Operant response topographies of rats receiving food or water reinforcers on FR or FI reinforcement schedules

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Separate groups of food- and water-deprived rats pressed a lever for food or water, respectively, on continuous reinforcement and various fixed-ratio and fixed-interval reinforcement schedules. Food-reinforced rats on continuous, FR 2-, or FI 10-sec schedules showed consistently longer mean lever contact durations per leverpress than did water-reinforced rats on the same schedules. Mean lever-contact-duration differences between food- and water-reinforced rats were greatly attenuated or disappeared under FR 4-, FR 8-, FI 20-sec, and FI 30-sec schedules of reinforcement. These results are interpreted as supporting earlier hypotheses that there are respondent components of operantly conditioned and autoshaped leverpresses, but that these respondent components weaken with partial reinforcement and the leverpress topography comes under the control of operant contingencies.

Using pigeons as subjects, Brown and Jenkins (1968) described a procedure labeled "auto-shaping," which conforms to a respondent conditioning paradigm. Their discrete trials procedure involved periodic key illuminations followed immediately by grain access; no operant response was necessary for grain presentation. Within 50 trials, most pigeons began to peck an illuminated key that signaled grain presentation.

Several subsequent studies (Jenkins, 1973; Jenkins & Moore, 1973; Moore, 1973) employing autoshaping procedures have compared response topographies of pigeons when food or water was the reinforcer. These studies have shown that when grain access is paired with key illumination, the pigeon "eats" the key, its pecks resembling subsequent grain pecking. When water presentation is paired with key illumination, the pigeon "drinks" the key, its pecks resembling subsequent drinking. One study (Peterson, Ackil, Frommer, & Hearst, 1972), using rats as subjects, showed that when food reinforcers were presented contingent upon presentation of a retractable lever, rats often bit or chewed on the lever; rats receiving brain stimulation contingent on lever presentation seldom bit or chewed the lever. Hearst and Jenkins (1974) stated that if acquisition and maintenance of autoshaped responses directed at the key (or lever) involve respondent conditioning, those response topographies ought to be similar to topographies of responses elicited by the specific reinforcer. The studies

mentioned above provide clear support for their position.

More recently, operant response topographies of pigeons (Spetch, Wilkie, & Skelton, 1981) and rats (Cook & Hull, 1979; Hull, 1977) have been studied as a function of reinforcer received. Spetch et al. deprived pigeons of both food and water, then alternately provided grain or water reinforcers for key-pecking on fixed-interval schedules. They found that, when different stimuli signaled impending food or water reinforcers, pigeons reliably showed different operant response topographies, as measured mechanically and as judged by human observers. The operant response topography differences were attenuated, however, when simple unsignaled alternation of food and water reinforcers was used, rather than specific stimuli signaling food or water reinforcers. Finally, operant response topography differences disappeared when pigeons were given no information—either explicit stimuli or alternation of reinforcers—about what the reinforcer at the end of a particular reinforcement schedule would be.

Hull (1977) studied operant response topographies of rats receiving food or water reinforcers on continuous reinforcement under a variety of conditions. He found that rats receiving food pellets for leverpressing often bit, pawed, or sniffed the lever; rats receiving water drops for leverpressing seldom exhibited these behaviors. When food-deprived rats received sucrose solution rather than food pellets for leverpressing, their leverpress response topographies did not differ from those of water-deprived rats receiving sucrose solution, showing that operant response topography depended mainly upon the specific reinforcer received, not upon deprivation con-

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dition. Hull also reported that operant response topography differences could be measured relatively easily by measuring numbers of long-duration leverpresses or mean lever contact per leverpress durations, since the pawing, sniffing, and biting of the lever by rats receiving food reinforcers resulted in comparatively large numbers of long-duration lever contacts and higher mean leverpress durations. Finally, it was suggested that the lever might act as a "reinforcer surrogate" in operant conditioning experiments, serving much the same function as a CS would in a traditional respondent conditioning procedure.

