Mediated transfer testing provides evidence for common coding of duration and line samples in many-to-one matching in pigeons

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A three-phase transfer design was used to determine whether pigeons use a single, common code to represent line and duration samples that are associated with the same comparison stimulus. In Phase 1, two sets of samples (two lines and two durations) were associated with either a single set of comparisons (Group MTO, many-to-one) or with different sets of comparisons (Group OTO, one-to-one). In Phase 2, one set of samples was associated with a new set of comparisons. In Phase 3 (transfer test), the alternate set of samples was substituted for the Phase 2 samples. Group MTO, but not Group OTO, demonstrated immediate transfer. It was concluded that associating a line and a duration sample with the same comparison stimulus results in representation of those samples by a single code.

Memory for duration in pigeons can be assessed by using a two-choice matching-to-sample procedure. In this procedure, pigeons are reinforced for choosing one comparison stimulus (e.g., a red key) after a short (e.g., 2-sec) sample presentation, and for choosing the alternative comparison stimulus (e.g., a green key) after a long (e.g., 10-sec) sample presentation. During a test in which retention interval is manipulated, pigeons make systematic errors; specifically, accuracy decreases to a much greater extent on trials initiated by a long sample presentation than on trials initiated by a short sample presentation. This *choose-short effect* has been obtained in numerous studies in which a choice matching-to-sample procedure was used (e.g., Grant & Spetch, 1991, 1993a; Kraemer, Mazmanian, & Roberts, 1985; Spetch, 1987; Spetch & Grant, 1993; Spetch & Rusak, 1989, 1992; Spetch & Wilkie, 1982, 1983).

One interpretation of the choose-short effect is provided by the subjective-shortening hypothesis. According to this hypothesis, pigeons normally retain an analogical representation of sample duration (e.g., the number of pulses generated by an internal pacemaker during sample presentation; see Church, 1989; Gibbon & Church, 1984) and assess duration retrospectively at the time of choice (e.g., Grant, 1993; Spetch & Sinha, 1989; Spetch & Wilkie, 1983; Wilkie & Willson, 1990). The choose-short effect is held to result from a process in which remembered duration shortens as a function of time since termi-

nation of the sample (e.g., Spetch, 1987; Spetch & Wilkie, 1983).

Recently, we tested the subjective-shortening account by attempting to induce nonanalogical coding of duration in pigeons (Grant & Spetch, 1993a). Because nonanalogical coding of duration would preclude a subjective-shortening process, the account predicts that the choose-short effect should fail to occur under these circumstances. To test this prediction, we employed a many-to-one sample-to-comparison mapping arrangement in which two samples, one duration and one line orientation, were associated with each comparison stimulus.

We reasoned, in accord with others (e.g., Grant, 1982, 1993; Maki, Moe, & Bierley, 1977; Urcuioli, Zentall, Jackson-Smith, & Steirn, 1989; Zentall, Sherburne, & Steirn, 1993; Zentall, Steirn, Sherburne, & Urcuioli, 1991; Zentall, Urcuioli, Jackson-Smith, & Steirn, 1991), that the samples associated with the same comparison stimulus would likely be represented by a single, common code. For example, a prospective coding scheme might be employed in which samples associated with the red comparison activate the common code "peck red," and samples associated with the green comparison activate the common code "peck green." Alternatively, a coding scheme might be employed in which samples associated with one comparison activate the common code "Sample A," and samples associated with the alternative comparison activate the common code "Sample B." If the subjective-shortening account of the choose-short effect is correct, then a retention test would fail to reveal such an effect if either form of common coding is employed.

In the experiment of primary interest (Grant & Spetch, 1993a, Experiment 2), two groups of pigeons were each trained on two two-choice matching-to-sample tasks, one involving line samples (horizontal and vertical) and the

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other involving duration samples (2- and 10-sec presentations of houselight). During initial training, all trials involved the line samples. Following acquisition of accurate matching to line samples, half of the trials within each session involved duration samples. The comparisons on duration-sample trials were the same for both groups (red and green colors), but differed on line-sample trials. On these latter trials, the comparisons were also red and green in Group MTO (many-to-one), whereas they were different line orientations in Group OTO (one-to-one). Thus, Group MTO experienced a many-to-one mapping in which pairs of line and duration samples were associated with common comparisons, whereas Group OTO experienced a one-to-one mapping in which every sample was associated with a different comparison stimulus.

