Dissociation of the effect of reinforcer type and response strength on the force of a conditioned response

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A dissociation between the effect of reinforcer type and response strength on the force of the pigeon's keypeck response was shown in three experiments. In Experiment 1, pigeons were trained to peck two conditioned stimuli, one paired with water and another paired with grain. The pigeons made more forceful pecks for grain than for water and also showed a tendency, albeit an unreliable one, to respond on a higher percentage of food trials than water trials. In Experiment 2, the pigeons from Experiment 1 were satiated with either food or water and were then presented with the two conditioned stimuli in an extinction test. It was found that, regardless of the drive state, the pigeons made more forceful pecks to the stimulus that predicted food than to the stimulus that predicted water. In the thirsty group, however, this difference in force was not accompanied by a difference in the percentage of trials with a response. In Experiment 3, pigeons trained with a single reinforcer pecked more often on instrumentally reinforced trials than on Pavlovian conditioning trials, but there was no difference in the force of the pecks. Taken together, these results imply that differences in response strength cannot account for the difference between the force of food- and water-reinforced pecks. Instead, stimulus-substitution theory may provide the best account of the topography of the two types of pecks.

The topography of the pigeon's appetitively reinforced keypeck has been found to be influenced by the nature of the unconditioned stimulus (US). Among other features, grain-reinforced keypecks tend to have a larger gape, a shorter duration, and a stronger force than do water-reinforced pecks (e.g., Jenkins & Moore, 1973; LaMon & Zeigler, 1984; Skelton, Spetch, & Wilkie, 1980; Spetch, Wilkie, & Skelton, 1981). These topographical differences are usually attributed to the fact that keypecks reinforced with water are long, gentle sipping motions that resemble the pigeon's unconditioned drinking behavior, whereas keypecks reinforced with food are brief, forceful thrusts of the head that resemble the unconditioned response of picking up kernels of grain (e.g., Jenkins & Moore, 1973; Spetch et al., 1981; Wolin, 1968; but see LaMon & Zeigler, 1988).

The difference between the force of conditioned keypecks for food and for water might be due to the fact that food and water strengthen *qualitatively* different behaviors. Alternatively, the force difference might be

related to the fact that food and water produce *quantitative* differences in responding. Quantitative differences between conditioned behaviors, traditionally referred to as differences in response strength, might include differences in the rate or the probability of a response. It is possible that changes in force also accompany changes in response strength. The present series of experiments was designed first to replicate the force differences reported in the earlier work and then to investigate this response-strength account of the force of the food- and water-related keypecks.

EXPERIMENT 1

Although a number of researchers have found that food-reinforced keypecks are more forceful than water-reinforced pecks (Jenkins & Moore, 1973; Skelton et al., 1980; Spetch et al., 1981), LaMon and Zeigler (1988) recently reported a failure to find a difference between the force of pecks to a conditioned stimulus (CS) for food and a CS for water. This failure might be a result of procedural differences from the earlier experiments. Most notably, LaMon and Zeigler used a key located on the floor, whereas the other experimenters used keys located on the chamber wall. Alternatively, it is possible that the force differences observed in the earlier experiments are simply difficult to reproduce. The main purpose of this first experiment was to determine whether the earlier force differences could be replicated.

Pigeons were trained with two conditioned stimuli (CSs). One CS was paired with grain and the other CS

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was paired with water. If the earlier results are reproduced, the force of pecks to the stimulus predictive of food should exceed the force of the pecks to the stimulus predictive of water. As pointed out by Jenkins and Moore (1973), the use of a within-subjects design will preclude the possibility that the form of the conditioned responding is due to the state of deprivation in effect at the time of training.

Method

Subjects

The subjects were 12 experimentally naive, feral pigeons with a mean free-feeding weight of 397 g. They were individually housed in a colony room on a natural light-dark cycle. The details of the deprivation regimen are given below but, in brief, the pigeons were given enough wheat to maintain their weights at 85% of their free-feeding weights and their water intake was adjusted to an amount (in milliliters) that ranged, between birds, from 65% to 110% of their daily food intake (in grams). Grit was freely available in the home cage.

Apparatus

Two Campden Instruments pigeon chambers with internal dimensions of 33.5×30.5×31.0 cm (length × width × height) were used. The front wall was a three-key intelligence panel with a central 24-V, 2.8-W houselight that was located 2.0 cm below the ceiling. Only the right-hand key was used. This key, which was 10.8 cm to the right of the center of the panel and 22.8 cm above the floor, could be illuminated with red or white light. Black electrical tape covered the center and the left-hand keys. The right-hand key was covered with tape only during magazine training.

A 6.5×5.0×11.0 cm food magazine was recessed into the center of the front panel 7.0 cm above the floor. A 28-V, 1.1-W light was positioned on the ceiling of the magazine above the 1.0×1.0 cm grain aperture centered in the magazine floor. Grain was presented at this opening by the operation of a solenoid that raised a grain tray. Water could be delivered through a small tube into a 3.2×1.0×0.5 cm water tray fixed to the back wall of the food magazine 3.0 cm above the grain aperture. Water was stored in a reservoir approximately 1.5 m above the chamber, and water delivery occurred when a 24-V Honeywell solenoid valve was operated.

