JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 2003, **79,** 21–35 NUMBER 1 (JANUARY)

A PROCEDURE FOR GENERATING DIFFERENTIAL "SAMPLE" RESPONDING WITHOUT DIFFERENT EXTEROCEPTIVE STIMULI

KAREN M. LIONELLO-DENOLF AND PETER J. URCUIOLI

PURDUE UNIVERSITY

Sidman (1994, 2000) suggested that responses as well as stimuli can join equivalence classes, a hypothesis difficult to test because differential responding typically requires different stimuli. The present experiments describe a procedure with pigeons that avoids this potential confounding effect. In Experiment 1, spacing two responses 3 s apart (a differential-reinforcement-of-low-rate [DRL] schedule) to a white stimulus on some trials produced food or the comparison stimuli in a matching task, whereas pecking 10 or more times with no temporal restrictions (a fixed-ratio [FR] schedule) produced the same effect on other trials. Completing the alternative (unscheduled) requirement terminated the white stimulus and repeated the trial. Following such errors, pigeons learned to switch to the alternative response pattern on the repeat trials. In addition, the correct response pattern functioned as a conditional cue for comparison choice. In Experiment 2, mixed DRL-FR training was preceded by two-sample/two-alternative matching-to-sample with DRL and FR sample-response requirements. In a subsequent transfer test in which the correct response pattern to white served as the sample, pigeons preferentially chose the comparison previously reinforced following that pattern in the baseline task. This "unsignaled response" procedure may be useful for assessing whether differential responses can be members of acquired equivalence classes.

Key words: stimulus equivalence, unsignaled response, fixed-ratio, differential-reinforcement-of-low-rate, key peck, pigeons

When subjects are trained on conditional discriminations such as symbolic matching-to-sample (MTS), the samples and comparisons often become members of classes of equivalent stimuli. The existence of these classes is inferred from new or emergent behavior that follows such training (Sidman & Tailby, 1982). Specifically, subjects are frequently able to match the training stimuli to each other in novel ways, such as matching each stimulus to itself (reflexivity), matching stimulus B to stimulus A after training on the reverse relations (symmetry), and matching stimulus A to stimulus C after training to match A to B and B to C (transitivity).

Researchers have offered different accounts of the origin of these effects. Some have proposed that the mechanism underlying the emergent behavior indicative of equivalence is language based (Hayes, 1991; Horne & Lowe, 1996). Others (e.g., McIlvane, Serna, Dube, & Stromer, 2000; Sidman 1994, 2000) suggest that stimulus equivalence is a basic stimulus function, not arising or derivable from other processes (e.g., naming or other mediational processes). In other words, they believe that reflexivity, symmetry, and transitivity are a direct consequence of the reinforcement contingencies comprising the training relations.

Although opinions vary about the origins of stimulus equivalence, relatively few data favor one position over another (Sidman, 2000). Sidman (1994, 2000), however, proposed a number of experimental tests that have the potential to falsify his own particular view. Many of these experiments have yet to be conducted, and some present difficult procedural and conceptual challenges. Two claims, in particular, distinguish the fundamental-stimulus-property view from those invoking language processes. One is that equivalence classes can include the reinforcers used in training as members providing that they differ across the relations comprising the baseline task; that is, that differential-outcome training is used (cf. Dube & McIlvane, 1995; McIlvane, Dube, Kledaras, de Rose, & Stoddard, 1992). The second is that responses to the baseline stimuli can also join these classes if they, too, differ for different com-

---

This research was supported by National Institute of Mental Health Grant MH56487 to Peter J. Urcuioli. Karen Lionello-DeNolf is now at the E. K. Shriver Center. We thank John Schmeling, Steve Zuska, and Maya Romero for their assistance in running subjects.

Correspondence concerning this article may be addressed to Karen Lionello-DeNolf, Behavioral Sciences Division, E. K. Shriver Center, 200 Trapelo Road, Waltham, Massachusetts 02452 (e-mail: Karen.Lionello-DeNolf@umassmed.edu).

ponent relations. The experiments reported here are relevant to this latter claim.

Our experiments, however, do *not* provide a direct test of Sidman's hypothesis regarding responses and equivalence classes. Rather, they set the stage for the development of such tests by demonstrating the efficacy of certain procedures for isolating differential responses from their occasioning stimuli.

One procedure suggested by Sidman (1994, chap. 10) for determining if responses can become members of equivalent classes involves training two symbolic matching tasks with different samples and comparisons and with a common set of different required responses to the correct comparisons. These details are shown under Matching Task 1 and Matching Task 2 in Figure 1. The A_n, B_n, and C_n represent the sample and comparison stimuli; R1 and R2 represent the different responses required to each correct comparison; S^R is the reinforcer; and R3 is a common but distinctive response required to all samples.

The sample-comparison relations comprising the two training tasks typically result, at least with humans, in two classes of equivalent stimuli: A1, B1, and C1; and A2, B2, and C2 (Adams, Fields, & Verhave, 1993; Sidman, 1971; Sidman, Cresson, & Willson-Morris, 1974). Sidman has hypothesized that the differential responses, R1 and R2, may also become class members, as indicated by the italics. The common response to all samples (R3) and the common reinforcer (S^R) cannot join the classes because doing so would cause them to merge, thus undermining the very baseline discriminations necessary for class formation.

Sidman (1994) indicated that the best way to test for class inclusion of R1 and R2 is to present them separately as samples with the A stimuli as comparison choices. The prediction is that the subjects should reliably choose A1 after making R1 and A2 after making R2. The main difficulty confronting the implementation of this test, however, is reliably generating R1 and R2 as samples in the absence of different occasioning stimuli. Separately training R1 and R2 to other stimuli off the matching baseline, and then using those stimuli to generate the two responses in testing is one possible solution. Unfortunately, if three-term contingencies are sufficient to produce classes of equivalent stimuli (cf. Sidman, 1994, 2000), then any positive test results could also be explained by membership of the off-baseline *stimuli* in the two classes.

Matching Task 1

Sample		Correct Comparison
A1: R3	→	B1: R1 → S^R
A2: R3	→	B2: R2 → S^R

Matching Task 2

Sample		Correct Comparison
B1: R3	→	C1: R1 → S^R
B2: R3	→	C2: R2 → S^R

Resulting Equivalence Classes

Class 1:	A1, B1, C1, *R1*
Class 2:	A2, B2, C2, *R2*

Ideal Test

Sample		Correct Comparison
R1	→	A1 → S^R
R2	→	A2 → S^R

Fig. 1. Design proposed by Sidman (1994) to test the hypothesis that a subject's responses to stimuli can join an equivalence class with those stimuli.

Thus, the challenge is to find a way to generate R1 and R2 to a common exteroceptive stimulus. The present experiments describe a procedure that meets that challenge and, thus, holds promise for eventual tests to confirm, or disconfirm, the prediction that responses as well as stimuli may join equivalence classes.

EXPERIMENT 1

Experiment 1 was designed to determine whether pigeons could learn to respond differentially to a single (white) stimulus. In order to obtain reinforcers, pigeons sometimes had to space two successive responses at least 3 s apart to white and, on other trials, to complete 10 pecks without any temporal restrictions. As soon as the pigeon completed the scheduled response requirement on a given trial, food was delivered. However, if the pigeon completed the *un*scheduled requirement (e.g., by spacing two pecks 3 s or more apart prior to making 10 pecks), food was not delivered upon termination of the white stimulus, and the trial was repeated after a short timeout period. Would pigeons eventually learn to switch immediately to the other response pattern on the first trial repeat after making such "errors?" And, if so, would completion of the "correct" response pattern effectively cue choice between comparison alternatives in a two-choice matching task?

