

*THE DEVELOPMENT OF EMERGENT DIFFERENTIAL  
SAMPLE BEHAVIOR IN PIGEONS*

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Three experiments attempted to replicate Manabe, Kawashima, and Staddon's (1995) finding of emergent differential sample behavior in budgerigars that has been interpreted as evidence of functional equivalence class formation. In Experiments 1 and 2, pigeons initially learned two-sample/two-alternative matching to sample in which comparison presentation was contingent on pecking one sample on a differential-reinforcement-of-low-rate (DRL) schedule and the other on a fixed-ratio (FR) schedule. Later, two new samples were added to the task. Comparison presentation on these trials occurred after the first sample peck following a predetermined interval (Experiment 1) or after completion of either the DRL or FR requirement, whichever occurred first (Experiment 2). Experiment 1 found no evidence for emergent spaced versus rapid responding to the new samples as they established conditional control over the familiar choices. By contrast, differential responding did emerge for some pigeons in Experiment 2, with responding to each new sample coinciding with the pattern explicitly conditioned to the original sample occasioning the same comparison choice. This emergent effect, however, disappeared for most pigeons with continued training. Experiment 3 systematically replicated Experiment 2 using differential peck location as the sample behavior. Differential location pecking emerged to the new samples for most pigeons and remained intact throughout training. Our findings demonstrate a viable pigeon analogue to the budgerigar emergent calling paradigm and are discussed in terms of equivalence- and non-equivalence-based processes.

*Key words:* emergent behavior, differential sample responding, acquired equivalence, adventitious reinforcement, key peck, pigeons

The vibrant interest in human equivalence class formation and in animal categorization has led to a number of studies that have shown emergent stimulus control relations in animals other than humans. These relations are so named because, following certain types of discrimination training, new behavior or new forms of behavioral control appear despite the absence of any explicit reinforcement for them. Such emergent effects are the behavioral manifestations of equivalence classes, given that the members of such classes are, by definition, interchangeable in a wide

variety of novel or previously nonreinforced contexts (Goldiamond, 1962).

An example can be seen in pigeons' conditional discrimination performances after their acquisition of many-to-one (or comparison-as-node) matching to sample in which correct selection of each comparison alternative is reinforced following two or more sample stimuli. When pigeons that have acquired many-to-one matching are also explicitly trained to match a subset of the samples to new or different comparison stimuli, they can immediately match the remaining samples to those comparisons (Urcuioli & Lionello-DeNolf, 2001; Urcuioli, Zentall, & DeMarse, 1995; Urcuioli, Zentall, Jackson-Smith, & Steirn, 1989, Experiment 2; Wasserman, DeVolder, & Coppage, 1992; see also Astley & Wasserman, 1999). These accurate transfer performances illustrate the emergence of new sample-comparison relations from those explicitly reinforced in training and, more specifically, indicate the development of an acquired or functional equivalence between samples that occasion the same comparison choice (Urcuioli, 2001; Urcuioli & Lionello-DeNolf, 2001; cf. Goldiamond, 1962).

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Another, rather unique, example of an emergent effect was recently reported by Manabe, Kawashima, and Staddon (1995, Experiments 2 and 3). They found that budgerigars (budgies) that were explicitly trained to produce the comparisons by making different vocal calls to two samples began to call differentially to two other samples even though differential calling to them was not required. For example, in Manabe *et al.*'s Experiment 2 (with Subject S4) and Experiment 3 (with Subjects S5 and S6), budgies initially learned two-sample/two-alternative matching to sample in which the comparisons appeared following a high-frequency call to one sample versus a low-frequency call to the other. After the budgies were consistently making the correct sample vocal calls and consistently pecking the correct (reinforced) comparisons, two additional samples were added to each training session. Unlike with the original baseline samples, however, making either a high or a low vocal call to the new samples produced the comparisons; in other words, the sample-response contingencies on these trials were nondifferential. Despite this, the budgies began to make a high call to one of the new samples and a low call to the other as they learned to match accurately with them.

This finding of emergent differential sample behavior has attracted special interest because of its potential implications for the types of events that may join equivalence classes (*viz.*, topographically distinct responses) and for the types of contingencies (*viz.*, three term) sufficient to produce them (Sidman, 1994, 2000). Although the issues raised by Manabe *et al.*'s provocative results are important theoretically, they await resolution of a more fundamental issue—namely, the replicability of the findings themselves. Toward this end, the present investigation sought to establish an effective analogue to the Manabe *et al.* (1995) procedures with the pigeon, a species commonly used in studies of categorization and acquired equivalence (e.g., Bhatt, Wasserman, Reynolds, & Knauss, 1988; Urcuioli, 1996; Wasserman & Astley, 1994; Zentall, 1998). Our particular focus was on the training conditions sufficient to produce emergent differential sample behavior.

Close examination of Manabe *et al.*'s (1995) study reveals that the strongest evi-

dence of emergent differential vocalization appeared when training involved many-to-one relations, the same ones routinely used to generate acquired sample equivalence in pigeons (e.g., Grant & Spetch, 1994; Kaiser, Sherburne, Steirn, & Zentall, 1997; Urcuioli, DeMarse, & Zentall, 1994; Urcuioli *et al.*, 1995; Wasserman *et al.*, 1992; Zentall, Sherburne, & Urcuioli, 1993). Note that adding two new samples to an existing two-sample/two-alternative task creates many-to-one matching. We suspected that these many-to-one relations were the source of Manabe *et al.*'s effect. Indeed, the particular vocal call that emerged to each new sample was similar in pitch to the call the pigeon was explicitly required to make to the baseline sample that occasioned the same comparison choice. In other words, high calls emerged to the new sample that cued the same correct choice as the baseline sample to which a high call was required, and likewise for the low call.

Our working hypothesis was that Manabe *et al.*'s (1995) results reflect an acquired sample equivalence of the same sort often reported with pigeons. Typically, this equivalence is demonstrated by showing that new contingencies later applied to some samples in a class also affect the other samples in that class (e.g., Spradlin, Cotter, & Baxley, 1973; Urcuioli *et al.*, 1995). The Manabe *et al.* assay, however, can be considered a slight variation of this: Contingencies already associated with some samples influenced other samples that presumably later joined them in a common class. In particular, the different vocal calls explicitly conditioned to some samples emerged to the added (new) samples that occasioned the same comparison choice.

Our immediate goal was to determine if a similar effect could be obtained with pigeons. Would differential sample behavior explicitly conditioned to one set of samples emerge to another set that subsequently served as conditional cues for the same comparison choices? All three experiments described here addressed this question, and all used sample stimuli that were physically different from the comparisons, because we assumed that many-to-one rather than identity relations (*cf.* Manabe *et al.*, 1995) were crucial. Experiment 1 differed from Experiments 2 and 3 in the sample-response requirements scheduled for the added samples, whereas Experiment 3

differed from the other two in the differential behavior explicitly conditioned to the original baseline samples.

### EXPERIMENT 1

In Experiment 1, pigeons initially were trained on symbolic matching in which comparison presentation was contingent on spacing two successive pecks at least 3 s apart to one sample stimulus (differential reinforcement of low rate [DRL] 3 s) versus pecking the other sample 20 times with no temporal restrictions (fixed-ratio [FR] 20; see Urcuioli, 1984, 1985; Urcuioli & Honig, 1980). After sample responding was differential and high levels of matching accuracy were achieved, two new samples were added and served as conditional cues for the same comparison choices as the original baseline samples. Pigeons were still required to respond differentially to the baseline samples but, on trials with the newly introduced samples, comparison presentation was contingent upon a single peck following a fixed temporal interval. In other words, neither DRL nor FR was required to the new samples. We selected this nondifferential contingency because we wished to avoid adventitious reinforcement of any behavioral units incorporating DRL- or FR-like behavior and the pigeon's subsequent choice. Note that a detailed evaluation of adventitious reinforcement, which has been proposed as an alternative account of Manabe et al.'s (1995) results, appears in the General Discussion.

In short, we asked whether spaced versus rapid patterns of key pecking would emerge to the new samples as pigeons began to match accurately with them, even though such differential behavior was neither required nor encouraged by the sample-response contingencies. If the many-to-one relations resulting from the addition of new samples to an existing matching task produce an acquired sample equivalence, then the DRL and FR response patterns explicitly conditioned to the baseline samples might very well generalize to the new samples.

### METHOD

#### *Subjects*

Eight White Carneau retired breeders obtained from the Palmetto Pigeon Plant (Sum-

ter, SC) participated in this experiment. Each pigeon had previous experience in two-choice delayed matching with stimuli and contingencies different from those used here (cf. Lionello & Urcuioli, 1998). Each was maintained at 80% of its free-feeding body weight by restricted feeding in the home cage and by adjustment in the reinforcement duration for each daily session, as described below. Supplemental feedings in the home cage were given only when pigeons did not obtain enough food in a session to maintain their 80% weights and on the 1 day per week that the experiment did not occur. All pigeons were housed individually in stainless-steel wire cages in a colony room on 14:10 hr light/dark cycle. Water and grit were freely available at all times in the home cages.

#### *Apparatus*

A single BRS/LVE (Laurel, MD) Model SEC-002 chamber equipped with a three-key intelligence panel (Model PIP-016) was used. The pigeon's compartment and the layout of the panel have been described elsewhere (e.g., Lionello-DeNolf & Urcuioli, 2000). Briefly, stimuli were displayed on three horizontally aligned circular keys by back-mounted inline projectors (Model IC-901-IDD) equipped with GE 1820X bulbs. Center-key stimuli were a white dot on a black background and white, blue, and yellow homogeneous fields (BRS/LVE Pattern 692). The side-key stimuli were red and green homogeneous fields. A partially covered GE 1829 bulb mounted 7.6 cm above the center key provided general illumination. The opening in a metal covering surrounding the bulb directed its light toward the chamber ceiling. The food hopper was accessible through an opening (5.8 cm by 5.8 cm) centered approximately 13 cm below the center key. When raised, the hopper was lit by a miniature bulb (ESB-28) mounted near the top of the back wall of a surrounding metal housing. A blower fan on the outside of the experimental chamber ran continuously to provide ventilation and masking noise. An IBM-compatible computer located in an adjacent room controlled the presentation, scheduling, and recording of all experimental events.

#### *Procedure*

Preliminary training involved reinforcing single pecks to the stimuli the pigeons would

later encounter in the matching tasks. These four 60-trial sessions consisted of different combinations of individually presented center- and side-key stimuli, with pigeons receiving 3-s access to grain for pecking the illuminated key on each trial. The first and second sessions involved 30 randomized center-key presentations each of the blue and yellow or the dot and white stimuli, respectively. For the third and fourth sessions, red and green appeared 10 times each on either side key along with 10 presentations each of blue and yellow or dot and white, respectively, on the center key. In all sessions, successive stimulus presentations were separated by a 10-s intertrial interval (ITI). The houselight was on continuously.

