was 88.2%. Finally, the probability of press

Table 1

Definition of behavioral categories and interobserver reliabilities.

Bar-directed behavior (reliabilities Experiment 1/Experiment 2)		
Paw		
R	Right paw (.85/1.0)	Right paw contacting top of bar. Note: contact is scored when space cannot be seen between body and bar surface.
Ru	Right under	Right paw contacting underside of bar.
L	Left paw (.96/.83)	Left paw contacting top of bar.
Lu	Left under	Left paw contacting underside of bar.
B	Both paws (—/1.0)	Both paws contacting top of bar.
Gr	Grasp (1.0/—)	Bar contact with both paws: one on top surface; one contacting underside.
Sl	Slide	Glide paw over surface of bar.
Body		
BR	Bar rear (.81/.95)	Upward movement of body to position where angle between floor and a straight line extending from bottom of ear to top of haunch is 30° or more. Hindpaws within eight floor grids from wall behind bar, body facing bar. Frontpaws in air.
T	Torso	Contact bar with body part other than head or paws.
Snout		
H	Hole (.66/1.0)	Snout in hole at back of bar.
Bi	Bite (.66/1.0)	Grasping bar between teeth.
M	Mouth (1.0/—)	Any mouth contact with bar.
C	Chin (1.0/1.0)	Any head contact excluding mouth and bite.
N	Nose	Any bar contact with tip of snout.
O	Over (.88/1.0)	Moving of snout into space defined by imaginary vertical planes extending from sides of bar to ceiling. No bar contact. Score first time plane is broken.
U	Under (.87/1.0)	Moving of snout into space defined by imaginary vertical planes extending from sides of bar to floor. No bar contact. Score first time plane is broken.
Press		
X	Press (1.0/1.0)	Any depression of bar strong enough to activate microswitch.
Dipper-directed behavior		
D	Dipper (.97/1.0)	Snout inside dipper recess. Note: used to collapse all dipper categories.
Dp	Dipper paws (1.0/—)	Both paws on dipper ledge.
Dr	Dipper right (1.0/—)	Right paw on dipper ledge.
Dl	Dipper left (.87/—)	Left paw on dipper ledge.
DR	Dipper rear (1.0/—)	Same body behavior as bar rear: position within eight floor grids of dipper, body facing dipper.
*	Reinforcer	Receipt of reinforcer by subject. Can also be coded as drinking or eating to denote whether water or food was presented at the dipper.
Light-directed behavior		
Lite	Light (—/.89)	Light contact with any part of the body except open mouth. Note: used to collapse all light categories.
Lite/L	Light left (—/1.0)	Contact light above bar with left paw.
Lite/R	Light right (—/.72)	Contact light with right paw.
LBoth	Light both (—/.60)	Contact light with both paws.
Lsnout	Light snout	Contact light with snout
Ml	Mouth light	Contact light with open mouth: include licking and biting the light.
Orient	Orient (—/1.0)	Approach and come within one noselength of light.

Table 1 (*Continued*)

Other behavior		
F	Flail	Repeated waving back and forth of front paw(s): either up and down or side to side.
Ht	Head toss (1.0/—)	At least two up and backwards movements of the head in succession.
Wa	Walk (1.0/—)	Move with at least three paws on ground without contacting any other surface.
G	Groom (1.0/1.0)	Continuous rubbing, scratching or biting of body and/or head.
Fr	Freeze	Pause without motion for at least 3 s.
OR	Other rear (1.0/—)	Same behavior as bar rear: position—anywhere in box not specified by bar, light, or dipper rear.
No	Nose other	Snout contact with surface other than dipper, light, or bar: does not include top of box.
Mo	Mouth other	Lips moving in contact with surface other than dipper, light, or bar.
W	Wall	Paws contacting metal wall surface on either side of bar.
Wl	Wall left (1.0/—)	Left paw contacting metal wall surface on either side of bar.
Wr	Wall right	Right paw contacting metal wall surface on either side of bar.

given that left paw occurred was 26.7%. Notice that, although left paw leads to responses other than press, press is always preceded by left paw.

The bottom panel in Figure 2 presents backward transition probabilities, that is, the probability of each component (R_{n-1}) conditional on the component (R_n) immediately following it. For example, if a press occurred, the probability that left paw preceded it was 100%. Given that its left paw was on the bar, 100% of the time it was preceded by bar rear.

Backward transition probabilities conditional on two (R_{n-2} and R_{n-1}) and three (R_{n-3}, R_{n-2}, and R_{n-1}) component sequences preceding press (R) both with and without regard to specific order of components were also computed. Figure 3 shows the two or three component press sequences with the highest probability for all subjects in the rear group. For example, all of Rat 1's successful presses were preceded by the three component sequence hole → bar rear → left paw. All subjects in the rear group emitted rear as a component of the press sequences. However, individual variation is apparent in the other components and sequences. For example, Rat 1's presses were consistently hole → bar rear → left paw, but Rat 4 either reared over the bar or mouthed the bar before pressing with its right paw.

The highest probability press sequences for the nose group are presented in Figure 4. Reinforcing the nose approximations resulted in more variable topographies than did reinforcing the rear approximations. Whereas 3 subjects in the rear group pressed 100% of the time in the same way (bar rear → left), only 1 subject in the nose group displayed a consistent press sequence. Further, no 2 subjects emitted any of the same sequences. However, there does appear to be some effect of the nose approximation. Overall, 70% of the sequences emitted by the nose group contained components that either brought the snout either in proximity to (under, hole) or in contact with (chin, mouth), the bar. Only 35% of the sequences observed in the rear group contained these topographies.

Discussion

The results of Experiment 1 are consistent with the hypothesis that selectively reinforcing specific topographic components can affect final response form. Significantly more rears were recorded in the group in which rearing was reinforced than in the group in which nosing was reinforced. Rearing was incorporated into the press sequences of all subjects in the rear group.

There were not comparable effects in the nose group. Nosing the bar was not observed in any subject. There were no between-group differences in any topographically similar (i.e., snout–bar contact) categories. Although the total number of sequences containing components in which the snout approached or contacted the bar was double that of the rear group, only 1 subject emitted press sequences that always included a snout contact component. Each subject in the nose group displayed idiosyncratic component patterns.

