

SOME TESTS OF RESPONSE MEMBERSHIP IN ACQUIRED EQUIVALENCE CLASSES

PETER J. URCUIOLI

PURDUE UNIVERSITY

KAREN LIONELLO-DeNOLF

UNIVERSITY OF MASSACHUSETTS MEDICAL
SCHOOL/SHRIVER CENTER

AND

SARAH MICHALEK AND MARCO VASCONCELOS

PURDUE UNIVERSITY

Pigeons were trained on many-to-one matching in which pairs of samples, each consisting of a visual stimulus and a distinctive pattern of center-key responding, occasioned the same reinforced comparison choice. Acquired equivalence between the visual and response samples then was evaluated by reinforcing new comparison choices to one set of samples, and examining generalization of these choices to the other samples. Three separate experiments found no evidence of such generalization, as indexed by performance on class-consistent versus class-inconsistent tests. Other tests showed that the pigeons' center-key response patterns during training had indeed served as a conditional cue for choice. These results do not support the hypothesis that different defined responses can become members of acquired equivalence classes.

Key words: differential sample responding, acquired equivalence, response membership, transfer, key peck, pigeons

Sidman (1994, 2000) has argued that equivalence classes arise directly from reinforcement contingencies, just as the analytic units that define operant behavior do. One major implication of his theoretical view is that membership in equivalence classes is not confined simply to the conditional and discriminative stimuli comprising *n*-term contingencies. Thus, although it has been customary to think of equivalence relations in terms of the familiar exteroceptive (visual and auditory) stimuli used in most research, Sidman claims that responses and reinforcers are also "eligible" for class membership providing that they, too, are differential with respect to the discrimination contingencies in training.

This research was supported by National Institute of Mental Health Grant MH66195 to Peter J. Urcuioli.

The authors thank Crissy Hoeing and Kate Willaman for their assistance in running subjects.

Correspondence concerning this article may be addressed to Peter J. Urcuioli, Department of Psychological Sciences, Purdue University, 703 Third Street, West Lafayette, IN 47907-2004 (e-mail: uche@psych.purdue.edu).

doi: 10.1901/jeab.2006.52-05

Evidence consistent with this prediction can be found in the differential outcome literature (Urcuioli, 2005) where a number of findings indicate that reinforcers can join equivalence classes if they are differential with respect to reinforced discriminative responding. Indeed, Sidman (1994, 2000) cites the differential outcome effect itself (faster discrimination learning when each correct response produces its own reinforcing outcome) as supporting evidence, although the effect is explicable in other ways (e.g., Overmier & Linwick, 2001; Trapold, 1970). Nevertheless, the finding that following differential outcome training, humans will often match the former outcomes as samples to the conditional or discriminative stimuli with which they had been associated, is compelling evidence for Sidman's theoretical position (e.g., Dube & McIlvane, 1995; Dube, McIlvane, Mackay, & Stoddard, 1987; Elsner & Hommel, 2001; Joseph, Overmier, & Thompson, 1997; Schenk, 1994). Similar tests with rats and pigeons, however, have produced mixed results at best (Astley & Wasserman, 2001, Experiment 3; Dickinson & deWit, 2003; Urcuioli & DeMarse, 1997, Experiment 2; see

also Meck, 1985). Nevertheless, there are sufficiently encouraging data here to prompt further empirical evaluation of Sidman's position.

The present experiments asked whether different responses can join equivalence classes. To date, the published data relevant to this issue are rather limited. Manabe, Kawashima, and Staddon (1995) provided perhaps the better known results with budgerigars. Their subjects were explicitly trained to produce the comparisons in two-alternative matching by making a high vocal call to one sample stimulus and a low vocal call to the other sample stimulus. Later, two more sample stimuli that cued these same comparison choices were added to the matching task. On trials with each new sample, the budgerigars could obtain the comparison alternatives by making either a high or a low vocal call. Despite these nondifferential sample-response contingencies, high vocal calling developed to the new sample stimulus that occasioned the same choice as the original sample to which a high call was required, and low vocal calling developed to the new sample that occasioned the same choice as the original sample to which a low call was required. Using an analog of this procedure, Urcuioli *et al.* (2002) also showed emergent differential sample behavior in pigeons that had learned to produce the comparison alternatives by completing a differential-reinforcement-of-low-rates-of-responding (DRL) versus a fixed-ratio (FR) sample-response requirement to the original sample stimuli or by pecking top versus bottom keys on which the samples were displayed.

The emergent differential sample behavior reported by Manabe *et al.* (1995) was interpreted by Sidman (1994, 2000) as evidence that the explicitly conditioned high and low vocal calls in training had joined equivalence classes that also contained their occasioning sample stimuli and the reinforced comparisons associated with them. However, Saunders and Williams (1998) pointed out that adventitious reinforcement of the two mutually exclusive vocals calls during acquisition of the [new sample-comparison] relations also could explain this effect. Moreover, the effect originally reported by Manabe *et al.* (1995) and later by Urcuioli *et al.* (2002) occurred within the context of training many-to-one

relations between samples and comparisons. These relations typically produce acquired equivalence between the sample stimuli, as evidenced by the fact that new behavior explicitly trained to one sample in each common-comparison class immediately generalizes to the other, "untrained" sample (e.g., Grant & Spetch, 1994; Spradlin, Cotter, & Baxley, 1973; Urcuioli, Zentall, Jackson-Smith, & Steirn, 1989; Wasserman, DeVolder, & Coppage, 1992). It is possible, then, that behavior already conditioned to one sample in a common-comparison class (e.g., explicitly reinforced differential vocal calling) will likewise generalize to other samples in the same class. If so, then emergent sample behavior is simply another index of acquired equivalence rather than evidence for its own class membership.

It is perhaps worth noting at this point that Sidman's (2000) predictions about defined responses and defined reinforcers were couched in terms of stimulus equivalence classes, as indexed by reflexivity, symmetry, and transitivity between the components of the baseline conditional relations (Sidman, 1997; Sidman & Tailby, 1982). For nonhuman animals, these behavioral effects are rarely obtained, bringing into question whether stimulus equivalence is demonstrable with them (but see Frank & Wasserman, 2005; Schusterman & Kastak, 1993). What is not in question, however, is the ability of nonhuman animals to show acquired or functional equivalence. Here, new (untrained) relations emerge after many-to-one training and separate, reassignment training in which some of the hypothesized class members occasion new behavior. Specifically, the untrained class members also occasion the newly learned behavior despite no history of reinforcement for doing so (Bovet & Vauclair, 1998; Honey & Hall, 1989; Urcuioli, 1996; Wasserman *et al.*, 1992). In view of this, it seems reasonable and appropriate to extend Sidman's predictions to acquired equivalence classes.

A priori, there are good reasons to expect that such classes might include differential sample responding. First, differential sample responding is known to act just like other sample stimuli in matching-to-sample. For example, when pigeons produce the comparison alternatives by completing a DRL requirement to one sample and a FR require-

ment to another sample, the slow and rapid patterns of sample key pecking, respectively, also develop control over comparison choice (Urcuioli, 1984, Urcuioli & Honig, 1980; see also Lionello-DeNolf & Urcuioli, 2003). In view of this and previous findings that conditional cues occasioning the same reinforced choice become functionally equivalent, acquired equivalence classes ought to include differential sample-response "samples".

Second, this prediction already has received some support from a previous study conducted in our lab (Urcuioli, DeMarse, & Zentall, 1994). Pigeons were initially trained to match a red hue, 20 pecks to a center-key stimulus, and a brief presentation of food to one comparison stimulus, and a green hue, 1 peck to the center-key stimulus, and a brief presentation of the food-hopper light only ("no food") to the alternative comparison. Each sample could appear individually, two or three times in succession, or once in concert with presentation of another sample or both samples in its common-comparison group. After learning this many-to-one task (cf. Grant, 1982) to high levels of accuracy, acquired equivalence between the hue, response, and food samples was evaluated by training pigeons to match one pair of samples to new comparisons (reassignment training) and then testing the remaining, "untrained" pairs for their ability to immediately cue those new choices. Transfer of control from the explicitly trained to the untrained pairs was evident for pigeons that matched the hue samples during reassignment training and were tested with the 20 versus 1 and food versus no-food samples, although not following other reassignment-testing combinations. In any event, there is some ambiguity about the nature of the 20-peck versus 1-peck samples: Are these really different responses or is the functional cue some feature correlated with them (e.g., different stimulus durations)?

Here, we approached the issue of response membership in acquired equivalence classes by requiring different and distinctive patterns of center-key pecking in pigeons: the slowed, spaced responding generated by DRL schedules versus the rapid, uninterrupted responding generated by FR schedules. Well-trained pigeons performing on a DRL schedule typically make an initial peck or pecks followed by movement away from the key (e.g., turning

the body to the left or to the right, circling, or pecking at the houselight) before making a subsequent peck. By contrast, performance on a FR schedule typically involves a steady position in front of the key while pecks are rapidly executed. Will these two response patterns, already known to act as potent conditional cues for choice, join acquired equivalence classes if the choices they occasion are the same as other samples (e.g., visual stimuli)?

EXPERIMENT 1

In Experiment 1, pigeons were initially trained to high levels of accuracy on many-to-one (MTO) matching with four samples and two comparisons. Two of the samples were red and green hues and the other two were different center-key response patterns, one of which involved spacing two consecutive key pecks at least 3 s apart (DRL 3"), and the other 10 consecutive pecks with no temporal restrictions (FR 10). One comparison choice was reinforced following either the red hue or the DRL pattern, whereas the alternative comparison choice was reinforced following either the green hue or the FR pattern. Afterwards, acquired equivalence between the visual and response samples was assessed by training the pigeons to match two of the original sample stimuli—the red and green hues—to new comparisons, and then testing them for generalization of those new choices to the remaining two samples (the DRL and FR response patterns).

The MTO task was unusual in that the two patterns of center-key pecking were not signaled by different visual stimuli, as is typical when such differential responding is desired. The reason we did not use multiple-schedule contingencies was to avoid a possible interpretive ambiguity later on. Specifically, with multiple-schedule training, we would not know if acquired equivalence classes (as indicated by potentially positive transfer-test results) contained a hue and a response pattern or, alternatively, a hue and whatever stimulus had occasioned that pattern.

Consequently, we employed a modified mixed schedule to generate the DRL and FR patterns. Mixed-schedule trials always began with a white stimulus on the center key. If the pigeon completed the scheduled contingency

prior to meeting the requirement for the alternative, unscheduled contingency (e.g., spacing two successive pecks at least 3-s apart before making 10 pecks on a DRL trial), then the comparison stimuli appeared on the side keys as the white center key went off. However, if the pigeon completed the alternative requirement (e.g., made 10 rapid pecks on a trial that required them to space two pecks at least 3 s apart), then the houselight flashed off and on once, and the white stimulus was turned off for a few seconds before reappearing on the center key. When white reappeared, pigeons then had another opportunity to complete the scheduled requirement. This correction procedure remained in effect until the pigeon successfully completed the response requirement for that trial. Our previous work (Lionello-DeNolf & Urcuioli, 2003) showed that with training, pigeons will learn to “switch” from one pattern to the other when its initial pattern of responding causes the white center-key stimulus to go off.

METHOD

Subjects

Six experimentally naïve, adult White Carneau pigeons (*Columba livia*) obtained from the Palmetto Pigeon Plant (Sumter, SC) participated in the experiment. All were retired breeders and had continuous access to Purina ProGrains upon arrival in the lab in order to determine their free-feeding body weights. Each pigeon's weight then was gradually reduced to and maintained at 80% of its free-feeding value by restricted feeding. During experimental participation, food was provided in the home cage only when food intake in a session was insufficient to maintain the 80% body weight and on days on which the experiment was not run.

Pigeons were housed individually in stainless-steel, wire-mesh cages in a temperature- and humidity-controlled colony room on a 14:10-hr day-night cycle. The light portion of the cycle began at 07:00 hr. Grit and water were always available in the home cage.

Apparatus

A single BRS/LVE (Laurel, MD) experimental chamber, consisting of a three-key panel (Model PIP-016) inside a Model SEC-002 enclosure with an aluminum grid floor, was

used in this experiment. The pigeon's compartment was 36.8 cm high x 30.5 cm wide x 34.3 cm deep. Sample and comparison stimuli were displayed via in-line projectors (Model IC-901-IDD) mounted behind the keys, each 2.5 cm in diameter, spaced 8.3 cm apart center-to-center, and positioned approximately 25 cm from the grid floor. The center-key projector could display red, green, and white homogeneous fields and an inverted white triangle on a black background (BRS/LVE Pattern No. 692). The side-key projectors could display blue and yellow homogeneous fields, and a white “X” and a white circular annulus (“O”) both on black backgrounds (BRS/LVE Pattern No. 696). A partially covered GE #1829 bulb 5.7 cm above the center key directed light toward the ceiling of the enclosure to provide general chamber illumination. Food (Purina ProGrains) could be accessed through a 5.8 x 5.8 cm opening centered approximately 13 cm below the center key. The metal housing in back of this opening was lit by a miniature bulb (ESB-28) when the food hopper was raised. A constantly running blower fan attached to the enclosure provided ventilation and masking noise. An IBM-compatible 386 computer in an adjacent room controlled the presentation and recording of all events via an interface connected to the experimental apparatus.