On the basis of the subjective-shortening hypothesis, we predicted a choose-short effect for Group OTO (because they would presumably code the duration samples analogically), but not for Group MTO (because their codes would presumably be nonanalogical). The results confirmed these predictions. As retention interval increased, accuracy declined to a much greater extent on long- than on short-sample trials in Group OTO, whereas accuracy declined at an equivalent rate on long- and short-sample trials in Group MTO.

The purpose of the present experiment was to provide further evidence that pigeons engage in common coding when duration and visual samples are used in many-to-one matching. A mediated-transfer technique developed by Urcuioli et al. (1989) was used to index common coding. Urcuioli et al. argued that if samples associated with the same comparison stimulus activate a single, common code, then transfer of control between those samples should occur. To assess such transfer, Urcuioli et al. (Experiment 2) initially trained pigeons in a many-to-one mapping task in which one color sample and one line sample were associated with each line comparison. In a second phase, the color samples were associated with new comparison stimuli (circle and dot). In the final (transfer) phase, the line samples were followed by the circle and dot comparisons. As anticipated by the common coding view, the choice behavior controlled by the color samples in Phase 2 transferred to the line samples in Phase 3.

The design that we used to assess common coding of visual and duration samples in the present experiment (see Table 1) was similar to that employed by Urcuioli et al. (1989). Following the training and testing reported by Grant and Spetch (1993a, Experiment 2), Groups MTO and OTO received a second phase of training in which one set of samples (lines for some birds and durations for others) was associated with a new set of comparisons (circle and dot). In Phase 3, the circle and dot comparisons were presented on trials initiated by the alternative set of samples.

Notice that the discrimination tasks presented in Phases 2 and 3 were identical for Groups OTO and MTO (see Table 1). Thus, any between-group differences in performance in either Phase 2 or 3 (or both) could be attributed to differences in prior training history. It was anticipated

Table 1
Summary of Procedure

Group	n	Phase 1	Phase 2	Phase 3
		Transferred to Durations		
MTO	3	S→G+/R−		
		L→R+/R−	H→D+/C−	S→D+/C−
		H→R+/G−	V→C+/D−	L→C+/D−
		V→G+/R−		
OTO	3	S→G+/R−		
		L→R+/G−	H→D+/C−	S→D+/C−
		H→H+/V−	V→C+/D−	L→C+/D−
		V→V+/H−		
		Transferred to Lines		
MTO	4	S→G+/R−		
		L→R+/G−	S→D+/C−	H→D+/C−
		H→R+/G−	L→C+/D−	V→C+/D−
		V→G+/R−		
OTO	4	S→G+/R−		
		L→R+/G−	S→D+/C−	H→D+/C−
		H→H+/V−	L→C+/D−	V→C+/D−
		V→V+/H−		

Note—S = 2-sec houselight; L = 10-sec houselight; V = vertical line; H = horizontal line; G = green field; R = red field; D = dot; C = circle. Samples are represented by letters to the left of the arrows, and comparisons are represented by letters to the right of the arrows. Counterbalancing of comparisons has been omitted for clarity. + = correct comparison; − = incorrect comparison. MTO = many-to-one; OTO = one-to-one.

that the two groups would perform similarly in Phase 2 and that their initial accuracy would approximate chance level. In Phase 3, on the other hand, between-group differences in performance were anticipated. If samples associated with the same comparison in Phase 1 activate a single, common code, then Phase 2 training would provide a basis for subsequent transfer in Group MTO, but not in Group OTO, during Phase 3. The contingencies in Phases 2 and 3 required Group MTO to make *opposite* choices on trials initiated by samples that had been associated with the same comparison in Phase 1. It was therefore anticipated that Group MTO would (1) demonstrate lower accuracy than Group OTO, and (2) initially match at a level below chance.

