

Analogical and Nonanalogical Coding of Samples Differing in Duration in a Choice-Matching Task in Pigeons

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When trained in a symbolic choice-matching task involving short (2-s) and long (10-s) durations as samples, pigeons tend to choose the comparison associated with a short sample as delay increases (choose-short effect). The present experiments showed that the choose-short effect can be eliminated by training in many-to-one (MTO) procedures in which 2 or more sets of sample stimuli are associated with 1 set of comparison stimuli. It is concluded that (a) the choose-short effect results from a process of subjective shortening that occurs during a delay if duration samples are coded analogically and (b) samples of duration are coded nonanalogically in at least some MTO mapping arrangements.

Grant and Spetch (1991) investigated memory for samples differing in duration, using both choice-matching and successive-matching procedures. In the choice-matching procedure, pigeons were reinforced for choosing one comparison stimulus (e.g., a red key) after a short (e.g., 2-s) sample presentation and for choosing the alternative comparison stimulus (e.g., a green key) after a long (e.g., 10-s) sample presentation. In the successive-matching procedure, only one of the two comparison stimuli was presented on any given trial. Whether the stimulus presented was positive or negative depended on both the duration of the sample and the identity of the comparison stimulus: One comparison stimulus was positive following one sample duration and negative following the other sample duration, and the contingencies were reversed for the other comparison.

Grant and Spetch (1991) reported that pigeons made systematic errors when the retention interval was manipulated in the choice-matching task. Pigeons demonstrated an asymmetrical decline in accuracy as retention interval was lengthened. Specifically, accuracy decreased to a much greater extent on trials initiated by a long sample than on trials initiated by a short sample. This effect is referred to as the *choose-short effect* and has been obtained in numerous studies in which a choice-matching procedure was used (e.g., Kraemer, Mazmanian, & Roberts, 1985; Spetch, 1987; Spetch & Rusak, 1989, 1992; Spetch & Wilkie, 1982, 1983).

In contrast to the asymmetrical retention of duration samples observed in choice procedures, Grant and Spetch (1991) observed symmetrical retention functions in the successive procedure. That is, the decline in accuracy as a function of increases in retention-interval length was similar on both short- and long-sample trials. Thus, an analogous *respond-short effect* did not emerge in the successive task.

We concluded that the type of memory code used to retain temporal information in the successive-matching task differs from that normally used to retain temporal information in the choice-matching task (Grant & Spetch, 1991). Specifically, we endorsed the notion that in the choice task, pigeons normally retain an analogical representation of the sample duration (e.g., the number of pulses generated by an internal pacemaker during sample presentation) and assess duration retrospectively at the time of choice (e.g., Spetch & Sinha, 1989; Spetch & Wilkie, 1983; Wilkie & Willson, 1990). The choose-short effect is held to result from a process of subjective shortening in which remembered duration shortens as a function of time since the termination of the event (e.g., Spetch, 1987; Spetch & Wilkie, 1983). We proposed that in the successive task, in contrast, pigeons do not retain information in its analogical form; instead, they transform information into prospective codes, such as *peck red* and *peck green*. These prospective codes then control performance directly at the time of testing. In our view, therefore, the failure to obtain a respond-short effect resulted from (a) the use of a prospective coding strategy in the successive procedure and (b) the fact that a prospective coding strategy precludes the operation of a process of subjective shortening.

Our analysis (Grant & Spetch, 1991) of the coding processes mediating retention of event duration in choice- and successive-matching procedures suggests that a choose-short effect is not an inevitable result in a choice-matching procedure. According to our analysis, any treatment that results in nonanalogical coding of event duration should produce symmetrical rather than asymmetrical retention functions on short- and long-sample trials in the choice-matching procedure.

In the experiments reported in this article, we attempted to induce nonanalogical coding of event duration by using many-to-one (MTO) sample-to-comparison mapping arrangements in which two samples were associated with each comparison stimulus. Several authors, in discussing research involving nontemporal samples, have noted that samples that are associated with the same comparison stimulus may be commonly coded (e.g., Grant, 1981, 1982; Maki, Moe, & Bierley, 1977; Urcuioli, Zentall, Jackson-Smith, &

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Steirn, 1989; Zentall, Steirn, Sherburne, & Urcuioli, 1991). In *common coding*, the same code is used to represent samples that are associated with the same comparison stimulus. Each of the studies cited has identified two categories of common coding: prospective and sample derived. In the prospective version of common coding, all samples associated with a given comparison stimulus are represented and remembered as an instruction to respond to that comparison stimulus. For example, all samples associated with the red comparison would be coded as *peck red*, and all samples associated with the green comparison would be coded as *peck green*. In the sample-derived version of common coding, all samples associated with a given comparison stimulus are represented and remembered as a single code, which is then associated with the comparison stimulus. For example, samples associated with the red comparison would be coded as *sample A*, and samples associated with the green comparison would be represented as *sample B*. The *sample A* code is associated with red, and the *sample B* code is associated with green. If an MTO mapping arrangement that includes temporal samples produces either form of common coding, then the temporal samples would be coded nonanalogically.