Procedure

Preliminary training. Each pigeon initially was trained to eat quickly and reliably out of the raised and lit food hopper, after which pecking the white inverted triangle on the center key was shaped by the method of successive approximations. Each pigeon then received a series of sessions during which single pecks to just the white center key, to red and green center-key stimuli, or to red and green center-key stimuli and blue and yellow (or X and O) side-key stimuli were reinforced with food. The 60 trials in each preliminary training session were divided equally among all of the stimuli scheduled to appear in a session. Successive trials were separated by a 10-s intertrial interval (ITI). The houselight remained on continuously.

After pecking was established to the various stimuli that would later appear as samples or comparisons in the matching tasks, pigeons learned to peck white on the center key

multiple times to obtain food. This was accomplished by gradually increasing the value of a FR reinforcement schedule from 2 to 20. (Although a FR 10 was used for subsequent mixed-schedule pretraining, we trained to a FR 20 to increase the likelihood that pecking white would persist when a DRL schedule was introduced.) Each session contained 60 reinforced trials separated by a 10-s ITI, the first 9 s of which was spent in darkness. The houselight was on for the last 1 s and remained on until the end of the reinforcement cycle. Reinforcement duration was constant within a session but varied between 2 to 6 s across sessions to maintain 80% body weights.

Mixed-schedule pretraining. Next, pigeons received extensive training on a mixed DRL–FR schedule. On half of the trials in each 96-trial session, food reinforcement was contingent upon completion of a DRL 3-s schedule for pecking the white center-key stimulus; on the other half of the trials, completion of a FR 10 schedule produced food. The two reinforcement schedules were randomized across trials with the constraint that neither schedule was in effect on more than three consecutive trials. Successive trials were again separated by a 10-s ITI, the first 9 s of which was spent in darkness. Reinforcement durations were again adjusted on a daily basis to maintain each pigeon's body weight at 80% of its free-feeding value.

Each mixed-schedule trial began with white appearing on the center key. If the DRL 3-s schedule was in effect, pigeons obtained food by spacing two successive center-key pecks at least 3 s apart. However, if the pigeons made 10 successive center-key pecks prior to completing the DRL requirement, the houselight went off for 250 ms, the white stimulus was turned off for a period of time equal to the reinforcement duration for that session, and then white reappeared on the center key. Conversely, if the FR 10 schedule was in effect, pigeons obtained food by pecking white 10 consecutive times without any interresponse time (IRT) exceeding 3 s. If any peck following the initial peck had an IRT of 3 s or longer (meeting the alternative (DRL) requirement), this too caused the houselight to go off for 250 ms and turned off the white stimulus for a short while before its reappearance on the center key. In short, a correction procedure was in effect whenever pigeons completed the

alternative response requirement before completing the scheduled response requirement on a given trial.

On their initial attempts, pigeons would be expected to successfully complete the programmed requirement only 50% of the time. With training, however, pigeons should learn to “switch” to the opposite response pattern whenever their initial pattern caused the white center stimulus to go off (Lionello-DeNolf & Urcuioli, 2003). Consequently, the main dependent variable for the mixed schedule was the percentage of time that pigeons successfully completed the scheduled DRL or FR requirement on their first repeat attempt (viz., on their first correction opportunity after completing the unscheduled requirement).

Each pigeon received a minimum of 20 sessions of mixed-schedule pretraining, and this training was continued until the percentage of correct first repeats or “switches” was 90% or higher for five of six consecutive sessions. One pigeon was unable to meet the 90% criterion after 70 sessions, but was permitted to continue because it routinely switched to the scheduled requirement about 85% of the time.

Next, additional pretraining sessions were run in which 96 mixed-schedule trials were intermixed with trials on which red and green appeared on the center key (12 trials each). A single peck to either red or green turned off the hue and produced food reinforcement (continuous reinforcement or CRF). The intermixing of trial types was conducted in order to accustom pigeons to seeing different center-key stimuli with different reinforcement contingencies like those they would later experience during MTO matching. Each pigeon was run under these conditions until the percentage of switches on the mixed-schedule trials was 90% or higher for three consecutive sessions.

Many-to-one matching. After finishing pretraining, pigeons were trained on MTO matching-to-sample in which they learned to match the red and green hues and DRL and FR white-center-key response patterns to blue and yellow comparisons. The eight possible sample-comparison combinations (four samples x two left–right positions of the comparisons) in each 96-trial session were randomized within successive blocks of 48 trials with the constraints that each trial type occur equally

often and none occur more than three times in a row. On all trials, the center-key/sample stimulus went off as the comparison stimuli appeared on the two side keys (i.e., a 0-delay procedure was used). On trials involving red and green, a single peck to either sample hue produced the comparisons. On trials involving DRL and FR samples, the mixed-schedule contingencies were in effect with white on the center key. Now, completion of the scheduled requirement produced the comparison stimuli rather than food.

When the comparison alternatives appeared, a single peck to either one immediately turned both off and produced either food or timeout. For 3 pigeons, pecking the blue comparison stimulus was reinforced following the red sample and successful completion of the mixed-schedule DRL requirement (hereafter referred to as the "DRL" sample), whereas pecking the yellow comparison stimulus was reinforced following the green sample and successful completion of the mixed-schedule FR requirement (hereafter referred to as the "FR" sample). These reinforced sample-comparison contingencies were reversed for the remaining 3 pigeons. Pecking the alternative, "incorrect" comparison stimulus on any trial immediately turned off the houselight for a period of time equal to the reinforcement duration for that session. Successive matching trials were separated by a 10-s ITI, with the first 9 s spent in darkness. As before, reinforcement duration was adjusted on a session-by-session basis for each pigeon to maintain its 80% body weight as closely as possible.

MTO training for each pigeon continued until it met the following three criteria: 1) overall choice accuracy of 90% correct or better for five of six consecutive sessions, 2) at least 85% choice accuracy with each set of samples (hues and response patterns) over these same sessions, and 3) a switch percentage for center-key mixed-schedule performances of at least 80% over these same sessions. These three criteria ensured stable and high levels of choice accuracy with all four samples and, moreover, accurate and stable switching to the mixed-schedule stimulus. After meeting these criteria, each pigeon received 10 overtraining sessions on MTO matching.

Reassignment training. Next, each pigeon learned to match the red and green samples

to new comparisons, the white "X" and white "O" stimuli. Each 100-trial session was divided equally among the four possible trial types (two samples x two left-right positions of the comparisons), none of which could appear more than three times in a row. As in MTO matching, a single peck to the sample hue turned it off and immediately produced the comparison alternatives on the adjacent side keys (viz., a 0-delay procedure was used). For 3 pigeons, pecking the "X" comparison was reinforced after red and pecking "O" was reinforced after green; for the remaining 3 pigeons, the opposite sample-comparison relations were reinforced. Pecking the alternative (incorrect) comparison on any trial produced a timeout equal to the reinforcement duration for that session. All other procedural details were identical to those for MTO matching.

Given the relatively small number of subjects, it was not possible to completely balance the reinforced sample-comparison relations during reassignment with the reinforced relations during MTO training. Nevertheless, partial counterbalancing was implemented such that all pigeons had the same reinforced sample-comparison relations in testing (see below).

Each reassignment-training session alternated with continued training on each pigeon's respective MTO task to ensure that MTO performances remained intact. Reassignment training continued until choice accuracy on this task was 90% correct or better for five of six consecutive reassignment sessions. Two pigeons were unable to meet this performance criterion after 35 and 60 sessions, respectively, but were nonetheless advanced to testing because they consistently matched at accuracy levels near or above 85% correct.

On the day prior to testing, each pigeon received one final session on MTO matching.

Testing. In testing, pigeons matched the newly learned comparison choices ("X" and "O") to the remaining (DRL and FR) samples from the MTO task. Every trial began with the white center-key stimulus and the mixed DRL-FR schedule in effect. Successful completion of the scheduled requirement immediately turned off white and produced the X and O comparison stimuli on the adjacent side keys. As before, if the other mixed-schedule requirement was completed, the houselight flashed for 250 ms, the white stimulus went

off for a period equal to the reinforcement duration for that session, and white then reappeared on the center key.

A single peck to either comparison stimulus turned both off and produced either food or time out. For all 6 pigeons, choosing the X comparison following the DRL sample and the O comparison following the FR sample produced food, whereas choosing the alternative comparison following each sample produced a time-out equal in duration to the reinforcement period. The four possible trial types (two samples x two left-right positions of the comparisons) occurred equally often in each 100-trial session with the constraint that none occur more than three times in a row. All other details of the five test sessions were identical to those described for the preceding training phases.

Although the sample-comparison contingencies in testing were identical for all pigeons, the reinforced relations for 3 of them were consistent with any acquired equivalence that may have developed between the hue and response samples during MTO training, but inconsistent with acquired sample equivalence for the remaining 3 pigeons. To illustrate the difference, assume that the reinforced selection of the blue comparison following the red and DRL samples and the yellow comparison following the green and FR samples during MTO training produced two acquired equivalence classes: {red, DRL} and {green, FR}. If the pigeons then learned to choose X following red and O following green, these choices should now generalize to the other member in each respective class—namely, DRL and FR, respectively. Thus, reinforcing the choice of the X comparison on DRL trials and the O comparison on FR trials would be consistent with a {red, DRL} and a {green, FR} class and should generate relatively high levels of accuracy in testing. Conversely, if the pigeons learned during reassignment to choose O following red and X following green, generalization of these choices to DRL and FR, respectively, would be at odds (inconsistent) with the reinforced test relations (viz., X after DRL, and O after FR) and, thus, should yield relatively low levels of accuracy in testing.

At a minimum, then, accuracy should be higher in the consistent than in the inconsistent test condition. Additionally, the expectation was that accuracy should be above chance

Table 1
Design of Experiment 1.

Training		
Many-to-One	Reassignment	Testing
DRL → C1+		DRL → C3+ [C]
FR → C2+		FR → C4+
S3 → C1+	S3 → C3+	or
S4 → C2+	S4 → C4+	
		DRL → C4+ [I]
		FR → C3+

Note. DRL = differential-reinforcement-of-low-rates-of responding component of mixed schedule, FR = fixed-ratio component of mixed schedule, S3-S4 = different visual sample stimuli, C1-C4 = comparison stimuli, + = reinforced comparison choice, [C] = consistent test condition, [I] = inconsistent test condition.

and below chance, respectively, in these two conditions at the outset of testing.

Design Summary and Statistical Analyses

Table 1 shows a summary schematic of the two training phases and the test conditions. Only the reinforced (+) comparison choices (C1 to C4) are shown following each sample (S3 and S4, and DRL and FR); the nonreinforced comparison choice is simply the alternative comparison.

For the analyses of variance reported in this experiment and those that follow, Type I error rate was set at 0.05.

RESULTS

Mixed-schedule pretraining. Figure 1 shows the average performances of the 6 pigeons over the first 20 sessions of mixed-schedule pretraining. The open circles plot the percentage of trials on which the pigeons completed the scheduled requirement on their initial attempt. As expected, this value was at, or very close, to 50% correct. The pigeons mostly made 10 short-IRT pecks at the beginning of each mixed-schedule trial; in other words, they initially completed the FR requirement. When this caused the white stimulus to go off, pigeons learned to space successive center-key pecks to satisfy the scheduled DRL 3-s requirement when white reappeared. This is illustrated by the "Switches" function which plots the percentage of times that pigeons completed the scheduled requirement on their first repeat attempt. By the end of this pretraining phase, all pigeons (except one)

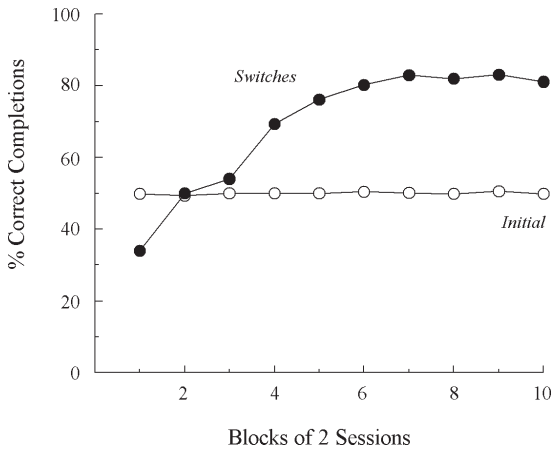


Fig. 1. The average number of initial-attempt completions of the mixed DRL-FR schedule and the average number of completions on the first repeat attempt ("Switches") during pretraining in Experiment 1.

were routinely completing the scheduled requirement on 90% or more of their first repeats.