METHOD

Subjects

The subjects were four experimentally experienced White Carneau retired breeders obtained from the Palmetto Pigeon Plant (Sumter, SC). All had previously participated in two other experiments in which they received matching-to-sample training with stimuli different from those used in this experiment. They also had been previously trained to respond on a differential-reinforcement-of-low-rates (DRL) 3-s schedule and a fixed-ratio 20 (FR 20) schedule to different samples. Each was maintained at 80% of its free-feeding weight and obtained its daily food allotment during each experimental session. Pigeons were fed in their home cages only if they did not earn enough food to maintain their 80% weights and on the one day per week in which experimental sessions were not conducted. They were housed in stainless steel wire-mesh cages in a room with a 14:10 light-dark cycle. Water and health grit were freely available in the home cages.

Apparatus

The experiment was conducted in a BRS/LVE Model SEC-002 conditioning chamber equipped with a 3-key response panel (Model PIP-016). The pigeon's compartment in the chamber measured 30.5 × 36.8 × 34.3 cm and was equipped with an aluminum grid floor. Three horizontally aligned, circular response keys, 2.5 cm in diameter and 8.3 cm apart center-to-center, were centered on the response panel 25.4 cm from the grid floor. An inline projector mounted behind each key could present the following stimuli: a white homogeneous field, a solid white triangle on a black background, and a row of three solid white dots slanted at a 45° angle on a black background (BRS/LVE Pattern 692). A food magazine containing Purina Pigeon ProGrains was accessible through a 5.8 × 5.8 cm opening located 9 cm below the center key. Chamber illumination was provided by a GE # 1829 houselight located at the top center of the panel. A blower fan mounted on the outside of the chamber provided ventilation and masking noise. A Gateway 2000 386SX/25 computer collected data and controlled experimental events.

Procedure

Phase 1 (mixed-schedule) training. In Phase 1 training, the white homogenous field appeared on the center key at the beginning of a trial and remained lit until the pigeon completed one of two response requirements. On a random half of trials, the scheduled requirement was 10 pecks to white (i.e., a FR 10 schedule). On the remaining trials, the requirement was spacing two responses at least 3 s apart (i.e., a DRL 3-s schedule). Upon completion of the scheduled requirement, the white stimulus turned off and the food hopper was raised. After a 10-s intertrial interval (ITI), the pigeon advanced to the next trial. If, however, the pigeon completed the other, unscheduled requirement (e.g., by spacing two pecks 3 s or more apart when the FR 10 was in effect), the white stimulus turned off and a dark timeout period equal to the reinforcer duration began. Following the ensuing 10-s ITI, the trial was repeated (i.e., a correction procedure was in effect until the pigeon completed the scheduled response requirement). Following reinforcement or timeout, a 10-s ITI began. Reinforcer duration varied between 2 and 6 s across subjects and sessions in order to maintain 80% weights. Each ITI consisted of an initially dark period lasting 9 s (house light turned off) and a final, lit 1-s period with the house light turned on. The house light then remained on throughout the subsequent trial.

Each Phase 1 session consisted of 96 trials, of which 48 had the FR schedule in effect for pecking white. The remaining 48 trails had the DRL schedule in effect. The FR requirement was increased to 20 pecks after 20 training sessions for UN1, UN2, and UN3 and after 26 sessions for UN4. The DRL requirement remained constant at 3 s throughout training. On this mixed DRL-FR schedule, a pigeon's *hit rate*—the percentage of trials in which it *initially* completed the scheduled response requirement—was expected to be 50% throughout training. The main dependent measure of interest, then, was *switch rate*: The percentage of time following completion of the unscheduled requirement that pigeons met the scheduled requirement on the *first repeat* of a trial. If pigeons adopted a lose-shift strategy as training progressed, switch rates should increase systematically. Pigeons remained in Phase 1 training until their switch rates reached a criterion level of 85% or better for five of six successive sessions, or 80 training sessions, whichever occurred first.

Phase 2 (matching-to-sample) training. Next, the pigeons received matching-to-sample training in which the response patterns that completed the scheduled requirements to the white stimulus served as the samples, and the triangle and dot stimuli served as comparisons. At the beginning of each matching trial, the center key was illuminated white and remained on until the pigeon either spaced two successive responses 3 s or more apart (DRL 3-s) or made 20 consecutive pecks (FR 20), whichever occurred first. On a random one-half of the trials, completing the FR response requirement produced the two comparisons on the side keys; whereas on the remaining trials, completing the DRL response requirement produced the comparisons. The two comparisons appeared equally often on the left and right side keys following each sample. When pigeons completed the unscheduled response requirement, the white center-key stimulus turned off and, instead of the comparisons, a dark timeout period equal to the reinforcer duration ensued. This was followed by a 10-s ITI, after which the white stimulus again appeared on the center key and the trial was repeated. This cycle was repeated until the pigeon completed the scheduled requirement to white.

Upon completion of the scheduled requirement, the two comparisons appeared as the white center-key stimulus was turned off (i.e., the matching procedure was zero delay). A single peck to either comparison then turned both off and resulted in reinforcement or timeout depending upon which was pecked. For 2 pigeons, pecking the triangle comparison after completing the DRL 3-s requirement and pecking the dot comparison after completing the FR 20 requirement were reinforced. Pecking the alternative comparison on each trial type was "incorrect" and produced the timeout. For the remaining two subjects, the opposite sample-comparison contingencies were in effect.

Each matching session consisted of 96 fully completed trials (i.e., trials on which the comparisons appeared). As before, the reinforcer duration varied between 2 and 6 s across sessions and subjects to maintain 80% weights. Pigeons were trained on this matching task until their choice accuracies reached a level of 90% correct or better for five of six successive sessions. Sessions were conducted six days per week.

RESULTS

Phase 1 (Mixed Schedule) Performances

The behavior of most interest during this phase was how the pigeons responded on repeat trials after initially completing the unscheduled (incorrect) response requirement to the white stimulus. Figure 2 shows each subject's switch rate (the percentage of first-repeat trials that it completed the scheduled requirement after failing to do so initially); and its hit rate (the percentage of times that the scheduled response requirement was initially met). Given the mixed schedule contingencies, hit rates should remain close to chance throughout training. By contrast, if pigeons discriminated the prevailing response requirement on a given trial after failing to meet it initially, switch rates should increase with training.