There are several possible reasons for the

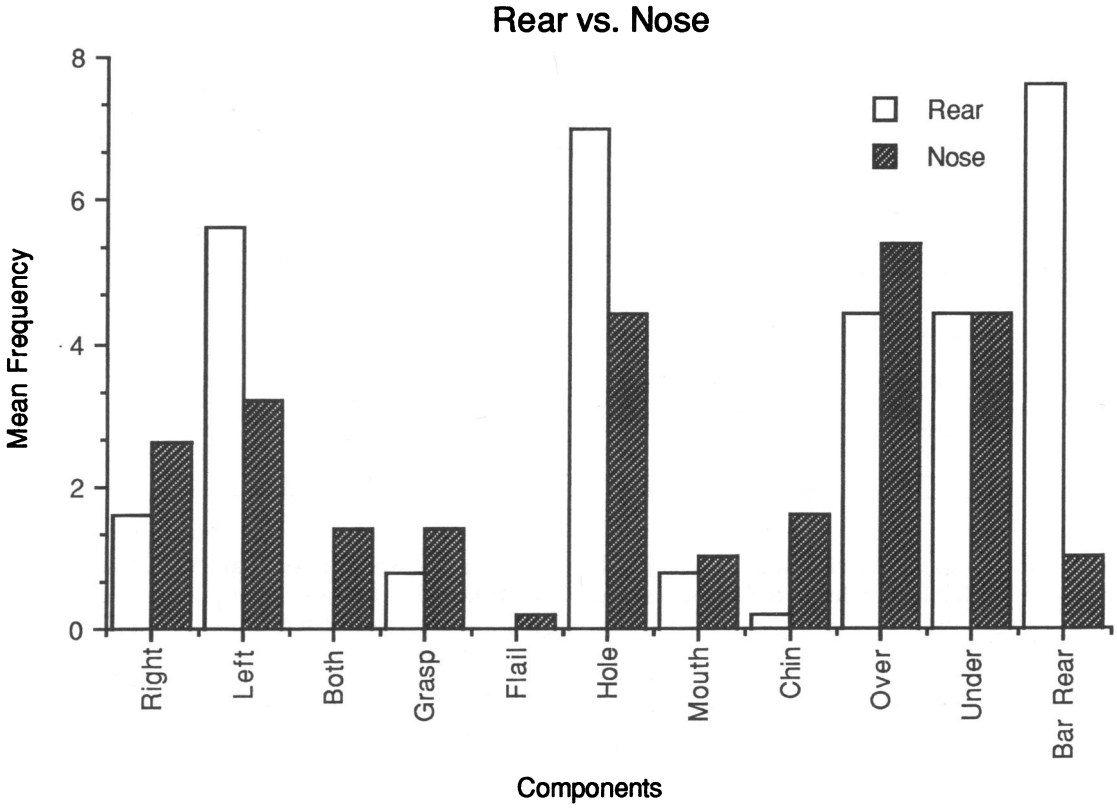

Fig. 1. Mean frequency of bar-directed components emitted by rear (unfilled bars) and nose (hatched bars) group rats.

failure to observe nosing in the subjects for whom snout proximity or contact with the bar was reinforced. Skinner (1938) suggested that only unambiguous responses (i.e., ones that are not components of other responses and that occur repeatedly in almost the same way) are easily conditioned. The shaping instructions specified reinforcement of snout proximity to the bar. Snout proximity (i.e., nose in the air) could be a precursor to, or component of, many different bar-directed responses. Earlier work with cats and vervet monkeys (Iversen, Ragnarsdottir, & Randrup, 1984; Konorski, 1967) found that reinforcing paws in the air rather than a complete grooming episode failed to strengthen the normal grooming response. However, when complete grooming episodes were reinforced, grooming bouts increased in frequency. This suggests that the failure of nosing to increase selectively and be incorporated in press sequences may not be the result of subjects' incapacity to emit this response as a component of the bar press, but instead may have resulted from the nature of the contingency. Rather than a specific form of snout contact (nose) being selectively reinforced in all subjects, it is possible that a range of snout orientation (over, under) or contact (hole, chin, mouth) topographies were differently reinforced in different subjects. In addition, subsequent to the current study, several subjects were exposed to a different response contingency that required contacting the bar with the tip of the snout. Nose was incorporated into the press sequences of all subjects; 1 pressed the bar the exclusively with the tip of its snout. Thus, responding in the nose group may also be understood as the direct result of the contingencies on response form.

A strict Pavlovian model cannot account for the results of Experiment 1. First, the form of bar-directed behavior in both groups was different from that reported by Davey and Cleland (1982) for a Pavlovian preparation in which bar presentations were paired with water presentation. However, the lever employed

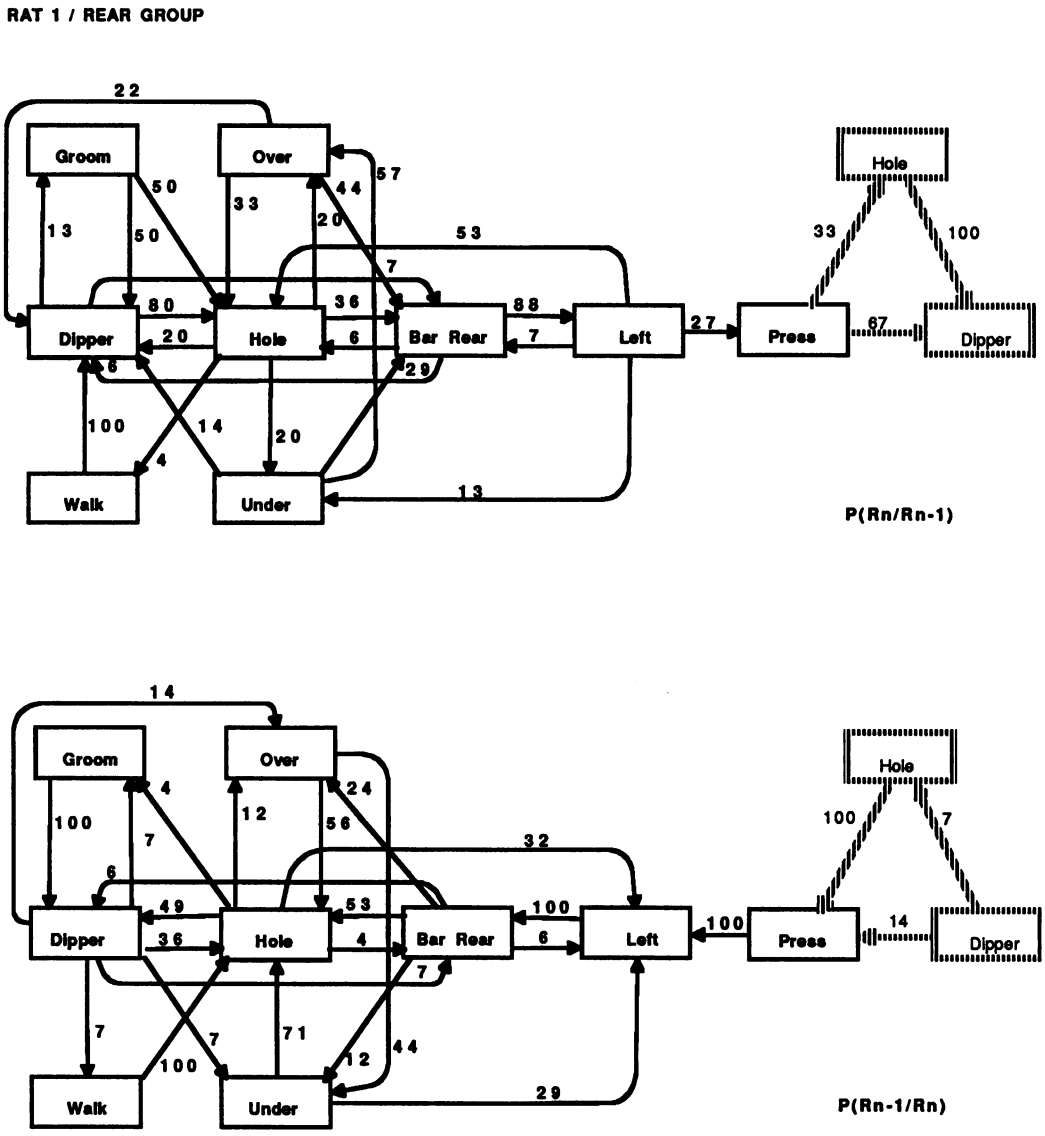

Fig. 2. Conditional probabilities for Rat 1 in the rear group. Arrowheads point in the direction of the transition between components. Solid arrows indicate component transitions that occurred between the drinking of water at the dipper and a bar press. Broken arrows indicate component transitions between press and going to the dipper. Diagrams in the top panel show conditional probabilities of each behavior following each other behavior (R_n/R_{n-1}); those in the bottom panel show the probabilities that each behavior was preceded by each other behavior (R_{n-1}/R_n).

in the current study had different dimensions from that of Davey and Cleland. Thus, topographic differences between the two studies may have been due, in part, to properties of the CS. Second, and more important, if response forms were determined by Pavlovian associations, there should have been little individual variation in response form. However, every rat in the nose group pressed the bar in a different way. Further, the approximations reinforced in each group strongly influenced the topography of pressing, even though the reinforcer and manipulandum were probably paired equally often in both experimental groups.

