Matching-to-sample performance by pigeons trained with visual-duration compound samples

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Pigeons were trained on duration matching-to-sample in which each of four combinations of signal type (red or white light) and duration (2 or 10 sec) was mapped onto a different choice stimulus. Probe trials in Experiments 1 and 2 involved a successive presentation of two duration samples. In each experiment, birds tended to summate two durations when the same signal was presented twice, but not when two different signals appeared. These results contrast with those reported by Spetch and Sinha (1989), who found a summation effect with both same-signal and different-signal compounds. In Experiment 3, pigeons chose among two alternatives which were both associated with the duration of the sample but of which only one was also associated with the signal type of the sample. Pigeons systematically chose the stimulus that matched both sample duration and signal type. The implications of these findings are discussed in terms of transfer of training and coding of event duration.

Studies of duration matching-to-sample (MTS) have shown that animals are quite adept at judging stimulus duration, and that they can use perceived duration as a conditional cue for subsequent discriminative responding (Church, 1980, 1984; S. Roberts & Church, 1978; Spetch & Wilkie, 1983). Recent evidence also indicates that animals can segregate the duration of a stimulus from its other sensory-specific properties. For example, after training on a conditional duration discrimination with tones, both rats (Church & Meck, 1984) and pigeons (W. A. Roberts, Cheng, & Cohen, 1989) have shown excellent transfer when tested with light durations.

Related findings have been reported with interdimensional attributes. Spetch and Sinha (1989, Experiment 2) first trained pigeons to respond to two durations of two different signals—for example, a houselight and illumination of the food hopper. The same set of choice stimuli was used on all trials such that a short duration (2 sec) of either signal type was associated with one choice stimulus, and a long duration (10 sec) of either signal type was associated with the other choice stimulus. The critical manipulation involved probe trials during which two sample durations occurred successively, separated by a brief (e.g., 2 sec) interstimulus interval. On some test trials, durations of the same signal appeared; on others, durations of two different signals appeared. The important finding was that the birds behaved as if they were summing the two durations, regardless of whether the signals were the same or different. The most striking indication of summation was found on trials in which the first sample was 10 sec and the second was 2 sec: Birds re-

sponded as if a single long-duration sample had appeared, and the effect was equally strong on same-signal and different-signal trials.

A procedural feature of the Spetch and Sinha (1989) study shared by the experiments on cross-modal transfer involves the use of a single set of choice stimuli (e.g., W. A. Roberts et al., 1989). Kraemer (1991), however, recently reported that the use of unique choice alternatives can influence the degree to which pigeons transfer duration matching across two stimulus modalities or dimensions. In one of Kraemer's experiments, samples consisted of 2- and 10-sec durations of either a white houselight or a tone, with different choice stimuli associated with each signal type (e.g., short and long tones were mapped onto red and blue comparisons, and short and long lights were mapped onto green and yellow comparisons). Throughout training, the same set of choice stimuli always followed these two sample types, but during testing, the comparison sets were periodically reversed (e.g., after a houselight duration, green and yellow appeared instead of red and blue).

If birds had learned to respond to sample duration independently of its sensory-specific properties, then test-trial performance should have remained high. To the contrary, however, accuracy was extremely low when the choice stimuli were not those originally associated with the preceding sample. These results suggest that pigeons trained with different choice stimuli mapped onto different signal types are responsive to the sensory-specific features of the duration sample. This is interesting, given that sample duration alone was a sufficient cue for accurate responding and that the sensory-specific features of the samples did not provide any additional information regarding which choices were correct.

The present study further examined the degree to which training with unique comparison sets alters processing of

This research was supported by a grant from the National Institute of Mental Health (1 R01 MH 44082-02) to P. J. Kraemer. Correspondence should be addressed to P. J. Kraemer, Department of Psychology, University of Kentucky, Lexington, KY 40506-0044.

duration samples in a symbolic MTS task. In Experiment 1, we used a modified version of the procedure described by Spetch and Sinha (1989). Pigeons were first trained with unique comparison sets associated with short and long durations of two different signals. Pigeons then received probe trials in which 10- and 2-sec samples were presented successively, separated by a 1-sec interstimulus interval. The two samples were either the same or different signals. On half of the trials in which two different signals appeared, the choice stimuli were those appropriate for the 10-sec sample; on the remaining trials, the choice stimuli were those appropriate for the 2-sec sample.