After completing preliminary training, each pigeon received eight sessions of successive discrimination training involving blue and yellow center-key stimuli. Both hues were presented 30 times per session in random order, with the constraint that neither appear more than three times in a row. Pecking one hue was reinforced on a DRL 3-s schedule, whereas pecking the other hue was reinforced on an FR schedule. These reinforcement contingencies were counterbalanced across pigeons. The 3-s DRL parameter was in effect from the outset of training. By contrast, the FR requirement was increased gradually over successive training sessions as follows: FR 2 (one session), FR 5 (one session), FR 10 (two sessions), FR 15 (two sessions), FR 20 (two sessions). Each trial was separated from the next by a 10-s ITI with the first 9 s spent in darkness. The houselight was turned on for the last 1 s of the ITI and remained on until the end of the subsequent reinforcement cycle. Reinforcement duration for each pigeon was constant within a session but varied between 2 and 6 s across sessions so as to maintain the pigeon's 80% body weight as closely as possible.

Next, all pigeons were trained on zero-delay matching to sample with blue and yellow samples, red and green comparisons, and DRL 3-s and FR 20 sample-response requirements. Each matching trial began with either the blue or yellow sample on the center key. Completion of either the DRL 3-s or the FR 20 requirement, in accord with each pigeon's prior successive discrimination contingencies, immediately turned off the sample and pro-

duced the red and green comparisons on the two adjacent side keys. A single peck to either comparison turned both off and produced either reinforcement (if correct) or a timeout (if incorrect) during which the houselight was turned off. For all pigeons, pecking the red comparison on blue-sample trials and the green comparison on yellow-sample trials was reinforced, whereas pecking the alternative comparison on each trial type produced a timeout of equivalent duration. As before, the daily reinforcement duration for each pigeon varied between 2 and 6 s.

Each matching session consisted of 100 trials divided equally among the four possible trial types (two samples and two left-right configurations of the comparisons). These trials occurred in random order, with the constraint that no one trial type could occur more than three times in a row. Successive trials were separated by a 10-s ITI, the first 9 s of which was spent in darkness. Each pigeon was trained for a minimum of 10 sessions and until it reached a criterion of 90% or greater accuracy on five of six consecutive sessions.

After each pigeon reached criterion, two new samples (the dot and white stimuli) were added to the matching procedure, creating a many-to-one conditional discrimination. Each trial in the many-to-one sessions began with the center-key presentation of blue, yellow, dot, or white. On blue- and yellow-sample trials, pigeons obtained the red and green comparisons by completing the DRL 3-s or FR 20 sample-response requirement, as before. On trials with the dot and white samples, pigeons obtained the comparisons by completing a fixed-interval (FI) schedule that was initiated by the first sample key peck. The FI value was identical for both the dot and white samples and was determined individually for each pigeon by averaging the times to complete the DRL and FR response requirements for the blue and yellow samples over the last four or five zero-delay symbolic matching sessions. The FI value for each pigeon was as follows: Pigeon BD1: 8 s; Pigeon BD2: 8 s; Pigeon BD3: 14 s; Pigeon BD4: 12 s; Pigeon BF1: 7 s; Pigeon BF2: 8 s; Pigeon BF3: 10 s; and Pigeon BF4: 6 s.

A single peck to the red comparison on dot-sample trials and a single peck to the green comparison on white-sample trials were correct and were reinforced, whereas a single

peck to the alternative comparison was incorrect and produced the timeout. In this many-to-one procedure, then, both the blue and the dot samples were conditional cues for a red-comparison choice, and both the yellow and the white samples were conditional cues for a green-comparison choice. Each many-to-one session consisted of 96 trials divided equally among the eight possible trial types (four samples and two left-right configurations of the comparisons). These trial types were randomized within successive blocks of 48 trials, with the constraint that none could occur more than three times in a row. All other details of the procedure were identical to those described for the two-sample matching task. Each pigeon completed 25 to 30 many-to-one matching sessions.

### RESULTS

The eight blue and yellow successive discrimination sessions were sufficient to differentiate the pigeons' response patterns to these hues. The pigeons tended to space their successive key pecks to the center-key hue that signaled DRL 3 s, whereas they pecked rapidly and without interruption to the hue that signaled FR 20. The average percentage of all interresponse times (IRTs) to the DRL hue  $\geq 1,500$  ms over the last two sessions was 62% (range across pigeons, 51.5% to 77.6%) compared to only 2.4% to the FR hue (range, 0.1% to 5.0%). This differentiation continued and became even more pronounced for most pigeons when blue and yellow served as samples in zero-delay matching. For instance, over the last five criterion-level matching sessions, the average percentage of IRTs  $\geq 1,500$  ms for pecking the DRL sample was 70.8% (range, 64.3% to 82.7%) versus only 1% for the FR sample (range, 0.2% to 2.6%).

Acquisition of zero-delay matching with the blue and yellow hue samples proceeded rapidly: Pigeons required only three sessions on average (range, two to four sessions) to reach 90% accuracy. The average choice accuracy over the last five criterion-level matching sessions was 98.7% (range, 98.0% to 99.4%).

Figure 1 shows choice accuracy averaged over pigeons with the dot and white samples for the first 15 sessions after their introduction into the matching task and average percentages of all IRTs  $\geq 1,500$  ms to those sam-

ples. The IRT functions are labeled *drl* and *fr* to indicate which sample occasioned the same correct comparison choice as the hue sample to which the pigeons were required to complete the DRL or FR sample-response requirement. Sample and choice performances with the blue and yellow samples are not shown because they were essentially unchanged from those at the end of baseline matching training. Individual-subject data are not depicted because those data are adequately represented by the average results.

Two trends are apparent in Figure 1. First, acquisition of accurate choice responding with the dot and white samples proceeded smoothly and rapidly during many-to-one training. Six of the 8 pigeons reached 90% accuracy with the dot and white samples within 11 sessions (approximately 530 trials); by the 15th session, the remaining 2 pigeons chose correctly on 79% and 90% of the dot- and white-sample trials. Second, there was no indication at any point of differential responding to the newly introduced samples. Relatively long IRTs ( $\geq 1,500$  ms) were somewhat more frequent during the initial many-to-one sessions, but this was true for both the dot and white samples. As training progressed, pigeons began pecking rapidly at each sample throughout the time it appeared on the center key, as evidenced by the low percentages of IRTs  $\geq 1,500$  ms.

Continued training on many-to-one matching beyond the 15 sessions shown in Figure 1 did not change the results. For instance, matching accuracy with the dot and white samples over Sessions 25 through 30 averaged 95.4% correct (range, 90.0% to 99.2%), and the average percentages of IRTs  $\geq 1,500$  ms were identical (4.0%) for both samples (ranges, 0% to 11.7% and 0.5% to 10.4%). Matching accuracy with the baseline (blue and yellow) samples over these same sessions averaged 98.5% correct (range, 96.2% to 100%), and the average percentage of hue-sample IRTs  $\geq 1,500$  ms was 64% for the DRL hue (range, 38.3% to 87.7%) versus 1.7% for the FR hue (range, 0% to 6.4%).

### DISCUSSION

Many-to-one training was not sufficient for differential responding to emerge to samples that cued the same correct comparison choice as the samples to which differential re-

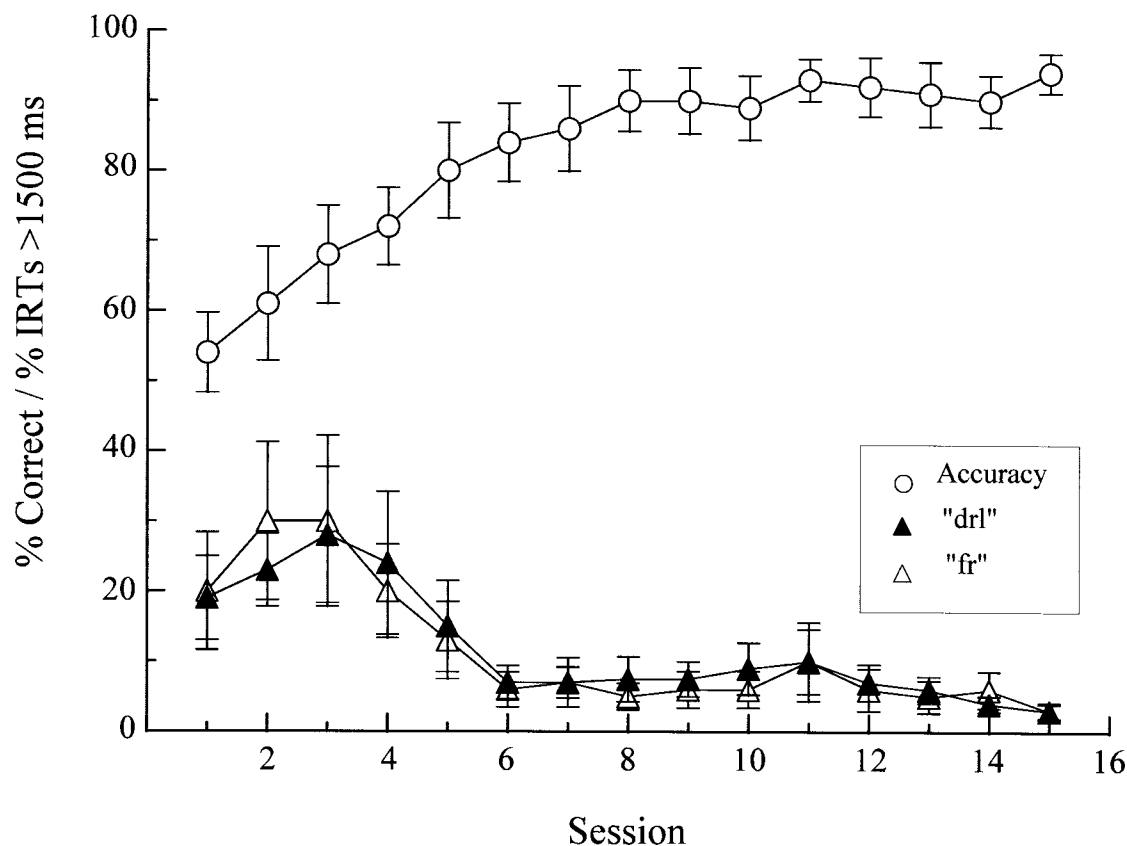


Fig. 1. Average percentage of correct choice responses (accuracy) on the new-sample trials and the average percentage of sample IRTs  $\geq 1,500$  ms for each new sample that occasioned the same comparison choice as the baseline DRL or FR sample during many-to-one training in Experiment 1.

sponding was explicitly conditioned and maintained. The absence of emergent differential sample behavior of the sort observed by Manabe *et al.* (1995) may be due to any number of factors. One possibility is that unlike budgerigars, pigeons will not exhibit such emergent behavior. This seems rather unlikely, however, given other data showing emergent sample-comparison relations in pigeons trained on many-to-one matching (e.g., Urcuioli *et al.*, 1995; Wasserman *et al.*, 1992). Another possibility is that differential sample behavior will not, or is unlikely to, emerge if that behavior involves a pattern of responding over time (such as the spaced vs. rapid responding characteristic of DRL and FR schedules) versus something relatively discrete (such as high vs. low vocal calls by budgerigars). Our second experiment will dispel this idea.