In contrast to a strict Pavlovian account of shaping, Timberlake's (1983) behavioral systems model provides somewhat greater flexi-

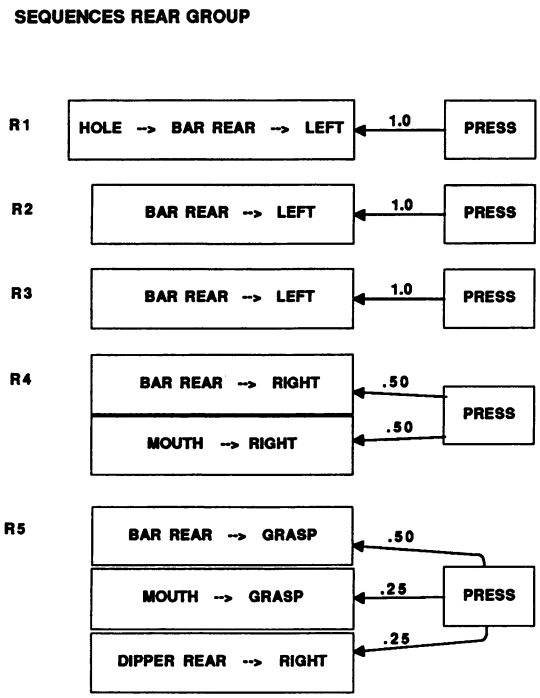

Fig. 3. Highest probability two- (R_{n-2} and R_{n-1}) or three- (R_{n-3}, R_{n-2}, and R_{n-1}) component sequences preceding press for all subjects in the rear group.

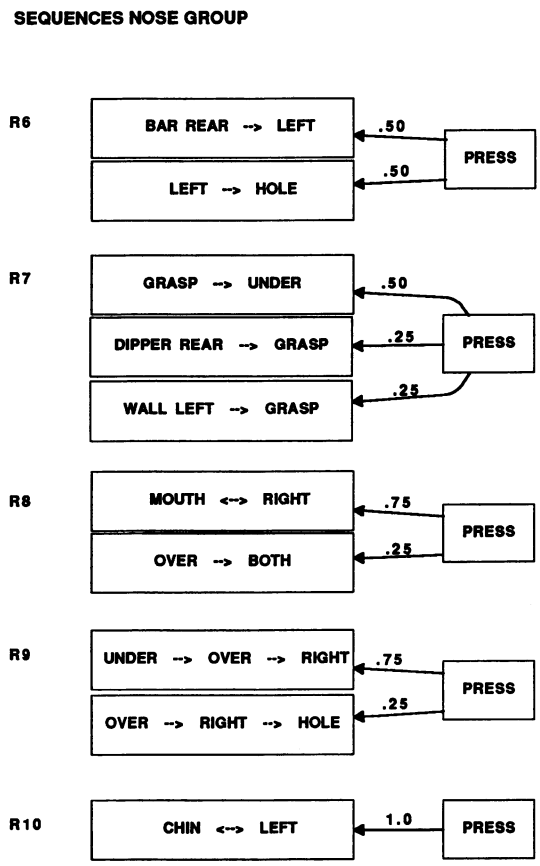

Fig. 4. Highest probability two- or three-component sequences preceding a press for all subjects in the nose group. Double headed arrows indicate that the sequence consisted of two components either preceding or following each other. For example, in the case of Rat 10, chin → left or left → chin preceded press 100% of the time.

bility in response form. However, it is difficult to predict the topographies of the rear group from this point of view. The behavior systems model specifies that "the closer in time to (reinforcer) presentation a particular stimulus occurs, the more likely that the stimulus will elicit preconsummatory or ingestive forms of appetitive behavior . . . the farther away . . . the more likely it will be to elicit patterns of search and approach behavior" (Timberlake & Lucas, 1985, p. 297). In this view, bar-press topographies should consist of handling/consummatory and focal search responses. But then, it is surprising that rear, a general exploratory behavior (Shettleworth, 1975, p. 67), could be incorporated into the press sequence. Thus, if there is constraint on the topographies that can be strengthened by water reinforcement, it appears to be on a very high level of behavioral organization—at least as high as the subsystem level of Timberlake and Lucas' (1989, p. 243) representation of this model. However, species-typical handling and consummatory responses may not be manifest early in training. Timberlake and Lucas (1985) observed that topographies are first variable and only later settle into species-typical patterns. Experiment 1 analyzed only a brief sample of behavior early in conditioning. It is possible that species-based stereotypy might emerge later in training and interfere with or alter press sequences established during shaping (Breland & Breland, 1961).

EXPERIMENT 2

The results of Experiment 1 indicate that a strict Pavlovian model cannot account for response form early in shaping. To determine whether subjects settle into species-typical patterns, we need to analyze the effects of shaping history on response form during extended training. If a constrained behavioral systems view is correct, the effects of the approxima-

tions might decrease as training proceeds and responding comes to reflect species-typical patterns.

The models of Skinner (0000), Hull (0000), and Bindra (0000) are more complex in their predictions about the effects of early training. All three views predict that topographies reinforced during shaping may be maintained if chained to or incorporated into the response sequence (Hull, Skinner), or if they are elicited by conditioned incentive stimuli that are still encountered late in training (Bindra). However, none precludes changes in response form. Skinner (1938) suggested that response forms might "narrow" through elimination of unnecessary or awkward components. Similarly, Bindra indicated that unnecessary responses would drop out as subjects pay "progressively greater selective attention to the conditioned incentive stimuli closer to the incentive" (Bindra, 1976, p. 239). Finally, Hull (1934) postulated that the shortest path in a particular goal hierarchy would be the most probable one. Thus, one could anticipate that response forms might become simpler or more stereotyped as training progresses.

On the other hand, response forms might be complex and variable throughout training. Either induction or generalization could induce novel response forms throughout training (Skinner, 1953). According to Hull (1943), variability in form would follow from oscillations in underlying neural response thresholds that inhibit different response components on a moment-to-moment basis. The behavioral systems formulation of Timberlake and Lucas (1989) allows for oscillation between several responses when the training situation "fits several filters or the filters are connected to a variety of response components" (p. 265). Bindra (1976) might be interpreted as predicting that components would not be added to well-established sequences because, with extended practice, an entire response sequence could be triggered by the first of a series of response-eliciting stimuli that initially produced each component separately. However, there is nothing in his model that specifically precludes addition of components later in training.

Experiment 2 was designed to investigate whether response forms acquired during shaping would persist during extended training when the specific approximations were no longer required for reinforcement. As in Experiment 1, if these approximations are incorporated into subject's press sequences, they may be retained even though they are no longer necessary. However, with extended training, subjects may well drift into simpler forms, which could be either idiosyncratic or shared species-typical patterns.

METHOD

Subjects and Apparatus

The subjects were 4 experimentally naive adult female Sprague-Dawley albino rats. Subjects were housed and deprived as in Experiment 1. The apparatus was the same as in Experiment 1.

Procedure

All rats were first trained to drink from the dipper by exposure to a VT 30-s schedule for approximately 1 hr. At the end of dipper training, all subjects reliably and promptly drank from the dipper.