When red and green CRF trials were intermixed with the mixed-schedule trials, there was some minor disruption in performance: On average, pigeons required an additional 7.7 sessions (range: 3 to 17 sessions) to return to the 90% switch criterion. Over the last three (criterion) sessions, however, the average percentage of switches was 94.0 (range: 91.2% to 96.6%).

MTO and reassignment training. On average, 20 training sessions were needed for pigeons to reach criterion levels of accuracy on MTO matching (range: 8 to 42 sessions). More noteworthy was the finding that matching acquisition was more rapid with the DRL and FR samples than with the red and green samples, as shown in Figure 2. This difference indicates more potent conditional stimulus control by the response than by hue samples, although the shorter sample durations associated with red and green (where a single peck terminated the hue sample on a given trial) may have also contributed to this difference.

Choice accuracy over the last five reassignment sessions with the red and green samples averaged 91.1% across pigeons. Average accuracies for pigeons subsequently tested with class-consistent versus class-inconsistent relations were comparable: 90.6% versus 91.7% correct, respectively, $F(1, 4) = 0.07$.

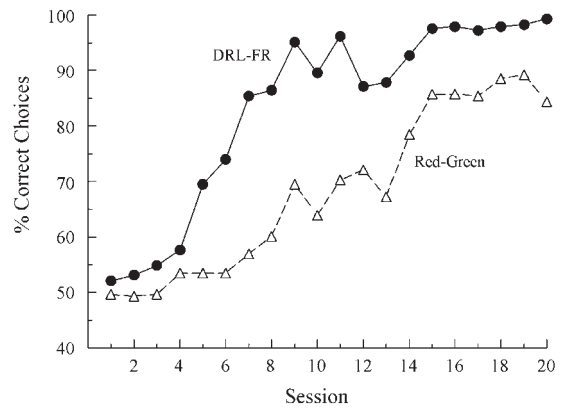


Fig. 2. The average percentage of correct choices with DRL versus FR mixed-schedule samples and red versus green samples during many-to-one matching acquisition in Experiment 1.

For the last five MTO sessions preceding testing, matching performances with each set of samples did not differ between pigeons assigned to the different test conditions. On DRL- and FR-sample trials, the class-consistent pigeons averaged 96.1% correct versus 97.8% for the class-inconsistent pigeons, $F(1, 4) = 0.38$. The corresponding figures for the red- and green-sample trials were 96.4% and 93.2% correct, respectively, $F(1, 4) = 0.96$. Finally, pigeons continued to perform accurately on the center-key mixed schedule: The average percentage of switches was 84.8% versus 92.0%, respectively, for the class-consistent and class-inconsistent pigeons, $F(1, 4) = 0.66$.

Testing. The top portion of Figure 3 plots each pigeon's matching accuracy on the first test session. Data from pigeons tested with sample-comparison relations consistent with acquired equivalence are shown on the left; those from pigeons tested with inconsistent relations are shown on the right. Most pigeons matched close to the level expected by chance (50%), although 2 exhibited accuracies suggestive of acquired equivalence. Specifically, 1 consistent pigeon matched at 60% accuracy, whereas 1 inconsistent pigeon matched at only 41% accuracy. However, overall first-session accuracies for the two test conditions were comparable (52.7% and 47.7% correct, respectively) and not significantly different, $F(1, 4) = 0.92$. The same was true for performances over just the first 20 or 50 test trials (data not shown).

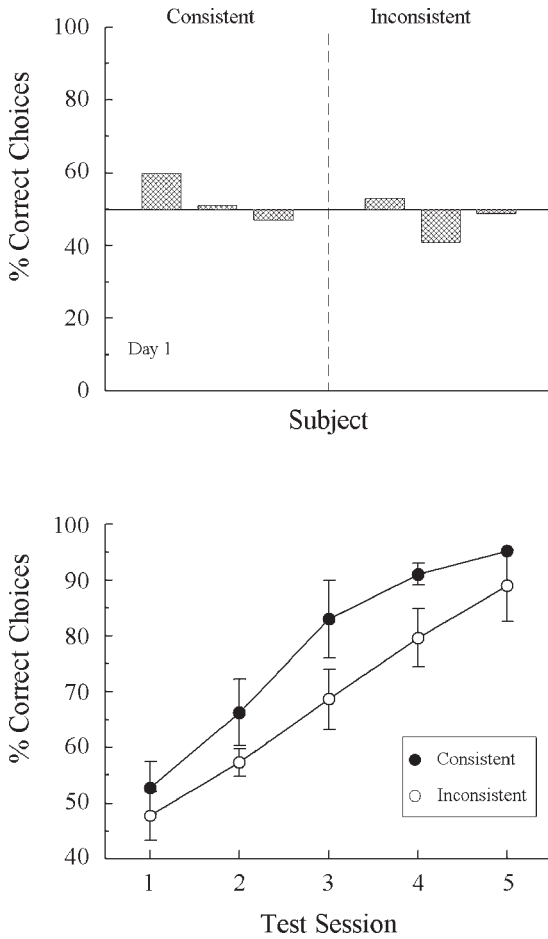


Fig. 3. Top: The percentage of correct choice responses by each subject in Experiment 1 on its first transfer-test session. Bottom: The average percentage of correct choices by each group on the five transfer-test sessions in Experiment 1. (Error bars represent \pm SEM.)

With repeated testing, pigeons in the consistent test condition matched more accurately on average than pigeons in the inconsistent condition, as shown in the bottom portion of Figure 3. By the fifth test session, every consistent pigeon chose the correct comparison on 90% or more of the test trials, whereas only 1 of the 3 inconsistent pigeons had achieved that level of performance. Analysis of variance (ANOVA) on these data, however, showed neither an overall between-group difference, $F(1, 4) = 5.56$, $p = .08$, nor a Group \times Test session interaction, $F(4, 16) = 0.78$.

There was no between-group difference in mixed-schedule center-key performance dur-

ing testing and, indeed, none was expected. On the first test session, for example, the percentage of switches in the class-consistent group was 79.2% versus 85.3% in the class-inconsistent group, $F(1, 4) = 0.19$. On the fifth session, these percentages equaled 96.6% and 93.9%, respectively, $F(1, 4) = 0.76$.

DISCUSSION

The results of this experiment did not provide evidence that different patterns of responding were members of the same acquired equivalence classes as other samples with which they shared a common reinforced comparison choice. In contrast to the test-performance differences observed in many previous studies of MTO matching and acquired equivalence in nonhuman animals (Urcuioli & Lionello-DeNolf, 2001, 2005; Urcuioli, Zentall, & DeMarse, 1995; Urcuioli et al., 1989), first-session accuracies in the class-consistent and class-inconsistent test conditions here were comparable. Of course, unlike previous studies, the samples used here were drawn from very different dimensions: visual (red and green hues) and proprioceptive (different response patterns characteristic of DRL and FR schedules), and this may be an important variable. However, establishing conditional control by these different stimulus dimensions is not an issue: Pigeons readily learn to choose between the comparison alternatives on the basis of how they have just responded as well as on the basis of what they have just seen (Urcuioli & Honig, 1980; Zentall, Hogan, Howard, & Moore, 1978). If the same was true here, as the data in Figure 2 suggest, then the conditions normally promoting acquired sample equivalence (different sample stimuli occasioning a common reinforced choice response) were clearly realized. But these conditions did not appear to generate a {red, DRL} and a {green, FR} class.

Nevertheless, the repeated-test-session data (Figure 3, bottom) were very much in the direction expected on the basis of acquired sample equivalence. Perhaps detection of a true between-group difference was difficult because of the relatively small number of subjects per condition and because the DRL and FR samples in testing produced rapid acquisition of the transfer task independently of the test manipulation (Cohen, Looney, Brady, & Aucella, 1976; Urcuioli & Honig,

1980). With these considerations in mind, Experiment 2 was run with more subjects and a design in which the samples used in testing versus reassignment were switched vis-à-vis Experiment 1.

EXPERIMENT 2

In Experiment 2, reassignment training was conducted with the DRL and FR samples and testing with the red and green samples, the opposite of that in Experiment 1 (cf. Table 1). Although red and green samples typically support relatively fast matching acquisition (e.g., Carter & Eckerman, 1975; Urcuioli & Zentall, 1986), acquisition of the transfer task with these samples should still be slower than with DRL and FR samples, especially given that only a single peck to each sample is required to produce the comparisons (cf. Sacks, Kamil, & Mack, 1972; Spetch & Treit, 1986). A slower overall rate of acquisition in testing should enhance the detection of a class-consistent versus class-inconsistent difference, assuming that one exists.

Experiment 2 also included a control group for which there were no common comparison-response associations in training. In other words, these pigeons initially matched all four samples (red, green, DRL and FR) to different comparisons. This one-to-one (OTO) group provides a no-acquired-equivalence baseline that permits the possibility of detecting both positive transfer by the MTO pigeons tested with class-consistent relations, and negative transfer by the MTO pigeons tested with class-inconsistent relations, while controlling for other, general features of MTO training (e.g., number of samples, type of sample, etc.).

METHOD

Subjects and Apparatus

Twelve White Carneau retired breeders obtained from the same supplier as in Experiment 1 served in this experiment. Eight were experimentally naïve. The 4 non-naïve pigeons had limited experience orthogonal to the contingencies they encountered here. Prior to the start of the experiment, the pigeons were divided equally among three groups: OTO, MTO with consistent testing (MTO-C), and MTO with inconsistent testing (MTO-I). Two of the experienced pigeons were assigned

to the OTO training condition; the other 2 were assigned to MTO training, 1 in Group MTO-C and 1 in Group MTO-I. Body weight determinations, feeding regimens, and home cage and colony-room conditions were identical to those described in Experiment 1.

Two experimental chambers, identical in size and configuration to the one used for Experiment 1, were used. An equal number of pigeons from each training condition were run in each chamber. In addition to displaying the stimuli used in Experiment 1, the in-line projectors also could display three white vertical and three white horizontal lines on black backgrounds on the left and right keys (BRS/LVE Pattern No. 696), and single white vertical and horizontal lines on black backgrounds on the center key (BRS/LVE Pattern No. 692). A single IBM-compatible computer controlled and recorded all experimental events in both chambers.

Procedure

Preliminary training. The experimentally naïve pigeons were initially trained to eat quickly and consistently out of a periodically raised and lit food hopper. Afterwards, pecking to a white center-key stimulus was shaped by the method of successive approximations. This was followed for all pigeons by 60-trial sessions during which single pecks to the following stimuli were reinforced: 1) a white center key (two sessions), 2) red and green center-key stimuli (one session), 3) red and green on the center key and blue and yellow on the left and right side keys (one session), 4) red and green on the center key and X and O on the side keys (one session), and 5) a white center key (one session). When multiple stimuli were presented, they appeared equally often in their respective locations during a session.

Next, each pigeon learned to obtain food by pecking the white center key on a FR schedule, the parameter of which was gradually raised from 2 to 10 over six 60-trial sessions. All other details of these preliminary training sessions were identical to those in Experiment 1.

Mixed-schedule pretraining. Training on the mixed DRL-FR schedule to the white center key was conducted in the same fashion and to the same performance criteria as in Experiment 1. One procedural difference was that the initial two pretraining sessions were run

with a FR 5, after which the FR 10 was introduced. One pigeon in Group MTO-I was dropped from the experiment during this phase when it was unable to learn to switch to the opposite response pattern when its initial pattern of center-key pecking was non-reinforced. The FR value for 2 other pigeons, one each in Groups MTO-C and MTO-I, was raised from 10 to 20 after 30 and 70 pretraining sessions, respectively, in a successful attempt to obtain stable switching performances. One never reached the stringent 90% switch criterion but was advanced after 106 sessions to the sessions with intermixed trials of CRF reinforcement for pecking red and green because its percentage of switches was routinely around 85%. This pigeon also had difficulty achieving three consecutive sessions with 90% or more switches during these latter sessions, but was advanced to MTO training after 58 sessions because it consistently switched on about 87% to 90% of all trials.