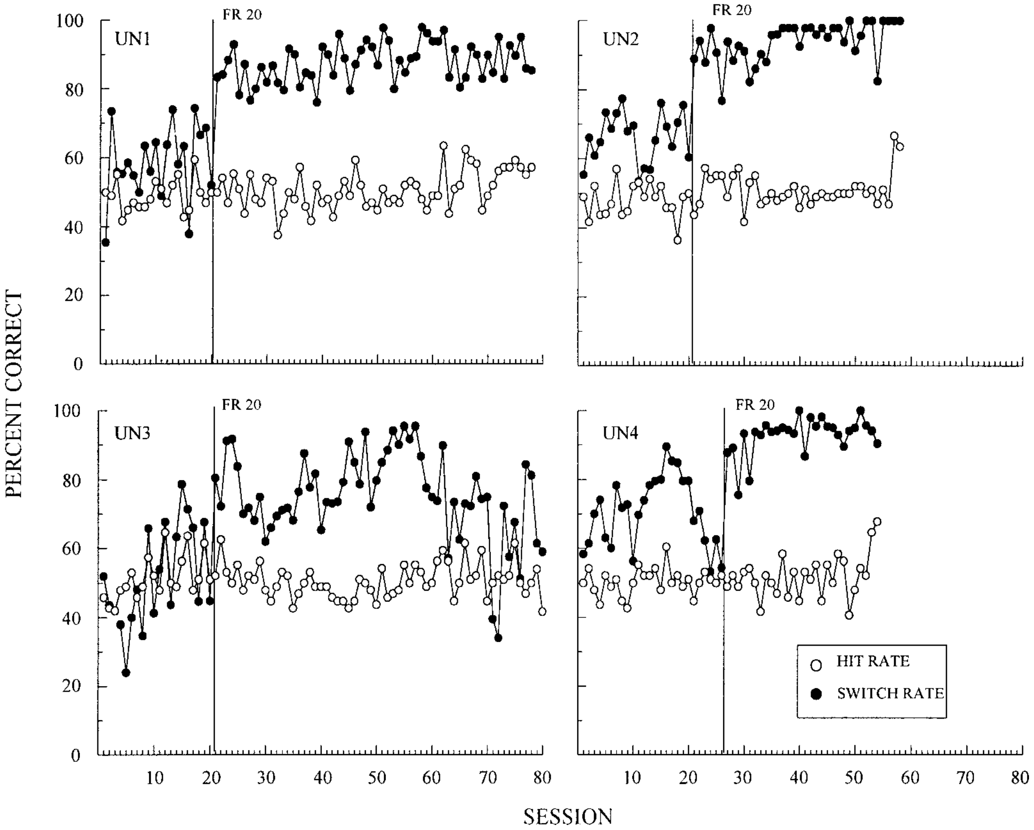

Fig. 2. Percentage of times each pigeon in Experiment 1 initially met the scheduled response requirement to white (hit rate) and the percentage of times they met that requirement on the first repeat of a trial (switch rate) during mixed-schedule (Phase 1) training. Vertical lines labeled FR 20 indicate when the FR requirement was increased from 10 to 20 pecks.

As expected, hit rates remained close to chance throughout training for all four pigeons. With FR 10 as one component of the mixed schedule, switch rates increased only slightly with training (shown in the left section of each panel), but the effect, when present, was short-lived. When the FR requirement was increased to 20 pecks, switch rates for pigeons UN1, UN2, and UN4 improved rapidly and remained stable with extended training. The percentage of times that these pigeons met the scheduled response requirement on the first repeat trial consistently exceeded 80%, and exceeded 90% on many sessions. Switch rates for the remaining pigeon (UN3) also increased with the larger FR requirement, but its performance on the repeat trials was highly variable throughout training. Its rates eventually dropped to low levels (< 70%) around Session 60 and did not recover. Pigeon UN3 was dropped from the experiment after Session 80.

Unfortunately, due to a programming oversight, trial-by-trial interresponse time (IRT) data were not recorded for this experiment (or for Experiment 2) so we do not have a complete picture of response patterns on initial or repeat trials. Nonetheless, we know for certain that with continued training the probability of the pigeons emitting a *long* (3 s or greater) IRT prior to making 20 pecks increased substantially on first-repeat DRL trials, and the probability of the pigeons emitting a *long* IRT decreased on first-repeat FR trials.

Phase 2 (Matching) Performances

Of most interest during this phase was whether pigeons learned to select one comparison stimulus when the completion of one

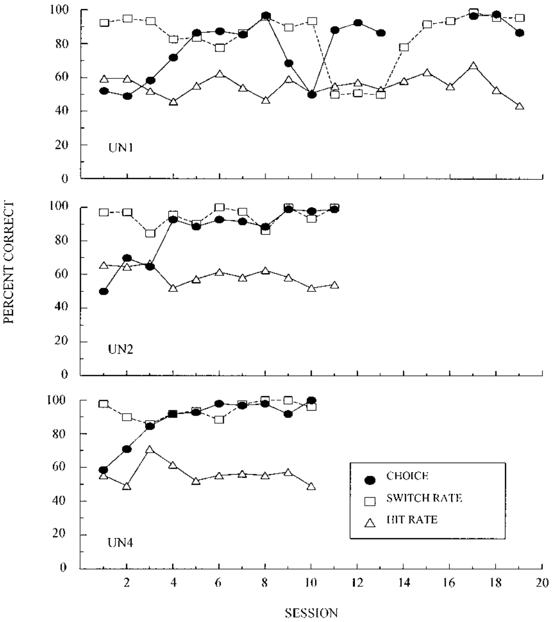

Fig. 3. Percentage of correct comparison choices following successful completion of the mixed-schedule response requirement during Phase 2 in Experiment 1. Also shown are percentage of times each pigeon initially met that requirement (hit rate) and the percentage of times they met the requirement on the first repeat of a trial (switch rate).

schedule requirement to white produced the two choice alternatives, and the other comparison when completion of the other scheduled requirement produced the alternatives. Figure 3 shows performances by each subject that was advanced to matching-to-sample training. In the figure, *Choice* refers to the average percentage of correct comparison choices in each session. *Hit rate* and *Switch rate* refer to the same measures of responding to the white center-key stimulus previously described.

As before, hit rates hovered around chance throughout training. Likewise, all three pigeons continued to switch immediately to the other response pattern after completing the unscheduled response requirement to white. The percentage of time that each subject met the scheduled response requirement to white on repeat trials remained above 80%. Finally, all three subjects learned to select the triangle versus dot comparisons following successful completion of the DRL and FR sample-response requirements. Matching acquisition was rapid for Pigeons UN2 and UN4, which reached better than 80% accuracy by the fourth session. Pigeon UN1 also learned to select one comparison over the other depending upon which schedule requirement produced the two alternatives, but its performance subsequently collapsed to chance levels for two sessions despite no concomitant decrease in switch rates. It subsequently recovered its previously accurate matching performances, stabilizing at accuracy levels of about 90% correct.

DISCUSSION

This experiment showed that it is possible to generate differential sample responding in the absence of different exteroceptive stimuli, and that such responding can serve as a conditional cue for subsequent comparison choice. In typical differential sample-response paradigms (e.g., Cohen, Looney, Brady, & Aucella, 1976; Urcuioli & Honig, 1980), different visual stimuli serve as the nominal sample stimuli. In such tasks, it is a relatively straightforward matter to condition different sample-response patterns to those stimuli. In the presence of one distinctive sample, the comparisons appear only upon completion of one response requirement (e.g., DRL); whereas in the presence of the other distinctive sample, the comparisons appear only upon completion of a different requirement (e.g., FR). Urcuioli and Honig also demonstrated that the different sample-response patterns exert strong control over comparison choice, even to the point of overshadowing the samples that occasion them (Urcuioli, 1984, 1985).

Here we were also able to generate differential responding on a mixed schedule that included a correction procedure. In particular, when pigeons initially failed to complete the response requirement actually scheduled on a trial, that trial repeated until the pigeon did complete the requirement. Good control by these contingencies developed in three of four pigeons. Specifically, with training, these pigeons switched to the alternative response pattern *on the first repeat trial* after their initial response pattern to white was nonreinforced.

The pigeons did not learn to switch to the alternative response pattern when the FR 10 contingency was in effect but did when the requirement was increased to 20 pecks. Longer pausing following a nonreinforced FR 20, if it occurred, cannot explain this result because the DRL contingency in force required a minimum of two responses (the first to start the DRL timer). Alternatively, when the FR requirement was increased, repeating the same *non*reinforced FR may have become more aversive because pigeons had to work longer to complete this requirement just to advance.