We chose transfer contingencies that would interfere with (rather than facilitate) Phase 3 performance in Group MTO because we anticipated that the familiar samples and comparisons used in training might allow very rapid learning in Group OTO. If so, detecting a relative facilitation in performance in Group MTO would be more difficult than detecting reduced accuracy in Group MTO.

METHOD

Subjects

Sixteen pigeons that had served in Grant and Spetch's (1993a) Experiment 2 were employed: 8 from Group OTO and 8 from Group MTO. In addition to serving in that experiment, the subjects had also received double-sample testing in which two duration samples were presented successively on a trial (Grant & Spetch, 1993b, Experiment 1). Two birds, 1 from each group, became ill during the course of training and did not complete the present experiment. Thus, Groups OTO and MTO each consisted of 7 birds.

The birds were maintained at 80% of their free-feeding weights and were maintained on a 14:10-h light:dark cycle with light onset at 6:00 a.m. Each bird received six or seven sessions per week at the rate of one session per day. Sessions were conducted in the mid- and late morning. For each bird, session starting times varied across days by no more than 30 min.

Apparatus

Eight identical chambers, 29 × 29 × 24 cm, were employed. Three pecking keys (2.5 cm in diameter) were mounted horizontally in a row, 23 cm above the floor and spaced 8 cm apart. A force of approximately 0.15 N or greater was required to operate the keys. An Industrial Electronics, Inc. (Van Nuys, CA), in-line projector mounted behind each key was used to project stimuli onto the pecking key. A 5.0 × 5.5 cm opening, the top of which was 10 cm below the center pecking key, provided access to a food magazine that was illuminated when activated. A 28-V houselight, the shield of which was adjusted so that the light emitted was directed toward the ceiling of the chamber, was mounted 4 cm above the center pecking key. Each test chamber was enclosed in a sound- and light-attenuating enclosure. Masking noise was provided by an exhaust fan within the enclosure and by white noise delivered through a speaker in the testing room. The presentation of events within the chambers and the recording of data was accomplished by using a microcomputer located in a separate room.

Procedure

Phase 1. Prior to the present experiment, the birds in the MTO and OTO groups had acquired the Phase 1 matching task shown in Table 1 (see Grant & Spetch, 1993a, Experiment 2, for details). Prior to the beginning of Phase 2 training, the birds received 32 refresher sessions of Phase 1 training. These sessions consisted of 64 trials separated by a variable intertrial interval with a mean of 20 sec (range of 10–30 sec). Each trial began with the illumination of the center key by the preparatory stimulus (a white triangle on a black background). The preparatory stimulus was terminated by a single peck or, in the absence of a peck, after 5 sec. Termination of the preparatory stimulus was followed immediately by onset of the overhead houselight on half of the trials and by onset of a white vertical or horizontal line on a black background on the center key on the other half of the trials. The duration of the houselight was equally often short (2 sec) and long (10 sec), and the line orientation was equally often vertical and horizontal. The determination of the sample to be presented on any particular trial was random in each session, with the restriction that each of the four samples (2-sec houselight, 10-sec houselight, vertical line, and horizontal line) was presented 16 times. The position of the correct comparison stimulus was balanced within sample type.

For the birds in both groups, termination of a temporal sample was followed immediately (0-sec delay) by illumination of the two side keys, one with red light and the other with green light. A single peck on either comparison stimulus terminated both comparison stimuli. If the correct comparison was pecked, a 3-sec presentation of grain occurred as reinforcement. If the incorrect comparison was pecked, the trial terminated without reinforcement and 3 sec were added to the intertrial interval. For 4 of the birds in each group, green was correct on short-sample trials and red was correct on long-sample trials; for the 3 remaining birds in each group, the contingencies were reversed.

For the birds in the OTO group, the line sample terminated after 6 sec and was followed immediately (0-sec delay) by illumination of the two side keys, one with a horizontal line and the other with a vertical line. For all 7 birds, horizontal was the correct comparison on horizontal-sample trials and vertical was the correct comparison on vertical-sample trials. Correct responses were followed

by 3-sec access to food; incorrect trials terminated without food and 3 sec were added to the intertrial interval. For the birds in the MTO group, trials involving the line samples were the same as those for the birds in the OTO group, except that red and green, rather than horizontal and vertical, were used as the comparison stimuli. For all 7 birds, red was the correct comparison on horizontal-sample trials and green was the correct comparison on vertical-sample trials.