Spetch and Sinha's (1989) results suggested that we would find a summation effect both when the same signal was presented twice and when two different signals appeared. However, given Kraemer's (1991) finding that pigeons do not readily transfer choice responding from one duration signal to another when trained with unique choices, an alternative prediction was that pigeons would discriminate, rather than summate, durations of two different signals.

EXPERIMENT 1

Method

Subjects and Apparatus. The subjects were 4 White Carneaux pigeons, obtained from a commercial breeder, that had been used in a previous duration MTS study (Kraemer, 1991, Experiment 2). The birds were housed in individual stainless steel cages located in a climate-controlled vivarium, which operated on a 16-h-on/8-h-off light cycle. All testing occurred during the light-on period. The apparatus consisted of a standard pigeon test chamber with three horizontally aligned pecking keys fitted with in-line stimulus projectors. The choice stimuli consisted of red, blue, green, and yellow solid colors presented on the side keys. The two signal types used for samples consisted of illumination of a red light (RL), which was attached to the front wall and fitted with a convex translucent plastic lens, and illumination of a white houselight (HL), which was centered in the ceiling and covered with a 4 × 5 cm translucent plastic lens. Both signal types provided diffuse ambient illumination. An electromechanical food hopper presented mixed grain through an aperture centered on the front wall and placed below the row of pecking keys. Stimulus presentations and recording of responses were controlled by a Commodore 64 computer and a locally constructed computer interface.

Procedure. Each of the 4 pigeons had previously been trained on two duration MTS problems, one in which HL was presented for 2 or 10 sec and one in which RL appeared for the same two durations. Two birds had first acquired the RL problem, and then the HL problem (Group RL-HL); the other two birds had acquired the two problems in the opposite order (Group HL-RL). During initial acquisition, each trial began with the presentation of a sample, which terminated after 2 or 10 sec and was followed immediately by the presentation of two choice stimuli on the two side keys. Peck responses to correct choices resulted in 2 sec of access to mixed grain followed by a 15-sec ITI; incorrect responses immediately initiated the ITI. Different sets of comparison stimuli were mapped onto the two signal types, according to the arrangement outlined in Table 1.

A noncorrection training procedure was used for each 48-trial session. Training continued until a criterion was reached in which each bird completed five consecutive sessions of 85% or greater accuracy. Once criterion was reached on the first problem, train-

Table 1
Samples and Correct Choice Arrangements Used in Experiment 1

Subject	Signal Type	Sample Duration (sec)	Correct Choice Stimulus
9	HL	2	Red
		10	Blue
	RL	2	Green
		10	Yellow
10	HL	2	Blue
		10	Red
	RL	2	Yellow
		10	Green
11	HL	2	Green
		10	Yellow
	RL	2	Red
		10	Blue
12	HL	2	Yellow
		10	Green
	RL	2	Blue
		10	Red

Note—HL = houselight; RL = red wall-light.

ing on the second problem began in the next session. Following acquisition of the two problems, additional training sessions were presented during which each of the four combinations of signal type and duration were presented equally often. The same comparison set (see Table 1) always followed the same signal type. Preliminary experimental testing (see Kraemer, 1991, Experiment 2) involved probe trials in which comparison sets were presented that were not those originally associated with the preceding sample. This test phase was followed by 10 additional baseline training sessions. The present experiment began immediately thereafter.

Each bird received a regimen in which test sessions alternated regularly with training sessions across days. The 48-trial mixed-signal training sessions presented the four possible sample types (2- and 10-sec presentations of HL or RL) 12 times each. The left/right position of the choice stimuli was balanced across trial types, which were randomly arranged during each session for each bird. Test sessions differed from training sessions in that 24 probe trials were interspersed among 40 nonprobe trials. Each probe trial consisted of two duration samples presented successively: The first was always 10 sec and the second was always 2 sec; a 1-sec interval separated the two. The choice stimuli appeared immediately after the last sample terminated. Half of all probe trials involved two presentations of the same signal type (same compound) followed by the choice stimuli associated with that signal type. The remaining probe trials involved two different signal types (different compound). On half of the different-compound trials, the choice stimuli were those appropriate for the 10-sec sample; on the other half, the choice stimuli were those appropriate for the 2-sec sample. Reinforcement was omitted on probe trials, and the left/right position of the choice stimuli was balanced across trial types. The 64 trials within a test session were arranged randomly for each bird during each of the 12 test sessions.