Initial matching acquisition. Next, all pigeons were trained to match the red and green hues, and their DRL and FR mixed-schedule performance, to either two (MTO groups) or four (OTO group) comparisons. The MTO pigeons matched the four samples to blue and yellow comparisons, with red and DRL responding occasioning one reinforced choice, and green and FR occasioning the alternative reinforced choice. The comparison choice reinforced following each pair of samples was counterbalanced such that the sample-comparison training relations were equally represented in each MTO training-test condition (viz. MTO-C and MTO-I).

For the OTO pigeons, blue and yellow comparisons appeared following the red and green samples, but vertical and horizontal lines appeared following the DRL and FR samples. For two pigeons, blue and yellow were the reinforced choices following red and green, respectively, and vertical and horizontal were the reinforced choices following DRL and FR. For the remaining OTO pigeons, the reinforced sample-comparison relations were reversed.

The two pigeons whose FR was raised to 20 during pretraining continued with that FR parameter during this experimental phase. All other details (including the performance criterion) were identical to those described for MTO training in Experiment 1. After

reaching criterion levels of performance, each pigeon received 10 overtraining sessions on its respective tasks.

Reassignment training. During reassignment, all pigeons matched their DRL and FR mixed-schedule performances to X and O comparisons. The reinforced sample-comparison choice relations were counterbalanced within each group and also were balanced with respect to the reinforced relations from their initial MTO or OTO matching task. Each reassignment training session was alternated daily with continued training on each pigeon's initial (MTO or OTO) task. Reassignment training for each pigeon continued until it correctly matched on 90% or more trials, and its percentage of switches on the center-key mixed schedule was 85% or greater, for five of six consecutive sessions. All other procedural details were the same as in Experiment 1.

On the day prior to the first test session, each pigeon received one final refresher session on its MTO or OTO matching task.

Testing. During the 10 sessions of testing, all pigeons matched the red and green samples to the X and O comparisons that had been introduced during reassignment. A single peck to the sample hue on each trial immediately turned it off and produced the comparison alternatives on the adjacent side keys. For half of the pigeons in each group, the reinforced comparison choices following red and green were to the X and O comparisons, respectively; for the remaining pigeons, these reinforced sample-comparison relations were reversed. More important, the reinforced relations for Group MTO-C were consistent with any acquired equivalence that may have developed between the samples that had occasioned the same reinforced choice during MTO training, whereas they were inconsistent with acquired sample equivalence for Group MTO-I. For instance, if DRL and red had both occasioned a reinforced blue comparison choice in MTO training, and DRL later occasioned a reinforced choice to the X comparison during reassignment, then choosing X was reinforced on red-sample trials in testing for Group MTO-C (class-consistent), whereas choosing O was reinforced after red for Group MTO-I (class-inconsistent).

Because there were no common comparison-response associations during initial training for Group OTO, their reinforced test

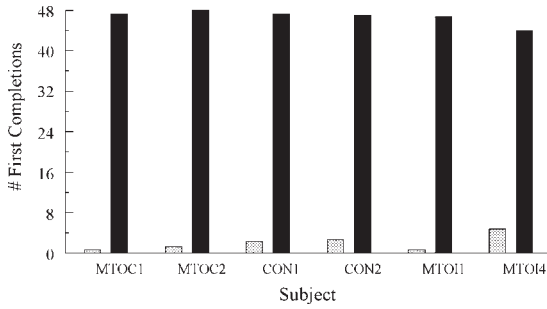


Fig. 4. The number of successful first-attempt completions of the DRL (striped bars) and FR (solid bars) requirement by 6 pigeons during mixed-schedule pretraining in Experiment 2.

relations were neither class-consistent nor class-inconsistent. Consequently, its test performance provided a baseline against which to evaluate the nature of transfer, if any, in each MTO group.

RESULTS

Mixed-schedule pretraining. As expected, the percentages of correct initial completions of the mixed DRL–FR schedule hovered around 50% throughout pretraining. Figure 4 shows, for a representative sample of pigeons, the average number of successful initial completions when the DRL or the FR requirement (stippled and filled bars, respectively) was in effect. The divergence in performance on the two schedule requirements illustrates how pigeons responded to the white center key at the outset of each trial: They routinely satisfied the FR requirement when it was scheduled but very rarely satisfied the DRL requirement when it was scheduled.

More important is the “switching” aspect of center-key responding when the initial response pattern to white was nonreinforced. Ten of the 12 pigeons eventually met the pretraining criterion of 90% or more completions of the scheduled requirement on their first repeat attempt, although there was considerable variability in the amount of training necessary to reach this level of performance (13 to 102 sessions). When red and green CRF trials were intermixed with the white mixed-schedule trials, there was a drop in the highly accurate switching on the latter. Nevertheless, all pigeons except one recovered to a switch rate at or above 90%: For the last three of these sessions, the average switch rates

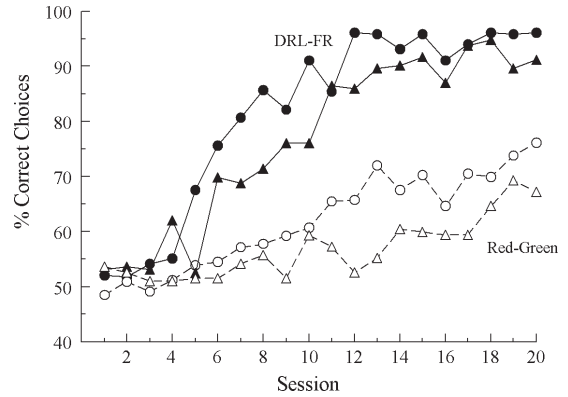


Fig. 5. The average percentage of correct choices with DRL versus FR mixed-schedule samples (closed symbols) and red versus green samples (open symbols) for the MTO groups (circles) and OTO control group (triangles) during many-to-one matching acquisition in Experiment 2.

for the pigeons in the MTO and OTO groups were 93.9% and 94.8%, respectively.

Initial matching-to-sample and reassignment training. Although differing in the comparison sets following the DRL–FR and red–green samples, Figure 5 shows that matching acquisition by the MTO and OTO groups with each sample set was comparable and similar to that in Experiment 1. Specifically, higher levels of choice accuracy were achieved more quickly on DRL–FR than on red–green sample trials, although the source of this difference is again confounded by different sample durations and, in the case of Group OTO, by the nature of the comparison alternatives following each set of samples. Nevertheless, these results are consistent with the idea that different center-key response patterns provided a conditional cue for choice.

The number of sessions needed to reach the performance criteria during initial matching training varied widely (range: 13 to 87 sessions). On average, however, the groups did not differ significantly from one another in sessions to criterion: 31.25 versus 51.0 versus 54.25 for Groups MTO-C, MTO-I, and OTO, respectively, $F(2, 8) = 1.38$, $p = .30$. For the last five baseline sessions preceding testing, matching accuracy with the DRL–FR samples was comparable in all three groups: 96.0%, 98.2%, and 95.7% correct, respectively, $F(2, 8) = 0.76$. Matching with the red–green samples, however, was more accurate in the two MTO groups (94.5% and 96.7%) than in Group

OTO (89.1%), $F(2, 8) = 10.32$. Given that Group OTO nonetheless matched very accurately with red and green, however, this latter difference was not thought to be problematic. Finally, all pigeons maintained high levels of switching on their mixed-schedule performances: 89.6%, 89.7% and 94.2% for Groups MTO-C, MTO-I, and OTO, respectively, $F(2, 8) = 0.65$.

As expected, acquisition of the reassignment task occurred quickly, requiring an average of only 9.2, 11.3, and 6.8 sessions to reach criterion in Groups MTO-C, MTO-I, and OTO, respectively, $F(2, 8) = 0.70$. Matching accuracies for the last five reassignment sessions averaged 93.2%, 95.6%, and 94.6% correct, respectively, in the three groups, $F(2, 8) = 1.14$, and switch rates for the center-key mixed schedule averaged 94.3%, 91.6%, and 96.0%, respectively $F(2, 8) = 1.32$.

Testing. The top and bottom portions of Figure 6 show matching accuracy for each pigeon on its first transfer test session and the average matching accuracy by group for all 10 test sessions, respectively. Both the first-session and overall test results tell the same story: There were no between-group differences in performance. The MTO pigeons tested with class-consistent relations (Group MTO-C) were no more accurate in their choices than the MTO pigeons tested with class-inconsistent relations (Group MTO-I). On the first test session, Group MTO-C chose the reinforced comparison stimulus 49% of the time versus 49.3% for Group MTO-I. Average first-session accuracy for Group OTO was 46.2% correct. ANOVA confirmed the absence of a between-group effect, $F(2, 8) = 1.48$, $p = .28$. Not surprisingly, the same was true for performance over just the first 20 or the first 50 test trials (data not shown).

Furthermore, repeated testing did not result in the emergence of a between-group difference: Group MTO-C did not acquire its transfer task any faster than Group MTO-I. Indeed, performances by these two groups were very similar to those by Group OTO that had been trained without any common sample-comparison relations. ANOVA on these data showed that the only statistically significant effect was Test Session, $F(9, 72) = 15.33$, confirming the steady increase in matching accuracy averaged over all three groups with repeated testing. These latter results demonstrate that the

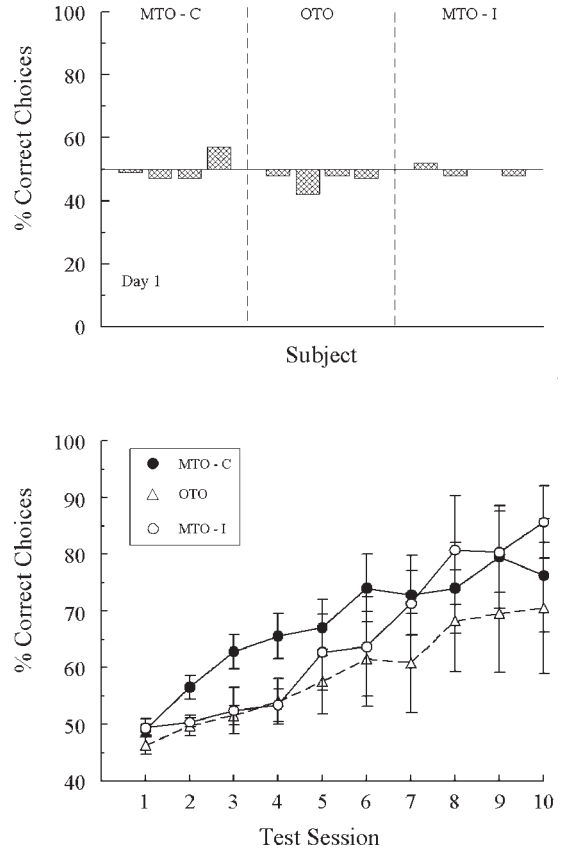


Fig. 6. Top: The percentage of correct choice responses by each subject in Experiment 2 on its first transfer-test session. Bottom: The average percentage of correct choices by each group on the 10 transfer-test sessions in Experiment 2. (Error bars represent \pm SEM.)

novelty of the sample-comparison combinations encountered in testing had not simply obscured a true between-group difference on the first session. Even when these combinations were no longer novel, all three groups still performed similarly.

DISCUSSION

Despite the suggestive evidence in Experiment 1 that MTO training might produce an acquired equivalence between samples consisting of differential responding and different visual stimuli, the results from this experiment show otherwise. Following MTO training identical to that in Experiment 1, pigeons that subsequently learned to make new comparison choices following their DRL and FR samples did not generalize these new choices to the red

and green samples. More specifically, pigeons did not match any more accurately in testing when their reinforced [hue sample–new comparison] relations were consistent with acquired equivalence than when those relations were inconsistent with acquired equivalence. Indeed, in contrast to first-session transfer results previously observed in the three-stage acquired equivalence paradigm (Urcuioli & Lionello-DeNolf, 2001; Urcuioli *et al.*, 1995; Urcuioli *et al.*, 1989, Experiment 2), pigeons in both MTO test conditions here matched at or near chance levels of accuracy. Furthermore, their performance throughout testing was indistinguishable from that of pigeons whose initial training did not involve many-to-one relations.

We had surmised that the numerical difference observed between the MTO groups over the five test sessions in Experiment 1 would increase with more subjects and with a slower overall rate of learning of the reinforced sample–comparison test relations (*viz.*, if ceiling effects, or something approximating them, were avoided in testing). Swapping the samples used in reassignment versus testing *vis-à-vis* Experiment 1 did slow the rate of acquisition of the transfer task, but it did not yield the larger between-group effect we were looking for. Indeed, the numerical difference between Groups MTO-C and MTO-I diminished.

Should we conclude, then, that differential responses will not join acquired equivalence classes despite occasioning the same reinforced choices as other samples? Perhaps. But before fully addressing this question and the implication of the results obtained so far, we should first demonstrate what, to this point, we have simply assumed—namely, that the DRL and FR response patterns on the mixed-schedule trials did, in fact, cue the pigeons' comparison choices.