Research has long shown decrements in respondent magnitudes with partial reinforcement (e.g., Grant & Schipper, 1952; Ross, 1959). Ross examined the effect of partial reinforcement on acquisition of the conditioned eyelid response in humans, finding higher response magnitude with CS-US pairings on all, as opposed to only some, trials. Grant and Schipper found very low CR strength with CS-US pairings on 25% of experimental trials. If leverpress topographies have some respondent components, these components ought to change when partial reinforcement, as opposed to continuous reinforcement, is used. Specifically, differences in rats' leverpress durations which occur during continuous reinforcement with food or with water ought to be attenuated when partial reinforcement is used.

The present study examined operant response topographies of rats pressing a lever either for food or for water reinforcers on a variety of fixed-ratio (FR) and fixed-interval (FI) reinforcement schedules. Pilot studies had shown that doubly depriving rats of food and water—as Spetch et al. (1981) did with pigeons—and then training them to respond alternatively for food and water was difficult to accomplish. Therefore, we used a between-groups (rather than a repeated measures) design.

EXPERIMENT 1

Method

Subjects. The subjects were 24 experimentally naive adult female albino rats from Hilltop Lab Animals. All rats were housed individually under a 14/10-h light-dark cycle.

Apparatus. One standard rodent test chamber, 28 × 21.5 × 21 cm high, was used on all experimental days for all rats. A 5.1-cm-wide response lever was mounted 6.5 cm above the chamber's grid floor and centered on one of the narrower walls of the chamber. A static force of approximately 15 g was sufficient to close a microswitch and dispense one 45-mg food pellet into a cup 4.5 cm to the right of the lever or a .1-cc water drop into a similar cup 4.5 cm to the left of the lever. The grid floor was electrically isolated from the chamber wall and the lever, the lever was electrically isolated from the chamber wall, and the bars in the grid floor were yoked. Drinkometer leads were attached to the grid floor and the lever. A circuit was completed when the rat touched

the lever, allowing recording of number of leverpresses and duration of lever contact to the nearest .1 sec.

Procedure. The rats were divided randomly into two groups; one group was food-deprived, the other water-deprived, until the rats were at 80% of their ad-lib weights. Rats in both groups received lever pretraining for 3 days; each rat made 100 leverpresses per day during pretraining. For each press, food-deprived rats received one 45-mg food pellet, water-deprived rats one .1 cc water drop. Operant response topographies could not depend upon idiosyncrasies of handshaping procedures, since none were used in pretraining; rats simply were left in the chamber until they made 100 leverpresses.

On Days 4-16, four randomly selected rats from each group were continuously reinforced (CRF) for 100 leverpresses; on Days 4-16, another four rats, selected randomly from each group, received FR 2 reinforcement. The remaining four rats from each group received FR 2 reinforcement on Days 4-6, FR 4 reinforcement on Days 7-9, and FR 8 reinforcement on Days 10-16. All rats on FR schedules remained in the experimental chamber until they had received 100 reinforcers each day. On Days 4-16, mean lever contact durations per leverpress were computed for all rats. After daily sessions, all rats received supplementary food or water in their home cages to maintain their weights at 80% of ad lib.

Results

Three separate 2 (food vs. water reinforcers) × 3 (CRF vs. FR 2 vs. FR 4, or FR 8) repeated measures (experimental days) analyses of variance were performed on mean lever contact durations per leverpress for the phases of Experiment 1. Since the experimental days factor produced no main or interactive effects in any of the three phases of the experiment (all p s > .05), Table 1 shows mean lever contact durations collapsed across days for the three phases of Experiment 1.

The analysis for Days 4-6 showed a statistically significant effect only for food vs. water reinforcers [$F(1,18) = 35.70$, $p < .001$], with food-reinforced rats having longer mean lever contact durations per leverpress. The analysis for Days 7-9 showed significant main effects of food vs. water reinforcers [$F(1,18) = 48.50$, $p < .001$] and schedule of reinforcement [$F(2,18) = 4.77$, $p < .05$] and a significant reinforcer × schedule interaction [$F(2,18) = 7.12$, $p < .01$]. Subsequent Newman-Keuls analyses showed that rats receiving food reinforcers on CRF or FR 2 schedules