Finally, our pigeons were not required to

complete either the DRL or the FR schedule to the dot and white samples in order to produce the comparisons. By contrast, the budgerigars in Manabe *et al.* (1995) produced the comparisons on the added sample trials by making either of the two calls they were required to make to the explicitly conditioned stimuli or samples. Our contingencies, then, placed far less constraint on responding to the added samples than those scheduled by Manabe *et al.* Perhaps, then, differential responding would be more likely to emerge by constraining the "acceptable" response patterns. Experiment 2 tested this hypothesis.

## EXPERIMENT 2

Experiment 2 systematically replicated Experiment 1 with the following modification. Pigeons obtained the comparison alternatives on trials with the new (added) samples by

completing either the DRL 3-s or the FR 20 sample-response requirement. In other words, the comparisons on these trials appeared as soon as the pigeon spaced two successive pecks 3 s or more apart or pecked 20 times, whichever occurred first.

#### METHOD

##### *Subjects*

Twelve White Carneau retired breeders served in Experiment 2. These pigeons were maintained identically to those in Experiment 1. All had previous experience on two-sample identity and many-to-one matching tasks with stimuli different from those used here.

##### *Apparatus*

Two pigeon chambers were used in this experiment, the one used in Experiment 1 and another configured identically. For this experiment, the center key was equipped to display blue and yellow hues and three small circular white dots oriented either vertically or at  $-45^\circ$  on a black background (BRS/LVE Pattern 692). The side keys in one experimental chamber displayed a white homogeneous field and a large white dot on a black background (Pattern 692). The side key stimuli in the other experimental chamber were single white lines oriented either vertically or horizontally (Pattern 696). Eight pigeons were assigned to the former experimental chamber and the remaining 4 pigeons were assigned to the latter.

##### *Procedure*

Four 60-trial preliminary training sessions similar to those in Experiment 1 were conducted. The first and second sessions involved 30 randomized presentations each of the vertical and rotated dots and the blue and yellow hues, respectively, on the center key. The third session consisted of 10 presentations each of the vertical and rotated dots on the center key along with 10 presentation each of dot and white (Chamber 1) or vertical and horizontal lines (Chamber 2) on the left and right side keys. The fourth session was like the third except that blue and yellow appeared on the center key. A single peck to the lit key on each trial immediately turned off the stimulus and provided 3-s access to

food. All other details were identical to those described in Experiment 1.

Next, each pigeon received successive discrimination training between the vertical and rotated dots on the center key. Food delivery depended on completing a DRL 3-s schedule for one stimulus and an FR schedule for the other, counterbalanced across the pigeons assigned to each experimental chamber. The value of the FR was gradually raised from 2 to 20 over the eight 60-trial sessions, whereas the 3-s DRL parameter was in effect from the outset of training. All other details were identical to those in Experiment 1.

Following completion of the successive discrimination phase, each pigeon was trained on zero-delay matching to sample with the vertical and rotated dots as sample stimuli, the dot and white stimuli (Chamber 1) or the vertical and horizontal lines (Chamber 2) as comparison alternatives, and DRL 3-s versus FR 20 sample-response contingencies identical to those in the preceding phase. The correct comparison choice following each sample stimulus was counterbalanced across the pigeons assigned to each experimental chamber. This was also done in such a way that the correct choice alternatives following the DRL and FR requirements were counterbalanced across the pigeons in each chamber. The remaining details of these 100-trial sessions were identical to those of the two-sample matching task in Experiment 1. As before, each pigeon was trained for at least 10 sessions and until it reached a criterion of 90% or more correct choices for five of six consecutive sessions.

Once criterion was reached, two new samples, the blue and yellow hues, were added to each training session, creating many-to-one contingencies. On blue- and yellow-sample trials, the sample went off and comparison alternatives appeared when the pigeon either spaced two successive sample key pecks 3 s or more apart or pecked 20 times. The sample-response contingencies with the baseline (vertical- and rotated-dots) samples remained the same as before. For all pigeons, the reinforced choice response on blue-sample trials was identical to that on the rotated-dots-sample trials, and the reinforced choice on yellow-sample trials was identical to that on vertical-dots-sample trials. All other details of these 96-trial many-to-one sessions were iden-

tical to those of Experiment 1. Each pigeon was trained for at least 30 many-to-one sessions and until it achieved 90% or better overall matching accuracy.

### RESULTS

All pigeons pecked the dot center-key stimuli differentially over the eight successive discrimination sessions that preceded matching-to-sample training. On the last two of these sessions, the percentage of all IRTs  $\geq 1,500$  ms to the DRL stimulus averaged 54% (range, 33.9% to 65.4%) versus only 3.2% (range, 0% to 12.8%) to the FR stimulus. This spaced versus rapid pattern of key pecking continued when the dot stimuli appeared as samples in zero-delay matching: For example, over the last five matching sessions, the percentage of IRTs  $\geq 1,500$  ms to the DRL sample averaged 63.5% (range, 46.2% to 90.0%) versus 1.1% to the FR sample (range, 0.1% to 4.3%).

Accurate choice responding following the dot samples developed quickly during the zero-delay task, with pigeons reaching 90% accuracy in an average of 7.4 sessions (range, 3 to 14 sessions). Acquisition was slower for the 4 pigeons trained with the line-orientation comparisons than for the 8 pigeons trained with the dot-white comparisons: The former took average of 10 sessions to reach criterion (range, 6 to 14) versus only 6.1 for the latter (range, 3 to 10). Despite this difference, choice accuracies were similar over the last five matching sessions, averaging 94.4% correct (range, 93.8% to 95.8%) and 96.1% correct (range, 92.2% to 98.0%), respectively, for the two sets of pigeons.

Figures 2 and 3 show correct choice responding for each pigeon with the blue and yellow samples that were subsequently added to the zero-delay task and the percentage of IRTs  $\geq 1,500$  ms to each hue sample during the 30 many-to-one training sessions. The hue samples are labeled "drl" and "fr" to indicate which hue occasioned the same correct comparison choice as the dot sample to which the pigeons were required to complete the DRL 3-s or FR 20 sample-response requirement. Recall that, on hue-sample trials, pigeons obtained the comparisons by completing either requirement.

Matching acquisition with the blue and yellow samples was variable across pigeons, with

some reaching 90% accuracy in two or three sessions (D3 and D8) and others reaching that criterion in 10 or more sessions (e.g., D4 and F4). One pigeon (F6) reached 90% accuracy within 15 sessions but did not consistently maintain this level of performance. After the 15th session, its choice accuracy on hue-sample trials averaged 80.3%.

The 6 pigeons whose data appear in Figure 2 showed emergent differential responding to the hue samples as they learned to match accurately with them during many-to-one training. Moreover, there was a consistent pattern of sample responding across all 6 pigeons. Specifically, they tended to space successive key pecks to the hue sample that cued the same comparison choice as the dot sample to which they were required to complete the DRL 3-s requirement, and they tended to peck rapidly to the hue sample that cued the same comparison choice as the dot sample to which they were required to complete the FR 20 requirement. This differential pattern emerged primarily via the increasing frequency of relatively long IRTs ( $\geq 1,500$  ms) to the hue sample occasioning the same comparison choice as the explicitly trained DRL sample.

Curiously, only 2 pigeons (F5 and F8) maintained differential responding to the hue samples throughout many-to-one training. The sample-response patterns of the remaining 4 pigeons (Figure 2) became increasingly undifferentiated across sessions. Three of them (D4, D6, and D8) eventually pecked rapidly to both hue samples, whereas Pigeon D3 eventually pecked both with a pattern of spaced responding characteristic of DRL schedules. Choice accuracy with the blue and yellow samples showed no concomitant deterioration.

Figure 3 shows the data from the 6 pigeons that did not show this pattern of emergent behavior. Three (D5, F4, and F7) pecked rapidly to both hue samples throughout many-to-one training, whereas 2 (D7 and F3) developed a mostly nondifferential pattern of spaced responding. Pigeon F6 pecked the hue samples differentially, especially after the eighth session, but in a manner opposite to that shown by the pigeons in Figure 2. It tended to space its key pecks (i.e., made a relatively high proportion of long IRTs) to the hue sample occasioning the same com-