Although our assumption is supported by faster matching acquisition on the DRL–FR than on the red-green trials (Cohen *et al.*, 1976; see also Urcuioli, 1984; Urcuioli & Honig, 1980), it is possible that pigeons made their choices on the mixed-schedule trials on the basis of some other cue. For example, since the pigeons typically completed the FR requirement at the start of each mixed-schedule trial, this produced the comparisons on half of the matching trials, but caused white

to briefly go off and later reappear on the remaining trials. Consequently, how often the white center-key stimulus was seen prior to choice—once or more than once—could potentially cue which comparison to choose (*cf.* Lionello-DeNolf & Urcuioli, 2003). The next experiment was designed to distinguish between this number cue and one arising directly from the DRL versus FR response patterns.

EXPERIMENT 3

The next experiment was a continuation of Experiment 2. Using the pigeons that had just finished testing, we explicitly evaluated conditional control by their DRL and FR response patterns by seeing whether those patterns would continue to cue the same comparison choices when DRL and FR patterns were occasioned by different center-key stimuli.

Toward this end, each pigeon from Experiment 2 received off-baseline training in which food was contingent upon completing a FR requirement to a new, center-key stimulus and upon completing a DRL requirement to another, new center-key stimulus. These multiple-schedule stimuli then were substituted for the white mixed-schedule stimulus in matching-to-sample. Two substitution tests were possible, the first involving the comparisons from MTO or OTO matching and the second involving the comparisons from reassignment training. All pigeons received both tests, although the reinforced choices for one test were the same as those following completion of the DRL and FR requirements in the mixed schedule (consistent test), whereas the reinforced choices for the other test were the opposite (inconsistent test).

If the mixed-schedule DRL and FR performances had cued comparison choice in the baseline matching tasks, then each pigeon should exhibit above-chance levels of accuracy during its consistent test and below-chance levels of accuracy during its inconsistent test. In contrast, if their comparison choices had been cued by whether the white center-key stimulus appeared once or more than once, then the pigeons should match at chance levels of accuracy on both tests. More specifically, they should have a strong bias to peck the comparison previously reinforced after one presentation of white, given that the

multiple-schedule stimuli appeared only once prior to choice in testing.

METHOD

Subjects and Apparatus

The pigeons and apparatus were the same as those in Experiment 2. One Group OTO pigeon was not run because it was participating in another research study.

Procedure

Baseline retraining for Test 1. Each pigeon initially was trained for a minimum of five sessions on its baseline MTO or OTO task (cf. Experiment 2) and continued this training until accuracy on the mixed-schedule matching trials was 90% or higher, and the percentage of switches for mixed-schedule center-key pecking was 80% or higher, for three consecutive sessions.

Multiple-schedule training. Next, the pigeons were trained to obtain food by completing DRL and FR schedules for pecking vertical and horizontal lines on the center key. The particular schedule requirement for vertical and horizontal was counterbalanced across pigeons in both the MTO and OTO groups. The 3-s DRL requirement was in effect from the outset of training. The FR parameter, however, was gradually raised from 3 to either 10 or 20 (depending upon each pigeon's FR value in Experiment 2) across sessions.

The vertical and horizontal lines were each presented 30 times in pseudorandom order in each 60-trial session with neither stimulus appearing more than three times in succession. Multiple-schedule training ended when it appeared that the discrimination was well formed and stable (e.g., there were few short IRTs on DRL trials and few long IRTs on FR trials). This required between 6 and 26 sessions including at least two sessions at the terminal FR value.

Baseline refresher for Test 1. Following multiple DRL-FR training, refresher training again was provided on each pigeon's MTO or OTO matching task until it met the performance criteria mentioned above for a single session.

Test 1. Next, a single test session was run with vertical and horizontal center-key lines and vertical and horizontal comparisons (OTO pigeons) or blue and yellow comparisons (MTO pigeons). Completion of the

sample-response requirement (DRL or FR) for pecking each center-key line immediately turned it off and produced the comparison alternatives. For half of the pigeons, the reinforced comparison choices were the same as the reinforced choices following completion of the DRL and FR mixed-schedule requirements in their baseline MTO or OTO tasks. For the remaining pigeons, the reinforced choices were the opposite of those in baseline. All other details of this 100-trial test session were identical to those for the baseline tasks.

Reassignment retraining for Test 2. Immediately after Test 1, the pigeons were returned to their reassignment matching tasks from Experiment 2 in which completing the mixed-schedule DRL and FR requirements for pecking the white center-key stimulus were followed by X and O comparison alternatives. This refresher training continued until the pigeons matched correctly on 90% or more of all trials and switched at least 80% of the time to the reinforced response pattern on the center-key mixed schedule for three consecutive sessions.

Multiple-schedule refresher. After recovering their reassignment matching performance, pigeons received a single 60-trial refresher session on their multiple-schedule task.

Test 2. Finally, each pigeon received a second 100-trial test session in which the X and O comparison alternatives appeared after completing the DRL or FR sample-response requirement to vertical or horizontal lines on the center key. The reinforced comparison choices for half of the pigeons were the same as their reinforced choices following completion of the DRL and FR mixed-schedule requirements in the reassignment task; for the remaining pigeons, they were the opposite. In addition, if a pigeon's first test involved sample-comparison relations that were consistent with conditional stimulus control by its DRL and FR response patterns, they were inconsistent in its second test, and vice versa.

RESULTS AND DISCUSSION

Baseline performances. Recovery of MTO and OTO matching to criterion levels of performance prior to Test 1 took between 6 and 16 sessions. Recovery of the reassignment matching task prior to Test 2 required between 3 and 7 sessions of training.

On the two multiple-schedule training sessions preceding Test 1, all pigeons pecked the vertical and horizontal stimuli in schedule-appropriate manner, with long and short interresponse times (IRTs) occurring predominately on DRL and FR trials, respectively. For example, the average percentage of all IRTs greater than 1500 ms on DRL trials ranged from 32.5% to 85.0% compared to 0 to 1.2% on FR trials (where the vast majority of IRTs were less than 500 ms). On the multiple-schedule refresher session preceding Test 2, the corresponding ranges of IRTs greater than 1500 ms were 29.0% to 78.2% and 0 to 0.7%, respectively.

Test results. Figure 7 shows individual subject data for each test. The filled bars plot matching accuracy when the reinforced comparison choice following completion of the DRL or FR requirement to the line samples was the same as it was following completion of the mixed-schedule DRL or FR requirement (consistent test). The stippled bars plot matching accuracy when the reinforced comparison choice following completion of the DRL or FR requirement in testing was the opposite of what it had been during baseline training (inconsistent test). Note that the order in which the consistent and inconsistent tests were run was balanced across pigeons, and that the comparison alternatives for the two tests differed (*viz.*, one set came from each pigeon's MTO or OTO task and the other from its reassignment task).

The pattern of results was the same for every pigeon: Matching accuracy was above the level expected by chance alone on the consistent test and below chance on the inconsistent test. Across pigeons, the average matching accuracy on the consistent test was 80.0% correct (range: 56% to 98%) versus 28.8% on the inconsistent test (range: 8% to 47%), $F(1, 9) = 39.63$. The difference in accuracy on the consistent versus inconsistent test averaged 49.0%, 50.7%, and 56.0% for the pigeons previously assigned to Groups MTO-C, MTO-I, and OTO, respectively.

Clearly, then, the DRL and FR center-key response patterns to the white mixed-schedule stimulus during original matching training and reassignment training in Experiment 2 had exerted control over comparison choice. The finding that the DRL and FR patterns of responding conditioned to vertical and hori-

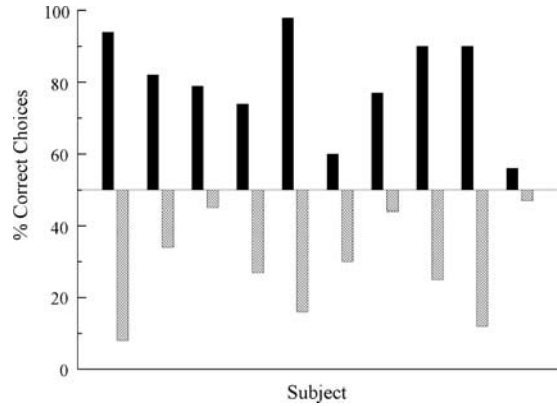


Fig. 7. The percentage of correct choices by each pigeon in Experiment 3 on its two tests for conditional control by DRL versus FR sample responding. Filled bars = tests in which the reinforced comparison choices following DRL and FR were the same as in training. Stippled bars = tests in which the reinforced comparison choices following DRL and FR were the opposite from those in training.

zontal immediately cued the same comparison choices that had been reinforced after completing the mixed-schedule DRL or FR requirement to white clearly demonstrates that these center-key response patterns had cued the comparison choices in Experiment 2. The results cannot be explained in terms of conditional stimulus control by vertical and horizontal per se because 1) these lines had never before appeared as sample stimuli in matching tasks with these comparison alternatives, and 2) the reinforced comparison choices following them were balanced across pigeons.

The test results also disconfirm the hypothesis that choice performance on the mixed-schedule trials in Experiment 2 was simply cued by whether the white center-key stimulus appeared once or more than once prior to the choice alternatives. In testing, the vertical and horizontal center-key stimuli appeared just once before the comparisons. Thus, if the number of stimulus presentations was the conditional cue for the pigeons' baseline preference for the comparison previously reinforced after one white stimulus presentation, resulting in accuracy levels of around 50%. With the possible exception of one pigeon (*cf.* Figure 7), this was clearly not the case. Interestingly, this pigeon also exhibited

one of the poorest DRL versus FR discriminations.

EXPERIMENT 4

In yet another attempt to demonstrate the inclusion of differential sample responses in acquired equivalence classes, Experiment 4 was run. As before, initial training involved a common reinforced comparison choice following a particular pattern of responding and a particular visual sample stimulus. In this experiment, however, different center-key stimuli were used to occasion the DRL and FR response patterns during MTO training. We had avoided the use of such center-key multiple schedules in Experiments 1 and 2 because they would have required us to distinguish between the DRL versus FR response patterns and the visual stimuli that occasioned them as potential class members.

Experiment 4, then, was explicitly designed to make this distinction. Specifically, during the transfer test, the DRL and FR response patterns (whose potential class membership was in question) were occasioned by center-key stimuli that had not appeared in any baseline matching task. Consequently, given that these stimuli had not participated in the common-choice relations of MTO training and, indeed, were never established as conditional cues for any choice, the only basis for transfer would be the differential response patterns they occasioned.

METHOD

Subjects and Apparatus

Eight White Carneau pigeons obtained from the Palmetto Pigeon Plant (Sumter, SC) served in this experiment. They were housed and maintained in the same fashion as previously described. All had previously participated in studies orthogonal to the present work. Prior to the start of the experiment, they were randomly divided into two groups of four defined in terms of whether their reinforced sample-comparison relations in testing were consistent (C) or inconsistent (I) with acquired sample equivalence.

The single experimental apparatus used for this experiment was equipped with a center-key projector that could display homogeneous green, yellow, and white fields, three white

vertical and three white horizontal lines on black backgrounds, and a solid white dot and a solid white triangle also on black backgrounds (BRS/LVE Pattern No. 692). The side-key projectors could display homogeneous red, blue and white fields, and a white "X" on a black background (BRS/LVE Pattern No. 696).

Design Summary

The design of this experiment consisted of three training phases followed by a single test phase, as shown in Table 2. S1 to S6 denote different sample/center-key stimuli, and C1 to C4 denote the different reinforced (+) comparisons.

During initial MTO training, selection of C1 was reinforced on trials on which the comparisons were produced by completing a DRL sample-response requirement to S1 and on trials on which those same comparisons were produced by a single sample peck (CRF) to S3. Similarly, selection of C2 was reinforced on trials on which the comparisons were produced by completing a FR sample-response requirement to S2 and on trials on which the comparisons were produced by a single sample peck to S4. If these common reinforced choices created {DRL, S3} and {FR, S4} acquired equivalence classes, then explicitly training new comparison choices (C3 and C4) to the S3 and S4 samples during reassignment training should yield generalization of those new choices to DRL and FR responding in testing.

However, because S1 and S2 occasioned DRL and FR responding, respectively, during MTO training, they too shared common comparison-response associations with S3 and S4. This commonality might produce a {S1, S3} and a {S2, S4} class in which case the new comparison choices learned to S3 and S4 might also generalize to S1 and S2. Consequently, to assess generalization to DRL and FR, the S1 and S2 samples must not appear in testing. To meet this requirement, DRL and FR responding were conditioned to different center-key stimuli, S5 and S6, off-the-matching-baselines prior to testing. Afterwards, S5-DRL and S6-FR replaced S3 and S4 as conditional cues for the new comparison choices in testing. Given that S5 and S3, and S6 and S4, did not share a common comparison-response association, an acquired equivalence

Table 2
Design of Experiment 4.