Furthermore, the cue ostensibly arising from the pigeons' successful differential behavior was sufficient to support accurate matching performances. We say ostensibly because it is possible that pigeons based their choices on some other cue; for example, how many times white appeared on the center key prior to the appearance of the comparison alternatives. For instance, if pigeons always completed the FR requirement on the initial presentation of white, they could then use the immediate appearance of the comparisons following the offset of white as a cue for pecking one particular comparison. If the comparisons did not appear at the offset of the initial white presentation (i.e., if the DRL requirement happened to be in effect), the second presentation of white could then serve as a cue for pecking the other comparison when the choice alternatives appeared upon completion of the DRL contingency. The second experiment was conducted to test whether number of white presentations on a trial could have been the sole cue governing choice.

EXPERIMENT 2

Experiment 2 sought to replicate the results of Experiment 1 with different subjects and, more importantly, to assess whether the differential behavior occurring to the mixed-schedule stimulus would effectively substitute for independently trained DRL versus FR sample-specific behavior in the control over matching choices. Pigeons were initially trained on hue-line symbolic matching with differential (DRL vs. FR) sample-response requirements. Afterwards, they received off-baseline, mixed-schedule training involving those same response requirements. Finally, they were given a transfer-of-control test in which the differential response patterns occurring to white served as the sample stimuli for the same comparison choices as in the symbolic matching task. Would the differential response patterns producing the comparison alternatives on each white-stimulus test trial occasion the same comparison choice that had been reinforced following the DRL and FR sample-specific behavior in the baseline matching task?

METHOD

Subjects

Six experimentally experienced White Carneau pigeons served as subjects. Their previous experience involved matching blue, yellow, red, and green samples to red and green comparisons and simple discrimination training between vertical and horizontal lines with different probabilities of food reinforcement. Four pigeons had previous experience with a FR 20 schedule and two with a FR 10 schedule. No pigeon had a prior history of responding on a DRL schedule. The housing and daily care procedures were the same as in Experiment 1.

Apparatus

The apparatus was identical to the one used in Experiment 1 except that the inline projectors were modified to present the following stimuli: red, green, and white homogeneous fields, a set of three white horizontal lines on a black background, and a set of three white vertical lines on a black background (BRS/LVE Pattern No. 692).

Procedure

Phase 1 symbolic matching. In Phase 1, the pigeons learned to match red and green sample stimuli to vertical and horizontal comparison stimuli. Each matching trial began with either red or green appearing on the center key. For half of the subjects, pecking 20 times to red (FR 20) versus spacing two successive key pecks at least 3 s apart to green (DRL 3 s) turned off the sample and immediately produced the two comparison alternatives on the adjacent side keys. These sample response requirements were reversed for the remaining pigeons. A single peck to either comparison stimulus then turned both off and produced either food reinforcement or an equivalent timeout period depending on which comparison was pecked. For half of the pigeons, vertical choices on red-sample trials and horizontal choices on green-sample trials were reinforced, whereas the opposite choices produced the timeout. These contingencies were reversed for the remaining pigeons.

The four possible trial types (2 samples × 2 left-right configurations of the comparisons) appeared equally often and in pseudorandom order in each 100-trial training session. Matching trials were separated by a 10-s ITI, the first 9 s of which were spent in darkness. The house light was turned on for the final second of the ITI and remained on throughout the next trial until the end of reinforcement or the onset of timeout. Each pigeon received symbolic matching training for a minimum of 10 sessions and until it achieved an accuracy criterion of 90% correct or better for five of six consecutive sessions. Sessions were conducted six days per week.

Phase 2 mixed-schedule training. In Phase 2, pigeons were trained to respond to a white center-key stimulus on a mixed DRL 3-s FR 20 schedule in a manner identical to that described in Experiment 1. The white stimulus remained lit on each trial until the pigeons completed one or the other schedule requirement. If the completed requirement was the one scheduled for that trial, reinforcement was delivered coincident with the offset of white. If it did not match the scheduled requirement, the white stimulus was turned off, the 10-s ITI was initiated, and the trial was repeated. This correction procedure was in effect until the pigeon completed the scheduled requirement for that trial.

Each pigeon was trained on this task until its switch rate, the percentage of times it completed the scheduled response requirement on the first repeat of a trial, was 87.5% or better for five of six consecutive sessions. Because Pigeon UN5 failed to show much evidence of learning, its FR requirement was increased to 30 pecks after 39 sessions. Upon reaching criterion levels of performance on the mixed-schedule task, three pigeons (UN6, UN7, and UN10) received refresher sessions on Phase 1 symbolic matching until accuracies of 90% correct or better were reestablished for one session. Three other pigeons (UN5, UN8, and UN9) did not receive refresher sessions due to experimenter error.

Testing. In the final experimental phase, each pigeon was tested on matching-to-sample with the familiar vertical and horizontal comparisons but with the completed scheduled response requirements (DRL and FR) to white as the samples. As before, the white center-key stimulus remained lit on each trial until the pigeon completed either of the two requirements. If the *un*scheduled requirement was completed, the white stimulus simply turned off and the trial was repeated following a 10-s ITI. Completing the scheduled response requirement now produced the vertical and horizontal comparisons on the side keys. A single peck to either comparison then turned both off and produced either reinforcement or an equivalent timeout period with the house light off depending on which comparison was chosen.

For half the pigeons, comparison choices that were *consistent* with the baseline (sample behavior-choice) contingencies were reinforced. For example, if a vertical comparison choice had been reinforced on trials with the FR requirement in Phase 1 symbolic matching, and a horizontal choice had been reinforced on trials with the DRL requirement, then these same contingencies were in effect during testing, although now pigeons completed those response requirements to the same (white) stimulus. For the remaining pigeons, reinforced choices in testing were *inconsistent* with the Phase 1 contingencies. So, for example, if vertical and horizontal choices had been previously reinforced on baseline matching trials with the FR and DRL requirements, respectively, the horizontal choice was now reinforced after completing the FR requirement to white and the vertical choice was reinforced after completing the DRL requirement. All other procedural details were identical to those described for Phase 1. Each pigeon remained in testing until its choice accuracy was 90% or better for five of six consecutive sessions.

The rationale for the consistent-inconsistent test manipulation was as follows. If the pigeons' sample-specific behavior had *not* acquired control over choice during Phase 1 symbolic matching, and if their behavior to white on trials in which they met the scheduled requirement did not provide a functional cue, then choice accuracy in both of these test conditions should be similarly low. Specifically, accuracy should begin at chance levels in both conditions and, with repeated testing, should rise with equal rapidity. If,