Table 1
Mean Lever Contact Durations per Leverpress (Seconds)
for Rats Receiving Food or Water Reinforcers During
Days 4-6, 7-9, and 10-16 of Experiment 1

Days 4-6	Days 7-9	Days 10-16
Food-Reinforced Rats		
CRF 2.19	CRF 1.97	CRF 2.07
FR2 1.88	FR2 1.74	FR2 1.25
FR2 1.99	FR4 .98	FR8 .65
Water-Reinforced Rats		
CRF .99	CRF .56	CRF .64
FR2 1.29	FR2 .76	FR2 .65
FR2 .91	FR4 .74	FR8 .58

had significantly longer mean lever contact durations than all other groups. No other pairwise comparisons were statistically significant. The final analysis of variance for Days 10-16 again indicated significant effects of type of reinforcer [$F(1,18) = 35.07$, $p < .001$], reinforcer schedule [$F(2,18) = 13.23$, $p < .001$], and a significant reinforcer $\times$ schedule interaction [$F(2,18) = 11.55$, $p < .001$]. Newman-Keuls tests showed that rats receiving food on CRF had significantly longer mean lever contact durations than all other groups, while rats receiving food on FR 2 had significantly longer mean lever contact durations than the other four groups, which did not differ significantly from one another.

In summary, rats receiving food reinforcers on CRF or FR 2 schedules showed significantly longer mean lever contact durations per leverpress than did rats responding for water on CRF or FR 2 schedules, respectively. Rats receiving food on FR 4 or FR 8 schedules, however, did not have significantly longer mean lever contact durations per leverpress than rats responding for water.

EXPERIMENT 2

The first experiment confirmed prior reports that rats' operant leverpress topographies differ when food or water reinforcers are presented during CRF or FR 2 reinforcement schedules. It also demonstrated that the differences in response topographies measured by mean lever contact durations are attenuated or disappear with leaner FR schedules. Experiment 2 examined operant leverpress topographies of rats under FI schedules of reinforcement.

Method

Subjects and Apparatus. The subjects were 24 experimentally naive adult female albino rats from Hilltop Lab Animals, housed individually under a 14/10-h light-dark cycle. The apparatus was identical to that used in Experiment 1.

Procedure. The rats were divided randomly into two groups; one was food-deprived, the other water-deprived, to 80% of their ad-lib weights. All rats received lever pretraining for 3 days, with all rats making 100 leverpresses per day. Water-deprived rats received one .1-cc water drop, and food-deprived rats received one 45-mg food pellet for each leverpress. As in Experiment 1, no handshaping was used.

On Days 4-17, four rats randomly selected from each group were continuously reinforced for 100 leverpresses; four other randomly selected rats from each group received FI 10-sec reinforcement on Days 4-17. The remaining four rats from each group received FI 10-sec reinforcement on Days 4-7, FI 20-sec reinforcement on Days 8-12, and FI 30-sec reinforcement on Days 13-17. All rats remained in the experimental chamber until they had received 100 reinforcers during each day.

Results

Three separate 2 (food vs. water reinforcers) $\times$ 3 (CRF vs. FI 10-sec vs. FI 20-sec, or FI 30-sec) repeated measures (experimental days) analyses of variance were performed on mean lever contact

Table 2
Mean Lever Contact Durations per Leverpress (Seconds)
for Rats Receiving Food or Water Reinforcers During
Days 4-7, 8-12, and 13-17 of Experiment 2

Days 4-7	Days 8-12	Days 13-17
Food-Reinforced Rats		
CRF 1.16	CRF 1.34	CRF 1.09
FI10 1.14	FI10 1.07	FI10 .95
FI10 1.06	FI20 .99	FI30 1.02
Water-Reinforced Rats		
CRF .69	CRF .75	CRF .65
FI10 .86	FI10 .69	FI10 .66
FI10 .89	FI20 .90	FI30 1.29

Frequency interval measured in seconds.

durations per leverpress for the phases of Experiment 2. Except as noted, there were no significant main or interactive effects of experimental days in the three phases of the experiment. Table 2 shows mean lever contact durations collapsed across days for the three phases of Experiment 2.