Many-to-One Matching	Reassignment Matching	Off-baseline Training	Testing
S1 • DRL → C1+			S5 • DRL → C3+ [C]
S2 • FR → C2+			S6 • FR → C4+
S3 • CRF → C1+	S3 • CRF → C3+	S5 • DRL	<i>or</i>
S4 • CRF → C2+	S4 • CRF → C4+	S6 • FR	
			S5 • DRL → C4+ [I]
			S6 • FR → C3+

Note. S1–S6 = sample stimuli, C1–C4 = comparison stimuli, DRL = differential-reinforcement-of-low-rates-of-responding schedule, FR = fixed-ratio schedule, CRF = continuous reinforcement schedule, + = reinforced comparison choices, [C] = consistent test condition, [I] = inconsistent test condition.

lence between them could not develop on this basis and, so, no generalization of the C3 and C4 choices should occur to S5 and S6. Thus, if generalization does occur—specifically, if a consistent (C) versus inconsistent (I) performance difference appears in testing, this would indicate the development of acquired equivalence classes in which the pigeon's differential (DRL vs. FR) sample-response patterns were class members.

Procedure

Preliminary training. Initially, single pecks to each stimulus that later would appear on the center and side keys during the main experimental phases were reinforced. The first three sessions involved reinforced center-key pecking to the triangle and dot, green and yellow, and vertical and horizontal lines, in that order. Each stimulus appeared 30 times/session in pseudorandom order. The next two sessions consisted of 10 reinforced trials each with white and the “X” on the left and right side keys and 10 reinforced trials with green and yellow, or with vertical and horizontal lines, on the center key. The last preliminary training session involved 10 reinforced trials each with the triangle and dot on the center key and red and green on each side key. All other procedural details were identical to those for preliminary training in the preceding experiments.

Multiple-schedule pretraining. Next, each pigeon learned to obtain food by completing DRL and FR schedules for pecking the triangle and dot center-key stimuli, respectively. Each pretraining session consisted of 60 trials, 30 with each stimulus. Over successive sessions, the DRL parameter was gradually raised from

1 s to 3 s and the FR parameter was raised from 3 to 20. Between 14 and 16 sessions were needed to reach the final parameter values, with at least two sessions at these values. Two or three pretraining sessions were then run in which 20 center-key presentations each of green and yellow were intermixed with 20 presentations each of the triangle and dot center-key stimuli. Single pecks to green and yellow produced food (CRF schedule), whereas pecking the triangle and the dot were reinforced on DRL 3-s and FR 20 schedules, respectively. All other procedural details were identical to those previously described for pretraining.

Many-to-one acquisition. Each pigeon then began training on MTO matching. The 96 trials in each session started equally often with triangle, dot, green, or yellow on the center key. Completing the DRL 3-s and FR 20 requirement, respectively, to the triangle and dot or the CRF requirement to green and yellow turned off the sample stimulus and immediately produced red and blue comparisons on the side keys. A single peck to either comparison then turned both off and produced food or timeout depending on which was chosen. Pecking the red comparison was reinforced following the green sample and after completing the DRL requirement to the triangle, whereas pecking the blue comparison was reinforced following the yellow sample and after completing the FR requirement to the dot. Pecking the alternative comparison on each of these trials immediately turned off the houselight for a period of time equal to the reinforcement duration for that session. Successive trials were separated by a 10-s ITI, the first 9 s of which was spent in darkness.

The eight possible trial types (four samples x two left-right positions of the comparisons) were randomized within each session with the restriction that none appear more than three times in a row. MTO training for each pigeon continued until overall accuracy was 90% correct or better and accuracy with each set of samples (green and yellow, DRL and FR) was at least 87.5% correct for five of six consecutive sessions. Twenty overtraining sessions then followed.

Reassignment training. During reassignment, pigeons matched the green and yellow samples to white and X comparison stimuli. As in MTO training, a single peck to each of these sample hues turned it off and produced the comparisons on the adjacent side keys. A single peck to either comparison then turned both off and produced either food or time out. For half of the pigeons, pecking white on green-sample trials and the X on yellow-sample trials was reinforced, and vice versa for the remaining pigeons. Pecking the alternative comparison again produced a time out equal in duration to the reinforcement cycle.

Each trial type (two samples x two left-right positions of the comparisons) was presented equally often in pseudo-random order in each 100-trial session with none appearing more than three times in a row. Each reassignment training session was alternated daily with continued training on MTO matching. Training on the reassignment task ended when accuracy was 90% correct or better on five of six consecutive reassignment sessions.

Multiple-schedule pretraining with vertical and horizontal. Next, pigeons received off-baseline multiple-schedule training with vertical and horizontal center-key lines. Food reinforcement was contingent upon completing a DRL 3-s schedule for pecking one line orientation and a FR schedule for pecking the other, with the schedule requirement for each stimulus counterbalanced across pigeons. The DRL and FR parameters were gradually raised across successive training sessions until the terminal 3-s DRL value and 20-peck FR value were achieved. This took between 8 and 10 sessions, with at least two sessions conducted at the terminal schedule values. These 60-trial sessions were otherwise structured in the same way as the earlier pretraining sessions involving the triangle and dot center-key stimuli.

Refresher training. Immediately prior to testing, refresher training on MTO matching and on the reassignment matching task was given until performance on each was at or above criterion levels for at least one session. If this required more than two consecutive sessions on either task, the pigeon was returned to multiple DRL-FR training with vertical and horizontal followed by an additional refresher on each matching task. The last baseline refresher prior to testing involved reassignment matching.

Testing. In testing, pigeons matched the white and X comparison alternatives from the reassignment phase to the DRL and FR response patterns conditioned off baseline to the two line orientations. For Group C, the reinforced comparison choices in testing were consistent with any acquired sample equivalence that may have developed during MTO training. Thus, if {green, DRL} and {yellow, FR} classes developed from the common reinforced choice each potential member had occasioned, and if green and yellow were later established as conditional cues for choosing X and W, respectively, then choices of X and W were reinforced following completion of the DRL and FR, respectively, to the center-key lines during testing. For Group I, the corresponding sample-comparison test relations were inconsistent with acquired equivalence.

The two 100-trial test sessions were separated by a single refresher session on all training tasks described above. Each test session contained equal numbers of four possible trial types (two samples x two left-right positions of the comparisons). Procedural details were the same as those previously described for transfer testing. One pigeon in Group I did not receive a second test because it stopped responding altogether to the vertical and horizontal lines after its first test.

RESULTS

Baseline training. Responding to the triangle and dot, and to the vertical and horizontal, center-key stimuli was clearly differentiated by the end of each multiple-schedule pretraining phase. The pigeons pecked rapidly (viz. with short IRTs) on the FR 20 schedule and tended to space their successive key pecks (viz. with long IRTs) on the DRL 3-s schedule. On the last two sessions with triangle and dot stimuli, the percentage

of IRTs greater than 1500 ms on DRL trials averaged 60% across all 8 pigeons (range: 42.9% to 82.2%) versus 0.6% on FR trials (range: 0 to 4.2%). On the last two sessions with the vertical and horizontal lines, the corresponding figures were 69.7% (range: 44.7% to 97.4%) versus 0.8% (range: 0.1% to 2.5%), respectively.

Acquisition of MTO matching was comparable in Groups C and I, requiring an average of 15.3 and 20.3 sessions, respectively, to reach criterion, $F(1, 6) = 0.54$. For both groups, accurate matching was acquired more rapidly on the triangle-dot trials with the DRL versus FR sample-response requirements than on the green- and yellow-sample trials in which a single peck produced the comparisons. Figure 8 shows this difference over the first 15 acquisition sessions.

Matching acquisition during reassignment training was slow and variable but was nonetheless comparable between groups. The average number of sessions to the 90% accuracy criterion was 25.8 for Group C versus 22.8 for Group I, $F(1, 6) = 0.06$.

Refresher-session performances on each baseline task were essentially indistinguishable between groups. For example, matching accuracy on the reassignment refresher was 93% for both groups, and accuracy on the last MTO refresher averaged 95.3% in Group C versus 95.8% in Group I. Finally, the percentage of IRTs greater than 1500 ms on the DRL versus FR trials with the vertical and horizontal lines were 59.3% versus 0.8%, respectively, in Group C and 66.4% versus 1.8%, respectively, in Group I.

Testing. The top half of Figure 9 shows individual performances in each group on the first test session. There was no discernable pattern that distinguished the consistent from the inconsistent group. Although 3 pigeons in Group I matched at accuracy levels below 50%, 1 matched well above chance. Likewise, although 2 pigeons in Group C matched at levels above 50%, 1 matched at chance and 1 below. Averaged across pigeons, first-session accuracy in Group C was 53.8% versus 50.0% in Group I, $F(1, 6) = 0.20$. No between-group differences were evident over the first 20 or 50 test trials either (data not shown).

The second test session, conducted after all baseline performances were reestablished, yielded much higher levels of accuracy, but

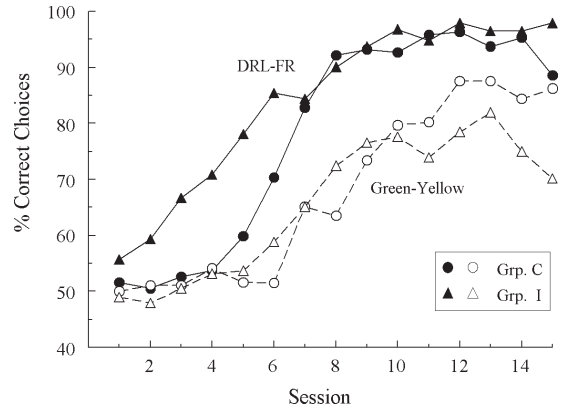


Fig. 8. The percentage of correct choices by each group in Experiment 4 on trials with DRL and FR sample-response requirements (closed symbols) and on single-sample-peck trials with green and yellow (open symbols) during many-to-one acquisition.

the level of improvement was independent of group assignment, as seen in the bottom half of Figure 9. Matching accuracy on the second test session averaged 71% correct in Group C versus 64.3% correct in Group I, $F(1, 5) = 0.28$.

DISCUSSION

The data from this experiment corroborate the findings of Experiments 1 and 2 by showing no evidence for acquired equivalence between different visual stimuli and different patterns of center-key responding that occasioned the same reinforced choice in MTO matching. Once again, class-consistent sample-comparison relations in testing yielded matching performances that were no more accurate than class-inconsistent relations. In one respect, the “failure-to-find” results from this experiment are particularly convincing. Although not previously mentioned, there were actually two ways in which acquired sample equivalence might have developed. The first, already discussed, was via the common reinforced comparison choices on DRL and S3 trials, and on FR and S4, trials.

The second was via the common sample responses occasioned by some pairs of center-key stimuli in combination with the common comparison choices occasioned by other, overlapping pairs. Assume that the triangle and dot samples (S1 and S2) had acquired some degree of control over the C1 and C2 choices

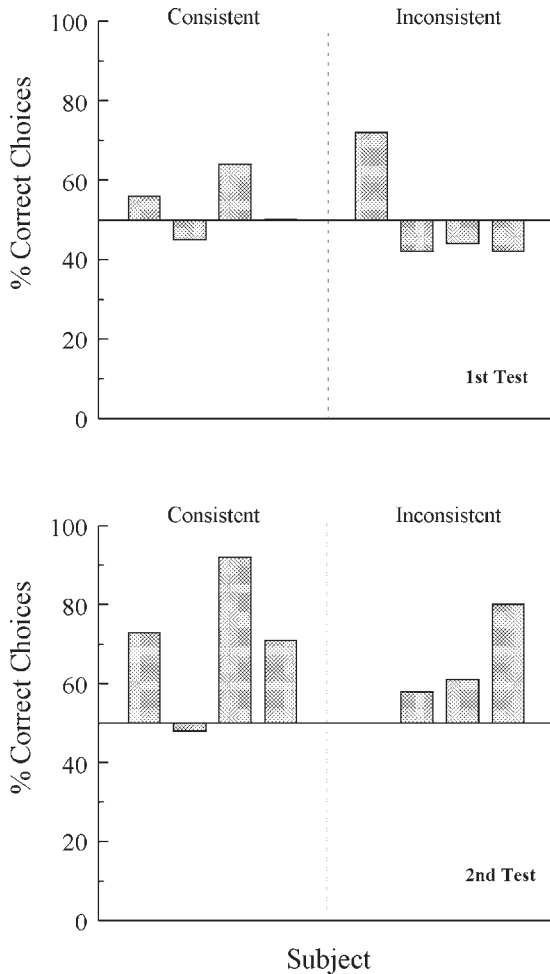


Fig. 9. The percentage of correct choice responses by each subject in Experiment 4 on its first (top graph) and second (bottom graph) acquired equivalence transfer test.

in MTO matching. Given that the S3 and S4 samples also occasioned the C1 and C2 choices, two acquired equivalence classes—{S1, S3} and {S2, S4}—should develop. Note, however, that S1 and S2 occasioned the same DRL and FR patterns of center-key pecking as did the vertical and horizontal lines (S5 and S6). If stimuli participating in three-term contingencies also become functionally equivalent (Sidman, 1994), then the original classes formed from MTO training should expand via class union to {S1, S3, S5} and {S2, S4, S6}. Here, all class members are visual stimuli appearing on the center key brought together either by occasioning the same reinforced

comparison choice (e.g., S1 and S3) or by occasioning the same DRL versus FR pattern of stimulus-directed pecking (e.g., S1 and S5). The resulting proposed classes, had they formed, should have yielded a difference between Groups C and I in their transfer-test performances. Clearly, this was not the case.