Two days after dipper training, bar pressing was shaped. Reinforcement was initially specified for two general sets of responses: (a) approach and/or contact with the unilluminated light above the bar and (b) paw contact with the bar. Once pressing began, only presses with a single paw were reinforced. Reinforcers were then delivered only for sequences in which proximity to or contact with the light and single-paw contact with the bar and press occurred in any order without any intervening components (i.e., light-paw-press, paw-light-press, or paw-press-light). Except for Rat G, shaping continued until at least 100 presses occurred and at least 20 of 30 consecutive sequences included both light and single-paw press topographies (in the judgment of the person shaping). Rat G did not reach this criterion in 80 min of shaping. Nonetheless, the shaping phase was terminated even though only 7 of the final 30 sequences included light and single-paw presses. In the next session, the light and single-paw requirements were removed for all subjects. No specific topographic requirements were included in the specification of the contingency. All bar presses were reinforced (continuous reinforcement, CRF) during two additional half-hour sessions.

All sessions were videotaped and sequentially coded by two independent observers as in Experiment 1. Averaged across all categories, interobserver agreement (shown in Table

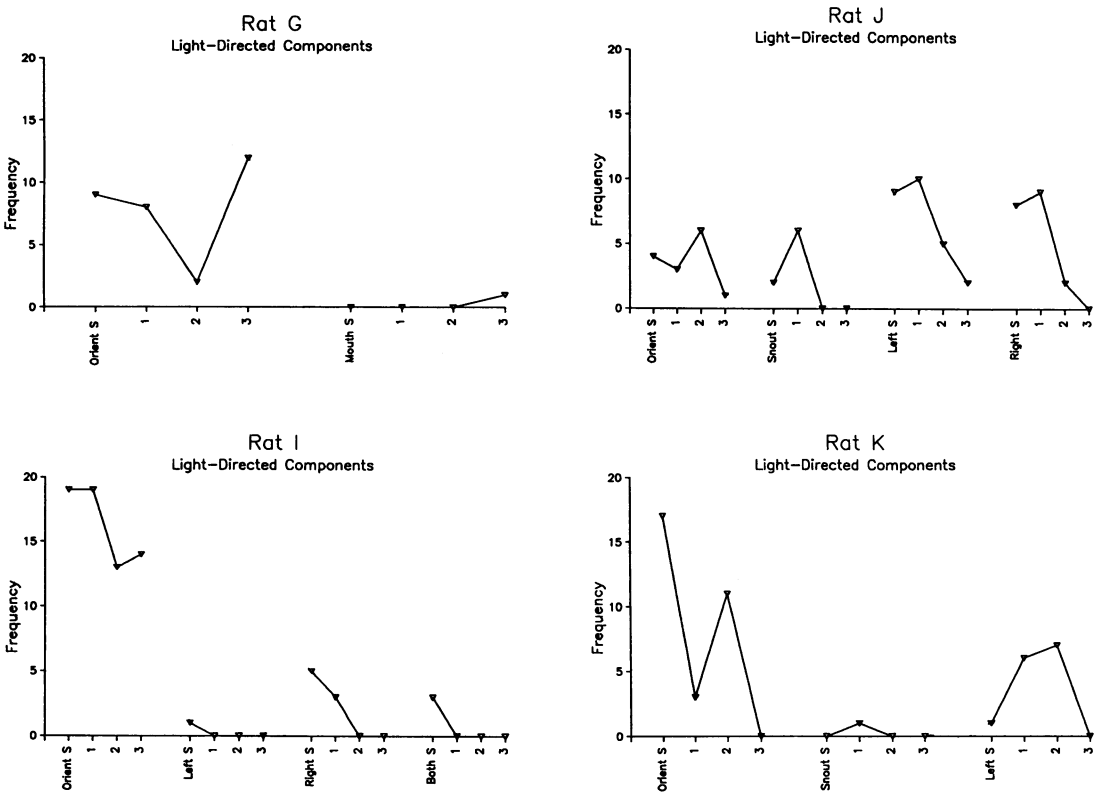

Fig. 5. Frequency of all light-directed components for each subject. The frequency of each component is shown for the last 20 reinforcers earned in shaping (S) and for Presses 1–20(1), 91–110(2), and 191–210(3) during CRF.

1) was .93 in this experiment. Responses during the last 20 reinforcers earned in shaping and during CRF Trials 1–20, 91–110, and 191–210 were analyzed. For Rat G, all sampled CRF trials came from the first CRF session; for the other subjects, the 191st to 210th trials occurred in the second CRF session.

Results

Figure 5 shows the frequencies of all light-directed components for each subject during the 20-reinforcer blocks listed above. By the end of shaping, all rats oriented toward the light. Three (I, J, and K) contacted it with their left paw; 2 (J and I) with their right, and 1 (I) with both paws at once. One subject (J) contacted the light with its snout. During the CRF phase, the frequency of light-directed behavior declined in 3 of the 4 subjects. However, the specific topographies continued to be variable across subjects. Although all oriented toward the light, 1 subject (G) mouthed it, 2 (J and K) contacted it with their snouts, 2 (J and K) contacted it with their left paws, and 2 (I and J) contacted it with their right paws.

Figure 6 shows the frequency of bar-related behavior and the sum of all light categories for all subjects. During shaping, the three components selected for reinforcement were observed in all subjects: Each rat contacted the bar with a single paw and approached or contacted the light. For each subject either the left or right paw predominated. Because the light was located over the bar, all subjects positioned themselves over the bar (over and/or bar rear). Three of the 4 rats continued to favor one paw, made some light-directed responding, and positioned themselves over the bar throughout CRF. One (Rat K) did not direct any responses at the light during the last 20 presses of CRF. Components other than light, left, right, over, and bar rear were observed in all subjects. However, with one exception (for Rat 1, hole increased during training), these components appeared intermittently and at low frequencies as compared to the specifically reinforced ap-

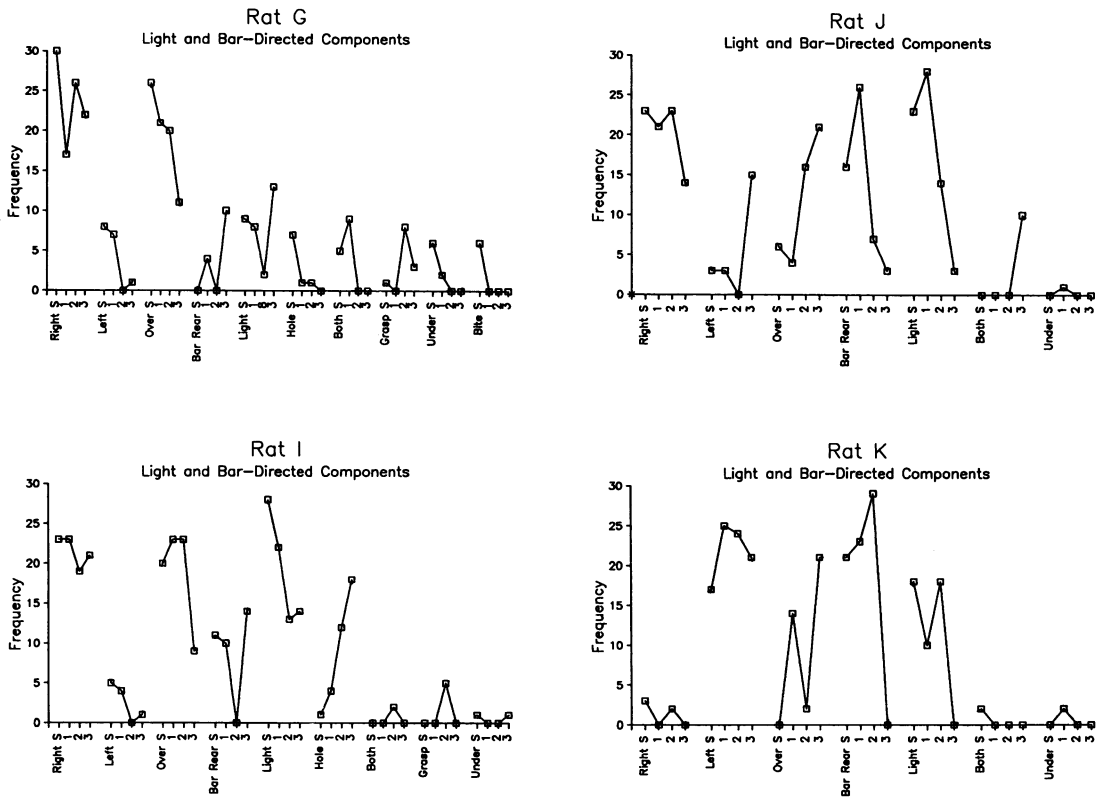

Fig. 6. Frequency of all bar-directed and total light-directed components for each subject. The frequency of each component is shown for the last 20 reinforcers earned in shaping (S) and for Presses 1-20(1), 91-110(2), and 191-210(3) during CRF.

proximations and positioning the body over the bar. One subject (G) bit the bar during shaping, but this behavior was not maintained during subsequent exposure to the CRF contingency.