Results

For purposes of data analysis, correct choices were arbitrarily defined either by the 2-sec sample on same-compound trials or by the duration of the signal type tested, irrespective of its sensory-specific features, on different-compound trials. The mean percent correct responses for each of the five trial types, collapsed over signal type, are presented in Figure 1.

Figure 1. Mean percent correct choices in Experiment 1 on short (S) and long (L) element samples and on compound duration samples involving the same signal type (same compound) or different signal types (different compound). The asterisk (*) indicates the duration component of the compound that was used to define the correct choice alternative for same-compound and different-compound probe trials.

As can be seen, subjects were quite accurate on short and long nonprobe ("element") trials in which only a single sample appeared. It is also clear that accuracy was substantially higher on these trials than on each type of probe trial. The most striking aspect of these results is the high degree of inaccuracy found on same-compound trials, during which the same signal type appeared twice. Although accuracy was lower on different-compound trials than on nonprobe trials, it was much higher on different-compound trials than on same-compound trials. These conclusions were confirmed by the results of a mixed factorial analysis of variance (ANOVA) performed on the percent correct choices. A significant main effect of trial type appeared [$F(4,8) = 25.05, p < .001$], but neither the main effect of group (specified by the order in which the birds acquired the two problems during initial training) nor the group $\times$ trial type interaction reached significance. Individual mean comparisons across trial types were analyzed with Fisher's least significant difference test (Keppel, 1991). This analysis revealed that accuracy on short- and long-element sample trials was equivalent but significantly higher than on each of the remaining trial types. Accuracy was significantly lower on same-compound trials than on each of the two types of different-compound trials, which did not differ significantly from each other.

Discussion

These results indicate that processing of compound duration samples was influenced by the nature of the signals. When the same signal appeared twice, pigeons be-

haved as if only a single sample had appeared for a long duration, but when two durations of two different signals appeared, the birds were much less inclined to summate durations (i.e., to respond as if only a long-duration signal had appeared), although their performance was somewhat disrupted, relative to performance on element-sample trials. The degree of the disruption of matching the 2-sec component of the different compound, however, is less than would have been expected had there been a strong tendency to summate the two durations, and accuracy of matching the 10-sec component is lower than would have been expected if the birds had been processing the two signals as a long-duration sample. The decreased accuracy of matching the first element of different compounds could have been due to the test delay imposed by presentation of the second sample, or it could reflect a retroactive interference effect resulting from presentation of the second component of the sample. Likewise, the performance decrement found in matching the second element of a different-compound sample could reflect a proactive interference effect (W. A. Roberts & Grant, 1976; Zentall & Hogan, 1977).

The tendency for pigeons to respond on same-compound trials as if only a long duration had appeared is consistent with the results of Spetch and Sinha (1989). According to their analysis, pigeons respond to the cumulative sample exposure and retrospectively code each trial in terms of an analogue representation of total sample duration. This would account for the observed tendency of birds in the current experiment to prefer the choice alternative associated with a long sample duration.

Performance on different-compound trials in this experiment, however, contrasts with what Spetch and Sinha (1989) found. They also tested pigeons by presenting compound duration samples that involved two different signal types, but unlike in our experiment, the same duration of each signal type was associated with the same correct choice stimulus. Under these conditions, their pigeons behaved as if they were processing cumulative sample duration. By contrast, our pigeons performed differently from what would be expected had they summated the two signal durations. The discrepancy between these results implies that when a unique set of choice stimuli is associated with two different signal types, pigeons may attend to the sensory-specific features of the samples. It should be mentioned, however, that aspects of our test procedure differed from that followed by Spetch and Sinha, and that it is possible that these differences could have contributed to the discrepancy in results.

EXPERIMENT 2

A major procedural difference between our Experiment 1 and Spetch and Sinha's (1989) experiment is that we tested only one type of duration compound; all probe trials involved a 10-sec signal followed by a 2-sec signal. In addition, we were concerned that the prior test experience of birds used in our Experiment 1 could have influenced their performance. In order to better compare our results with those of Spetch and Sinha, we decided to test a group of experimentally naive pigeons with all possible duration compounds (i.e., short-short, short-long, long-long, and long-short).