Phase 2. On the session following the end of Phase 1, each bird began training on a new conditional discrimination (see Table 1) involving one of the sets of samples from Phase 1 (lines for 3 birds in each group and durations for 4 birds in each group) and new comparison stimuli: a white circle on a black background and a black dot on a white background. For the birds trained with line samples, the dot was correct on horizontal-sample trials and the circle was correct on vertical-sample trials. For those trained with duration samples, the dot was correct on short-sample trials and the circle was correct on long-sample trials. Phase 2 sessions consisted of 64 trials, 32 with each of the two samples. All other aspects of Phase 2 sessions were identical to those of Phase 1. Phase 2 involved the daily alternation of Phase 1 and Phase 2 training sessions. A total of 56 sessions were conducted; 28 Phase 1 sessions and 28 Phase 2 sessions.

Phase 3. On the session following the end of Phase 2, each bird was transferred to a matching task involving the alternate set of samples from Phase 1 (i.e., durations for the birds trained with lines in Phase 2, and lines for the birds trained with durations in Phase 2) and the dot and circle comparisons from Phase 2 (see Table 1). The reinforcement contingencies on Phase 3 trials were identical in the MTO and OTO groups and were arranged so that common coding in the MTO group in Phase 1 would result in negative transfer in Phase 3. Specifically, samples that had been associated with the same comparison in Phase 1 (e.g., short and vertical with green) were associated with different comparisons in Phases 2 and 3 (e.g., vertical with circle and short with dot).

Phase 3 sessions consisted of five cycles of 12 trials each. Within each cycle, each of the two samples (short and long durations of houselight for 3 birds in each group, and horizontal and vertical lines for the 4 remaining birds in each group) was presented six times and position of the correct comparison was balanced within sample type. The order in which the four trial types (2 samples × 2 correct comparison positions) occurred within a cycle varied randomly from cycle to cycle, both within and between sessions. All other aspects of Phase 3 sessions were identical to those of Phases 1 and 2.

There were three Phase 3 sessions. Five Phase 1 and five Phase 2 sessions, presented in alternating order, preceded the second Phase 3 session. The third Phase 3 session was preceded by a single Phase 1 and a single Phase 2 session.

Data analysis. In all statistical analyses, the rejection criterion was set at $p < .05$.

RESULTS

Phase 1

Matching accuracy was 96.3% correct during the last four refresher sessions of Phase 1 (OTO and MTO training). A group (OTO and MTO) × transfer type (birds to be transferred to duration samples in Phase 3 and birds to be transferred to line samples in Phase 3) × sample type (durations and lines) analysis of variance (ANOVA) was performed on the data from the final four sessions. The only significant term was sample type [$F(1,10) = 44.23$], revealing that accuracy on line-sample trials

(97.6%) was higher than accuracy on duration-sample trials (95.0%).

Phase 2

In Phase 2, the birds were trained on a matching task involving familiar samples and new comparisons. Matching accuracy in Groups OTO and MTO during the first three sessions of Phase 2, collapsed across sample type, is shown in the left half of Table 2. It is clear from inspection of the table that the two groups did not perform differently during the first three sessions and that initial accuracy approximated chance level.

During the last four sessions of Phase 2 (not shown in the table), matching accuracy was 95.2% correct in Group OTO and 96.5% correct in Group MTO. Collapsed across the OTO and MTO groups, accuracy was 94.5% correct for the birds trained with line samples, versus 97.2% correct for those birds trained with duration samples. A group × sample type (lines and durations) ANOVA performed on the final four sessions revealed no significant terms.

A group × sample type × session ANOVA performed on the data from all 28 Phase 2 training sessions revealed a significant main effect of session [$F(27,270) = 40.01$]. Neither the main effect of group ($F < 1$) nor sample type [$F(1,10) = 1.18$] was significant. There were no significant interactions.