The right-hand key consisted of a translucent 4.5×5.5 cm Perspex flap attached to the back of the intelligence panel. The flap was hinged at the top so that when force was applied to the front of the key, it was pushed back. An RS strain gauge with a resistance of 120 Ω and a 2:1 gauge factor was glued to a 4.0 mm × 0.5 cm × 0.03 cm curved brass spring. When the key was depressed, the spring was deflected backwards. The resulting resistance changes in the strain gauge were fed into a strain-gauge amplifier and then into the analog interface of an Acorn System 4 microcomputer. The System 4 was used to collect and store the amplified strain-gauge output and an Acorn Atom microcomputer was used to control the events in the experimental chambers. On the basis of the output from the strain gauge, a peck could be counted when as little as 7.8×10^{-2} N of force (i.e., 8 g) was applied to the key.

Before the start of Experiment 1, a calibration curve for the force-measuring apparatus was constructed. The intelligence panel was placed in a horizontal position and weights of 10 to 120 g were placed on top of the key in an ascending and descending series with 10-g steps. Regression analysis of the analog-to-digital converter (ADC) output in response to the amount of weight placed on the keys revealed that the slopes and intercepts were similar in the two boxes (the slope and intercept for Box 1 were .698 and 15.0, respectively; the slope and intercept for Box 2 were .587 and 14.5, respec-

tively). The linear functions accounted for 98.8% and 98.5% of the variability in the readings for Boxes 1 and 2, respectively.

Procedure

Preliminary training. The pigeons were food-deprived to 85% of their free-feeding weights with water freely available. Once the pigeons reached their criterion weights, food was provided on a daily basis in an amount sufficient to maintain them at that level. Then the pigeons' water intake was also restricted. Water was removed from the home cage on Day 1, no water was provided on Day 2, and 8 ml of water was given to each bird on Day 3. Subsequently, each bird was provided with water in an amount (in milliliters) that was 80% of its daily food intake (in grams).

On Days 1-11, the birds were given sessions of hand-magazine training for wheat intermixed with sessions of hand-magazine training for water. Usually the pigeons received only one 20-min training session per day, but on some of the days, the birds that were not eating and/or drinking reliably received an additional session(s) for the US that was not consumed.

Automated magazine training commenced on Day 12. Fifteen deliveries of both food and water were scheduled to occur in a random sequence on average once every minute. Grain presentations were 4 sec long and water deliveries were 0.1 ml in volume. Both grain and water deliveries were accompanied by 4 sec of magazine illumination. Pigeons that were consuming the two USs with what appeared to be equal latencies received an automated session on average every third day. For birds that were not eating and/or drinking reliably, the automated sessions alternated with hand-training sessions for the US(s) that were not readily consumed. During the two final automated-magazine training sessions (on Days 26 and 27), the number of food and water deliveries was decreased from 15 to 8, and the intertrial interval (ITI) was increased from 1 to 2 min.

The long time required for magazine training was probably due to a lack of sufficient motivation for one reinforcer or the other. Therefore, birds that would not eat, or that were slow to eat, had their water allotment increased by 5% and, in addition, received an extra 10 ml of water on that day. Birds that would not drink or that were slow to drink had their water allotment decreased by 5% and were not given any water outside the training session on that day. By the end of Day 27, all the birds were consuming both reinforcers with what casual observation would suggest to be approximately equal latencies.

Experimental training. In each session, the birds received eight pairings of one CS with a 4-sec presentation of wheat and eight pairings of another CS with a 0.1-ml water delivery. Each CS was 5 sec long. For 6 of the birds, a red keylight was used as the CS predicting food (Sf) and a dark key was used as the CS predicting water (Sw). The converse was true for the remaining 6 birds: the red keylight was the Sw and the darkened key was the Sf. The key was illuminated with a white light during the ITI. The Sf and Sw trials were scheduled to occur in a random sequence with the constraint that in a block of four trials, two of each type must occur. The mean ITI was 2.15 min with a range of 20 sec to 6.15 min.

The houselight and the white keylight were off when a pigeon was placed in the chamber. After about 3 min, the keylight and the houselight were illuminated and the session began. Training continued for 26 sessions.

Data collection and analysis. The System 4 microcomputer was devoted entirely to collecting, storing, and analyzing the data from the force-measuring apparatus. The baseline value in the ADC was determined at the beginning of each session. During each CS in the following session, an assembler program examined the value in the ADC once every millisecond and a peck was counted when the voltage exceeded the baseline value for a minimum duration

of 4 msec. This method of measurement prevented contact bounces from being scored as pecks and corrected for any drift in baseline. The ADC output was used to record the number of pecks, the trials on which a peck occurred, and the peak peck force.

In the statistical analysis for this experiment, and for subsequent experiments, alpha was set to .05.

Results

All the data presented below were entered into analyses that included stimulus type (red- or dark-key CS) and reinforcer type (wheat or water) as factors. Because the stimulus type was not found to produce any reliable main effects or interactions, only the main effect of reinforcer type is reported.

The pigeons responded to the Sf before responding to the Sw. The pigeons pecked the Sf for the first time after a mean of 29.0 trials and the Sw for the first time after a mean of 48.3 trials. This difference was statistically significant [$F(1,10) = 7.60$].