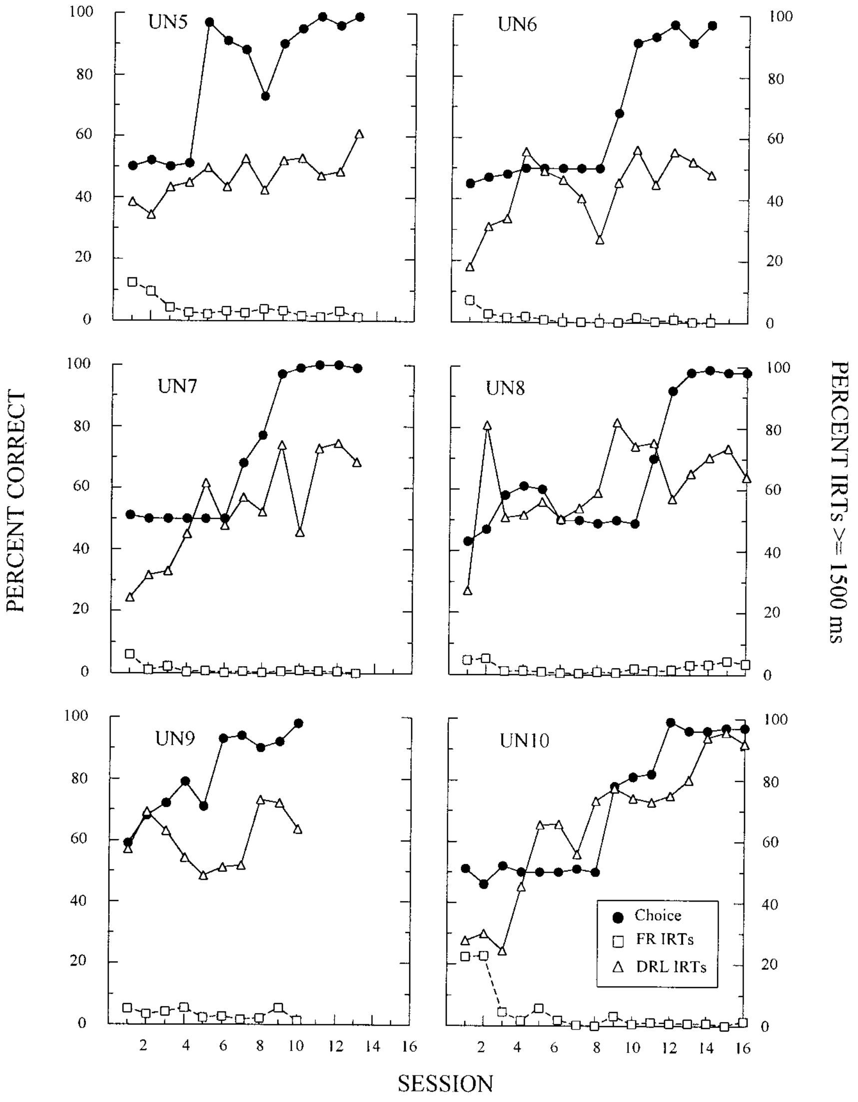

Fig. 4. Acquisition of symbolic matching (choice) with differential sample-response requirements for each pigeon in Experiment 2. Also shown are the percentages of all sample-interresponse times (IRTs) ≥ 1,500 ms for hue sample with the FR requirement and the hue sample with the DRL requirement.

however, the pigeons' sample-specific behavior *had* acquired control over comparison choice in the baseline task, and if their behavior on the successfully completed trials with white was similar to DRL versus FR response patterns, then pigeons in the consistent test condition should initially match at levels above chance, whereas pigeons in the inconsistent test condition should initially match at levels below chance. In addition, criterion levels of matching accuracy should be reached sooner for pigeons tested in the consistent than in the inconsistent condition.

RESULTS

Figure 4 depicts choice accuracies for individual subjects over all symbolic matching (Phase 1) sessions. It also provides the percentages of all interresponse times (IRTs) ≥1,500 ms which is a measure of how the pigeons pecked the two hue samples. The latter

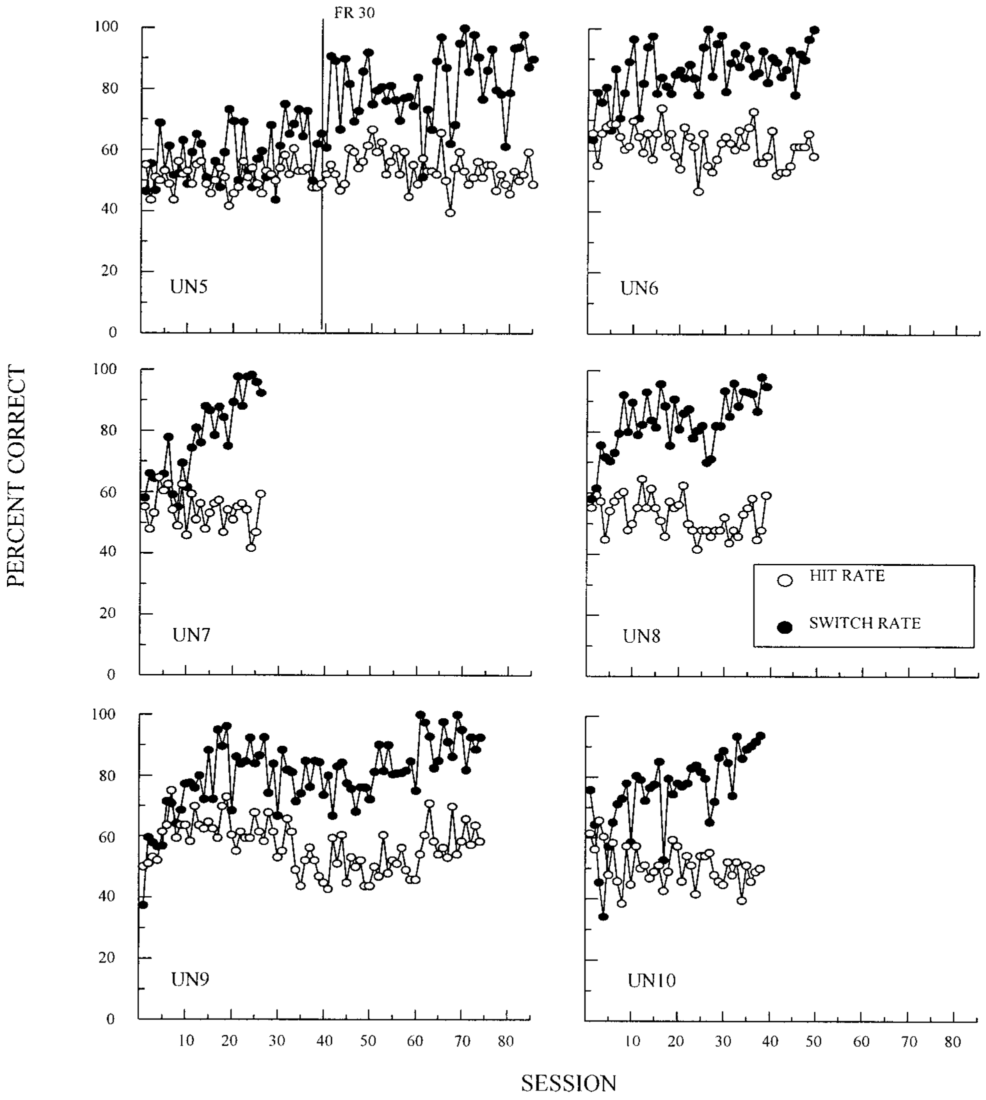

Fig. 5. Percentages of hit and switch rates during mixed-schedule training for each pigeon in Experiment 2. The vertical line labeled FR 30 indicates when the FR requirement was increased from 20 to 30 pecks.

measure should be relatively high for the sample associated with the DRL 3-s schedule and relatively low for the sample associated with the FR 20 schedule (cf. Urcuioli & Honig, 1980).

Accuracy reached criterion levels in the Phase 1 symbolic matching task after an average of 9.7 sessions (range, 6 to 12 sessions). Four of the 6 pigeons (UN5, UN7, UN8, and UN9) responded differentially to the hue samples from outset of training, exhibiting a substantially greater proportion of long IRTs to the sample with DRL response requirement than to the sample with the FR requirement. The other 2 pigeons (UN6 and UN10) developed a similar pattern within two or three sessions.