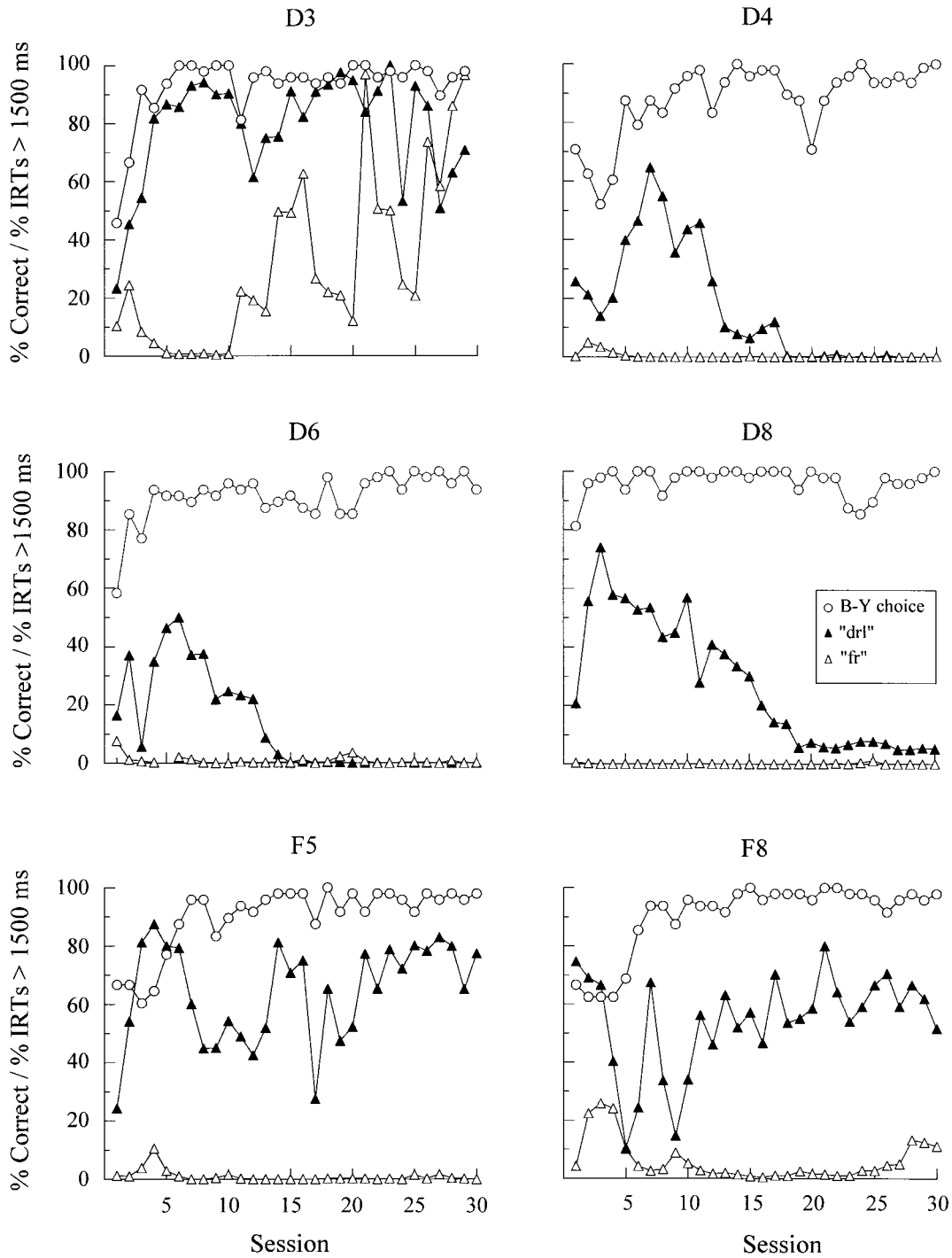


Fig. 2. The percentages of correct choice responses with, and percentages of IRTs  $\geq 1,500$  ms to, the new (blue and yellow) samples occasioning the same choices as the baseline DRL and FR samples during many-to-one training in Experiment 2. Data are shown for the 6 pigeons that exhibited emergent differential sample behavior.

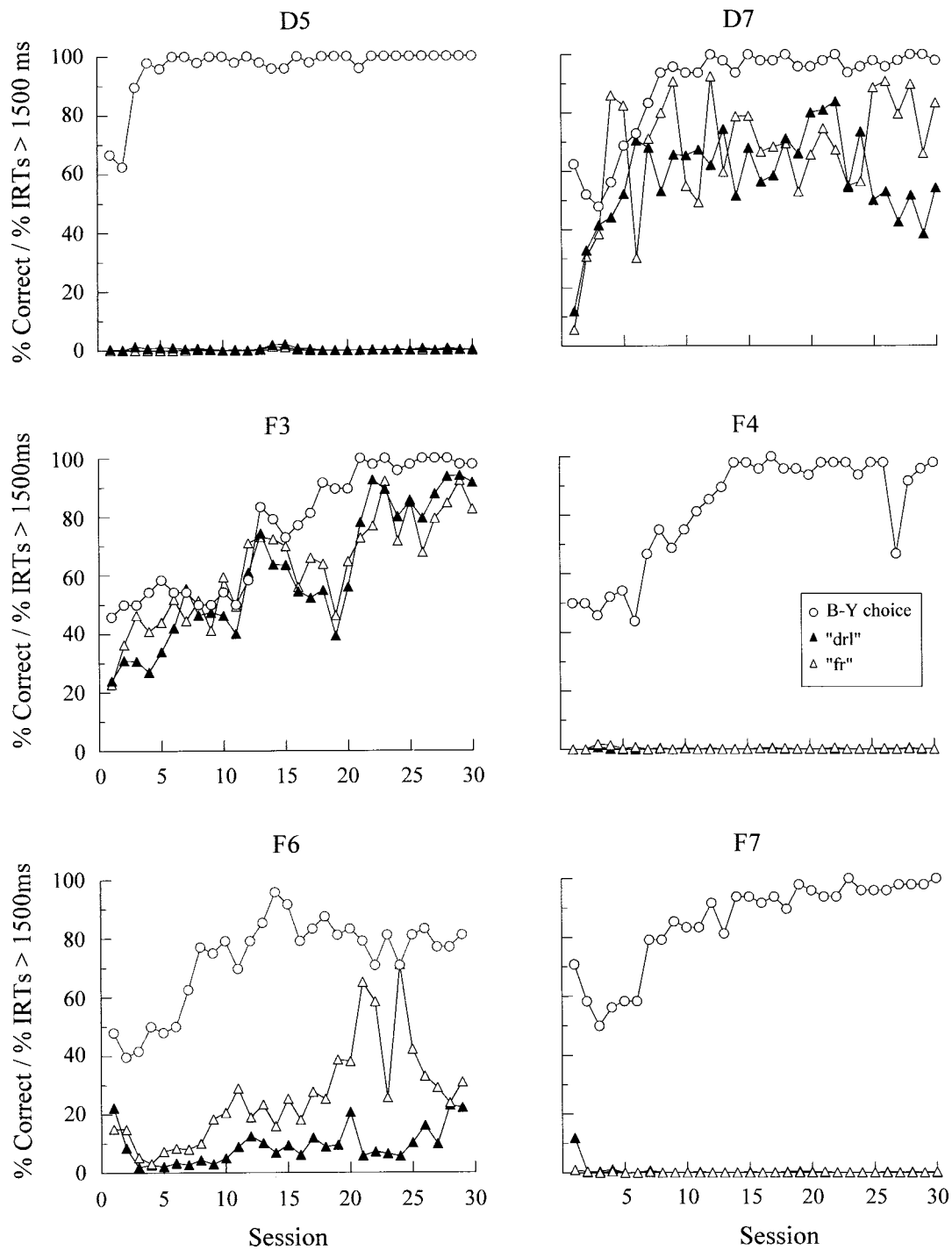


Fig. 3. The percentages of correct choice responses with, and percentages of IRTs  $\geq 1,500$  ms to, the new (blue and yellow) samples occasioning the same comparison choices as the baseline DRL and FR samples during many-to-one training in Experiment 2. Data are shown for the 6 pigeons that did not exhibit emergent effects like those of the other pigeons.

parison choice as the FR 20 dot sample, and to peck rapidly to the hue sample occasioning the same choice as the DRL 3-s dot sample. Interestingly, F6 was the pigeon that was unable to maintain 90% accuracy levels with the blue and yellow samples.

Figure 4 shows choice accuracy and the IRT data with the baseline (dot) samples by each of the 12 pigeons during many-to-one acquisition. Recall that comparison presentation on the baseline trials was contingent upon completing the DRL 3-s requirement to one sample and the FR 20 requirement to the other. The baseline data for the 6 pigeons showing emergent differential sample responding (cf. Figure 2) are in the top two rows of Figure 4, whereas the baseline data for the other 6 pigeons (cf. Figure 3) are in the bottom two rows.

There are three noteworthy features about the baseline results. First, every pigeon maintained high levels of matching accuracy with the dot (baseline) samples as they learned to match accurately with the hue (added) samples. Matching accuracy on the baseline trials (open circles) remained at or above 90% correct during most sessions, and well above 80% in all cases. Second, the pattern of responding to the dot samples remained appropriate to the sample-response contingencies: Pigeons regularly spaced their successive key pecks to the DRL sample and responded rapidly to the FR sample. Third, baseline choice and sample-behavior performances of the pigeons that showed emergent differential responding (top two rows) did not appear to differ from the baseline performances of those that did not (bottom two rows).

#### DISCUSSION

This experiment arranged training and testing conditions more similar to those of Manabe et al. (1995) than were the conditions of Experiment 1. Here, to produce the comparisons on trials with the newly introduced samples, pigeons had to complete one of the two sample-response requirements in effect for the baseline samples just as Manabe et al.'s budgerigars had to make a call in either of two frequency classes (i.e., high or low) that were explicitly required to the originally trained samples. Manabe et al. reported that under these conditions, their budgies began to call differentially to the new samples

as they learned to match accurately with them and that each emergent call coincided with the call required to the baseline sample that occasioned the same reinforced choice. In our experiment, 6 of the 12 pigeons showed this same pattern of results. Spaced versus rapid responding developed to the added hue samples as these 6 pigeons learned to match accurately with them, and each emergent sample-response pattern coincided with the one explicitly trained to the baseline sample with which the hue shared a common comparison choice. Thus, in both our experiment and that of Manabe et al., conditional cues signaling the same reinforced choice yielded similar sample behavior.

It is, of course, possible that the difference between the results of Experiment 2 and Experiment 1 arose from the use of different sample and comparison stimuli. We had little choice in this matter, unfortunately, because the pigeons in each experiment had prior experimental histories, so it was imperative to use unfamiliar stimuli to avoid unwanted carryover effects. It is important to note, however, that experimenter choice of stimuli did not dictate the response pattern that emerged to each sample. Some other factor is required to explain the fact that emergent sample-response patterns were consistent with the patterns explicitly trained to the samples with which they shared a common comparison choice. One possibility is that samples occasioning the same correct comparison choice become functionally equivalent (Urcioli, 1996), thus leading to equivalent or similar forms of sample responding. A second possibility is adventitious reinforcement (Saunders & Williams, 1998). We will discuss these alternatives later.

Only half of the pigeons showed the emergent differential sample-behavior effect. Perhaps more puzzling is the fact that for those pigeons that showed emergent behavior, most were no longer responding differentially to the new samples by the 15th to 20th session. The latter finding was unexpected given no corresponding deterioration in differential vocalizations by Manabe et al.'s (1995) budgies. Why, then, did the differential sample-response patterns for 4 of our 6 pigeons become increasingly undifferentiated with continued many-to-one training?