As in Experiment 1, we expected that a summation effect would appear when the same signal appeared for two durations but not when durations of two different signals appeared.

Method

Subjects and Apparatus. Four naive White Carneaux pigeons, obtained from a commercial breeder, served as subjects. The birds were housed and maintained as in Experiment 1, and the apparatus was the same as that used in the first experiment.

Procedure. All birds were hand-shaped to peck at an amber pecking key for food reinforcement, followed by training on duration MTS. Birds 6 and 7 (Group RL-HL) were trained with 2- and 10-sec durations of RL first, followed by training with 2- and 10-sec durations of HL; Birds 14 and 15 (Group HL-RL) were trained on the two problems in the opposite order. The test procedure differed from that used in Experiment 1 in that each session included 16 probe trial types, as designated in Table 2.

Each probe trial type was tested twice, and each nonprobe trial was tested eight times within a session. A 2-sec interstimulus interval separated the two components of a compound sample. Trial types were arranged randomly for each bird during each session, and each bird completed 12 test sessions presented successively over two blocks of 6 days.

Results

For purposes of data analysis, correct responses on compound sample trials were arbitrarily defined in terms of the duration of the second sample. The mean percent cor-

rect for each trial type tested, collapsed over signal type, appears in Figure 2.

These scores were subjected to a group (specified by the order in which the birds acquired the two problems) $\times$ trial type (10 values; see Table 2) mixed ANOVA. A significant main effect appeared for trial type [$F(9,18) = 17.9, p < .001$], but neither the main effect of training condition nor the training condition $\times$ trial type interaction reached significance. Additional post hoc comparisons, using Fisher's least significant difference test, revealed that accuracy was significantly lower on L-S same-compound trials than on each of the other nine trial types. Accuracy on S-S same-compound and L-S different-compound trials was equivalent, but accuracy was significantly higher on these two trial types than on L-S same compounds and significantly lower than on the remaining trial types.

Discussion

The results are similar, but not identical, to those reported by Spetch and Sinha (1989). Pigeons performed very poorly on trials in which a long duration was followed by a short duration of the same signal type. Rather than responding to the second duration sample as short, they tended to respond as if it were long. This result is like that reported by Spetch and Sinha, and it suggests that birds were summating the two durations. In contrast, unlike what Spetch and Sinha found, accuracy remained quite high on long-short compound trials in which two

Table 2
Samples and Correct Choice Arrangements Used in Experiment 2

Trial Type	Signal Type	Sample Duration (sec)	Choice Stimuli
Nonprobe			
Short	HL	2	A-B
	RL	2	X-Y
Long	HL	10	A-B
	RL	10	X-Y
Probe			
Short-Short	HL-HL	2-2	A-B
	HL-RL		X-Y
	RL-RL		X-Y
	RL-HL		A-B
Long-Long	HL-HL	10-10	A-B
	HL-RL		X-Y
	RL-RL		X-Y
	RL-HL		A-B
Short-Long	HL-HL	2-10	A-B
	HL-RL		X-Y
	RL-RL		X-Y
	RL-HL		A-B
Long-Short	HL-HL	10-2	A-B
	HL-RL		X-Y
	RL-RL		X-Y
	RL-HL		A-B

Note—Choice stimuli A-B were associated with houselight samples (A-2 sec, B-10 sec) and choice stimuli X-Y were associated with red wall-light samples (X-2 sec, Y-10 sec). See Table 1 for further clarification. Short = 2 sec, long = 10 sec, HL = houselight, RL = red wall-light.

Figure 2. Mean percent correct choices in Experiment 2 on short (S) and long (L) element duration samples and on short-short (S-S), short-long (S-L), long-long (L-L), and long-short (L-S) compound duration samples that involved either the same signal type (same compound) or different signal types (different compound).

different signal types were presented. In Spetch and Sinha's study, pigeons behaved with different signals as they did with identical signals; the birds seemed to summate over the two duration samples and respond as if a long duration had occurred. Finally, our pigeons were significantly less accurate when short-short compounds involved the same signal type than when they involved different signals. This too is unlike what Spetch and Sinha found: their birds behaved in the same manner for short-short compounds involving either the same or different signal types.