Experiment 1

Birds in each of three groups were trained on a choice-matching task in which the samples differed in duration (2- and 10-s presentations of houselight) and the comparisons were colored fields (red and green). Birds in the control group were trained with duration samples only, whereas birds in the remaining two groups received concurrent training with a second pair of samples (horizontal and vertical line orientations). The two groups differed in terms of the comparison stimuli that were presented following line-orientation samples. In the MTO group, the comparisons on line-sample trials were the same as those on duration-sample trials, namely, red and green fields. In the one-to-one (OTO) group, however, the comparisons on line-sample trials were horizontal and vertical lines. Thus, birds in the MTO group experienced a 2:1 sample-to-comparison mapping arrangement in which two samples (one duration and one orientation) were associated with each comparison stimulus, whereas birds in the OTO group experienced a 1:1 sample-to-comparison mapping arrangement in which each sample was associated with a unique comparison stimulus.

We anticipated that the MTO mapping would result in the duration samples being coded nonanalogically. Specifically, we anticipated that, for birds in the MTO group, one duration sample and one line sample would activate one common code (*sample A* or *peck red*), and the alternate duration sample and alternate line sample would activate the second common code (*sample B* or *peck green*). If these outcomes occurred, and if (a) nonanalogical coding precludes the operation of a process of subjective shortening and (b) a process of subjective shortening is responsible for the choose-short effect, then the MTO group should not display a choose-short effect.

On the other hand, we anticipated analogical coding of event duration, and, hence, a choose-short effect during retention testing, in both the control and OTO groups. Although birds in the OTO group received training with line samples, as did birds in the MTO group, the training regimen in the OTO group provided no basis for common sample-coding because the line samples and duration samples were associated with different sets of comparisons. Hence, we anticipated analogical coding of event duration in the OTO group.

Method

Subjects

Twelve naive, adult, Silver King pigeons (*Columba livia*) were reduced to and maintained at 80% of their free-feeding weight throughout the experiment. At the time of their arrival in the laboratory, 4 birds were assigned at random to each of three groups: control, OTO, and MTO. The birds were maintained on a 14:10-hr 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, the interior dimensions of which were 29 cm tall, 29 cm wide, and 24 cm deep, were used. Three pecking keys (2.5 cm in diameter) were mounted horizontally in a row, spaced 8 cm center to center, 23 cm above the floor. A force of approximately 0.15 N or greater was required to operate the keys. An in-line projector (Industrial Electronics, Inc., Van Nuys, CA) 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, which was illuminated whenever it was activated. A 28-V houselight, the shield of which was adjusted such 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 were accomplished using a microcomputer located in a separate room.

Procedure

The birds were magazine trained and then autoshaped to peck red and green fields and horizontal and vertical lines. Training on 0-s delayed matching to sample began after each bird was pecking reliably.

Delayed-matching training. For birds in the OTO and MTO groups, sessions consisted of 64 trials separated by a variable intertrial interval with a mean of 20 s (range = 10–30 s). Each trial began with the illumination of the center key by the preparatory stimulus (a white triangle on a black ground). The preparatory stimulus was terminated by a single peck or, in the absence of a peck, terminated after 5 s. 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 ground on the center key on the other half

of the trials. The duration of the houselight was short (2 s) or long (10 s), equally often, and the line orientation was vertical and horizontal, equally often. The sample presented on any particular trial was determined randomly each session, with the restriction that each of the four samples (2-s houselight, 10-s houselight, vertical line, and horizontal line) was presented 16 times. For birds in the control group, sessions were identical except that only 32 trials, each of which involved the temporal samples, were presented.

For birds in all three groups, termination of the temporal sample was followed immediately (0-s 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-s presentation of grain occurred as reinforcement. If the incorrect comparison was pecked, the trial terminated without reinforcement, and 3 s was added to the intertrial interval. For 2 of the birds in each group, red was correct on short-sample trials and green was correct on long-sample trials; for the 2 remaining birds in each group, the contingencies were reversed. Position of the correct comparison stimulus was balanced within sample duration.