One possibility (A. C. Catania, personal

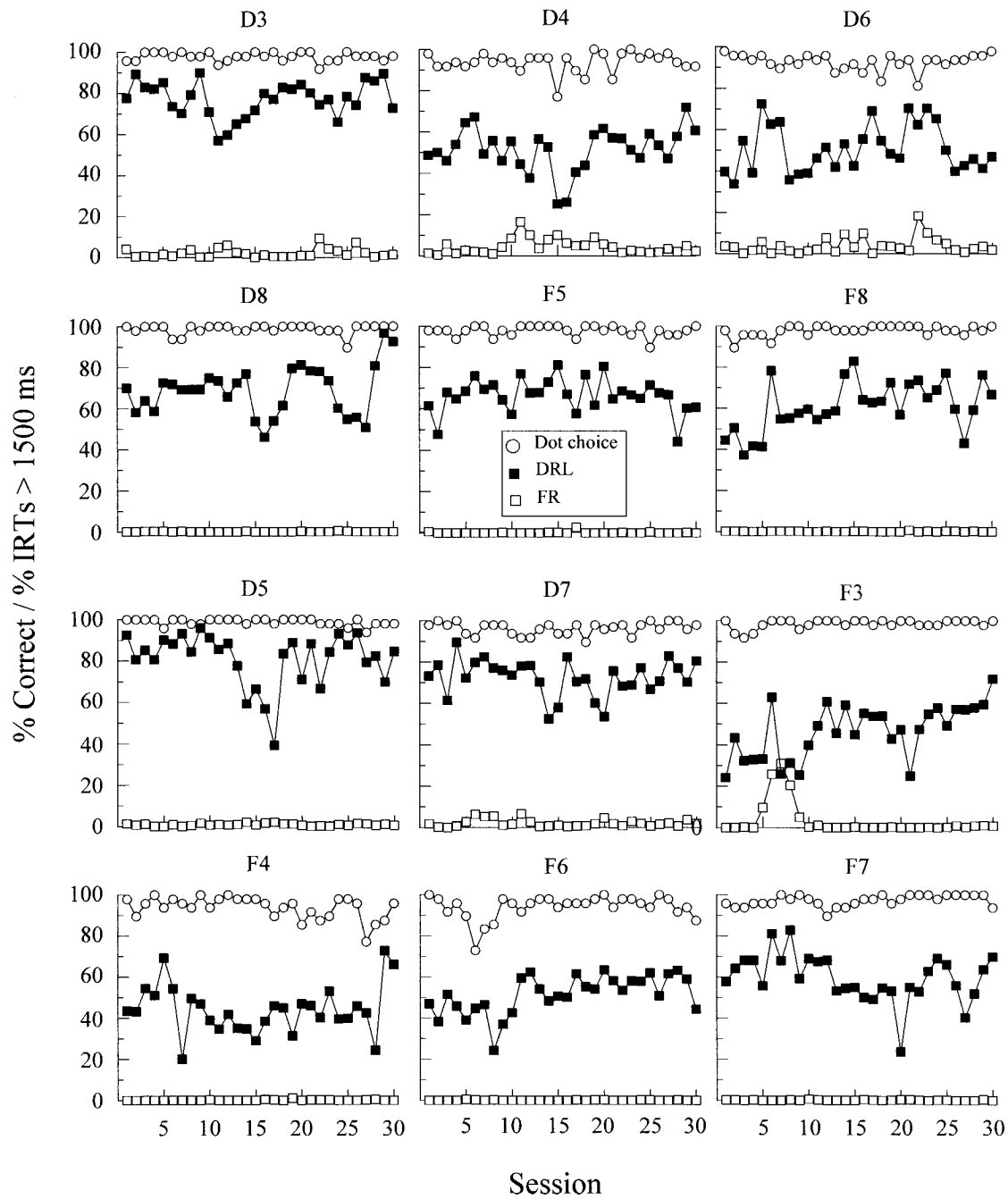


Fig. 4. The percentages of correct choice responses with, and percentages of IRTs  $\geq 1,500$  ms to, each baseline (dot) sample associated with the explicit DRL or FR sample-response requirement during many-to-one training in Experiment 2. Baseline data for the 6 pigeons that exhibited the emergent effect on the added-sample (hue) trials are shown in the top two rows; those for the remaining 6 pigeons are shown in the bottom two rows.

communication, July 2000) is that DRL and FR performances could effectively “blend” and still meet the requirements of those schedules. For example, pigeons could produce the comparisons by pecking rapidly, say, 17 times, and then making their 18th peck after 3 s or more had elapsed from the 17th. Likewise, pigeons could produce one or more relatively long IRTs (but less than 3 s) and then rapidly peck the sample until 20 pecks had been made. Although this blending could also occur on the baseline (dot-sample) trials, the specific sample-response contingencies on those trials would make such blending much less likely. In other words, except for the 20th peck, no other peck with an IRT greater than 3 s would terminate the dot sample associated with the FR 20 schedule. Likewise, pecking 20 times with short IRTs to the dot sample associated with the DRL 3-s schedule would never terminate it.

In Manabe et al. (1995), blending of sample responses was not possible. Each vocal call fell into either a high- or low-frequency category; there was no overlap between categories. In view of this difference, Experiment 3 used mutually exclusive sample-response contingencies designed to reduce blending—namely, pecking one location versus another. Would emergent differential location pecking develop under training conditions like those of Experiment 2, and would any such differential behavior remain intact after extended testing?

### EXPERIMENT 3

In Experiment 3, each sample stimulus appeared simultaneously on two vertically aligned response keys. During the initial (two-sample) matching task, pigeons produced the comparisons by pecking the top key five consecutive times for one sample and the bottom key five times for the other sample. Once this baseline task was learned to high levels of accuracy for both comparison choice and sample peck location, two new samples were added. They, too, appeared on both the top and bottom response keys, but on these trials, completing five consecutive pecks to either the top or bottom location produced the comparisons. Although pigeons could switch between locations on

these trials, any switch reset the response requirement. Thus, as with the baseline samples, only five consecutive pecks to one location produced the comparisons. Would pigeons consistently peck the same location to which they pecked the sample that occasioned the same comparison choice?

### METHOD

#### *Subjects*

The subjects were 6 adult male White Carneaux pigeons (*Columba livia*) maintained at approximately 85% of the free-feeding weights. The pigeons received unlimited access to water and grit in their home cages and supplemental feedings, when necessary, to maintain them at their experimental weights. All were experimentally naive and were maintained on a 12:12 hr light/dark cycle with light onset at 7:00 a.m.

#### *Apparatus*

The single apparatus used in this experiment consisted of a specially designed BRS/LVE four-key intelligence panel mounted inside a BRS/LVE SEC-002 chamber. The panel contained three circular response keys aligned horizontally and spaced 8 cm apart center to center and about 22 cm above the chamber floor. The fourth response key was located directly above the center key of the array, approximately 30 cm above the floor. Mounted behind each key was an in-line projector equipped to display red, green, white, and amber hues and three vertical and three black horizontal lines on white backgrounds (BRS/LVE Pattern 715). The feeder opening measured 5 cm by 5 cm and was located directly below the center response keys. The bottom lip of the opening was 10 cm above the chamber floor. White noise masked extraneous sounds. Additional masking and ventilation were provided by a fan attached to the chamber wall. Experimental events were scheduled and recorded by an IBM-compatible computer located in an adjacent room.

#### *Procedure*

Preliminary training involved initially training each pigeon to eat reliably from the food hopper followed by daily 120-trial autoshaping sessions. At the beginning of each autoshaping trial, one of the four response keys

was illuminated by the white stimulus for 5 s, after which the key was darkened and the hopper was raised for 2.5 s. This was followed by a 15-s ITI. If the pigeon pecked the lit key before 5 s had elapsed, the hopper was raised immediately. Each key was lit by the white stimulus 30 times in each session, with the order of keylight presentations randomized in successive blocks of 12 trials. All pigeons were reliably pecking all four keys within five sessions.

Each pigeon was then trained to peck at different locations depending on which of two stimuli (red or white) appeared. Pecking one location was reinforced by 2.5-s access to food in the presence of one stimulus, whereas pecking the other location was reinforced in the presence of the other stimulus. The reinforced locations were the top key and the center key (hereafter referred to as the bottom key) of the three-key array. For three sessions, red and white appeared only at the correct location, and a single peck was reinforced. Afterwards, each stimulus appeared at both locations, and pigeons were required to peck at the correct location to receive food. During the first two of these latter sessions, a single peck at the correct location produced food, and pecks to the incorrect location had no scheduled consequences. For the next two sessions, the response requirement was raised to three successive pecks, and pecks to the incorrect location reset the response requirement. After the fourth session, and for the rest of the experiment, the response requirement was five consecutive pecks. The stimulus and peck-location contingencies were counterbalanced such that for 3 pigeons, reinforcement was contingent upon pecking the top key when red appeared and the bottom key when white appeared, and vice versa for the other 3 pigeons. Each session ended after 60 reinforcers. All pigeons reliably pecked the correct location within eight sessions.

Next, training on symbolic matching to sample began. Each matching trial started with presentation of red or white on the two sample keys. Five consecutive pecks to the correct sample location turned off the sample stimulus and illuminated the left and right side keys with green and amber lights. As before, any peck to the incorrect sample location reset the five-peck response require-

ment and delayed the onset of the comparison stimuli. The left-right positions of the two comparisons alternated randomly across trials, with the constraint that each configuration occur equally often with each sample color. A single peck to one comparison was reinforced after the red sample, and a single peck to the alternative comparison was reinforced after the white sample, with sample-comparison contingencies counterbalanced across pigeons. Correct comparison choices produced 2.5-s access to food followed by a 10-s ITI, whereas incorrect comparison choices produced only the ITI. A noncorrection procedure was used throughout training. The houselight was on during the first 9 s of the ITI and off during the last 1 s and for the remainder of the matching trial.

During the first three matching sessions, only the correct comparison stimulus appeared following each sample. Thereafter, both comparisons appeared. Each matching session consisted of 96 trials, 48 trials each with the red and white samples. Sample presentation was randomized within blocks of 12 trials with equal numbers of red and white samples per block. Pigeons were trained for 20 sessions, by which point all had achieved accuracy levels of 95% correct or better for five consecutive sessions.

Following these 20 symbolic matching sessions, two new samples (black vertical and horizontal lines superimposed on white backgrounds) were introduced into the task. The same comparison alternatives (amber and green) appeared following the line samples as after the red and white samples, so the addition of the line samples to the symbolic matching baseline task created many-to-one matching. On baseline (red- and white-sample) trials, the differential peck-location contingencies remained in effect. By contrast, on trials with the vertical- and horizontal-line samples, five consecutive pecks at either location (top or bottom) produced the comparisons (cf. Experiment 2). If a pigeon pecked fewer than five times at one location before pecking the other location, the response requirement was reset as with the red and white samples. For each pigeon, the reinforced comparison choice on vertical-sample trials was identical to that on red-sample trials, and the reinforced choice on horizon-

tal-sample trials was identical to that on white-sample trials.