The number of sequences between reinforcers that contained at least one instance of a light component and a single-paw bar contact was analyzed to see whether the conjunctive requirement during shaping caused both components to persist during CRF sequences (though not necessarily without intervening components). Figure 7 shows the results of this analysis. For 2 subjects, the frequency of these sequences declined by the end of the CRF phase. It did not decline for the other 2 (G and I).

Response sequences for each subject at the end of shaping and at the end of CRF were analyzed as in Experiment 1 to see if the sequence required during shaping persisted as a successful press sequence. The probabilities of sequences preceding reinforcement that included the approximations (with no other intervening components) went from 25% to 40% for Rat G, from 65% to 5% for Rat 1, from 80% to 10% for Rat J, and from 75% to 0% for Rat K. Thus, 3 subjects showed a decline in the probability of a press being preceded by both approximations.

To examine more closely how reinforced sequences changed between shaping and the end of CRF, the frequencies of the most highly reinforced sequences were analyzed over time; if a sequence was reinforced more often than any other in one block, it is shown for every block. Because sequences consisting of single-paw, light, and press in any order were reinforced, these were collapsed across orders. The few light/single-paw sequences that did not include press but that were reinforced during the last block of shaping were also included. Figure 8 shows the frequency of each subject's most highly reinforced sequences and

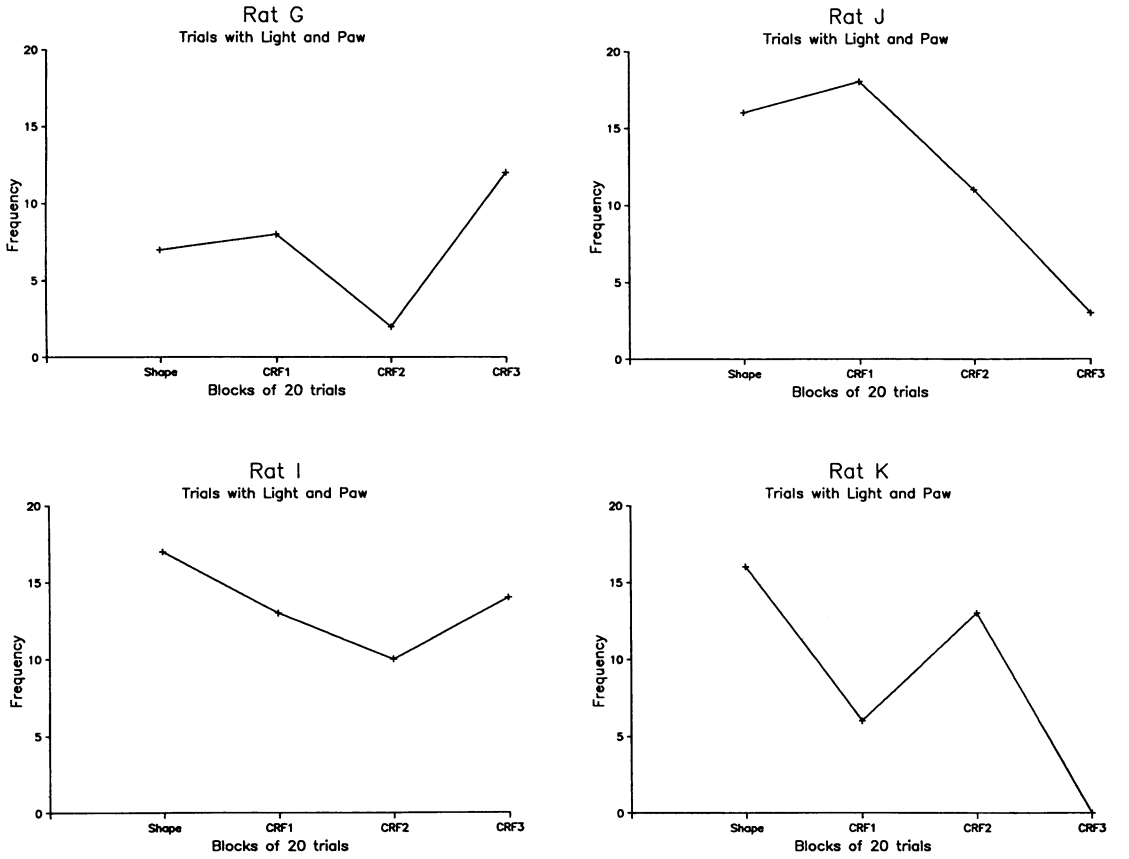

Fig. 7. Frequency of trials with at least one occurrence of both light-directed responding and single-paw bar contact for each subject. The frequency is shown for the last 20 reinforcers earned in shaping (Shape) and for Presses 1–20 (CRF1), 91–110 (CRF2), and 191–210 (CRF3) during CRF.

the number of different sequences in each phase.

At the end of shaping, the dominant sequence for all subjects included light, single-paw, and press. All subjects positioned themselves over the bar at the start of these sequences. For 2 subjects (G and I), the predominant form of this response was over; for the other two (J and K), it was bar rear. At the end of CRF, the dominant sequence for Rats G and I still included light, single-paw, and press, preceded, however, by bar rear rather than over. In contrast, the dominant paw-only press sequence for the other 2 subjects was preceded by over rather than bar rear.

There was considerable variability both within and among subjects. For all subjects, no one sequence was dominant throughout training. Dominant sequences earned less than 50% of the reinforcers in all phases for Rat G, in three phases for Rat I, in two phases for Rat J, and in three phases for Rat K. Only Rat K pressed 100% of the time with a single sequence, and only in the last CRF block.

To determine whether there were systematic changes in variability of sequential organization over time, the number of different two- or three-component reinforced sequences during the last phases in shaping and CRF, as well as the frequency of the dominant sequence in both phases, were compared (cf. Schwartz, 1980, 1982). For 3 subjects (G, I, and K), the number of different reinforced sequences declined and the frequency of their dominant sequence increased. The 4th subject, Rat J, exhibited the opposite pattern of change: The number of different sequences increased and the frequency of the dominant