Although the pigeons were slower to respond to the Sw than to the Sf, on the last 2 days of training, there was no reliable difference between the percentages of Sf (63.8) and Sw trials (52.1) with a response [$F(1,10) = 1.25$]. There was, however, a difference in the peak force of the pecks on the Sf and Sw trials. On the last two sessions of training, 9 of the 12 pigeons responded on both the Sf and the Sw trials. These 9 pigeons pecked with a reliably greater force on the Sf trials (39.9 arbitrary units) than on the Sw trials (23.2 arbitrary units) [$F(1,7) = 22.61$].

Discussion

The pigeons in the present experiment made more forceful pecks on the Sf trials than on the Sw trials. This difference in force replicates earlier findings that keypecks conditioned with food are more forceful than keypecks conditioned with water (Jenkins & Moore, 1973; Skelton et al., 1980; Spetch et al., 1981). Thus, it appears that LaMon and Zeigler's (1988) failure to find a differential force might be attributable to procedural differences between their experiments and the others cited here. It is possible, for example, that LaMon and Zeigler's use of a key on the floor as opposed to on the wall resulted in a different sort of conditioned keypeck. (A discussion of the importance of the nature of the CS in determining the form of the conditioned response is found in the General Discussion.)

The present difference between the force of the pecks occurring on the Sf and on the Sw trials could be due to the fact that the food and water USs strengthened qualitatively different conditioned responses (CRs). Topographical differences between these CRs might include differences in the force with which the pigeon strikes the key. Alternatively, the present force differences could be accounted for by assuming that peck force is determined by response strength and that the strength of responding on the Sf trials was higher than the strength of responding on the Sw trials. In support of the latter point, the pigeons in this experiment showed a slight tendency, al-

beit an unreliable one, to peck on a higher percentage of Sf trials than Sw trials. In addition, the pigeons acquired responding on the Sf trials before they acquired responding on the Sw trials. These findings are consistent with the suggestion that the strength of conditioned responding on grain-reinforced trials is higher than the strength of responding on water-reinforced trials.

EXPERIMENT 2

There is good reason to suppose that the force of conditioned keypecks is, at least in part, controlled by the strength of the CR. One could imagine, for instance, that a well-trained pigeon would stand close to the key and strike it forcefully, whereas a less well-trained pigeon might stand further back from the key and strike it with weaker, glancing blows. This notion is supported by results from studies in which the duration of grain-reinforced keypecks on a variety of different training schedules has been examined. Ziriak and Silberberg (1978) noted that the duration of grain-reinforced pecks is directly related to the rate of conditioned responding and is inversely related to the latency to make a response. It is reasonable to assume that force, like duration, would also be related to response strength. The finding that the force of grain-reinforced pecks increases in acquisition and declines during extinction (Cole, 1965) is consistent with this proposal.

The purpose of Experiment 2 was to determine whether the force differences in Experiment 1 could be accounted for in terms of response strength alone. One way to address this question is to determine whether the difference between the force of grain- and water-reinforced pecks would be preserved in a situation in which the strength of conditioned responding on the Sf and the Sw trials does not differ. To do this, the pigeons used in Experiment 1 were subjected to a drive-shift procedure that should manipulate the strength of the food and water CRs. Pigeons satiated with water and tested while hungry, for example, should respond more for food than for water, whereas pigeons satiated with food and tested while thirsty should respond more for water than for food. If response force is correlated with response strength, then these selective declines in responding should be accompanied by declines in response force. To test this hypothesis, the pigeons from Experiment 1 were assigned to one of two groups: Group Hungry and Group Thirsty. The pigeons in Group Hungry were satiated with water and the pigeons in Group Thirsty were satiated with food. Finally, the pigeons were presented with the Sf and the Sw in an extinction session.

Method

Subjects and Apparatus

The housing, subjects, and apparatus were the same in this experiment as in Experiment 1.

Procedure

Additional training. The procedure was similar to that described in Experiment 1 but, in an effort to increase the amount of condi-

tioned responding, some of the experimental parameters were modified: the number of presentations of both the Sf and the Sw was doubled from 8 to 16, and the size of the water delivery was increased to 0.2 ml. The average ITI was 2 min. All other aspects of the procedure were the same as in Experiment 1. Training continued for five sessions.

Selective satiation test. At the end of the five training sessions, the birds were assigned to two groups, Group Hungry and Group Thirsty, such that an equal number of birds from the two counterbalance conditions were in each. The two groups were matched as closely as possible on the percentage of Sf and Sw trials on which responding had occurred. In the home cage, the birds in Group Hungry were provided with free access to water, whereas the birds in Group Thirsty were given free access to grain. Beginning on the next day, the pigeons were given four daily test sessions. These sessions were conducted in extinction, but otherwise the procedure was the same as during training. In the home cage after each session, the pigeons in Group Thirsty were given 8 ml of water and the pigeons in Group Hungry were given 10 g of wheat.

Results

The mean numbers of Sf and Sw trials with a response on the last 2 days of training were 10.2 and 9.3, respectively, for the pigeons in Group Hungry, and 12.2 and 9.5, respectively, for the pigeons in Group Thirsty. An analysis of variance (ANOVA) on these baseline scores revealed no effect of group ($F < 1$), reinforcer type [$F(1,10) = 1.17$], or group $\times$ reinforcer type ($F < 1$).