The current findings show that pigeons were able to differentiate the durations of two different signal types presented in succession, but not the durations of the same signal presented twice. Training with unique sets of comparison stimuli for different signal types appears to affect processing of stimulus properties that are otherwise ignored when a single set of comparisons is associated with both signal types (Spetch & Sinha, 1989).

EXPERIMENT 3

Experiment 3 attempted one additional test of the degree to which sensory-specific features of duration samples might influence matching performance. Following several retraining sessions during which probe trials were omitted, birds from Experiment 2 were given probe tests in which the short or long duration of one signal was followed by a set of comparisons that included *both* alternatives appropriate for that duration, irrespective of signal type. For

instance, if blue was the correct choice following a 2-sec HL and green was correct following a 2-sec RL, then blue and green would both appear on probe trials after 2 sec of either stimulus. Long duration samples were tested in a similar fashion. The question of interest was whether accuracy would be diminished by forcing pigeons to choose between two stimuli that were both correct with respect to duration alone. This question relates to previous findings indicating that pigeons do not readily transfer performance across sets of choice stimuli when they are trained with two signal types, each mapped onto a different set of choices (Kraemer, 1991). One possible explanation for the absence of such transfer is that presentation of unexpected choice stimuli generally disrupts performance. If that is the case, then performance should also be disrupted here; the pigeons should not expect to choose between stimuli from different sets of choice alternatives. A high level of accuracy on probe trials would indicate that pigeons are not necessarily disrupted by general alterations in the test procedure, and that their choice responses in duration MTS are sometimes based on more than just sample duration.

Method

Subjects and Apparatus. The subjects and apparatus were the same as those used in Experiment 2. Prior to testing in this experiment, all subjects completed 12 retraining sessions on the procedure used during initial acquisition of the two MTS problems.

Procedure. Test sessions involved 16 probe trials intermixed randomly among 48 standard training trials. The configuration of the probe trials is outlined in Table 3. Each probe was presented 4 times

Table 3
Configuration of Trial Types Tested in Experiment 3 and
Mean Percent Correct Responses for Each Trial Type

			% Correct	
Sample				
Duration (sec)	Signal Type	Choice Stimuli	$\bar{X}$	SE
Nonprobe				
2	HL	A-B	95	3.0
	RL	X-Y	97	2.2
10	HL	A-B	91	4.5
	RL	X-Y	92	3.3
Probe				
2	HL	A-X	84	6.2
	RL	A-X	94	2.2
10	HL	B-Y	84	6.2
	RL	B-Y	86	4.6

Note—Choice stimuli A-B were associated with houselight samples (A-2 sec, B-10 sec) and choice stimuli X-Y were associated with red wall-light samples (X-2 sec, Y-10 sec). See Table 1 for further clarification.

within a session, and each of the four nonprobe trials was tested 12 times. The left/right spatial arrangement of choice stimuli was balanced across trial types. All trial types were randomly arranged during each session for each bird. A single peck to one of the choice stimuli terminated a trial and initiated the ITI; reinforcement was omitted on all probe trials. Each pigeon completed a total of 16 test sessions, which occurred over 16 consecutive days.

Results and Discussion

For purposes of data analysis, correct responses were arbitrarily defined in terms of the choice stimulus associated with both the duration and sensory features of the sample. Mean percent correct responses for each of the four nonprobe and four probe trials appear in Table 3. These scores were subjected to a group (specified by the order in which the birds acquired the two problems) $\times$ trial type (nonprobe or probe) $\times$ sample type (short HL, long HL, short RL, and long RL) mixed ANOVA. This analysis yielded no significant main effects for group, trial type, or sample type, and none of the interactions reached significance.

The results indicate that pigeons did quite well at matching a specific choice stimulus to short and long durations of the two signal types. Even when forced to choose between two stimuli that were both associated with the duration of the preceding sample, the pigeons were able to select the alternative appropriate for a specific combination of signal type and duration. Despite presentation of unexpected choice stimuli (stimuli not previously paired together), the birds performed at high levels of accuracy. Thus, matching accuracy was not diminished by testing with a set of choice alternatives that had not been previously paired.