For birds in the OTO group, the line sample terminated after 6 s and was followed immediately (0-s delay) by illumination of the two side keys, one with a vertical line and the other with a horizontal line. For all 4 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-s access to food; incorrect trials terminated without food, and 3 s was added to the intertrial interval. For birds in the MTO group, trials involving the line samples were the same as those for birds in the OTO group except that red and green, rather than vertical and horizontal, were used as the comparison stimuli. For all 4 birds, green was the correct comparison on horizontal-sample trials, and red was the correct comparison on vertical-sample trials. In both groups, position of the correct comparison stimulus was balanced within sample type. Each bird received 80 sessions of training.

Delay Test 1. Retention testing began on the day following the end of training. Retention-testing sessions were identical for birds in each of the 3 groups and consisted of 64 trials involving duration samples; 48 involved a 0-s delay (as in training), 8 involved a 5-s delay interpolated between the termination of the sample and onset of the comparison stimuli, and 8 involved a 10-s delay interpolated between the termination of the sample and onset of the comparison stimuli. The reinforcement contingencies on 5-s and 10-s delay trials were identical with those on 0-s delay trials, which in turn were identical with those of training. The sample was short or long at each delay equally often, and the position of the correct comparison was balanced within each combination of sample duration and delay. The order in which the different trial types appeared was determined randomly each session.

Each bird received eight sessions of retention testing. Each of retention-testing Sessions 2–8 was preceded by two baseline-training sessions identical in all aspects to those used during delayed-matching training.

Delay Test 2. On the day following the end of the first delay test, eight consecutive sessions of baseline training, identical in all aspects to those of delayed-matching training, were conducted. The second delay test began on the following day and was identical to the first delay test in all aspects except that the two longer delays were 10 s and 20 s, rather than 5 s and 10 s.

Results

Delayed-Matching Training

For all statistical analyses, the criterion for rejection of the null hypothesis was $p < .05$.

Figure 1 shows acquisition of matching to samples differing in duration and line orientation in the OTO and MTO groups. Acquisition in the two groups that received both line and duration samples was similar. However, acquisition of matching to duration occurred more rapidly than did acquisition of matching to line orientation. A Group (OTO and MTO) \times Block \times Sample-Type (duration and line orientation) analysis of variance (ANOVA) revealed that neither the main effect of group nor any interactions involving the group factor were significant. The Block \times Sample-Type interaction was significant, $F(19, 114) = 3.75$. Acquisition of matching to duration samples was similar in the control (not shown in Figure 1), OTO, and MTO groups. A Group (control, OTO, and MTO) \times Block ANOVA revealed that neither the main effect of group nor any interactions involving the group factor were significant.

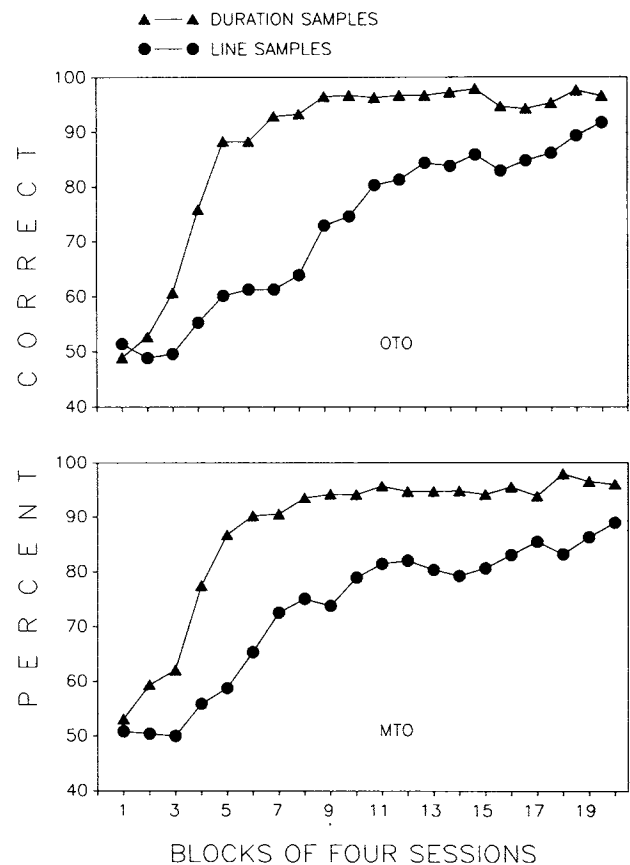


Figure 1. Percentage of correct responses on duration-sample (2-s and 10-s presentations of houselight) and line-sample (vertical and horizontal) trials as a function of blocks of four training sessions in Experiment 1. (Data from the one-to-one [OTO] group are shown in the upper portion, and data from the many-to-one [MTO] group are shown in the lower portion.)