Figure 1 depicts the mean peak force of the pecks to the Sf and the Sw collapsed across the four sessions of

Figure 1. Mean peak force of pecks on the food- (Sf) and water-reinforced (Sw) trials (top panel), and mean percentage of Sf and Sw trials with a response (bottom panel), for the two groups of pigeons during the selective satiation test in Experiment 2.

extinction. These data were collapsed across sessions because some of the pigeons failed to respond to the food and water CSs in all of the sessions. One of the pigeons in Group Hungry failed to peck the Sw during the extinction test. The force data for this pigeon were excluded from the statistical analyses.

The force data from both groups show a similar pattern. The mean force of the pecks on the Sf trials exceeded the mean force of the pecks on the Sw trials. The main point to be taken from the data displayed in the top panel of Figure 1 is that, in extinction, the birds in both groups continued to peck the CS associated with grain with a higher force than they pecked the CS associated with water. An ANOVA on the peck-force data collected during extinction revealed a reliable effect of reinforcer [$F(1,9) = 9.66$] but failed to find a statistically significant group effect or a reliable group $\times$ reinforcer interaction ($F_s < 1$).

Across the same sessions (and the same pigeons) that contributed force data to the means displayed in the top panel of Figure 1, the relationship between the percentage of Sf trials and Sw trials with a response differed between the two groups (see Figure 1, lower panel). The pigeons in Group Hungry responded on a higher percentage of Sf trials than Sw trials, whereas the pigeons in Group Thirsty responded on an equivalent number of the two types of trials. The statistical analysis revealed a reliable group $\times$ reinforcer type interaction [$F(1,9) = 7.47$] but failed to find a reliable effect of reinforcer type [$F(1,9) = 4.45$] or group ($F < 1$). A subsequent analysis of the main effects found that the difference between the percentage of Sf and Sw trials with a response for the hungry pigeons (i.e., 40.3% vs. 18.7%) was statistically significant [$F(1,9) = 9.03$], but that the difference between the percentage of Sf and Sw trials with a response for the thirsty pigeons (i.e., 26.4% vs. 28.0%) was not ($F < 1$).

Discussion

The present findings favor the conclusion that response strength is not the principal factor underlying the present force differences. During extinction, the pigeons in Group Thirsty made more forceful pecks on the Sf trials than on the Sw trials. At the same time, the pigeons in Group Thirsty pecked on the same number of Sf and Sw trials. Therefore, the difference between the force of keypecks conditioned with food or water was found in a situation in which there was no independent evidence of a difference in strength of the two responses. In addition, the dominant deprivation condition had no apparent effect on the force of the keypecks, a finding consistent with the conclusion reached by Jenkins and Moore (1973). The thirsty pigeons pecked both conditioned stimuli with the same force as did the hungry pigeons.

EXPERIMENT 3

In the previous experiment, a difference was found between the force of grain- and water-reinforced pecks

even when there was no apparent difference between the strength of responding for the two reinforcers. Although this result provides some evidence against the response-strength account of the difference between the force of food- and water-reinforced pecks, the evidence is not irrefutable. It is conceivable that force is simply a more reliable measure of the difference between the strength of responding to the Sf and to the Sw than is the percentage of trials with a response. Clearly, a stronger case against the response-strength account could be made if a double dissociation between response force and the percentage of trials with a response could be found. To that end, the purpose of the present experiment was to attempt to demonstrate that, within a reinforcer category, a difference in the percentage of trials with a response is not necessarily accompanied by a difference in response force.

Two groups of pigeons were trained. Those in the food group were trained hungry and were given grain as the reinforcer, whereas those in the water group were trained thirsty and were given water as the reinforcer. The pigeons in both groups were presented with three types of trials—instrumentally reinforced, Pavlovian, and extinction—each signaled by a different colored keylight. A fixed-interval (FI) schedule was in effect on the instrumental trials, whereas the reinforcer was delivered without regard to the pigeon's behavior at the end of each Pavlovian trial. This contingency manipulation was expected to produce a higher likelihood of response on the instrumental trials than on the Pavlovian trials. The non-reinforced extinction trials were included in an attempt to ensure that the pigeons attended to the color of the stimuli. Response rate and response latency were recorded in case the percentage of trials with a response proved to be an inadequate measure. Finally, to equate the rate of reinforcement associated with the Pavlovian CS and the instrumental discriminative stimulus (Sd), the durations of the Pavlovian trials were yoked to the durations of the instrumental trials.