Each many-to-one session consisted of 96 trials divided equally among the eight possible trial types (four samples and two left-right configurations of the comparisons). Each sample occurred equally often within each successive block of 12 trials. As before, correct choice responses were reinforced with 2.5-s access to grain. Training continued for 30 sessions for 5 pigeons, at which point each had met a criterion of 90% correct or better accuracy for three consecutive sessions with both the baseline and new samples. The remaining pigeon (P42) required 43 sessions to achieve this level of performance.

#### RESULTS AND DISCUSSION

On the last two peck-location discrimination sessions preceding symbolic matching acquisition, the proportion of all key pecks occurring to the correct location was 93% averaged across the 6 pigeons (range, 80% to 98%). This accurate performance was maintained during the symbolic matching phase as well. Over the last five criterion-level matching sessions, the corresponding proportion of all sample key pecks occurring to the correct location averaged 98% (range, 97% to 99%).

Figure 5 shows acquisition of correct choice responding with the added (vertical- and horizontal-line) samples for each pigeon and the percentages of all trials with each sample on which five consecutive pecks were made to the top location. The line samples are designated top and bottom to coincide with the explicitly conditioned peck locations of the samples with which they shared a common comparison choice.

The rate at which the criterion level of matching (choice) accuracy was achieved with the vertical- and horizontal-line samples varied considerably across pigeons, from a low of three sessions (144 trials) for Pigeon P43 to a high of 34 sessions (1,632 trials) for Pigeon P42. Nonetheless, all pigeons eventually matched consistently at accuracy levels at or above 90% correct with the line samples.

Of greater interest, however, was that differential sample responding to the vertical and horizontal lines emerged in 5 of the 6 pigeons, the exception being Pigeon P40. In particular, as these pigeons learned to match

accurately with the line samples, they began to peck differentially to them (i.e., to the top or bottom key location). As in Experiment 2, the pattern of differential sample pecking was consistent across the 5 pigeons: They preferentially pecked the same key location as that to which they were required to peck when the hue (red vs. white) sample that occasioned the same comparison choice appeared. Thus, on matching trials with the line sample that occasioned the same choice as the hue sample to which five consecutive top-key pecks were required, pigeons preferentially pecked the top key. Likewise, on trials with the line sample that occasioned the same choice as the hue sample to which five bottom-key pecks were required, pigeons preferentially pecked the bottom key. For these 5 pigeons, the average percentage of trials ending with top-key pecks over the last five many-to-one sessions was 97.0% (range, 89.4% to 99.8%) for the line sample that cued the same choice as the "top-pecked" hue sample versus 3.0% (range, 0.0% to 11.6%) for the line sample that cued the same choice as the "bottom-pecked" hue sample. The 1 pigeon (P40) that did not exhibit differential sample responding consistently pecked the top location for both lines.

Figure 5 also shows that the differential location pecking, once it emerged, appeared to be stable throughout many-to-one training. There were no signs of deterioration in this emergent pattern of differential sample responding, although P42's results are somewhat ambiguous in this regard, given the relatively late emergence of its top versus bottom pecking. Naturally, the possibility remains that these pigeons may have begun to peck the line samples nondifferentially had training been extended beyond 30 sessions (40 sessions for P42). But given the length of time that the differential pattern was maintained once it had emerged, this seems rather unlikely. Consequently, we believe that the data support the hypothesis that blending of the two response patterns in Experiment 2 contributed to its eventual collapse into a single, similar pattern for some pigeons.

#### GENERAL DISCUSSION

The main contribution of the present study to the equivalence literature is the replication

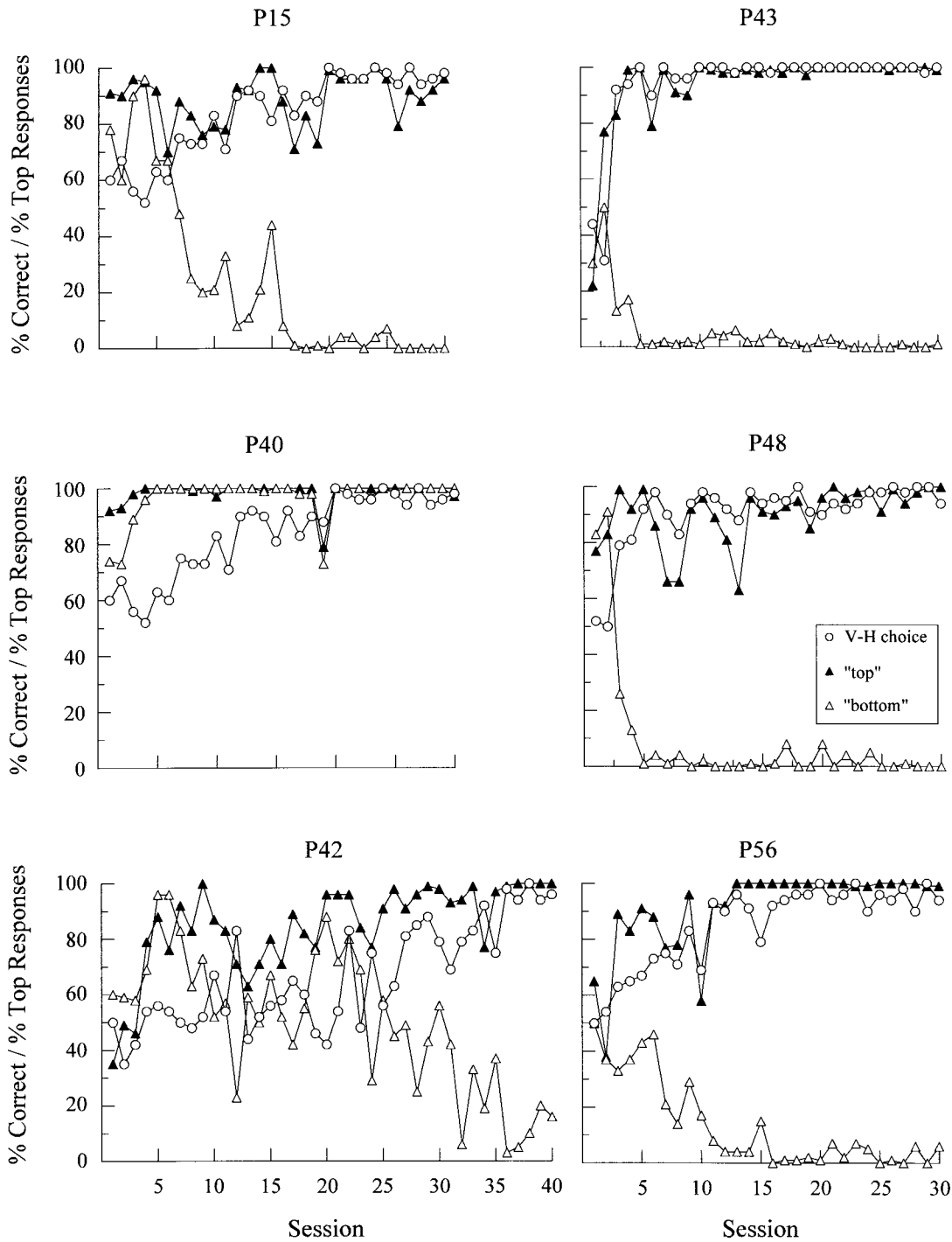


Fig. 5. The percentages of correct choice responses with, and the percentages of time that five consecutive top-location responses were completed to, the new (vertical and horizontal) samples that occasioned the same choice as the baseline top- and bottom-location samples for each pigeon during many-to-one training in Experiment 3.

in pigeons of Manabe et al.'s (1995) finding of emergent differential sample behavior in budgerigars. As mentioned earlier, Manabe et al.'s effect has potentially important theoretical implications. Thus, our success in replicating their effect with a more commonly used species opens the way for a more intensive examination of the origins of the effect and its implication for equivalence class formation. Toward these ends, the three experiments reported here begin to delineate what aspects of conditional discrimination training produce emergent differential sample behavior.

First, as in Manabe et al. (1995, Experiment 3), differential responding appears to emerge to samples that occasion the same comparison choices as other samples to which pigeons must respond differentially. Ideally, the claim that many-to-one relations are responsible for the emergent effect would be buttressed by direct comparison to a multiple-sample matching task that did not involve a many-to-one mapping (cf. Zentall, Urcuioli, Jagielo, & Jackson-Smith, 1989). The prediction, of course, is that training on such a task, in which each reinforced comparison choice is cued by only one sample, would not yield emergent differential sample behavior. Future experiments will be needed to establish this, although we hasten to add that there are no principled reasons to expect otherwise.

Second, identity relations between samples and comparisons are not necessary for the effect, in contrast to the symmetry interpretation offered by Manabe et al. (1995) for some of their results (see also Saunders & Williams, 1998). For 2 budgies, different vocal calls emerged to two form samples that had previously served as comparisons in another (baseline) matching task in which different sample vocal calls were required to produce the form comparisons. If the baseline (vocal call  $\rightarrow$  form) relations were symmetrical, then this would indeed yield the emergent (form  $\rightarrow$  vocal call) relations Manabe et al. later observed. A symmetry account, of course, requires a physical match between the samples occasioning the emergent behavior and the baseline comparisons. In our Experiments 2 and 3, however, differential sample responding emerged despite the absence of physical identity.

Third, the emergent effect appears to require that subjects fulfill either of the two response requirements explicitly programmed for the baseline samples. Without such restriction, differential responding did not emerge (Experiment 1). It is possible, of course, that the contrasting results from Experiments 1 and 2 reflect, in part, the particular response patterns (DRL or FR) conditioned to the baseline samples, and that differential location pecking would have emerged in Experiment 3 even with nondifferential contingencies of the sort used in Experiment 1. This uncertainty, too, will have to be resolved by future work.

Despite these uncertainties, it is worthwhile to consider possible mechanisms for the emergent sample behavior we observed. We have already mentioned acquired equivalence as one possibility, especially in view of other studies showing that samples that participate in many-to-one relations become functionally equivalent when those relations are trained concurrently from the outset (e.g., Astley & Wasserman, 1999; Urcuioli & Lionello-DeNolf, 2001; Urcuioli et al., 1989, Experiment 2; Wasserman et al., 1992). If acquired equivalence can also arise by adding new samples to an existing two-sample/two-alternative matching task (as was done here), then these samples, too, would be interchangeable not only in their reinforced control over choice but also in a new context (cf. Dougher & Markham, 1994; Goldiamond, 1962; Spradlin et al., 1973). In this case, "new context" refers to the manner in which pigeons respond to the samples themselves.