Phase 1 refresher sessions alternated with Phase 2 training sessions throughout Phase 2. Accuracy was 96.7% correct during the final four of these Phase 1 refresher sessions. A group × transfer type × sample type ANOVA performed on the final four Phase 1 refresher sessions revealed no significant terms.

Phase 3

In Phase 3, the birds were transferred to a matching task involving the comparisons from Phase 2 and the alternate set of samples from Phase 1. Matching accuracy in Groups OTO and MTO during each of the three Phase 3 sessions, collapsed across sample type, is shown in the right half of Table 2. As shown in the table, accuracy was significantly lower in Group MTO than in Group OTO in Sessions 1 and 2. In Session 3, accuracy level in the two groups did not differ.

A more molecular analysis of performance in Phase 3 is shown Figure 1, in which matching accuracy in each 12-trial cycle is plotted. Inspection of the figure reveals
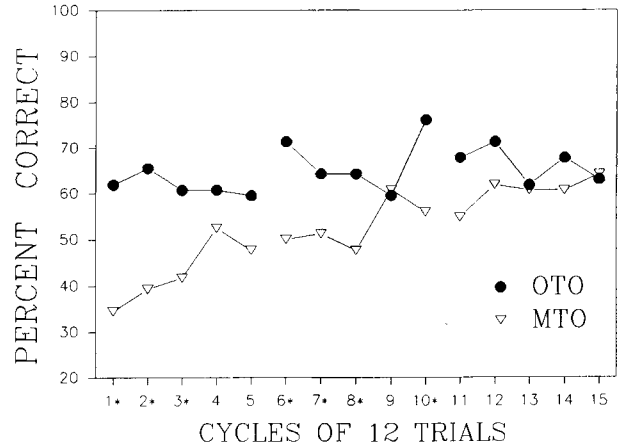

Figure 1. Percentage of correct responses in each 12-trial cycle during the three sessions of transfer testing (Phase 3). Cycles in which accuracy was significantly higher in Group OTO than in Group MTO are marked by an asterisk.

that initial accuracy in Group MTO was both below chance and lower than in Group OTO. The between-group difference (1) was more pronounced in the initial cycles of each session than in later cycles, and (2) decreased in magnitude across the three sessions. A group × sample type × cycle ANOVA revealed two significant terms: the main effect of cycle [$F(14,140) = 3.56$] and the group × cycle interaction [$F(14,140) = 2.27$].

To further evaluate the group × cycle interaction, two-tailed t tests were used to compare accuracy levels of the OTO versus MTO birds in each cycle. Significantly higher accuracy for the birds initially trained with an OTO mapping than for those initially trained with an MTO mapping is indicated in Figure 1 by an asterisk following the cycle number. Accuracy was significantly higher in Group OTO than in Group MTO in the first three cycles of both the first [$t(12) = 2.88$, 3.48, and 2.24] and second [$t(12) = 4.21$, 2.27, and 2.19] transfer sessions (recall that five Phase 1 and five Phase 2 sessions intervened between the first and second transfer sessions) and in the final cycle of the second transfer session [$t(12) = 2.54$].

Additional two-tailed t tests were used to determine whether accuracy in either group deviated significantly from chance (50%) during the initial cycles of Session 1. These tests revealed that accuracy was significantly below chance in Group MTO in Cycles 1 and 2 [$t(6) = 2.77$ and 2.47], but did not differ from chance in Cycles 3, 4, and 5 [$t(6) = 1.45$, 0.51, and 0.38]. A similar analysis performed on the data from Group OTO revealed that accuracy did not differ significantly from chance in any of the five cycles of Session 1 [$t(6) = 1.55$, 2.11, 1.36, 1.48, and 1.71].