As well as allowing for a sensitive, within-subjects comparison between the force and the strength of the pecks elicited by the Sd and the CS, the present procedure allows for a direct test of a dual-peck theory suggested by Schwartz and his colleagues (e.g., Schwartz, 1977a, 1977b; Schwartz & Gamzu, 1977; Schwartz, Hamilton, & Silberberg, 1975; Schwartz & Williams, 1972; but see Jenkins, 1981; Moore, 1973; Ziriak & Silberberg, 1978). According to this theory, pigeons make two topographically distinct types of pecks: one controlled by a Pavlovian stimulus-reinforcer association and the other controlled by an instrumental response-reinforcer contingency. Whereas the topography of the Pavlovian pecks may depend on the nature of the US, the instrumental pecks are said to be arbitrarily related to the reinforcer. If the Sd and the CS used in the present experiment are equally good predictors of the occurrence of the reinforcer, they should both evoke the same number of these reinforcer-specific Pavlovian pecks. However, because the Sd also predicts an explicit instrumental response-reinforcer con-

tingency, more instrumental pecks should be observed to that stimulus than to the stimulus that is trained only as the Pavlovian CS. If these pecks are topographically distinct from the Pavlovian pecks, the mean force of the pecks to the Pavlovian CS might differ from the mean force of the pecks to the instrumental Sd. Moreover, a bimodal frequency distribution of peck force might be observed in response to the Sd.

Method

Subjects

The subjects were 16 experimentally naive, feral pigeons with a mean free-feeding weight of 308 g. The pigeons were randomly assigned to one of two groups: the food group and the water group. The pigeons in the food group were maintained at 80% of their free-feeding weights by restricting their access to grain, whereas the pigeons in the water group had their water intake restricted to 5 ml each day. If a thirsty pigeon's weight dropped below 85% of its free-feeding weight, however, supplemental water was provided. Grit and the reinforcer for which a pigeon was not deprived were freely available in the home cage.

Apparatus

The training apparatus was the same as that employed in Experiments 1 and 2. In addition, using the method described in Experiment 1, the calibration of the key was checked on the first day of the second stage of training. The regression lines accounted for 98.3% and 99.0% of the variability in the ADC output from Boxes 1 and 2, respectively. For Box 1, the slope was .526 and the intercept was 13.5. The slope and intercept for Box 2 were .506 and 14.4, respectively.

Procedure

Magazine training. On each of the first 3 days of magazine training, the pigeons were individually placed into a chamber in which the house and magazine lights were on. For the hungry birds, the hopper was up and full of wheat; for the thirsty birds, the water tray contained 2 ml of water. Each pigeon was left, undisturbed, in the chamber for 60 min. Two 30-min sessions of hand-magazine training followed. The procedures during these grain- or water-magazine training sessions (for the pigeons in the food group and the water group, respectively) were identical to the grain- and water-magazine training procedures described in Experiment 1, with the exception that the size of the water deliveries during water-magazine training was increased to 0.2 ml. After these sessions, most of the pigeons were reliably consuming the reinforcer. The pigeons that were not performing reliably received an additional session of magazine training on the following day.

Stage 1 training. Throughout Stage 1 and Stage 2 training, the reinforcer for the pigeons in the food group was a 4-sec access to wheat and the reinforcer for the pigeons in the water group was a 0.15-ml water delivery. The presentation of the reinforcers was accompanied by 4 sec of magazine illumination. Unless otherwise mentioned, the experimental training was identical for the pigeons in both groups.

During each session, a pigeon was exposed to three types of trials that were signaled by the color of the right-hand key. The key was dark during the ITI and the houselight was on throughout the session. Within each group, the color of the keylight (either red or green) signaling the instrumental and the Pavlovian trials was counterbalanced. During this stage of the experiment, continuous reinforcement with a 10-sec limited hold was used on the instrumental trials. On this schedule, a response to the illuminated key produced immediate termination of the keylight and the delivery of the reinforcer. In the absence of a response, the keylight remained

on for 10 sec and then was turned off and the reinforcer was delivered.

The duration of the Pavlovian trials was determined by the pigeon's performance on the instrumental trials. The sequence of trials (described in detail below) was such that the duration of each Pavlovian trial could be yoked to the duration of an instrumental trial that had occurred earlier in the session. The first Pavlovian trial had the same duration as the first instrumental trial, the second Pavlovian trial had the same duration as the second instrumental trial, and so on throughout the session. As was the case on the instrumental trials, the delivery of the reinforcer coincided with the offset of the keylight on each of the Pavlovian trials. Sixteen each of instrumental and Pavlovian trials were scheduled in each session.

Finally, eight extinction trials, each signaled by a white keylight, were presented in each session. The durations of the extinction trials were yoked to the first eight instrumental trials. Extinction trials were never followed by reinforcers.

The order of the 40 trials (i.e., 16 instrumental, 16 Pavlovian, 8 extinction) was randomly determined with the following constraints: (1) two instrumental trials were scheduled at the start of the session, and (2) a session ended with one extinction trial followed by two Pavlovian trials. The 35 intervening trials were scheduled in blocks of five. Within each block, two instrumental trials, two Pavlovian trials, and one extinction trial were scheduled in a random order. This method of sequencing allowed for each of the Pavlovian trials to be yoked to the corresponding instrumental trial. The sequence also ensured that each pigeon was presented with no more than four consecutive instrumental or Pavlovian trials. The mean ITI was 36 sec, with a theoretical range between 13 sec and 4.5 min.

During the second session of Stage 1, all of the pigeons in the food group pecked on more than 75% of the instrumental trials. However, only half of the pigeons in the water group met this criterion. The 4 birds that did not reach the criterion were given additional daily sessions until they also pecked on more than 75% of the instrumental trials. After six additional training sessions, 1 pigeon still had not begun to peck the key and was excluded from the experiment. One pigeon from the food group was then randomly selected and excluded from the experiment. To ensure that all of the pigeons would respond within the first 10 sec of a high proportion of the instrumental trials, they were all given another session. After one or two additional sessions, all subjects responded on more than 75% of the trials.