The analysis for Days 4-7 showed statistically significant effects for reinforcer type [$F(1,18) = 10.15$, $p < .01$] and experimental days [$F(3,54) = 3.58$, $p < .05$]. Food-reinforced rats had longer mean lever contact durations. The analysis for Days 8-12 included only a significant effect of reinforcer type [$F(1,18) = 16.99$, $p < .001$], with food-reinforced rats again showing longer mean lever contact durations. The final analysis of variance for Days 13-17 indicated a significant main effect of reinforcement schedule [$F(2,18) = 4.27$, $p < .05$] and significant reinforcer $\times$ reinforcement schedule [$F(2,18) = 4.30$, $p < .05$] and reinforcer $\times$ reinforcement schedule $\times$ experimental days [$F(8,72) = 2.20$, $p < .05$] interactions. Newman-Keuls tests on group means for the three-way interaction showed that: food-reinforced rats on CRF had significantly longer mean lever contact durations on all 5 days than did water-reinforced rats on CRF; food-reinforced rats on FI 10-sec had significantly longer mean lever contact durations than did water-reinforced rats on Days 13, 14, 15, and 17; and food-reinforced rats on FI 30-sec had significantly *shorter* mean lever contact durations than did water-reinforced rats on FI 30-sec on Days 16 and 17.

In summary, rats receiving food on CRF or FI 10-sec schedules generally showed significantly longer mean lever contact durations than did rats responding for water on CRF or FI 10-sec schedules. These mean lever-contact-duration differences were attenuated on FI 30-sec schedules.

GENERAL DISCUSSION

The present experiments demonstrate that operant leverpress topographies of rats differ when food or

water reinforcers are presented on continuous, FR 2, and FI 10-sec reinforcement schedules. Similar leverpress topography differences have been demonstrated previously in studies of operant leverpress topographies in rats (Cook & Hull, 1979; Hull, 1977). Additionally, the present experiments indicate that leverpress topography differences, as measured by mean lever contact durations per leverpress, are reduced or disappear with training on FR 4, FR 8, FI 20-sec, and FI 30-sec reinforcement schedules. In contrast, Spetch et al. (1981) have reported that pigeons exhibit different keypeck topographies for food or water even on FI 30-sec reinforcement schedules. Whether such differences would eventually disappear with longer fixed intervals, or whether important species differences exist in this area, remains a topic for future research.

It is interesting to note that leverpress topography differences for food or water reinforcers "disappeared" in different ways, depending upon whether FR or FI reinforcement schedules were used. With FR reinforcement, lever contact durations for food-reinforced rats decreased with leaner schedules, reaching the durations of water-reinforced rats. With FI reinforcement, mean lever contact durations for water-reinforced rats increased with leaner schedules, reaching the durations of food-reinforced rats.

One might argue that the decreased mean lever contact durations by food-reinforced rats on leaner FR schedules resulted simply from an increase in response rates, which would allow less time for lever contacts. Indeed, a preliminary analysis of a recent study in our laboratory (Whitfield, Paquette, & Hull, Note 1) shows a median increase of 27% in response rates of rats switched from CRF to FR 8. If this hypothesis were true, however, there should be a substantial negative correlation between change in mean lever contact durations from CRF to FR 8 food reinforcement, and percent change in response rate from CRF to FR 8 food reinforcement. In other words, rats showing the greatest increases in response rates ought to show the greatest decreases in mean lever contact durations per leverpress. The same preliminary analysis does not support this hypothesis. In that analysis, the rank-order correlation between change in mean lever contact durations per leverpress from CRF to FR 8 and the percent change in response rate from CRF to FR 8 for the six food-reinforced rats was $-.37$ ($p > .05$). It is interesting also to note in this context that, while Zeiler and Buchman (1979) show that pigeons increase response rates for food from FR 5 through FR 10 or FR 20 reinforcement schedules, Zirias and Silberberg (1978) propose that pigeons actually show longer keypeck durations during FR responding for food than they do during CRF. Apparently, the higher response rates of rats for FR 8 as opposed to CRF reinforce-

ment are not alone sufficient to account for the decreases in mean lever contact durations measured in the present study.