One reason may be that acquired equivalence classes in pigeons cannot develop from the types of three-term contingencies used here. But this position seems untenable in view of other demonstrations of acquired equivalence involving simple discriminative conditioning (Vaughan, 1988; see also Honey & Hall, 1989). Later, we will consider other possible reasons for our replicable “failure-to-find”. First, however, we should once again verify that the DRL versus FR responding had indeed cued comparison choice in this experiment

EXPERIMENT 5

Experiment 5 was a continuation of Experiment 4 in which we explicitly tested for conditional stimulus control by the DRL and FR sample-response patterns conditioned to the S1 and S2 samples. To do this, we replaced the triangle (S1) and dot (S2) samples in the matching task with the vertical (S5) and horizontal (S6) lines to which DRL and FR had been conditioned off-baseline. We predicted that comparison choice would continue to be highly accurate despite this replacement.

METHOD

Subjects and Apparatus

The same pigeons and apparatus from Experiment 4 were used.

Procedure

After completing their second test session in Experiment 4, each pigeon was returned to its MTO baseline task until it matched at criterion levels of accuracy for a single session. Next, it received one refresher session on multiple-schedule (DRL vs. FR) training with the vertical and horizontal lines, followed by one final refresher session on MTO matching. Generally, only a single refresher session on each baseline task was necessary to recover baseline performances.

Finally, each pigeon was given a single 100-trial test session with vertical and horizontal

lines as sample stimuli, red and blue as comparison stimuli (from the MTO task), and DRL and FR sample-response requirements for producing the comparison alternatives. For all pigeons, the reinforced comparison choice on every test trial was the same comparison choice that had been reinforced following completion of the DRL or FR sample-response requirement during MTO matching (i.e., all pigeons received a consistent test).

RESULTS AND DISCUSSION

Figure 10 shows the individual test data for all seven pigeons. With the exception of 1 pigeon, matching accuracy was above the level expected by chance alone. The percentages of correct comparison choice ranged from 50% to 94%, with a mean of 77.8%. The 1 pigeon that matched at chance had a bias to choose the red comparison for unknown reasons.

Overall, the results from this test confirm that one of the sample cues governing choice during MTO matching in Experiment 4 arose from the pigeons' DRL versus FR response patterns. Thus, the finding that these patterns did not yield transfer to the new comparison choices learned during reassignment training indicates a true lack of acquired equivalence between the DRL versus FR patterns and the visual samples with which they shared a common comparison-response association.

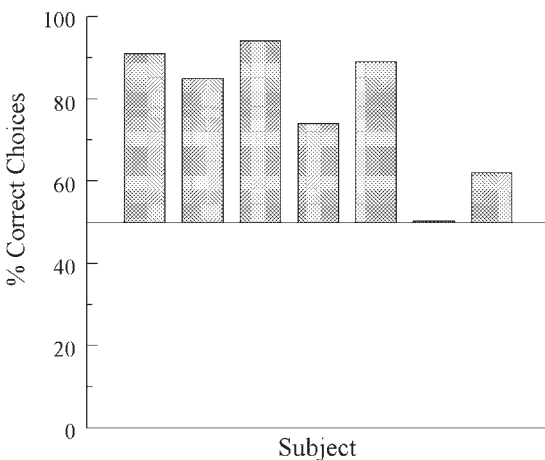


Fig. 10. The percentage of correct choices by each pigeon in Experiment 5 on tests for conditional control by DRL versus FR sample responding.

GENERAL DISCUSSION

The results of these five experiments can be summarized succinctly: Acquired equivalence did not develop between differential sample-response patterns that occasioned the same reinforced comparison choices as other, visual samples in matching-to-sample. It is important to appreciate that both findings mentioned in this summary statement were separately established. Specifically, Experiments 3 and 5 showed that the pigeons' DRL and FR patterns of center-key responding had indeed cued their comparison choices in MTO matching, a training task that normally produces acquired equivalence (Urcuioli, 2006). Experiments 1, 2, and 4 showed, however, that the common comparison-response associations shared by the response-pattern and visual samples in MTO training were insufficient to produce an acquired equivalence between them. When pigeons subsequently learned a new comparison choice to one member of each presumed class (the differential patterns or the visual samples), we found that those new choices did not transfer to the other member. Transfer to untrained sample-comparison relations is a standard metric for establishing acquired equivalence (Dougher & Markham, 1994; Zentall, 1998; see also Goldiamond, 1962; Hall, 1996). The fact that it was repeatedly absent here—there were no performance differences between class-consistent and class-inconsistent tests either during initial testing and over repeated sessions—indicates that those classes had, in fact, not formed as a result of MTO training. This was quite surprising, independently of the theoretical issues that motivated this work.

Our expectation of finding acquired equivalence between the different response patterns and the different sample hues was based in part on prior data showing that sample-specific behavior in conditional discrimination learning behaves much like typical, exteroceptive samples. For example, such behavior serves very effectively as source of conditional stimulus control in two-alternative matching (e.g., Cohen, Brady, & Lowry, 1981; Lionello-DeNolf & Urcuioli, 2003, Experiment 2; Urcuioli & Honig, 1980), a finding replicated here in Experiments 3 and 5. Also, cue-competition effects like those seen in many other operant, instrumental, and Pavlovian conditioning

paradigms (e.g., Mackintosh, 1976; March, Chamizo, & Mackintosh, 1992; Miles & Jenkins, 1973) are observed when differential sample responding provides one of the redundant cues. In particular, DRL versus FR responding overshadows different visual samples in the control over pigeons' matching choices (Urcuioli, 1984, 1985). In view of these functional similarities, we assumed that the similarity would also extend to conditions in which differential responding occasioned the same reinforced choices as other sample stimuli, resulting in acquired equivalence classes to which the response patterns belonged. But the present data indicate otherwise, so perhaps the similarities end here.

Curiously, our results seem to fly in the face of earlier work from this lab (Urcuioli et al., 1994) that ostensibly showed functional equivalence between differential responding and other samples participating in MTO relations. In that work, the sample stimuli were red versus green hues, the presentation of food versus the food-hopper light only ("no food"), and 1 versus 20 pecks to a common center-key stimulus. Retention functions obtained following acquisition and transfer-of-control results obtained after hue-sample reassignment training both pointed to an acquired equivalence between the hue, food, and response samples. Nevertheless, we may have overstated our case by labeling 1 versus 20 pecks as "response" samples. After all, it takes pigeons longer to make 20 pecks than a single peck, so the functional cue on these matching trials may not have been different responses per se, but a temporal cue correlated with number of pecks. Besides, the positive test results were confined to transfer tests conducted after reassignment training with the hue samples; they were not obtained after reassignment training with the other sample sets.

Assuming, then, that slow, spaced pecking on a DRL schedule versus rapid, uninterrupted pecking on a FR schedule are more defensible examples of different "responses" or "response patterns", why did they not become members of acquired equivalence classes? One possibility is that their stimulus properties are so unlike those associated with different visual cues that this precludes acquired equivalence. With humans, this does not seem to be a problem given that stimuli

from different modalities (e.g., visual and auditory) readily become members of the same stimulus equivalence class (e.g., Sidman, Cresson, & Willson-Morris, 1974; Wetherby, Karlan, & Spradlin, 1983). Of course, this does not mean that pigeons or other nonhuman animals will behave similarly. Nevertheless, other results indicate that relatively substantial stimulus differences do not prohibit the development of acquired sample equivalence in pigeons.

For example, Zentall, Sherburne, and Urcuioli (1995) trained pigeons to match food and no-food samples to the same comparisons as red and green samples in MTO matching. Following reassignment training in which one set of samples was matched to new comparisons, performances with the remaining set revealed class-consistent versus class-inconsistent test differences indicative of acquired equivalence. Similarly, Grant and Spetch (1993, 1994) trained pigeons to match different durations of a houselight (2 vs. 10 s) to the same comparison alternatives as vertical and horizontal line samples and found below-chance levels of accuracy on a subsequent class-inconsistent transfer test.

Of course, in each of the studies mentioned above, one could argue that the positive test results might have been made possible because food and temporal samples also have visual attributes—for example, food = seeing food in raised hopper and no-food = seeing a hopper light without seeing food; duration = seeing an illuminated chamber for a short versus long period of time. But the same could be said here. Pigeons often move away from the key while pecking it on a DRL schedule and stay in front of it while pecking on a FR schedule. Thus, the execution of those patterns is likely to give rise to different visual experiences. But this commonality across our sample sets was not sufficient to produce results like those reported by Grant and Spetch (1994) and Zentall et al. (1995).

Then again, if the functional cue on DRL- and FR-sample trials was the proprioceptive stimulation arising from these different patterns of responding, across-modality differences may indeed be responsible for our failure to find. By this argument, response membership in acquired equivalence classes might well occur if all potential class members involve a response or response pattern. This

could be tested with a MTO procedure in which each sample is a distinctive response or response pattern.

Another possibility to consider is that more rapid matching acquisition with the DRL-FR samples than with the hue samples (cf. Figures 2, 5, and 8) encouraged independent sample-comparison relations despite the common choice associations in the MTO task. In other studies where acquired sample equivalence has been demonstrated (and for which acquisition data are available), rates of acquisition of the component conditional discriminations were comparable (e.g., Urcuioli & Lionello-DeNolf, 2001; Urcuioli *et al.*, 1995) or, if there are differences, they tend to be relatively small (e.g., Urcuioli *et al.*, 1989, Experiment 2; Zentall *et al.*, 1995). But even large acquisition differences do not preclude acquired equivalence. For example, Grant and Spetch (1993, Experiment 2) initially trained pigeons with line-orientation samples prior to MTO training in which the line and temporal (houselight) samples were matched to the same (original) set of comparisons. Nevertheless, these pigeons showed evidence for acquired sample equivalence in a later class-inconsistent transfer test (Grant & Spetch, 1994). Furthermore, to the extent that emergent differential sample behavior (Manabe *et al.*, 1995; Urcuioli *et al.*, 2002) reflects acquired sample equivalence, this phenomenon, too, occurs despite the fact that one component of MTO matching is learned prior to the other.

Finally, in most (although not all) studies demonstrating acquired equivalence, the way in which pigeons respond to the sample stimuli is the same, and this point may be especially significant. For example, a common FR requirement is typically scheduled for all samples in a MTO procedure. With evidence for acquired sample equivalence, the implicit assumption is that class membership is accurately represented as: {S1, S3} and {S2, S4}, where S_n = the sample stimuli. But what if the class members are actually compounds consisting of the sample and the responding that occurs to them: {S1-FR, S3-FR} and {S2-FR, S4-FR}? Although the natural assumption is that irrelevant FR sample-response patterns should not contribute to conditional stimulus control, actual stimulus-control topographies can be different from what we think they are

or should be (McIlvane, Serna, Dube, & Stromer, 2000). After all, in standard matching-to-sample tasks, the conditional cue for choice is not simply what the pigeon sees on the sample key, but what it sees and where it sees it (*viz.*, the particular key on which the sample is displayed—Lionello & Urcuioli, 1998; see also Lionello-DeNolf & Urcuioli, 2000).