Stage 2 training. The schedule on the instrumental trials was changed to a fixed-interval 5-sec schedule: the first peck that occurred 5 sec after the onset of the stimulus resulted in the delivery of the reinforcer. The limited hold was no longer in effect on the instrumental trials. An instrumental trial continued until a response occurred. The mean ITI was 36 sec, with a theoretical range between 13 sec and infinity. Other aspects of the procedure remained the same in this phase of the experiment as in the first stage. The pigeons received 12 daily sessions of Stage-2 training.

Data collection and analysis. For the most part, the method for collecting data was the same in this experiment as in the preceding experiments. The resting output from the strain gauges was examined at the beginning of each session and used as a baseline. During Stage 1, the System 4 reported the occurrence of a peck to the Acorn Atom (which controlled the events in the training chambers) when the value in the ADC exceeded the baseline value by 8 units for 2 msec.

Throughout the second stage of training, peck data (i.e., number of pecks, latency to make a response, percentage of trials with a response, and peak force of a response) were collected during the first 5 sec of every trial. Within this period, a response was recorded when the value in the ADC exceeded the baseline value by 8 units for 3 msec. If a response was not recorded, the pigeon was assigned a response latency of 5 sec. Once the 5-sec interval

expired, no further peck data were recorded, but the ADC output continued to be examined every millisecond until the output exceeded the criterion value for 2 msec (2 msec was used for ease of programming). The System 4 then reported the occurrence of a peck to the Acorn Atom, which took the appropriate action.

Results

During Stage 2, a keypeck was only rarely recorded on the extinction trials. Therefore, only the data collected on the Pavlovian and the instrumental trials are included in the statistical analyses.

The mean number of pecks per minute across successive sessions of Stage 2 is shown in Figure 2. Over the course of training, the pigeons in both groups displayed a higher response rate on the instrumental trials than on the Pavlovian trials. A three-way ANOVA revealed a reliable effect of trial type [$F(1,12) = 24.29$] and a reliable trial type $\times$ session interaction [$F(11,132) = 2.14$]. Presumably, this interaction reflects the tendency for the effect of trial type to increase across sessions. The group $\times$ stimulus $\times$ session interaction was not statistically significant ($F < 1$).

Another notable aspect of the data displayed in Figure 2 is that response rate increased across sessions. This increase, however, appeared to be larger in the water group than in the food group. Both groups started off with equivalent response rates (50.4 pecks/minute in the food group and 47.2 pecks/minute in the water group), but by Session 12, the birds in the water group had increased their response rate to 153 pecks/minute, whereas the birds in the food group had increased to a rate of 97.4 pecks/minute. Consistent with this observation, a three-way ANOVA revealed a significant effect of session [$F(11,132) = 9.08$] and a significant group $\times$ session interaction [$F(11,132) = 2.57$]. The effect of group [$F(1,12) = 1.17$] was not reliable. Although the group $\times$ session interaction was statistically significant, the effect was small and subsequent attempts to analyze the interaction failed to reveal a reliable effect.

Figure 2. Mean number of responses per minute during the Pavlovian and the instrumental trials for the two groups of pigeons during successive sessions of Experiment 3.

The percentage of trials with a response are plotted in Figure 3. Across the final 12 training sessions, the number of trials with a response increased [$F(11,132) = 4.02$] and the pigeons in both the food and the water groups responded on a higher percentage of the instrumental trials than the Pavlovian trial [$F(1,12) = 7.07$]. Although, overall, the pigeons in the food group appeared to respond on a higher percentage of both types of trials than did the pigeons in the water group, this difference was not statistically significant [$F(1,12) = 3.26$]. The various interactions also failed to reach statistical significance ($F_s < 1.36$).

The latency data were log-transformed and are shown in Figure 4. Generally, the latency to make a response declined across the 12 training sessions [$F(1,12) = 9.05$] and the pigeons had a shorter mean latency to peck on the instrumental trials than on the Pavlovian trials [$F(1,12) = 4.77$]. A statistically significant effect of group was

Figure 3. Mean percentage of Pavlovian and instrumental trials with a response for the two groups of pigeons during successive sessions of Experiment 3.

Figure 4. Log of the mean latency until the first response on the Pavlovian and the instrumental trials for the two groups of pigeons during successive sessions of Experiment 3.

Figure 5. Mean peak force of pecks during the Pavlovian and the instrumental trials for the two groups of pigeons during successive sessions of Experiment 3.

also found [$F(1,12) = 8.61$], which supports the observation that, overall, the pigeons in the food group had a shorter latency to respond than did the pigeons in the water group. None of the interactions was reliable ($F_s < 1.60$).

One of the pigeons in the water group stopped pecking to the Pavlovian stimulus. The analysis of peck force therefore excluded this pigeon. As is demonstrated in Figure 5, there is a clear separation in the force of the pecks to stimuli signaling the availability of food or water. Throughout the 12 sessions of training in Stage 2, the pigeons in the food group pecked with a mean peak force between 47 and 59 units. The pigeons in the water group pecked with a mean peak force between 16 and 20 units. This level was relatively constant throughout the 12 sessions and was not affected by the contingency; that is, within each group of pigeons, there was no evidence that the peak peck force was different on the Pavlovian and the instrumental trials. A three-way ANOVA revealed a main effect of group [$F(1,11) = 12.05$]. The effect of trial types and sessions and the various interactions were not reliable ($F_s < 1$).