The argument that functionally equivalent samples will occasion similar sample behavior can be evaluated by correlating matching acquisition involving the added samples with the development of differential responding to them. The data from Experiment 3, which were most amenable to this analysis, were used to test the prediction that these two measures should be positively correlated. Figure 6 shows each pigeon's choice accuracy with the added (line) samples on every many-to-one session plotted against its sample discrimination for that same session. Sample discrimination was operationalized as the percentage of trials on which five consecutive line-sample pecks were made to the same location as that to which pecks were directed

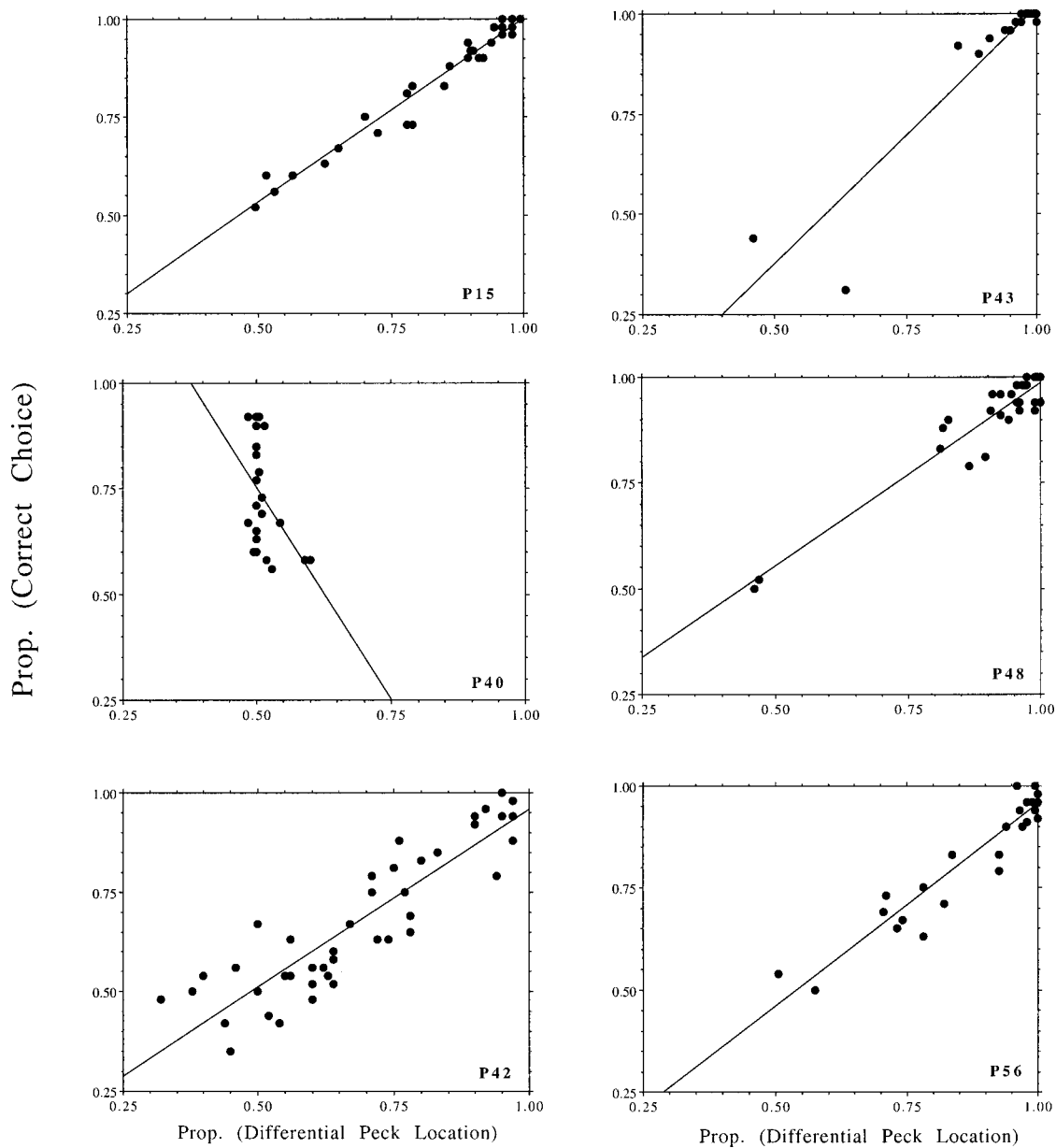


Fig. 6. Scatter plots showing each pigeon's choice accuracy and sample-peck-location accuracy on the added-sample trials of each many-to-one session in Experiment 3.

to the baseline (hue) sample associated with the same reinforced choice. As predicted, each pigeon showed a positive correlation between these two performance measures (range, .64 to .98), excluding the 1 pigeon (P40) that did not show any emergent differential behavior.

A stronger prediction is that differential sample responding should emerge after pi-

geons begin to match accurately with the added samples. In other words, peck-location discrimination should lag behind choice accuracy, assuming that accurate matching on each many-to-one component underlies acquired equivalence between samples occasioning the same reinforced choice. This prediction was evaluated by correlating choice accuracy with the added samples on each

Table 1

Correlations between choice accuracy with the new samples and peck-location discrimination (location accuracy) during many-to-one training in Experiment 3 for the 5 pigeons that showed emergent differential location pecking.  $n$  and  $n+1$  refer to successive many-to-one training sessions.

Pigeon	Choice accuracy ( $n$ ) Location accuracy ( $n+1$ )	Location accuracy ( $n$ ) Choice accuracy ( $n+1$ )
P15	.854	.846
P42	.789	.735
P43	.839	.795
P48	.564	.351
P56	.878	.840

many-to-one session (session  $n$ ) with peck-location “accuracy” on the subsequent session (session  $n + 1$ ) and comparing this value with the reverse correlation (the one between peck-location discrimination on session  $n$  and choice accuracy on session  $n + 1$ ). Table 1 shows these two correlations for the 5 pigeons that exhibited an emergent effect in Experiment 3. As predicted by the acquired equivalence account, the former correlation was higher than the latter for every pigeon, although admittedly most differences were rather small.

#### *An Adventitious Reinforcement Account*

Saunders and Williams (1998) proposed an alternative explanation of emergent differential sample behavior. According to their adventitious reinforcement account, differential behavior develops to the added samples because the two explicitly conditioned sample-response patterns generalize to them and eventually become segregated via reinforcement for the comparison choices that follow. This explanation depends upon a common set of reinforced comparison choices across the two sets of samples (baseline and added), but no appeal to acquired sample equivalence is made or required.

Adventitious reinforcement assumes that baseline matching training establishes two behavioral units, each consisting of an explicitly reinforced sample behavior and a subsequently reinforced comparison choice. When new samples are added to the baseline task, it is hypothesized that pigeons respond to them in a manner similar to the baseline samples. The sample-response pattern on each added-sample trial then occasions the choice

that is part of the established behavioral unit. If this choice is reinforced, the sample behavior that preceded it will tend to occur preferentially on subsequent trials with that sample.

Using Experiment 2 as an example, baseline training supposedly establishes a (DRL  $\rightarrow$  Choice 1) unit to one sample (S1) and an (FR  $\rightarrow$  Choice 2) unit to the other sample (S2) via the reinforcement (+) for these relations:

(S1): (DRL  $\rightarrow$  Choice 1) +

(S2): (FR  $\rightarrow$  Choice 2) +.

Note that the baseline contingencies require DRL to S1 and FR to S2 for the comparison choices to appear, and that Choice 1 is reinforced following S1 and Choice 2 is reinforced following S2.

When new samples (S3 and S4) are later added to this baseline task, pigeons purportedly respond to them with either the DRL or FR pattern, and this is followed by whatever comparison choice had been previously reinforced:

S3: DRL or FR      then      DRL  $\rightarrow$  Choice 1  
S4: DRL or FR      then      FR  $\rightarrow$  Choice 2.

Note that there is no segregation of the two sample-response patterns early in many-to-one training, as depicted on the left. However, if Comparison Choice 1 is consistently reinforced following S3 and Comparison Choice 2 is consistently reinforced following S4, then the (DRL  $\rightarrow$  Choice 1) unit will be preferentially strengthened to S3 and the (FR  $\rightarrow$  Choice 2) unit will be preferentially strengthened to S4. Likewise, nonreinforcement of the alternative choice on each trial should make it less likely for S3 to subsequently occasion the (FR  $\rightarrow$  Choice 2) unit and for S4 to subsequently occasion the (DRL  $\rightarrow$  Choice 1) unit. The net result, then, is the consistent occurrence of spaced (DRL) responding to S3 and rapid (FR) responding to S4:

(S3): (DRL  $\rightarrow$  Choice 1)

(S4): (FR  $\rightarrow$  Choice 2).

The adventitious reinforcement account makes a number of predictions. First, emergent differential sample behavior to S3 and S4 does not develop from undifferentiated

Table 2

Number of new-sample trials ending with a long ( $\geq 1,500$  ms) or short ( $< 1,500$  ms) IRT on the first many-to-one training session in Experiment 2.

Trial type	Emergent pigeon						Nonemergent pigeon					
	D3	D4	D6	D8	F5	F8	D5	D7	F3	F4	F6	F7
Long IRT	38	19	30	19	25	31	0	21	48	0	43	15
Short IRT	10	29	18	29	23	17	48	27	0	48	5	33

beginnings but, instead, arises from existing differential patterns. Second, the pigeon's differential sample behavior exerts conditional control over choice. Third, the reinforced choices following S3 and S4 must be the same as those following S1 and S2 (in other words, many-to-one relations are required). Fourth, the behavior emerging to each new sample should correspond to the behavior explicitly conditioned to the baseline sample that cues the same comparison choice. Fifth, if the sample-response contingencies on the added-sample trials do not require completion of either baseline pattern, different patterns on those trials are unlikely to persist, thus diminishing the chances of emergent differential responding to S3 and S4.

This last prediction is confirmed by the data from Experiment 1, in which the comparisons on S3 and S4 trials were contingent upon completing a nondifferential FI schedule. By contrast, pigeons did show emergent differential sample behavior to S3 and S4 when the comparisons could be obtained only after completing one or the other baseline sample-response contingency (Experiments 2 and 3). Moreover, the behavior emerging to each new sample in Experiments 2 and 3 almost always corresponded to the pattern explicitly conditioned to the baseline sample occasioning the same comparison choice, confirming the fourth prediction.