Mixed-schedule (Phase 2) performances are shown in Figure 5. Hit rates, the percentage of times that each pigeon met the scheduled response requirement to white on its initial presentation, clustered around 50% throughout training, as expected. More importantly, switch rates—the percentage of times that the scheduled requirement was met on the first repeat trial—increased steadily, albeit sometimes slowly, over successive training sessions. Subjects varied in the rapidity with which they achieved accurate switch rates (range, 27 to 85 sessions). Nonetheless, all pigeons learned to switch consistently ($>$ 87.5%) to the other response pattern on trials that immediately followed a nonreinforced pattern. By the end of Phase 2, switch rates were high and stable for all subjects.

For the 3 pigeons given a refresher session on their Phase 1 symbolic matching task prior to testing, average choice accuracy was 96% (range: 94–100). Their sample-response discriminations were also intact: The average percentages of IRTs $\geq$ 1500 ms were 80.3% on DRL-sample trials versus 1.7% on FR-sample trials.

Figure 6 shows each pigeon's matching-to-sample accuracy over the first 10 transfer test sessions along with the hit and switch rates to the white center-key stimulus. The left panels show the data from the 3 pigeons in the consistent test condition; the right panels show the corresponding data from the 3 in the inconsistent test condition.

As indicated by the first solid circle in each panel of Figure 6, all 3 pigeons in the consistent condition matched at levels above chance (range, 65% to 87%), whereas all three pigeons in the inconsistent condition matched at levels below chance (range, 29% to 47%) on the first transfer test session. Although two-tailed t-tests indicated that choice accuracy for only Pigeon UN7 was significantly different from chance, $t(2) = 5.23$, $p < .05$, the average first-session accuracy in the consistent test condition was significantly greater than it was in the inconsistent test condition, $F(1, 5) = 13.06$, $p < .05$. This result indicates that for all pigeons, the sample-response pattern that met the scheduled requirement to white tended to cue the same comparison choice that had previously been reinforced following a similar sample-response pattern during Phase 1 symbolic matching.

All three pigeons in the consistent condition were matching at criterion levels (90% correct or better) by the third test session, whereas the pigeons in the inconsistent condition did not reach that level of accuracy until the sixth or seventh test session. Hit rates for sample responding again remained at chance. Switch rates for all pigeons fluctuated across sessions, but larger and more sustained drops in these rates were evident for the three inconsistent pigeons during the first 6 test sessions.

DISCUSSION

The results of this experiment complement those of Experiment 1. First, we replicated the finding that pigeons learn to switch to an alternative pattern of key pecking after their initial pattern is nonreinforced. Second, we showed that the different response patterns themselves would cue comparison choices already conditioned to different sample stimuli to which DRL and FR responding were explicitly conditioned. In other words, the response requirement on a given trial substituted for the visually distinctive sample associated with the requirement. This transfer of control indicates that differential responding conditioned under mixed-schedule contingencies has cue properties like those observed in other differential sample-response situations (Urcuioli & Honig, 1980; Urcuioli & DeMarse, 1994).

One salient feature of the first-session test results, however, is that transfer was noticeably weaker overall than that observed in other differential sample-response studies (e.g., Urcuioli & Honig, 1980, Experiment 3). Still, this difference may be more apparent than real because the two pigeons showing the strongest effects (UN7 and UN10) received refresher training on the baseline matching task prior to testing. For three of the remaining four pigeons, performance might have been more accurate had such training not been omitted from their experimental protocols. If so, their results underestimate the actual control exerted by their differential sample responses over subsequent choices.

One other aspect of the transfer results was the greater disruption in switch rates of the pigeons in the inconsistent condition during the initial test sessions. This disruption might explain, at least in part, why these pigeons were slower to reach criterion levels of matching performance in testing than the consistent pigeons. But such an assertion must presuppose that the very behavior that was disrupted was a source of conditional stimulus control. Generating such control in the absence of different, exteroceptive stimuli

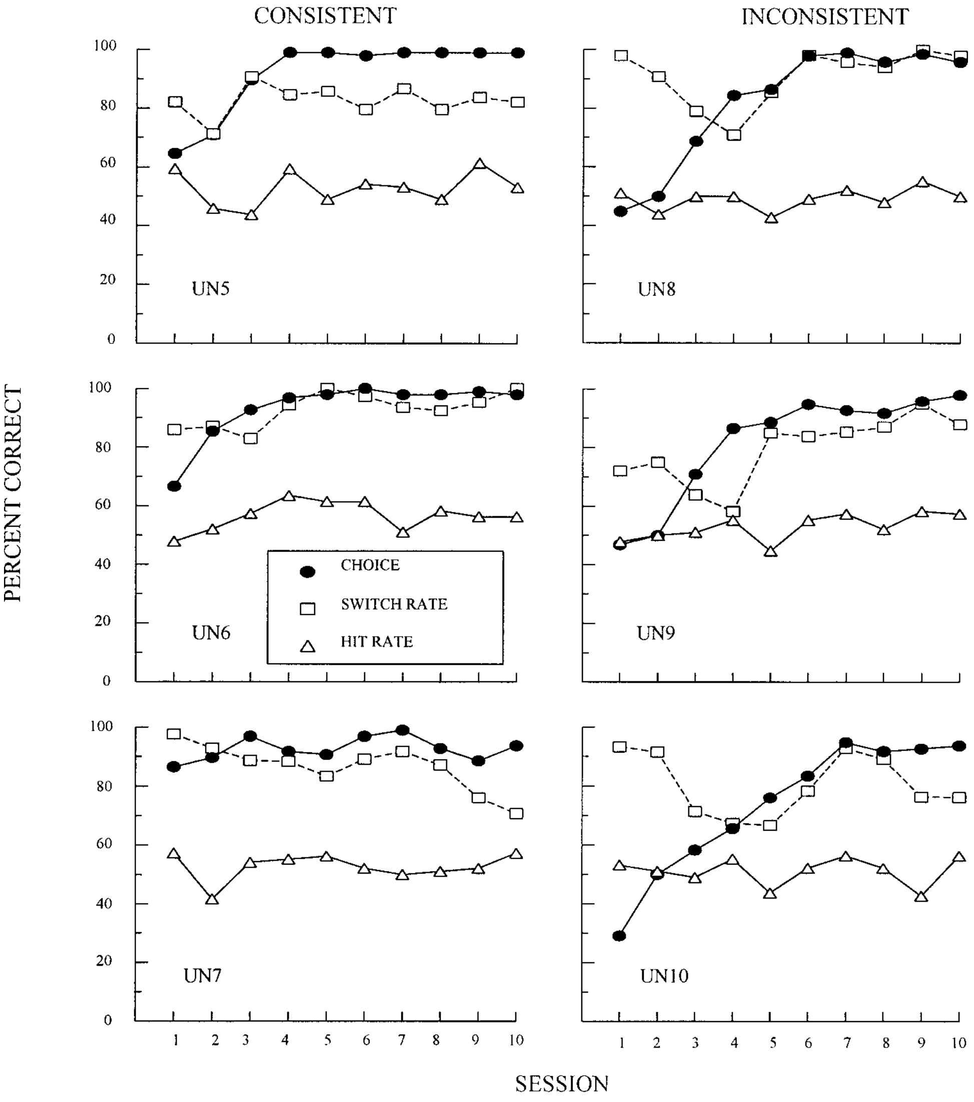

Fig. 6. Choice accuracy and hit and switch rates for each pigeon during the transfer-test sessions in Experiment 2. Data for the pigeons tested with sample behavior-choice contingencies consistent with Phase 1 symbolic matching contingencies are shown on the left; data for pigeons tested with inconsistent contingencies are shown on the right.

was one of the expressed purposes of this study.