DISCUSSION

The results reported in the present article converge with those reported by Grant and Spetch (1993a) and Santi

Table 2
Mean Percentage of Correct Responses in Sessions 1, 2, and 3 of Phases 2 and 3

Session	Phase 2			Phase 3		
	OTO	MTO	t	OTO	MTO	t
1	53.6	53.1	0.15	61.7	43.1	2.77*
2	61.3	61.4	−0.03	67.1	53.1	2.54*
3	63.9	69.6	−0.90	66.4	60.5	0.74

Note—OTO = one-to-one; MTO = many-to-one. *$p < .05$, two-tailed.

et al. (1993) and suggest that when duration samples are used in a many-to-one sample-to-comparison mapping arrangement, pigeons engage in common coding in which each sample associated with the same comparison is represented by a single, common code. It is significant that a methodology different from that employed by Grant and Spetch and by Santi et al. was used to obtain support for this conclusion in the present article. Specifically, Grant and Spetch and Santi et al. employed a retention test to diagnose the form of coding, whereas a mediated transfer test was used in the present experiment.

Grant and Spetch (1993a) and Santi et al. (1993) discovered that a retention test failed to reveal a choose-short effect following training in a many-to-one mapping, in which one duration sample and one visual sample were associated with each comparison stimulus. These investigators suggested that many-to-one training results in samples that are associated with the same comparison stimulus activating a single, nonanalogical common code (e.g., "peck red," "Sample A"). According to this view, the choose-short effect did not occur following many-to-one training because a process of subjective shortening of remembered duration is precluded if duration samples are coded nonanalogically.

The results reported here reinforce the conclusion that when duration samples are used in a many-to-one mapping, they activate nonanalogical common codes. The present evidence was obtained by using the mediated transfer test introduced by Urcuioli et al. (1989). Following training with two sets of sample stimuli (Phase 1), one set of samples was associated with a new set of comparison stimuli (Phase 2). In the transfer test (Phase 3), the alternate pair of samples was substituted for the Phase 2 samples. The birds that had experienced a many-to-one mapping in Phase 1 (Group MTO) demonstrated immediate transfer in Phase 3. That is, the choice of a comparison in Phase 3 depended upon which one had been associated with the alternate member of that sample pair. The finding that the birds that had experienced a one-to-one mapping in Phase 1 (Group OTO) did not demonstrate immediate transfer in Phase 3 indicates that the transfer in Group MTO was mediated by the common coding of the line and duration samples in Phase 1.

As an alternative to our interpretation based on mediated transfer, it might be suggested that the results of Phase 3 reflected the effects of the MTO versus OTO training per se. For example, the birds in Group OTO might have been able to learn new matching tasks faster than those in Group MTO because they had experienced more sample–comparison combinations in Phase 1. In our view, two considerations render such an account implausible. First, if differential performance in Phase 3 was due solely to the MTO versus OTO training, then performance differences should also have appeared in Phase 2. Recall, however, that neither of the main findings obtained in Phase 3 was present in Phase 2. That is, during initial Phase 2 sessions, Group MTO did not (1) perform below chance, or (2) perform less accurately

than Group OTO. Second, such an account provides no explanation for the finding that initial Phase 3 accuracy was *below chance* in Group MTO. Thus, we contend that the results in Phase 3 occurred because a common code was used to represent pairs of duration and line samples in Group MTO, whereas separate codes were used for each sample in Group OTO.

The results reported in the present article add to a growing body of literature that suggests that many-to-one training results in samples associated with the same comparison stimulus activating a single, common code (e.g., Grant, 1982, 1993; Maki et al., 1977; Urcuioli et al., 1989; Zentall et al., 1993; Zentall, Steirn, et al., 1991; Zentall, Urcuioli, et al., 1991). An interesting question requiring further research concerns the specific nature of the common code employed in a many-to-one mapping involving duration and visual samples. For example, the common code activated by a line and a duration associated with the same comparison might be a prospective code (e.g., "peck red") or a sample-derived code (e.g., "Sample A"). Although the precise form of the common code has yet to be definitively identified, it is clear that the coding of duration samples (e.g., Grant, 1993; Grant & Spetch, 1993a; Santi et al., 1993), hedonic samples (e.g., Grant, 1991), and visual samples (e.g., Urcuioli et al., 1989; Zentall, Urcuioli, et al., 1991) is a flexible process that is responsive to task demands.

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