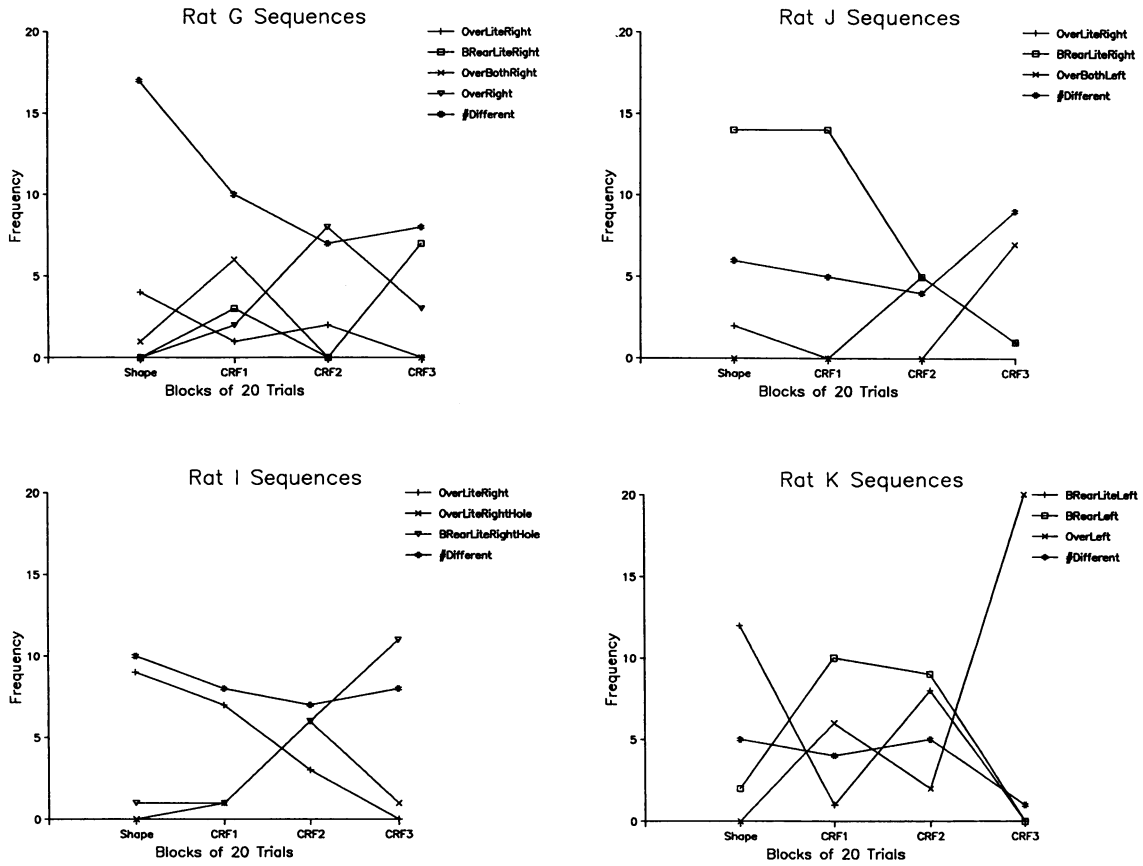

Fig. 8. Number of different press sequences and frequency of the dominant press sequence for each subject is shown for the last 20 reinforcers earned in shaping (Shape) and for Presses 1–20 (CRF1), 91–110 (CRF2), and 191–210 (CRF3) during CRF. If a sequence was dominant in any one phase, its frequency is given for all phases.

sequence decreased. By these measures, variability of sequences declined in 3 subjects (G, I, and K) and increased in 1 (J).

Discussion

The results of Experiment 2 extend the findings of Experiment 1 in showing that reinforcing topographically specified approximations during shaping can affect response form both early and late in training. All subjects performed the specified approximations (light, single-paw) and positioned themselves over the bar (bar rear, over) during shaping. Three of the 4 subjects continued to do so throughout training. Only 1 subject stopped responding to the light by the end of the CRF phase.

Reinforcement of the specific approximations influenced the press topography of all subjects, but there was still considerable variability among and within subjects in components and in their sequential organization. In terms of components, all rats oriented toward the light, but each emitted a different set of other light-directed components. No 2 rats showed the same complement of bar-directed components. Only 1 (G) emitted a consummatory topography (bite). With regard to organization of the dominant sequence, 3 subjects (G, I, and J) emitted over/light/right; 2 (G and J) also emitted bar rear/light/right. Subjects did not emit any other identical dominant sequences. Only 1 subject (K) displayed the same sequence every time, but only during the last CRF block.

According to the behavioral systems models, responding across subjects should have settled into species-typical patterns, possibly after an initial period of variability. Though sequential

variability declined from the end of the shaping to the end of the CRF phase, subjects did not settle into similar sequential patterns. Furthermore, as in Experiment 1, the continued presence of bar rear in close proximity to reinforcer delivery (Timberlake & Lucas, 1989), as well as the appearance of biting, a topography supposedly activated by food rather than by water deprivation (Timberlake, 1983), again indicates that there is less constraint on bar-press topography than earlier behavioral systems analyses might imply (Timberlake et al., 1982).

The results of Experiment 2 appear to be consistent with the views of Skinner (1938), Bindra (1976), and Hull (1934). Although all subjects drifted into simpler forms of responding (i.e., press sequences that did not include any light-directed behavior), individual light/single-paw/press sequences that were reinforced during shaping remained in subjects' repertoires during CRF when neither light nor single-paw was required for reinforcement. Furthermore, Bindra's model does not preclude continued variation in a stable training situation, and both Skinnerian and Hullian models provide specific mechanisms to account for it. Either response induction and generalization (Skinner, 1953) or behavioral oscillation (Hull, 1943) may account for the ongoing variability in response form observed during Experiment 2.

GENERAL DISCUSSION

The results of both experiments agree in showing that reinforcing specific topographic approximations during shaping can affect target response form both early and late in training. In Experiment 1, reinforcement for rearing resulted in all subjects emitting bar rear in their press sequences; reinforcement for nosing produced press sequences with snout proximity and/or contact components. In Experiment 2, reinforcing light and single-paw produced press sequences containing both approximations during shaping. Most rats continued to emit light/single-paw/press sequences throughout training.

Such results are inconsistent with a Pavlovian model of shaping. First, the form of the press was different from that reported in a Pavlovian procedure in which bar presentation was paired with the US (Davey & Cleland, 1982). Second, unlike the usual Pavlovian result, there was considerable individual variation in response form. Last, between-subject similarities were correlated with the reinforcement contingencies despite what appeared to be equivalent pairings of the CS and the US. Thus, a Pavlovian process cannot account for response form in shaping the rat's bar press as readily as it accommodates acquisition of the pigeon's key peck (Moore, 1973).

There are two ways in which shaping might influence response form. Reinforcement contingencies may induce new components and/or change the sequencing of components. The current study provides no evidence that contingencies create components. The data suggest that shaping works by reorganizing a repertoire of existing behavioral components that rats have in common. In both experiments, 14 different components were observed. One component (over) was seen in all subjects. Eight (right, left, grasp, hole, over, under, bar rear, and press) were common to all groups. Two (flail, bite) were emitted by individual subjects at low frequencies. Furthermore, the fact that rats in Experiment 2 contacted the light in the same ways that rats in both experiments contacted the bar (by rearing or positioning themselves over the target, and by contacting it with the tip of the snout, mouth, or one or both paws) is consistent with the view that the contingencies did not create novel components but rather combined and directed existing ones to target locations (viz., the light or bar).

A selection and reorganization of components by contingency hypothesis is consistent with the models of Skinner (1983, 1953), Hull (1932, 1934, 1935, 1943), and Bindra (1972, 1974, 1976). All three models can account for the incorporation and maintenance of the reinforced topographies in press sequences. All three can account for changes in form over training. However, only Skinner (1953) and Hull (1943) provide specific mechanisms to account for continued variability.

The hypothesis that contingencies select rather than create components is also consistent with the behavioral systems view. For example, Shettleworth (1975) suggests that, although food deprivation or anticipation facilitates a particular type of behavior, "the role of an instrumental contingency is to select

one of this group" (p. 71). Timberlake and Lucas (1989) regard all new responses as the rearrangement of existing perceptual-motor modules, constrained by subjects' motivational state, the stimulus, and the reinforcer type. However, component organization appears to be more flexible than prior experimental work has suggested (Timberlake et al., 1982).