GENERAL DISCUSSION

The results of all three experiments indicate that pigeons can sometimes process sample duration while also attending to sensory-specific attributes of the signal. Pigeons

were first trained with unique sets of choice stimuli mapped onto short and long durations of two different signal types. In Experiments 1 and 2, the tendency of pigeons to respond as if they were summing durations of two successively presented samples was influenced by the sensory features of the signals themselves. When a long duration was followed by a short duration of the same signal type, it appeared as though the birds combined the two durations and responded to cumulative sample exposure. When a long and a short duration of two different signal types were presented, however, the birds did not appear to summate the two durations. Experiment 3 further revealed that birds were quite precise in their selection of a choice alternative following a duration sample; they tended to select a stimulus that was associated with the duration of a specific signal type, rather than merely choosing according to sample duration alone.

Evidence of cross-modal transfer of duration discriminations (Church & Meck, 1984; S. Roberts, 1982; S. Roberts & Holder, 1984; W. A. Roberts et al., 1989) and interdimensional equivalence, as reflected in the "summation effect" (Spetch & Sinha, 1989), suggests that animals can identify and respond to sensory-independent attributes of a duration signal. The current results, as well as other evidence (Church & Meck, 1984; DeLong & Wasserman, 1985; Durlach & Dawson, 1991), further indicate that the ability of animals to abstract the duration of a sample does not necessarily preclude simultaneous processing of other sensory attributes. It is surprising, however, that in the present situation birds would attend to sensory-specific cues at all. Sample duration alone served as a valid cue for selecting an appropriate choice alternative, irrespective of the sensory nature of the sample.

The present results have important implications for coding models of duration MTS, although the experiments were not designed to distinguish among the theoretical alternatives. The analogue coding view posits that sample duration is coded along a temporal dimension (Spetch & Wilkie, 1983). There has been strong support for this position (Spetch, 1987; Spetch & Rusak, 1989; Wilkie & Willson, 1990), but not all of the available evidence can be accommodated by the analogue coding hypothesis (Kraemer, Mazmanian, & W. A. Roberts, 1985; Parker & Glover, 1987). In order to explain the present findings, an analogue model would need to assume that subjects process more than just the duration of a sample, even when signal duration alone is a sufficient cue for discriminating samples.

The same conclusion holds for a behavioral mediation model of duration MTS (Killeen & Fetterman, 1988). This model assumes that sample durations are coded in terms of differential behaviors. In order to explain the present results, such a model must also assume that differential behaviors occur for each combination of signal type and duration. Whether this assumption can be empirically supported remains to be seen.

According to a prospective coding model, trials are coded in terms of the choice stimulus associated with each

sample event (Kraemer et al., 1985). With some minor additional assumptions, a prospective model can account for the present results as well as those reported by Spetch and Sinha (1989), which seem to run counter to the prospective view.

The first assumption is that sensory-specific features of a sample, as well as its duration, are used to retrieve from reference memory into working memory a correct prospective code. Birds are clearly able to process both sensory information and duration when both types of attributes are relevant (DeLong & Wasserman, 1985), but the current results suggest that they may do so even when sensory-specific cues are less relevant or informative than duration cues. Other assumptions are: (1) The internal clock used to make the duration judgment does not reset when the same signal or its functional equivalent (i.e., a different signal associated with the same set of choice alternatives) is presented; (2) the clock can be restarted prior to a choice response; and (3) the prospective code can be changed (recoded), on the basis of the updated value of a restarted clock before the subject makes its choice. Evidence from a number of studies suggests that these assumptions are indeed tenable (Church, 1984; S. Roberts, 1981; S. Roberts & Church, 1978).