GENERAL DISCUSSION

The present experiments successfully developed a procedure in which differential responding occurred to the same exteroceptive stimulus and served as a cue for choice in symbolic matching. When trained on a mixed schedule in which pecking white on a FR schedule was required on some trials and pecking white on a DRL schedule was required on other trials, nine of ten pigeons learned to switch to the alternative response pattern if they initially completed the unreinforced requirement. This switching was no doubt conditioned because the incorrect pattern not only was nonreinforced but also caused the trial to be repeated. Thus, repetition of the unscheduled requirement may have been punished by extending the time to reinforcement. All nine of these pigeons also learned to match the different response patterns to different visual comparison stimuli.

These results support previous research indicating pigeons' sensitivity to their own differential behavior (Lattal, 1975; Reynolds, 1966; Shimp, 1982; Urcuioli, 1985; Urcuioli & Honig, 1980; Zentall, Clement, Bhatt, & Allen, 2001). For example, Lattal (1975) trained two pigeons on a matching procedure similar to that used here. Each trial began with a yellow center-key stimulus. On some trials, completing a DRL 10-s schedule produced the comparison stimuli. On other trials, a differential-reinforcement-of-other behaviors schedule was in effect for 10 s (DRO 10). Lattal found that pigeons learned to choose one comparison after completing the DRL schedule and the other comparison after completing the DRO schedule. The current procedure differed from Lattal's in that our white sample stimulus repeated until the pigeon completed the scheduled requirement. Our results, then, extend these earlier findings by showing that pigeons match correctly in situations in which they may have to switch from one response pattern to another in order to produce the comparisons.

This unsignaled differential response procedure holds promise for tests of the sort proposed by Sidman (1994, 2000) for determining if defined responses are also included in equivalence classes. As mentioned previously, this question is difficult to answer because different responses are usually occasioned by different conditional or discriminative stimuli. Consequently, one cannot distinguish which events are responsible for any equivalence-like performances: the different responses or the different stimuli. The present study offers one way to avoid this problem.

Specifically, training can be conducted in the manner depicted in Figure 1 with the addition of unsignaled response training. For instance, such training using the R1 and R2 responses could be conducted prior to the two symbolic matching tasks requiring those same responses. Then, in testing, R1 and R2 could be generated as samples using the mixed schedule plus correction procedure. This should test whether the R1 and R2 responses are class members while not compromising any other equivalence test (i.e., reflexivity, symmetry, and transitivity).

Conducting unsignaled response training in this manner, however, may make an initial unreinforced response pattern the discriminative stimulus for a subsequently successful pattern. If so, one might expect *both* patterns to enter the same equivalence class, thus creating the very situation the procedure was designed to avoid. In other words, why shouldn't the alternative pattern be regarded as a distinct discriminative stimulus in the same way as any visual stimulus? Although this is possible, we believe that the data from our transfer test in Experiment 2 allay such concerns. If both the DRL and FR response patterns had entered into a common acquired equivalence class, transfer should not have been observed because each pattern would cue conflicting choice responses. Figure 6 shows, however, that considerable transfer occurred.

Moreover, if both response patterns joined a common class, it is unlikely that the pigeons would have learned the mixed-schedule matching task (Figures 3 and 6). The reason is that only the cue properties of the scheduled response (that which produced the comparisons) signaled the correct choice. By contrast, the alternative pattern signaled choice of the incorrect comparison. Thus, if the alternative pattern (plus nonreinforcement) had exerted conditional stimulus control, it would have been difficult for pigeons to match accurately. Given that all nine pigeons learned the matching-to-sample task to a high degree of accuracy, the DRL and FR response patterns did not enter into a common acquired equivalence class.

It is questionable, however, whether this training and testing procedure would return evidence of stimulus equivalence with pigeons or other nonhuman animals (D'Amato, Salmon, Loukas, & Tomie, 1985; Dugdale & Lowe, 2000; Hayes, 1989; Lionello-DeNolf & Urcuioli, 2002; Sidman, Rauzin, Lazar, Cunningham, Tailby, & Carrigan, 1982; but see Schusterman & Kastak, 1993 and Kastak & Schusterman, 1994 for exceptions). By contrast, the results from tests with humans are more likely to be interpretable no matter which way they turn out, and few procedural modifications would be required to accommodate them. For example, subjects could be trained to make two different responses on a keyboard when a white stimulus is presented on a computer screen (e.g., press one of two keys located at opposite ends of the keyboard).

Although pigeons are unlikely to show positive results using a procedure like that shown in Figure 1, they might, nonetheless, show evidence that their different responses can become members of functional or acquired equivalence classes (Urcuioli, 1996; cf. Goldiamond, 1962). For example, after pigeons are trained on many-to-one matching-to-sample, when a subset of the samples that had originally occasioned the same comparison choice is later established as cue for new choices, the remaining samples also control those new choices despite no training for doing so (Grant & Spetch, 1994; Urcuioli, DeMarse, & Zentall, 1994; Urcuioli, Zentall, & DeMarse, 1995; Urcuioli, Zentall, Jackson-Smith, & Steirn, 1989; Wasserman, DeVolder, & Coppage, 1992). This effect is revealed by transfer-of-control tests similar to that used in Experiment 2.

A relatively small modification of the standard many-to-one matching paradigm should permit the evaluation of whether different sample responses can join such acquired equivalence classes. For example, one set of samples for many-to-one training could be different hues and the other set could be DRL and FR responding on mixed-schedule trials. Choices of one comparison would then be reinforced if the sample were one particular hue or the DRL response pattern, and the alternative choice would be reinforced if the sample were the other hue or the FR pattern. Once this task is acquired to high levels of accuracy with both sets of samples, new comparison choices could then be conditioned only to the two hue samples. Finally, the ability of those newly learned choices to transfer immediately to the response-pattern samples would be tested. If different response patterns can join acquired equivalence classes, then pigeons should preferentially choose the comparison alternative that had been reinforced following the hue sample with which the response pattern had shared a common comparison association during many-to-one training.

Thus, the unsignaled response procedure described here has the potential to be useful in both human and nonhuman equivalence research. With human subjects, it offers a potential way to falsify the claims made by Sidman (1994, 2000) that responses can become members of equivalence classes. With other animals, it may allow assessing a similar type of membership in functional equivalence classes. We suspect that however the results turn out, results with humans will correspond in some way to those obtained with other animals.

REFERENCES

Adams, B. J., Fields, L., & Verhave, T. (1993). Effects of test order on intersubject variability during equivalence class formation. *The Psychological Record, 43,* 133–152.

Cohen, L. R., Looney, T. A., Brady, J. H., & Aucella, A. F. (1976). Differential sample response schedules in the acquisition of conditional discriminations by pigeons. *Journal of the Experimental Analysis of Behavior, 26,* 301–316.

D'Amato, M. R., Salmon, D. P., Loukas, E., & Tomie, A. (1985). Symmetry and transitivity of conditional relations in monkeys (*Cebus apella*) and pigeons (*Columba livia*). *Journal of the Experimental Analysis of Behavior, 44,* 35–47.

Dube, W. V., & McIlvane, W. J. (1995). Stimulus-reinforcer relations and emergent matching to sample. *The Psychological Record, 45,* 591–612.