Finally, individual relative frequency distributions of peak peck force were constructed using the data collected on the last five training sessions. The percentages of the total number of pecks that fell within each 20-unit force bin on both types of training trials are shown for each bird in Figure 6. The relative frequency distributions reveal that the pecks of the birds in the water group tended to be weak and clustered at the lower end of the distribution, whereas the pecks of the birds in the food group tended to be more forceful. With the possible exception of Pigeon 70 (see Panel G), none of the birds showed any evidence of a bimodal frequency distribution. The mean of the relative frequency distributions displayed in Panels A-G is shown in Panel H. This figure reveals that, within each group, there was absolutely no difference between the shapes of the relative frequency distributions for the Pavlovian and the instrumental trials.

Figure 6. Relative frequency distributions of the peak force of pecks during the last five sessions of Experiment 3. Panels A–G contain individual relative frequency distributions of the force of pecks occurring during the Pavlovian and the instrumental trials for two pigeons—one trained in the food group and the other trained in the water group. The mean relative frequency distributions of the peak force of pecks occurring on the Pavlovian and the instrumental trials during the last five sessions of Experiment 3 are shown in Panel H. Because one of the pigeons in the water group (Pigeon 61) did not respond on the Pavlovian trials, the mean relative frequency distribution of the peak force of pecks on the Pavlovian trials was calculated using only the data from the remaining 6 pigeons.

Discussion

The instrumental training contingency increased the pigeons' propensity to respond. The pigeons responded with a higher rate, a shorter latency, and on a higher percentage of instrumental trials than Pavlovian trials. Despite this difference in response strength, there was no difference between the force of the pecks that occurred on the Pavlovian trials and on the instrumental trials; within each training condition, the pigeons responded with a mean force that was virtually identical on the two types of trials. Moreover, there was no evidence of a bimodal cumulative frequency distribution of the peak peck force. Taken together, these results provide no support for the notion that the force of the keypeck is simply a more sensitive measure of response strength than is the measure of the percentage of trials with a response.

These results also fail to support the hypothesis that an instrumental contingency strengthens a second, topographically distinct type of peck. The only factor that was found to influence the force of the keypecks reliably was group treatment: the pigeons that were trained hungry and given grain as the reinforcer made more forceful keypecks than did the pigeons that were trained thirsty and given water as the reinforcer.

It is often assumed that response rate, response latency, and the percentage of trials with a response would all provide converging information about response strength. A high response rate, a high percentage of trials with a response, and a short response latency would all be expected to reflect a high response strength. This was not the case in the present experiment. The present response-latency data suggest that the grain-reinforced keypecks had a higher response strength than did the water-reinforced keypecks. In contrast, the pigeons that received water as the reinforcer had a tendency, albeit an unreliable one, to peck with a higher rate than did the pigeons that received food.

This apparent inconsistency in the data is easily accounted for. Keypecks to stimuli predictive of water can result in the key oscillating back and forth, producing what Woodruff (1979) has described as a response "with a high natural frequency" (p. 344). When comparing the strengths of grain- and water-reinforced keypecks, response rate would be expected to be an overestimation of the strength of the water-reinforced peck. Therefore, the percentage of trials with a response or the latency to respond seem to be more valid measures of response strength than is rate.

GENERAL DISCUSSION

The results of the present series of experiments indicate that the difference between the force of food- and water-reinforced keypecks cannot be attributed to differences in response strength. Differences between the force of food- and water-reinforced pecks were found in a situation in which the pigeons responded on an equal number of the Sf and the Sw trials (Experiment 2). Moreover,

when the same reinforcer was used, even under conditions in which differences in the strength of responding were observed, there was no evidence of a corresponding difference in force (Experiment 3). Although differences in response strength may sometimes account for changes in the force of keypecks (e.g., Cole, 1965), they do not appear to account for the force differences observed in the present experiments.

How, then, can the finding that pigeons make more forceful pecks to stimuli predictive of grain than to stimuli predictive of water be accounted for? The traditional account of the topography of conditioned behavior is that of *stimulus substitution*. According to stimulus-substitution theory, the process of Pavlovian conditioning results in the formation of an associative structure that allows the CS to produce the response that is normally evoked only by the unconditioned stimulus. Although the associations thought to underlie stimulus substitution are rarely specified, the ability of a CS to evoke a response that resembles the unconditioned response is consistent with both stimulus-stimulus (S-S) and stimulus-response (S-R) theories of conditioning (see Holland, 1984).