To evaluate the prediction that emergent differential sample behavior arises via segregation of two preexisting sample-response patterns, we examined the IRTs on each new-sample trial during initial many-to-one training in Experiment 2. For simplicity, we categorized responding to S3 and S4 as (a) DRL responding = the sample ended with a long IRT ( $\geq 1,500$  ms), and (b) FR responding = the sample ended with a short IRT ( $< 1,500$  ms). (We used a 1,500-ms IRT category cutoff to be consistent with the sample discrimina-

tion analyses reported in Experiments 1 and 2.) By definition, each count in the FR responding (or short IRT) category was a trial with 20 sample pecks, which completed the FR 20 schedule requirement. Counts in the DRL responding (or long IRT) category could include IRTs that did not meet the DRL 3-s requirement, but the great majority of those IRTs in fact exceeded 3 s. (For the 6 pigeons that showed emergent differential sample behavior, 98.8% of their DRL category counts over the first 10 many-to-one sessions represented IRTs of 3 s or longer. It is also important to note that there was essentially no overlap between the two categories: Only 0.5% of all trials ending with a 20th peck had a terminal IRT  $\geq 3$  s. These were counted as DRL trials.)

Table 2 shows the number of new-sample trials categorized as DRL (long IRT) or FR (short IRT) responding during the first many-to-one session. The left columns show the results from the 6 pigeons that eventually exhibited emergent differential sample behavior. The right columns show the results from the other 6 pigeons. Every "emergent" pigeon showed instances of both DRL (long IRT) and FR (short IRT) responding to S3 and S4 during the first session, confirming the first prediction. The relative frequency of each type of sample behavior varied across pigeons, but even with the most extreme split (Pigeon D3), the less frequent pattern occurred quite often. By contrast, 3 of the "nonemergent" pigeons (D5, F3, and F4) responded exclusively with one pattern or the other. This latter result also supports the adventitious reinforcement account because without the emission of two distinct response patterns, there is nothing differential to segregate.

Next, we tested the prediction that these sample-response patterns cued the same comparison choices as on the baseline trials.

Table 3

Percentages of new-sample trials in the first many-to-one session of Experiment 2 in which pigeons made the same choice after a terminal long versus short IRT as on baseline DRL versus FR trials and the percentages of those trials that were reinforced. Total numbers of terminal long and short sample IRTs are shown in parentheses.

Pigeon	Same choice after		Same choice reinforced after	
	Long IRT	Short IRT	Long IRT	Short IRT
D3	78.9 (38)	40.0 (10)	53.3	50.0
D4	94.7 (19)	44.8 (29)	100.0	92.3
D6	100.0 (30)	88.9 (18)	60.0	62.5
D8	78.9 (19)	93.1 (29)	100.0	77.8
F5	80.0 (25)	65.2 (23)	90.0	93.3
F8	83.9 (31)	64.7 (17)	76.9	100.0
D7	76.2 (21)	70.4 (27)	75.0	63.2
F6	97.7 (43)	40.0 (5)	50.0	50.0
F7	93.3 (15)	63.6 (33)	85.7	71.4

Here, we calculated the percentages of all S3 and S4 trials terminating in long or short IRTs that were followed by the same choice made after DRL and FR responding on baseline (S1 and S2) trials. If these patterns were a cue for choice, then the percentages should be greater than 50%. The left columns of Table 3 show these percentages for the first many-to-one session in Experiment 2. The 6 pigeons that eventually showed emergent differential sample behavior are grouped together at the top, and the 3 nonemergent pigeons that initially exhibited both response patterns (cf. Table 2) are shown below them.

The comparison choices by each emergent pigeon appeared to be cued, at least in part, by its sample responding, as shown by the relatively high percentages of their new-sample matching trials in which they made the same choice after a long versus short IRT as on baseline trials. The effect was especially noticeable for Pigeons D6 and D8. However, the 3 nonemergent pigeons showed similar results, too. Thus, something in addition to conditional control by the pigeon's sample-response patterns (cf. Cohen, Brady, & Lowry, 1981; Urcuioli, 1984, Experiment 2; Urcuioli & DeMarse, 1994; Urcuioli & Honig, 1980, Experiment 3) determined the eventual development, or lack thereof, of emergent differential sample behavior.

It seems reasonable to expect that relatively frequent reinforcement for these choices would increase the likelihood that differential

Table 4

Percentages of new-sample trials in Experiment 2 in which the reinforced choice following a terminal long versus short IRT was different than on baseline DRL versus FR trials. Total number of different-choice trials (reinforced and nonreinforced) is shown in parentheses.

Pigeon	Session 1		Sessions 1 through 3	
	Long IRT different choice <sup>a</sup>	Short IRT different choice <sup>a</sup>	Long IRT different choice <sup>a</sup>	Short IRT different choice <sup>a</sup>
D3	37.5 (8)	16.7 (6)	65.6 (32)	33.3 (9)
D4	0.0 (1)	25.0 (16)	0.0 (4)	30.8 (39)
D6	(0)	0.0 (2)	25.0 (4)	42.9 (7)
D8	50.0 (4)	50.0 (2)	42.8 (7)	33.3 (3)
F5	0.0 (8)	0.0 (8)	12.5 (16)	0.0 (22)
F8	20.0 (5)	0.0 (6)	52.9 (17)	0.0 (7)
D7	60.0 (5)	37.5 (8)	55.6 (18)	33.3 (12)
F6	0.0 (1)	33.3 (3)	42.9 (7)	56.0 (25)
F7	100.0 (1)	50.0 (6)	100.0 (2)	51.7 (60)

<sup>a</sup> Reinforced.

responding would later emerge to the new samples. The right columns of Table 3 show the percentages of the same-choice trials that were reinforced during the first session. These results too, however, do not correspond in any sensible way to the subsequent new-sample performances. For instance, Pigeon D3 experienced a relatively low percentage of reinforcement on these trials early in training but nonetheless exhibited rapid emergence of differential responding to the new samples (cf. Figure 2). By contrast, both Pigeon F7 and Pigeon D8 experienced a relatively high percentage of reinforcement but only the latter showed the emergence effect.

Another potentially influential variable is how often reinforcement initially occurred for a comparison choice different from the one in each baseline (sample behavior/choice) unit. The expectation is that differential sample behavior should be more likely to emerge with relatively infrequent reinforcement of these different choices. Table 4 presents these data for the first many-to-one session and over the first three sessions for the same pigeons whose data appear in Table 3. Consistent with expectations, the average percentage of different choices that were reinforced for the 6 emergent pigeons was lower than for the 3 nonemergent ones: 18.2% versus 45.8% on Session 1, and 32.3% versus 51.6% over the first three sessions.

We did not record top-versus bottom-sam-

ple responding and comparison choice on a trial-by-trial basis in Experiment 3, so we cannot determine if the analyses described above would have given similar results. Obviously, the predicted pattern of results would be the same. In addition, there is no a priori reason to suspect that the observed pattern of results would have turned out any differently.

*Evaluation of the Adventitious Reinforcement Account and Comparison to Acquired Equivalence*

Despite confirmation of many of its predictions, the adventitious reinforcement account leaves some important questions unanswered. For instance, why would the differential sample behavior that did emerge disappear for some pigeons in Experiment 2, especially if that behavior provided another conditional cue for choice? At a minimum, choice accuracy on those trials should have been temporarily disrupted, but no such disruption was observed. One might dismiss this fact simply by appealing to conditional control by the added samples themselves. Differential sample responding of the sort studied in Experiment 2, however, is known to overshadow choice control by the samples (Urcuioli, 1984, 1985), so some signs of disruption are clearly expected.

Nonetheless, other data suggest the possibility that differential sample responding to S3 and S4 could emerge without such responding exercising substantial control over choice on those trials. Urcuioli and Honig (1980, Experiment 4), for instance, showed that when explicitly conditioned DRL versus FR sample-response patterns are uncorrelated with correct comparison choice in many-to-one matching, these ostensibly “nonpredictive” patterns still cued choices on trials with one pair of samples but not on trials with the other pair. In other words, the functional conditional cue differed across pairs of samples. Perhaps something similar happened for Pigeons D3, D4, D6, and D8 in Experiment 2 (cf. Figure 2): Differential sample responding governed their choices on the baseline (S1 and S2) trials but not on the new-sample (S3 and S4) trials. By contrast, perhaps the comparison choices of Pigeons F5 and F8 were governed by the same functional cue, their sample-specific behavior, on all trials.

In any event, a more important and challenging issue is distinguishing between the adventitious reinforcement account of emergent differential sample behavior and acquired equivalence. As mentioned before, many-to-one relations are indispensable to both accounts. For acquired equivalence, the common choices shared by the baseline and added samples are the very source of the sample equivalence that presumably generates the emergent behavior. For adventitious reinforcement, the reinforcement of the same comparison choices on added-sample trials as on baseline trials is necessary for the baseline behavioral units, the source of the emergent behavior, to develop to the new samples. In short, the two explanations will make the same predictions across a wide variety of procedural variations and designs.

For example, neither predicts emergent behavior when the comparisons on the added-sample trials differ from those on the baseline trials. Likewise, when the choices are identical across pairs of samples, both accounts predict emergent behavior independently of the specific nature of the sample-comparison relations (identity, oddity, or symbolic). Moreover, both predict the same pattern of segregation to the new samples. It appears, then, that the present paradigm cannot be used to distinguish between adventitious reinforcement and acquired equivalence, which is unfortunate because it provided the very data that prompted the adventitious reinforcement alternative in the first place.

Testing for emergent behavior outside the matching context may be the only way to establish, albeit indirectly, a role for acquired sample equivalence. For instance, pigeons could be taught many-to-one matching with a single-peck requirement to all samples. Afterwards, they could learn to obtain food by completing a DRL schedule to one of the former samples and an FR schedule to another. Would these two response patterns then develop to the remaining “samples” when completing either response requirement to them yields food? If so, this would demonstrate an acquired equivalence effect analogous to that seen when the new behavior conditioned after many-to-one training is choosing between comparisons that are different than those

that appear in many-to-one matching (e.g., Urcuioli & Lionello-DeNolf, 2001).

Emergent differential responding to the samples themselves in many-to-one matching may thus provide another index of acquired equivalence and, therefore, is a worthwhile pursuit. Even so, it should not direct attention away from another possible role of differential sample behavior in the Manabe et al. (1995) paradigm and our version of it. Specifically, could each of the explicitly conditioned differential sample-response patterns join an acquired equivalence class by cueing the same choice as another, nominal sample stimulus? After all, those patterns are known to function just like exteroceptive sample stimuli in matching paradigms (e.g., Urcuioli, 1984, 1985; Urcuioli & DeMarse, 1994). It should be possible to alter the present paradigm in such a way to test the intriguing idea, suggested by Sidman (1994, 2000), that responses as well as stimuli can join equivalence classes.

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