The important point is that acquired sample equivalence usually is observed when the members of each class, however defined, are responded to in a similar way. That was not the case here. Pigeons were required to peck the hue samples only once, in contrast to the center-key forms (Experiment 4) or white center key (Experiments 1 and 2) for which DRL versus FR patterns were required. Although the center-key stimuli were used solely to provide the differential response patterns whose possible class membership was in question, the functional cues may have been W-DRL and W-FR, for example. If so, then the classes potentially arising from MTO training should be represented as: {W-DRL, S3-CRF} and {W-FR, S4-CRF}. Notice the substantial within-class differences: One member is a stimulus pecked only once (and, thus, appearing relatively briefly) whereas the other is a stimulus occasioning multiple pecks or a sequence of behavior (and, thus, appearing for an extended time). From this perspective, then, W-DRL and W-FR may be more similar to one another than they are to the other member of their presumed classes. Could this have blocked the development of acquired equivalence?

At present, we don't know the answer to this question. But it is certainly worth considering the possibility that there is nothing inherent in differential responding that precludes their inclusion in equivalence classes. In our experiments, the required differences between one response pattern and another and the need to keep these distinct from the hue-sample response requirements (cf. Urcuioli & Honig, 1980) may have simply created unintended within-class differences and between-class similarities that worked against acquired equivalence.

If so, acquired equivalence effects typically reported with all visual stimuli in MTO matching might not occur if there are substantial within-class differences in the way

pigeons respond to these stimuli. Imagine, for example, a task in which pigeons peck 10 times to each hue sample but only once to each line sample. The common choice associations shared by one hue and one line would presumably promote the development of an acquired equivalence between them. However, if the functional conditional stimuli consist of the visual features of each sample and how many times the pigeons peck at them, the potential class members would actually be {S1–FR, S3–CRF} and {S2–FR, S4–CRF}. Once again, there are substantial within-class differences here, and these might preclude acquired sample equivalence. In other words, these MTO training conditions also might promote independent sample–comparison relations and, thus, yield no transfer-of-control following reassignment.

Until these matters are clarified, it would be premature to say that our findings are a strong disconfirmation of Sidman's (1994, 2000) theoretical position. Of course, in the final analysis, it may turn out that the present results are a strong disconfirmation (e.g., if an all-visual-sample MTO study of the sort mentioned above nonetheless demonstrates acquired sample equivalence). What might this mean? It would show that for some animals at least, equivalence classes do not arise directly from the reinforcement contingencies. Such a result would not be surprising to those who believe that only humans are capable of exhibiting emergent behavior indicative of stimulus equivalence. Of course, recent data showing symmetry in pigeons (Frank & Wasserman, 2005) bring that particular position itself into question. Also, Sidman (2000) himself acknowledged the possibility that the origins of equivalence classes may not be the same for humans and other animals. Our experiments were based on the supposition that common mechanisms are at work. Should it be the case, then, that membership in acquired equivalence classes for pigeons does not extend to their differential behavior, the real issue becomes whether such membership is demonstrable in humans.

REFERENCES

- Astley, S. L., & Wasserman, E. A. (2001). Superordinate categorization via learned stimulus equivalence: Quantity of reinforcement, hedonic value, and the nature of the mediator. *Journal of Experimental Psychology: Animal Behavior Processes*, 27, 252–268.
- Bovet, D., & Vauclair, J. (1998). Functional categorization of objects and of their pictures in baboons (*Papio anubis*). *Learning and Motivation*, 29, 309–322.
- Carter, D. E., & Eckerman, D. A. (1975, February 21). Symbolic matching by pigeons: Rate of learning complex discriminations predicted from simple discriminations. *Science*, 187, 662–664.
- Cohen, L. R., Brady, J. H., & Lowry, M. (1981). The role of differential responding in matching-to-sample and delayed matching performance. In M. L. Commons & J. A. Nevin (Eds.), *Quantitative analyses of behavior: Vol. 1. Discriminative properties of reinforcement schedules* (pp. 345–364). Cambridge, MA: Ballinger.
- 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, 301–314.
- Dickinson, A., & deWit, S. (2003). The interaction between discriminative stimuli and outcomes during discrimination learning. *Quarterly Journal of Experimental Psychology*, 56B, 127–139.
- Dougher, M. J., & Markham, M. R. (1994). Stimulus equivalence, functional equivalence, and the transfer of function. In S. C. Hayes, L. J. Hayes, M. Sato & K. Ono (Eds.), *Behavior analysis of language and cognition* (pp. 71–90). Reno, NV: Context Press.
- Dube, W. V., & McIlvane, W. J. (1995). Stimulus-reinforcer relations and emergent matching to sample. *Psychological Record*, 45, 591–612.
- Dube, W. V., McIlvane, W. J., Mackay, H. A., & Stoddard, L. T. (1987). Stimulus class membership established by stimulus-reinforcer relations. *Journal of the Experimental Analysis of Behavior*, 47, 159–175.
- Elsner, B., & Hommel, B. (2001). Effect anticipation and action control. *Journal of Experimental Psychology: Human Perception and Performance*, 27, 229–240.
- Frank, A. J., & Wasserman, E. A. (2005). Associative symmetry in the pigeon after successive matching-to-sample training. *Journal of the Experimental Analysis of Behavior*, 84, 147–165.
- Goldiamond, I. (1962). Perception. In A. J. Bachrach (Ed.), *Experimental foundations of clinical psychology* (pp. 280–340). New York: Basic Books.
- Grant, D. S. (1982). Prospective versus retrospective coding of samples of stimuli, responses, and reinforcers in delayed matching with pigeons. *Learning and Motivation*, 13, 265–280.
- Grant, D. S., & Spetch, M. L. (1993). Analogical and nonanalogical coding of samples differing in duration in a choice-matching task in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 19, 15–25.
- Grant, D. S., & Spetch, M. L. (1994). Mediated transfer testing evidence for common coding of duration and line samples in many-to-one matching. *Animal Learning & Behavior*, 22, 84–89.
- Hall, G. (1996). Learning about associatively activated stimulus representations: Implications for acquired equivalence and perceptual learning. *Animal Learning & Behavior*, 24, 233–255.

- Honey, R. C., & Hall, G. (1989). The acquired equivalence and distinctiveness of cues. *Journal of Experimental Psychology: Animal Behavior Processes*, *15*, 338–346.
- Joseph, B., Overmier, J. B., & Thompson, T. (1997). Food- and nonfood-related differential outcomes in equivalence learning by adults with Prader-Willi syndrome. *American Journal on Mental Retardation*, *101*, 374–386.
- Lionello, K. M., & Urcuioli, P. J. (1998). Control by sample location in pigeons' matching to sample. *Journal of the Experimental Analysis of Behavior*, *70*, 235–251.
- Lionello-DeNolf, K. M., & Urcuioli, P. J. (2000). Transfer of pigeons' matching to sample to novel sample locations. *Journal of the Experimental Analysis of Behavior*, *73*, 141–161.
- Lionello-DeNolf, K. M., & Urcuioli, P. J. (2003). A procedure for generating differential "sample" responding without different exteroceptive stimuli. *Journal of the Experimental Analysis of Behavior*, *79*, 21–35.
- Mackintosh, N. J. (1976). Overshadowing and stimulus intensity. *Animal Learning & Behavior*, *4*, 186–192.
- Manabe, K., Kawashima, T., & Staddon, J. E. R. (1995). Differential vocalization in budgerigars: Towards an experimental analysis of naming. *Journal of the Experimental Analysis of Behavior*, *63*, 111–126.
- March, J., Chamizo, V. D., & Mackintosh, N. J. (1992). Reciprocal overshadowing between intra-maze and extra-maze cues. *Quarterly Journal of Experimental Psychology*, *45*, 49–63.
- McIlvane, W. J., Serna, R. W., Dube, W. V., & Stromer, R. (2000). Stimulus control topography coherence and stimulus equivalence: Reconciling test outcomes and theory. In J. Leslie & D. E. Blackman (Eds.), *Experimental and applied analysis of human behavior* (pp. 85–110). Reno, NV: Context Press.
- Meck, W. H. (1985). Postreinforcement signal processing. *Journal of Experimental Psychology: Animal Behavior Processes*, *11*, 52–70.
- Miles, C. G., & Jenkins, H. M. (1973). Overshadowing in operant conditioning as a function of discriminability. *Learning and Motivation*, *4*, 11–27.
- Overmier, J. B., & Linwick, D. (2001). Conditional choice-unique outcomes establish expectancies that mediate choice behavior. *Integrative Physiological and Behavioral Science*, *36*, 173–181.
- Sacks, R. A., Kamil, A. C., & Mack, R. (1972). The effects of fixed-ratio sample requirements on matching to sample in the pigeon. *Psychonomic Science*, *36*, 291–293.
- Saunders, K. J., & Williams, D. C. (1998). Do parakeets exhibit derived stimulus control? Some thoughts on experimental control procedures. *Journal of the Experimental Analysis of Behavior*, *70*, 321–324.
- Schenk, J. J. (1994). Emergent relations of equivalence generated by outcome-specific consequences in conditional discrimination. *Psychological Record*, *44*, 537–558.
- Schusterman, R. J., & Kastak, D. (1993). A California sea lion (*Zalophus Californianus*) is capable of forming equivalence relations. *Psychological Record*, *43*, 823–839.
- Sidman, M. (1994). *Equivalence relations and behavior: A research story*. Boston, MA: Authors Cooperative.
- Sidman, M. (1997). Equivalence: A theoretical or a descriptive model? *Mexican Journal of Behavior Analysis*, *23*, 125–145.
- 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., & 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.
- Spetch, M. L., & Treit, D. (1986). Does effort play a role in the effect of response requirements on delayed matching to sample? *Journal of the Experimental Analysis of Behavior*, *45*, 19–31.
- Spradlin, J. E., Cotter, V. W., & Baxley, N. (1973). Establishing a conditional discrimination without direct training: A study of transfer with retarded adolescents. *American Journal of Mental Deficiency*, *77*, 556–566.
- Trapold, M. A. (1970). Are expectancies based upon different positive reinforcing events discriminably different? *Learning and Motivation*, *1*, 129–140.
- 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 pigeon's 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. (2005). Behavioral and associative effects of differential outcomes in discrimination learning. *Learning & Behavior*, *33*, 1–21.
- Urcuioli, P. J. (2006). Responses and acquired equivalence classes. In E. A. Wasserman & T. R. Zentall (Eds.), *Comparative cognition: Experimental explorations of animal intelligence* (pp. 405–421). New York: Oxford University Press.
- Urcuioli, P. J., & DeMarse, T. B. (1997). Further tests of response-outcome associations in differential-outcome matching-to-sample. *Journal of Experimental Psychology: Animal Behavior Processes*, *23*, 171–182.
- 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 and 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., & Lionello-DeNolf, K. M. (2001). Some tests of the anticipatory mediated generalization model of acquired sample equivalence in pigeons' many-to-one matching. *Animal Learning & Behavior*, *29*, 265–280.
- Urcuioli, P. J., & Lionello-DeNolf, K. M. (2005). The role of common reinforced comparison responses in acquired sample equivalence. *Behavioural Processes*, *69*, 207–222.

- Urcuioli, P. J., Pierce, J. N., Lionello-DeNolf, K. M., Friedrich, A., Fetterman, J. G., & Green, C. (2002). The development of emergent differential sample behavior in pigeons. *Journal of the Experimental Analysis of Behavior*, 78, 409–432.
- Urcuioli, P. J., & Zentall, T. R. (1986). Retrospective coding of samples in pigeons' delayed matching-to-sample. *Journal of Experimental Psychology: Animal Behavior Processes*, 12, 69–77.
- Urcuioli, P. J., Zentall, T. R., & DeMarse, T. (1995). Transfer to derived sample-comparison relations by pigeons following many-to-one and 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.
- Vaughan, W., Jr. (1988). The formation of equivalence sets in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 14, 36–42.
- Wasserman, E. A., DeVolder, C. L., & Coppage, D. J. (1992). Non-similarity-based conceptualization in pigeons via secondary or mediated generalization. *Psychological Science*, 3, 374–379.
- Wetherby, B., Karlan, G. R., & Spradlin, J. E. (1983). The development of derived stimulus relations through training in arbitrary-matching sequences. *Journal of the Experimental Analysis of Behavior*, 40, 69–78.
- Zentall, T. R. (1998). Symbolic representation in animals: Emergent stimulus relations in conditional discrimination learning. *Animal Learning & Behavior*, 26, 363–377.
- Zentall, T. R., Hogan, D. E., Howard, M. M., & Moore, B. S. (1978). Delayed matching in the pigeon: Effect on performance of sample-specific observing responses and differential delay behavior. *Learning and Motivation*, 9, 202–218.
- Zentall, T. R., Sherburne, L. M., & Urcuioli, P. J. (1995). Coding of hedonic and nonhedonic samples by pigeons in many-to-one delayed matching. *Animal Learning & Behavior*, 23, 189–196.

Received: July 3, 2005

Final acceptance: January 10, 2006