According to the above assumptions, the tendency of pigeons to summate two durations of the same signal will be determined by whether or not the internal clock resets and whether or not recoding occurs prior to a choice response. For example, it is assumed that after a long duration sample the bird retrieves into working memory an appropriate prospective code that is associated with both the sensory features of the sample and the current value of the internal clock, which stops after the sample terminates but does not reset. The clock then restarts upon presentation of a second duration sample. When the choice stimuli are then presented, the code held in working memory would more accurately match the "long" clock value, resulting in a tendency for the bird to respond as if one long duration sample had appeared. The same process would occur in the case of a short duration followed by a long duration, but the clock value would be incongruent with the working memory code retrieved after presentation of the first (short) duration sample, and recoding would occur. Whether or not the same process occurs when two different signal types are presented will be determined by the nature of the sample-choice mapping rule. When a different choice stimulus is associated with each combination of signal type and duration, the summation effect would not be expected. Presentation of two functionally independent signals (i.e., two duration signals not associated with the same set of choice alternatives) either resets and then restarts the same internal clock or results in the timing of each signal by a separate clock. That animals can stop and restart their internal clocks (Church, 1978, 1984; S. Roberts & Church, 1978; S. Roberts & Holder, 1984), accurately time two independent events (Meck & Church, 1984), and behave as if their clocks are reset when salient events, such as food presentation

(S. Roberts, 1981), follow a duration signal lend credence to these possibilities. As long as the clock value following a second duration signal is incongruent with the available code in working memory, recoding may occur.

A different result is expected when the same prospective code is associated with each combination of duration and signal type, as in the Spetch and Sinha (1989) study. Under these conditions, pigeons should process mixed-signal compounds in the same manner as outlined above for same-signal compounds. The internal clock will restart without resetting, and the cumulative clock value would lead birds to choose the long choice alternative following short-long and long-short compounds.

Clearly, our explanation is speculative, and it is not uniquely supported by our results. We believe, however, that it offers at least a tenable account of the summation effect and deserves further empirical evaluation. There are two other issues that are also relevant to the present findings. The first pertains to the concept of common coding, and the second involves miscuing.

In many-to-one matching, pigeons are trained to select the same choice stimulus following different samples. Pigeons trained under these conditions often perform as if they categorized or commonly coded samples that are associated with the same choice stimulus (Grant, 1982; Santi & W. A. Roberts, 1985; Urcuioli, Zentall, Jackson-Smith, & Steirn, 1989; Zentall, Urcuioli, Jagielo, & Jackson-Smith, 1989). In both the W. A. Roberts et al. (1989) study of cross-modal transfer and the Spetch and Sinha (1989) study, pigeons were trained with a many-to-one mapping rule; the same duration of two different signal types was mapped onto the same choice stimulus. This procedure could have induced common coding of the sample. The procedure used here and by Kraemer (1991) involved a different mapping rule. The same durations of different signal types were not associated with the same comparison, so perhaps common coding was disrupted. In short, the presence versus absence of common coding could determine whether durations of two different signals will or will not be combined by preventing or promoting resetting of the internal clock.

A final issue relevant to the use of unique sets of choice stimuli is the cuing phenomenon. In MTS studies in which the same sample is mapped onto two different choice stimuli and the choice stimuli are cued prior to testing, deficits often occur when the choice stimuli are miscued (Grant & MacDonald, 1990; Santi, Musgrave, & Bradford, 1988; Stonebraker & Rilling, 1984). It could be argued that pigeons in this study were trained to match the same sample duration to two different choice stimuli, and that signal type cued a specific set of choice alternatives. Kraemer (1991) found that with unique sets of choice stimuli pigeons do not transfer performance across different signals of equal duration; birds tested with choice stimuli not originally associated with a given signal type performed poorly. This effect could have been due to miscuing. Perhaps pigeons were anticipating a particular set of choice alternatives based on the signal properties of

the sample, and performance suffered when an unexpected set of choices was presented.

The results of Experiment 3 are germane to the miscuing interpretation of Kraemer's (1991) results. Pigeons were tested with two choices, with both correct in terms of the duration of the preceding sample, but with only one being from the set of choice alternatives associated with the signal type presented. Despite the appearance of a set of choice alternatives not anticipated, pigeons performed as well on test trials as they did on nonprobe trials. Thus, it does not appear that general variations in the test procedure or mere presentation of an unexpected test array is sufficient to disrupt matching accuracy, although it is unclear whether the manipulation used in Experiment 3 can be regarded as a legitimate case of miscuing.

The combined results of these experiments suggest that it may be valuable for future research to interrelate concepts relevant to stimulus functional equivalence, common coding, and timing in order to understand how animals represent duration events. In addition, phenomena such as the summation effect (Spetch & Sinha, 1989) may prove to be especially good analytical tools for examining these interrelationships.

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(Manuscript received June 10, 1991;
revision accepted for publication September 16, 1991.)