The increase in lever contact durations by rats receiving water on FI 30-sec schedules, as opposed to those on CRF, similarly cannot be explained simply by differing response rates. Mean leverpresses per minute were calculated across the last 3 days of Experiment 2 for rats receiving water on CRF, FI 10-sec, and FI 30-sec schedules; the means were 18.1, 21.9, and 18.8, respectively.

Cook and Hull (1979) and Hull (1977) have suggested that differences in leverpress topographies are due to respondent components in the response. Autoshaping experiments with pigeons (Jenkins & Moore, 1973; see Hearst & Jenkins, 1974) have suggested that a sort of "stimulus substitution" occurs in autoshaping procedures, whereby the source of the signal for trial onset serves as a reinforcer surrogate. Since, in the operant conditioning procedures in these experiments, lever contact reliably preceded reinforcer access—although less reliably with leaner reinforcement schedules—it is possible that the responses conditioned were not "arbitrary operants" but, to some extent, depended upon the reinforcers used. If there are respondent components of rats' leverpresses, these components ought to fade out as the reinforcement schedule is made leaner (e.g., Grant & Schipper, 1952; Ross, 1959); this is what the present study shows.

Perhaps what happens is that as the respondent components of leverpress topographies are weakened with partial reinforcement, leverpress topographies come increasingly under the control of operant contingencies. For example, the rat must "do" something to fill the interval of an FI reinforcement schedule. Part of what water-reinforced rats may do during the interval is to remain in contact with the lever longer during leverpressing, resulting in higher mean lever contact durations. Indeed, the one rat in these two experiments that developed "lever-hanging" was a water-reinforced rat on an FI 30-sec schedule. A subsequent repeated measures analysis of variance on mean lever contact duration for the four water-reinforced rats on FI 10-sec and then FI 20-sec and FI 30-sec reinforcement schedules showed that, while mean contact durations increased across the three phases, the trend was not statistically significant [$F(2,6) = 2.89$, $.10 < p < .20$]. Rats responding on FR schedules tend to respond in bursts, making continuous contact with the lever for several leverpresses; these bursts are interspersed with periods of non-responding while rats either consume reinforcers (if a ratio was completed) or move to and from the reinforcer cup (if a ratio was not completed). Momentarily high-rate bursts of leverpresses would tend to produce low mean contact durations for all rats re-

ceiving FR reinforcement. Water-reinforced rats on FR 8 schedules already have low mean contact durations as a function of receiving water reinforcement; the measurable change in mean contact should be a decrease for food-reinforced rats on leaner FR schedules. A subsequent repeated measures analysis of variance on contact duration for the four food-reinforced rats on FR 2 and then FR 4 and FR 8 reinforcement schedules showed a significant decline across the three phases [$F(2,6) = 42.47$, $p < .001$].

It should be noted that water-reinforced rats on CRF or FR 2 reinforcement schedules throughout Experiment 1 showed significant decreases in contact duration from the first to the second phase of that experiment. Previous studies (Cook & Hull, 1979; Hull, 1977) have shown that many water-reinforced rats show a decline in numbers of long-duration leverpresses, and therefore in mean lever contact during the first few days of lever training. Since data recording began on the 4th day of leverpressing, some water-reinforced rats in Experiment 1 may have not reached asymptotic duration until the middle of the first phase; an inspection of the data seems to indicate this possibility.

In summary, the present study provides more evidence for the possibility that respondent components exist in operantly conditioned leverpress topographies, that these respondent components extinguish with increasingly leaner reinforcement schedules, and that these respondent components are replaced by operantly controlled leverpress topographies. Present research in our laboratory is exploring operant leverpress topographies when discrimination training is employed in a repeated measures design. If respondent components do exist in operant responses, it should be possible to show different leverpress response topographies within the same rats when one stimulus signals continuous reinforcement and another stimulus signals another, leaner schedule of reinforcement.

REFERENCE NOTE

1. Whitfield, D. J., Paquette, L., & Hull, J. H. *Instrumental*

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