The difference between the current studies and previous studies of response form that show the induction of species-typical patterns may be explained in several ways. First, more extensive exposure to reinforcement procedures may be necessary for the induction of species-typical patterns, as it is in pigeons (Timberlake & Lucas, 1985). Second, the manner in which the terminal response was specified in the current studies may have precluded species-typical forms. Timberlake et al. (1982) simply required "contact" with the manipulandum. Given that the form of the contact was not constrained by their contingency, and in view of the fact that subjects generally share not only species but also environmental and reinforcement histories, we would expect the most probable responses to an identical CS to be similar across subjects (i.e., species typical). In the current experiments, the form of approach (bar rear or nose, Experiment 1) and/or contact (single-paw and light, Experiment 2) was specified in the contingencies and was different from the anticipated species-typical responses. Thus, whether or not a species-typical pattern appears and and is sustained may depend on specific response–reinforcer contingencies. If the reinforcement contingency does not dictate otherwise, then the most probable response form prior to conditioning (species-typical forms) will dominate. If the contingency specifies reinforcement for particular topographies, these will become the dominant form.

In conclusion, the current studies demonstrate that response–reinforcer contingencies should be added to the list of factors that influence response topography. Factors that influence the form of a conditioned response include (a) properties of the US (Jenkins & Moore, 1973; Peterson, Ackil, Frommer, & Hearst, 1972; Timberlake et al., 1982), (b) properties of the CS (Davey & Cleland, 1982; Holland, 1977; Timberlake & Grant, 1975), (c) motivational state of the subject (Shettleworth, 1973, 1975), (d) frequency of the reinforcer (Innes, Simmelhag-Grant, & Staddon, 1983; Staddon & Simmelhag, 1971), (e) CS duration (Holland, 1980), (f) properties of the context (Balsam, 1985; Moore, 1973), and (g) the response class or classes to which the operant belongs (Hull, 1934; Kazdin, 1982; Segal, 1972; Skinner, 1938). The current studies show that specific response–reinforcer contingencies can also modulate component availability and organization and thus influence the form of conditioned responding.

Finally, the current experiments demonstrate the utility of a component analysis of response form. Although we believe that the location and timing of a behavior may be changed through shaping along continuous dimensions (Galbicka, 1988), the form of the behavior itself may be best understood as a discrete unit composed of a sequence of subunits. Skinner (1938) thought that there were minimal units of behavior from which new behavior could emerge. We suggest that the emergence of these new types occurs when the minimal units are reorganized into new sequences.

REFERENCES

Alleman, H. D., & Platt, J R. (1973). Differential reinforcement of interresponse times with controlled probability of reinforcement per response. *Learning and Motivation,* **4,** 40–73.

Antonitis, J. J. (1951). Response variability in the white rat during conditioning, extinction, and reconditioning. *Journal of Experimental Psychology,* **42,** 273–281.

Balsam, P. D. (1985). The functions of context in learning and performance. In P. D. Balsam & A. Tomie (Eds.), *Context and learning* (pp. 1–21). Hillsdale, NJ: Erlbaum.

Balsam, P. D. (1988). Selection, representation, and equivalence of controlling stimuli. In R. C. Atkinston, R. J. Herrnstein, G. Lindzey, & R. D. Luce (Eds.), *Steven's handbook of experimental psychology, Volume 2: Learning and cognition* (2nd ed., pp. 111–166). New York: Wiley.

Bindra, D. (1972). A unified account of classical conditioning and operant training. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II: Current research and theory* (pp. 453–481). New York: Appleton-Century-Crofts.

Bindra, D. (1974). A motivational view of learning, performance, and behavior modification. *Psychological Review,* **81,** 199–213.

Bindra, D. (1976). *A theory of intelligent behavior.* New York: Wiley.

Birch, H. G. (1945). The relation of previous experience to insightful problem-solving. *Journal of Comparative Psychology,* **38,** 367–383.

Bolles, R. C. (1970). Species-specific defense reactions and avoidance learning. *Psychological Record,* **77,** 32–48.

Breland, K., & Breland, M. (1961). The misbehavior of organisms. *American Psychologist,* **16,** 681–684.

Davey, G. C. L., & Cleland, G. G. (1982). Topography of signal-centered behavior in the rat: Effects of deprivation state and reinforcer type. *Journal of the Experimental Analysis of Behavior,* **38,** 291–304.

Davis, E. R., & Platt, J. R. (1983). Contiguity and contingency in the acquisition and maintenance of an operant. *Learning and Motivation,* **14,** 487–512.

Deich, J. D., Allan, R. W., & Zeigler, H. P. (1988). Conjunctive differentiation of gape during food-reinforced keypecking in the pigeon. *Animal Learning & Behavior,* **16,** 268–276.

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.

Eckerman, D. A., & Lanson, R. N. (1969). Variability of response location for pigeons responding under continuous reinforcement, intermittent reinforcement, and extinction. *Journal of the Experimental Analysis of Behavior,* **12,** 73–80.

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

Fentress, J. C. (1983). Ethological models of hierarchy and patterning of species-specific behavior. In E. Satinoff & P. Teitelbaum (Eds.), *Handbook of behavioral neurobiology: Vol. 6. Motivation* (pp. 185–234). New York: Plenum Press.

Galbicka, G. (1988). Differentiating *The Behavior of Organisms. Journal of the Experimental Analysis of Behavior,* **50,** 343–354.

Galbicka, G., & Platt, J. R. (1986). Parametric manipulation of interresponse-time contingency independent of reinforcement rate. *Journal of Experimental Psychology: Animal Behavior Processes,* **12,** 371–380.

Galbicka, G., & Platt, J. R. (1989). Response–reinforcer contingency and spatially defined operants: Testing an invariance property of phi. *Journal of the Experimental Analysis of Behavior,* **51,** 145–162.

Gallistel, C. R. (1980). *The organization of action: A new synthesis.* Hillsdale, NJ: Erlbaum.

Goetz, E. M., & Baer, D. M. (1973). Social control of form diversity and the emergence of new forms in children's blockbuilding. *Journal of Applied Behavior Analysis,* **6,** 209–217.

Golani, I., & Fentress, J. C. (1985). Early ontogeny of face grooming in mice. *Developmental Psychobiology,* **18,** 529–544.

Herrick, R. M. (1965). Lever displacement under a fixed-ratio schedule and subsequent extinction. *Journal of Comparative and Physiological Psychology,* **59,** 263–270.

Herrick, R. M., & Bromberger, R. A. (1965). Lever displacement under a variable ratio schedule and subsequent extinction. *Journal of Comparative and Physiological Psychology,* **59,** 392–398.

Hinde, R. A., & Stevenson-Hinde, J. (Eds.). (1973). *Constraints on learning: Limitations and predispositions.* London: Academic Press.

Holland, P. C. (1977). Conditioned stimulus as a determinant of the form of the Pavlovian conditioned response. *Journal of Experimental Psychology: Animal Behavior Processes,* **3,** 77–104.

Holland, P. C. (1980). CS–US interval as a determinant of the form of Pavlovian appetitive conditioned responses. *Journal of Experimental Psychology: Animal Behavior Processes,* **6,** 155–174.

Holman, J., Goetz, E. M., & Baer, D. M. (1977). The training of creativity as an operant and an examination of its generalization characteristics. In B. C. Etzel, J. M. LeBlanc, & D. M. Baer (Eds.), *New developments in behavioral research: Theory, method, and application* (pp. 441–471). Hillsdale, NJ: Erlbaum.

Hull, C. L. (1932). The goal gradient hypothesis and maze learning. *Psychological Review,* **39,** 25–43.

Hull, C. L. (1934). The concept of the habit-family hierarchy and maze learning: Part I and Part II. *Psychological Review,* **41,** 33–54, 134–152.