Dugdale, N., & Lowe, C. F. (2000). Testing for symmetry in the conditional discriminations of language-trained chimpanzees. *Journal of the Experimental Analysis of Behavior, 73,* 5–22.

Goldiamond, I. (1962). Perception. In A. J. Bachrach (Ed.), *Experimental foundations of clinical psychology* (pp. 280–340). New York: Basic Books.

Grant, D. S., & Spetch, M. L. (1994). Mediated transfer testing provides evidence for common coding of duration and line samples in many-to-one matching in pigeons. *Animal Learning & Behavior, 22,* 84–89.

Hayes, S. C. (1989). Nonhumans have not yet shown stimulus equivalence. *Journal of the Experimental Analysis of Behavior, 51,* 385–392.

Hayes, S. C. (1991). A relational control theory of stimulus equivalence. In L. J. Hayes & P. N. Chase (Eds.), *Dialogues on verbal behavior: The first international institute on verbal relations* (pp. 19–40). Reno, NV: Context Press.

Horne, P. J., & Lowe, C. F. (1996). On the origins of naming and other symbolic behavior. *Journal of the Experimental Analysis of Behavior, 65,* 185–242.

Kastak, D. & Schusterman, R. J. (1994). Transfer of visual identity matching-to-sample in two California sea lions (*Zalophus californianus*). *Animal Learning & Behavior, 22,* 427–435.

Lattal, K. A. (1975). Reinforcement contingencies as discriminative stimuli. *Journal of the Experimental Analysis of Behavior, 23,* 241–246.

Lionello-DeNolf, K. M., & Urcuioli, P. J. (2002). Stimulus control topographies and tests of symmetry in pigeons. *Journal of the Experimental Analysis of Behavior, 78,* 467–495.

McIlvane, W. J., Dube, W. V., Kledaras, J. B., de Rose, J. C., & Stoddard, L. T. (1992). Stimulus-reinforcer relations and conditional discrimination. In S. C. Hayes & L. J. Hayes (Eds.), *Understanding verbal relations* (pp. 43–67). Reno, NV: Context Press.

McIlvane, W. J., Serna, R. W., Dube, W. V., & Stromer, R. (2000). Stimulus control topography coherence and stimulus equivalence: Reconciling test outcomes with theory. In J. Leslie & D. E. Blackman (Eds.), *Experimental and applied analysis of human behavior* (pp. 85–110). Reno, NV: Context Press.

Reynolds, G. S. (1966). Discrimination and emission of temporal intervals by pigeons. *Journal of the Experimental Analysis of Behavior, 9,* 65–68.

Schusterman, R. J., & Kastak, D. (1993). A California sea lion (*Zalophus californianus*) is capable of forming equivalence relations. *The Psychological Record, 43,* 823–839.

Shimp, C. P. (1982). On metaknowledge in the pigeon: An organism's knowledge about its own behavior. *Animal Learning & Behavior, 10,* 358–364.

Sidman, M. (1971). Reading and auditory-visual equivalences. *Journal of Speech and Hearing Research, 14,* 5–13.

Sidman, M. (1994). *Equivalence relations and behavior: A research story.* Boston: Authors Cooperative.

Sidman, M. (2000). Equivalence relations and the reinforcement contingency. *Journal of the Experimental Analysis of Behavior, 74,* 127–146.

Sidman, M., Cresson, O., Jr., & Willson-Morris, M. (1974). Acquisition of matching to sample via mediated transfer. *Journal of the Experimental Analysis of Behavior, 22,* 261–273.

Sidman, M., Rauzin, R., Lazar, R., Cunningham, S., Tailby, W., & Carrigan, P. (1982). A search for symmetry in the conditional discriminations of rhesus monkeys, baboons, and children. *Journal of the Experimental Analysis of Behavior, 37,* 23–44.

Sidman, M., & Tailby, W. (1982). Conditional discrimination vs. matching to sample: An expansion of the testing paradigm. *Journal of the Experimental Analysis of Behavior, 37,* 5–22.

Urcuioli, P. J. (1984). Overshadowing in matching-to-sample: Reduction in sample-stimulus control by differential sample behaviors. *Animal Learning & Behavior, 12,* 256–264.

Urcuioli, P. J. (1985). On the role of differential sample behaviors in matching-to-sample. *Journal of Experimental Psychology: Animal Behavior Processes, 11,* 502–519.

Urcuioli, P. J. (1996). Acquired equivalences and mediated generalization in pigeons' matching-to-sample. In T. R. Zentall & P. M. Smeets (Eds.), *Stimulus class formation in humans and animals* (pp. 55–70). Amsterdam: Elsevier.

Urcuioli, P. J., & DeMarse, T. (1994). On the relationship between differential outcomes and differential sample responding in matching-to-sample. *Journal of Experimental Psychology: Animal Behavior Processes, 20,* 249–263.

Urcuioli, P. J., DeMarse, T., & Zentall, T. R. (1994). Some properties of many-to-one matching with hue, response, and food samples: Retention and mediated transfer. *Learning & Motivation, 25,* 175–200.

Urcuioli, P. J., & Honig, W. K. (1980). Control of choice in conditional discriminations by sample-specific behaviors. *Journal of Experimental Psychology: Animal Behavior Processes, 6,* 251–277.

Urcuioli, P. J., Zentall, T. R., & DeMarse, T. (1995). Transfer to derived sample comparison relations by pigeons following many-to-one versus one-to-many matching with identical training relations. *Quarterly Journal of Experimental Psychology, 48B,* 158–178.

Urcuioli, P. J., Zentall, T. R., Jackson-Smith, P., & Steirn, J. N. (1989). Evidence for common coding in many-to-one matching: Retention, intertrial interference, and transfer. *Journal of Experimental Psychology: Animal Behavior Processes, 15,* 264–273.

Wasserman, E. A., DeVolder, C. L., & Coppage, D. J. (1992). Nonsimilarity-based conceptualization in pigeons. *Psychological Science, 3,* 374–379.

Zentall, T. R., Clement, T. S., Bhatt, R. S., & Allen, J. (2001). Episodic-like memory in pigeons. *Psychonomic Bulletin & Review, 8,* 685–690.

Received October 24, 2001
Final acceptance August 20, 2002

Kathy Hill

We wish to acknowledge the substantial contributions of Kathy Hill during her tenure as Managing Editor of the *Journal of the Experimental Analysis of Behavior* beginning with the May, 1987 issue and continuing through the November 2002 issue. She recently resigned her position with *JEAB* to assume the role of Business Manager of the *Journal of Applied Behavior Analysis.* During her tenure as Managing Editor of *JEAB,* Kathy processed every article, note, comment, and editorial published in the journal, reviewing each with her careful eye, keen sense of style, and good ear for the English language. She demonstrated a remarkable blend of efficiency and accuracy. Kathy not only is a master of those complex technical aspects of her task, but also of the considerable interpersonal skills and patience required in dealing with editors and authors alike. She has been flexible but also appropriately firm as the circumstances have dictated. She has helped each of us maintain the high standards of style and substance that our discipline expects of *JEAB.* On behalf of the entire community of scholars involved in *JEAB,* we thank her for her contributions to our journal and wish her the best in her new role in support of our discipline.

Philip N. Hineline (Editor, 1983–1987)

Edmund Fantino (Editor, 1987–1991)

Marc Branch (Editor, 1991–1995)

Richard L. Shull (Editor, 1995–1999)

Kennon A. Lattal (Editor, 1999–2003)