An S-R theory of stimulus substitution assumes that the CS acquires the ability to evoke the behavioral response directly. Therefore, S-R theory would predict a direct correspondence between the topography of the conditioned and the unconditioned response. In contrast to this prediction, however, conditioned behavior is frequently dissimilar to the unconditioned response directly evoked by the reinforcer. Pigeons approach and peck a key that is paired with a US (injection of water into the beak) that does not itself elicit approach-and-peck behavior (Woodruff & Williams, 1976); rats do not eat other rats used to signal the occurrence of food—they engage in social feeding behaviors (Timberlake & Grant, 1975); and dogs do not always attempt to eat lights predictive of food—they sometimes show begging and pointing behaviors (Jenkins, Barrera, Ireland, & Woodside, 1978). These and other examples (e.g., Timberlake, 1983; Wasserman, 1973) convincingly rule out an S-R version of stimulus substitution as a general account of the topography of the CR.

As an alternative, many authors have advocated an S-S theory of stimulus substitution (e.g., Dickinson & Mackintosh, 1978; Jenkins & Moore, 1973; Pavlov, 1927; Tolman, 1949). According to S-S theory, the CS evokes a central representation of the US which, in turn, evokes a behavioral response. The critical factor that distinguishes S-S theory from S-R theory is that in the former case, the performance of conditioned responding is mediated by an internal representation of the US, whereas in the latter case it is not.

Some previously unmentioned results from Experiment 2 support an S-S theory for the performance of the pigeons' conditioned keypeck. While deprived of both food and water, the pigeons in Experiment 2 were trained with two keylight stimuli—one predictive of grain and the other predictive of water. Then the pigeons were sated with either food or water and were presented with the two conditioned stimuli in an extinction test. If the performance

Figure 7. Mean suppression ratios for responding on the food- (Sf) and water-reinforced trials (Sw) for the pigeons in Experiment 2 that were trained both hungry and thirsty but tested while only hungry (Group Hungry) or thirsty (Group Thirsty).

of conditioned responding is mediated by a representation of the reinforcer that discriminates between food and water, then selectively satiating the birds for only one of the two reinforcers should selectively reduce responding for that reinforcer. Alternatively, if the conditioned behavior is mediated by an S-R link, then a selective satiation effect should not be observed. The data from Experiment 2 favor the former view. As can be seen in Figure 7, during the selective satiation test, the pigeons showed a greater decline in responding to the stimulus predictive of the reinforcer that was irrelevant, as opposed to the relevant reinforcer, to their current drive state (the lower the suppression ratio, the greater the decline in responding between training and test).¹ An ANOVA of these data revealed a reliable effect of reinforcer relevance [$F(1,10) = 9.12$].

More generally, an S-S theory also seems to provide an adequate account of the topography of conditioned behavior. As opposed to an S-R theory that will not tolerate differences between the form of the UR and the form of the CR, an S-S theory clearly will tolerate such differences. The CR could be any of a number of species-specific behaviors appropriate to the nature of the representation of the US. Of course, one of the important determinants of the nature of the CR would be the nature of the information encoded in the representation of the US. As Konorski (1967) has suggested, a CS associated with a representation that encodes only information about the motivational or affective value of the reinforcer should elicit only general preparatory behavior. Such behavior might include approach to a stimulus associated with an appetitive event, withdrawal from a stimulus associated with an aversive event, and perhaps conditioned orienting responses such as those reported by Holland (e.g., Holland, 1977). On the other hand, if the representation includes detailed information about the specific physical or sensory properties of the reinforcer,

more specific consummatory behaviors might also be observed. Examples of conditioned consummatory behaviors would include eye-blink responses and reinforcer-specific conditioned keypecks.

However, the nature of the representation of the reinforcer is not the only factor that might determine the form of the CR. The nature of the CS has repeatedly been found to influence the topography of the CR (e.g., Holland, 1984; Timberlake, 1983). Although it is tempting to try to account for these CS-dependent differences in the form of the CR by arguing that they are due to differences in learning, this is not always the case (e.g., Holland, 1977, Experiment 2); at least some CS-dependent differences in the form of the CR seem to be due to response selection. A theory that accounts for such differences has been developed by Timberlake (1983). According to Timberlake, animals have natural, species-specific patterns of behavior, or "behavior systems," that are appropriate to various biologically important events. One system of behavior, for example, would be related to procuring food, whereas a different system of behavior would be related to avoiding predators. Timberlake has suggested that these behavior systems can be divided into smaller subsets or modules, each of which is controlled by different sorts of naturally occurring stimuli. To the extent that the CS resembles natural signals for a particular module of behavior, that module will be expressed as a CR. Therefore, depending on their resemblance to natural stimuli, a CS might be expected to elicit any of a number of reactions related to the appropriate system.

Although Timberlake's theory allows some variations in the form of conditioned behavior, it appears to neglect the question, "What is learned?" On the other hand, many stimulus-substitution accounts of the form of the CR ignore the role of the nature of the CS in selecting among the many different behaviors that are appropriate to a particular US. It is at least intuitively plausible to suppose that a theory that adequately accounts for the form of the CR will need to include both of these ideas. Such a theory might suggest that the range of possible CRs will be constrained by the nature of the representation of the US. Within this constraint, however, the form of the CR might be determined according to the theory specified by Timberlake (1983).

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NOTE

1. Suppression ratios were used in an effort to reduce the variability during test that was due to individual differences during training. The ratios were calculated using the formula $A/(A+B)$, where A is the mean percentage of trials with a response during each session of the test and B is the mean percentage of trials with a response on the last two sessions of training. These baseline values were presented and analyzed in the results section of Experiment 2.

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