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

Hull, C. L. (1943). *Principles of behavior: An introduction to behavior theory.* New York: Appleton-Century-Crofts.

Innes, N. K., Simmelhag-Grant, V. L., & Staddon, J. E. R. (1983). Behavior induced by periodic food delivery: The effects of interfood interval. *Journal of the Experimental Analysis of Behavior,* **39,** 309–322.

Iversen, I. H. (1976). Interactions between reinforced responses and collateral responses. *Psychological Record,* **26,** 399–413.

Iversen, I. H. (1986). Time allocation, sequential, and kinematic analyses of behaviors controlled by an aperiodic reinforcement schedule. *Psychological Record,* **36,** 239–255.

Iversen, I. H., Ragnarsdottir, G. A., & Randrup, K. I. (1984). Operant conditioning of autogrooming in vervet monkeys (*Cercopithecus aethiops*). *Journal of the Experimental Analysis of Behavior,* **42,** 171–189.

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.

Kara, A., & Wahler, R. G. (1977). Organizational features of a young child's behaviors. *Journal of Experimental Child Psychology,* **24,** 24–39.

Kazdin, A. E. (1982). Symptom substitution, generalization, and response covariation: Implications for psychotherapy outcome. *Psychological Bulletin,* **91,** 349–365.

Köhler, W. (1925). *The mentality of apes.* (E. Winter, Trans., from 2nd rev. ed.). New York: Harcourt Brace.

Konorski, J. (1967). *Integrative activity of the brain.* Chicago: University of Chicago Press.

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 Monograph Supplement,* **74**(2, Whole No. 635).

Maier, N. R. F. (1929). Reasoning in white rats. *Comparative Psychology Monographs,* **6** (Whole No. 29).

Maier, N. R. F. (1931). Reasoning in humans. *Journal of Comparative Psychology,* **12,** 181–194.

Margulies, S. (1961). Response duration in operant level,

regular reinforcement, and extinction. *Journal of the Experimental Analysis of Behavior,* **4,** 317–321.

Midgley, M., Lea, S. E. G., & Kirby, R. M. (1989). Algorithmic shaping and misbehavior in the acquisition of token deposit by rats. *Journal of the Experimental Analysis of Behavior,* **52,** 27–40.

Millenson, J. R., & Hurwitz, H. M. B. (1961). Some temporal and sequential properties of behavior during conditioning and extinction. *Journal of the Experimental Analysis of Behavior,* **4,** 97–106.

Millenson, J. R., Hurwitz, H. M. B., & Nixon, W. L. B. (1961). Influence of reinforcement schedules on response duration. *Journal of the Experimental Analysis of Behavior,* **4,** 243–250.

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). London: Academic Press.

Muenzinger, K. F. (1928). Plasticity and mechanization of the problem box habit in guinea pigs. *Journal of Comparative Psychology,* **8,** 45–69.

Muenzinger, K. F., Koerner, L., & Irey, E. (1929). Variability of an habitual movement in guinea pigs. *Journal of Comparative Psychology,* **9,** 425–436.

Notterman, J. M. (1959). Force emission during bar pressing. *Journal of Experimental Psychology,* **58,** 341–347.

Notterman, J. M., & Mintz, D. E. (1965). *Dynamics of response.* New York: Wiley.

Pear, J. J., & Legris, J. A. (1987). Shaping by automated tracking of an arbitrary operant response. *Journal of the Experimental Analysis of Behavior,* **47,** 241–247.

Peterson, G. B., Ackil, J. E., Frommer, G. P., & Hearst, E. S. (1972). Conditioned approach and contact behavior for food or brain-stimulation reinforcement. *Science,* **177,** 1009–1011.

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

Russo, D. C., Cataldo, M. F., & Cushing, P. J. (1981). Compliance training and behavioral covariation in the treatment of multiple behavior problems. *Journal of Applied Behavior Analysis,* **14,** 209–222.

Schwartz, B. (1980). Development of complex, stereotyped behavior in pigeons. *Journal of the Experimental Analysis of Behavior,* **33,** 153–166.

Schwartz, B. (1982). Failure to produce response variability with reinforcement. *Journal of the Experimental Analysis of Behavior,* **37,** 171–181.

Scott, G. K., & Platt, J. R. (1985). Model of response-reinforcer contingency. *Journal of Experimental Psychology: Animal Behavior Processes,* **11,** 152–171.

Segal, E. F. (1972). Induction and the provenance of operants. In R. M. Gilbert & J. R. Millenson (Eds.), *Reinforcement: Behavioral analyses* (pp. 1–34). New York: Academic Press.

Shettleworth, S. J. (1972). Constraints on learning. In D. S. Lehrman, R. A. Hinde, & E. Shaw (Eds.), *Advances in the study of behavior* (Vol. 4, pp. 1–68). New York: Academic Press.

Shettleworth, S. J. (1973). Food reinforcement and the organization of behaviour in golden hamsters. In R. A. Hinde & J. Stevenson-Hinde (Eds.), *Constraints on learning: Limitations and predispositions* (pp. 243–263). London: Academic Press.

Shettleworth, S. J. (1975). Reinforcement and the organization of behavior in golden hamsters: Hunger, environment, and food reinforcement. *Journal of Experimental Psychology: Animal Behavior Processes,* **1,** 56–87.

Skinner, B. F. (1938). *The behavior of organisms.* New York: Appleton-Century.

Skinner, B. F. (1953). *Science and human behavior.* New York: Macmillan.

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

Stebbins, W. C., & Lanson, R. N. (1962). Response latency as a function of reinforcement schedule. *Journal of the Experimental Analysis of Behavior,* **5,** 299–304.

Teitelbaum, P. (1977). Levels of integration of the operant. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 7–27). Englewood Cliffs, NJ: Prentice-Hall.

Timberlake, W. (1983). Rat's responses to a moving object related to food or water: A behavior-systems analysis. *Animal Learning & Behavior,* **11,** 309–320.

Timberlake, W., & Grant, D. L. (1975). Auto-shaping in rats to the presentation of another rat predicting food. *Science,* **190,** 690–692.

Timberlake, W., & Lucas, G. A. (1985). The basis of superstitious behavior: Chance contingency, stimulus substitution, or appetitive behavior? *Journal of the Experimental Analysis of Behavior,* **44,** 279–299.

Timberlake, W., & Lucas, G. A. (1989). Behavior systems and learning: From misbehavior to general principles. In S. B. Klein & R. R. Mowrer (Eds.), *Contemporary learning theories* (Vol. 2, pp. 237–275). Hillsdale, NJ: Erlbaum.

Timberlake, W., Wahl, G., & King, D. (1982). Stimulus and response contingencies in the misbehavior of rats. *Journal of Experimental Psychology: Animal Behavior Processes,* **8,** 62–85.

Vogel, R., & Annau, Z. (1973). An operant discrimination task allowing variability of reinforced response patterning. *Journal of the Experimental Analysis of Behavior,* **20,** 1–6.

Wahler, R. G., & Fox, J. J. (1982). Response structure in deviant child-parent relationships: Implications for family therapy. In D. J. Bernstein (Ed.), *Nebraska Symposium on Motivation: Vol. 29. Response structure and motivation* (pp. 1–46). Lincoln: University of Nebraska Press.

Wolin, B. R. (1948/1968). Difference in manner of pecking a key between pigeons reinforced with food and with water. From Conference on the Experimental Analysis of Behavior. Note #4 (mimeographed), April 5, 1948. Reprinted in 1968 in A. C. Catania (Ed.), *Contemporary research in operant behavior* (p. 286). Glenview, IL: Scott, Foresman.

Received February 12, 1990
Final acceptance October 31, 1990