Delay Testing

On baseline-training sessions, which were interpolated between retention-testing sessions, accuracy was consistently above 90% correct on duration-matching trials in all three groups. In the OTO and MTO groups, which received line-matching trials in addition to duration-matching trials during baseline-training sessions, accuracy was at or above 90% correct on line-matching trials.

During retention-testing sessions, only duration samples were used, and retention functions on short- and long-sample trials in each group during each delay test are shown in Figure 2. The retention functions are asymmetrical in each group; accuracy declined more rapidly on trials initiated by a long sample than on trials initiated by a short sample (the choose-short effect). The choose-short tendency was somewhat stronger in the second test, in which the longer delays were used, than in the first test. In addition, the choose-short effect was somewhat stronger in the control and OTO groups than in the MTO group.

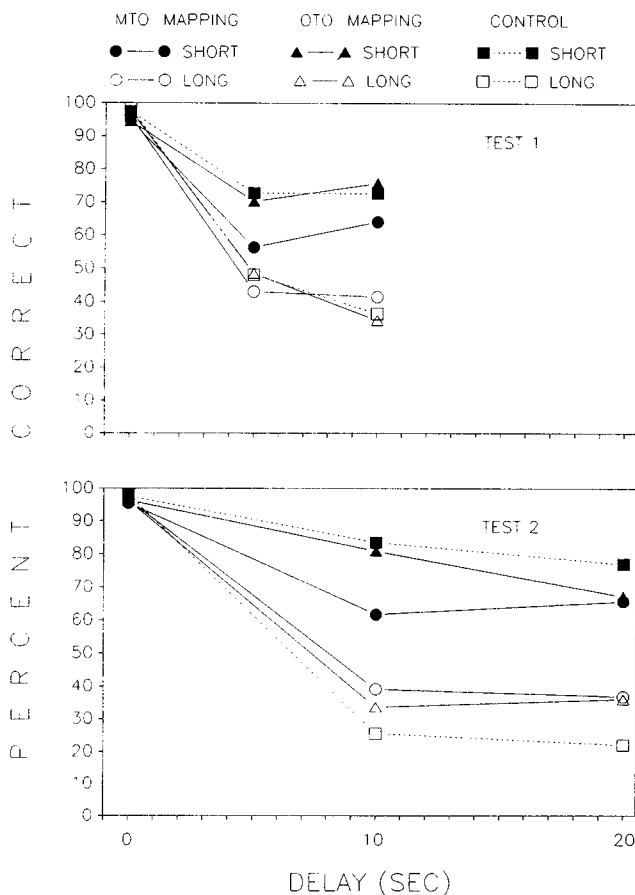


Figure 2. Percentage of correct responses on trials initiated by a short (2-s) and long (10-s) sample in each group as a function of delay in Experiment 1. (Data from the first test [delays of 0, 5, and 10 s] are shown in the upper portion, and data from the second test [delays of 0, 10, and 20 s] are shown in the lower portion. MTO = many-to-one; OTO = one-to-one.)

A Group \times Sample-Duration \times Delay ANOVA performed on the percentage of correct responses in the first delay test revealed significant main effects of sample duration, $F(1, 9) = 6.36$, and delay, $F(2, 18) = 207.40$. The only other significant term was the Sample-Duration \times Delay interaction, $F(2, 18) = 10.29$. Sample-Duration \times Delay ANOVAs were also performed on the data from each group separately. In all three cases, the Sample-Duration \times Delay interaction was not significant, $F_s(2, 6) = 4.01, 4.23,$ and 2.08 , in the control, OTO, and MTO groups, respectively.

An identical series of ANOVAs was performed on the percentage of correct responses in the second delay test. The ANOVA that included data from all three groups again revealed significant main effects of sample duration, $F(1, 9) = 21.03$, and delay, $F(2, 18) = 305.74$, and a significant Sample-Duration \times Delay interaction, $F(2, 18) = 15.77$. Separate Sample-Duration \times Delay ANOVAs revealed a reliable choose-short effect in the control group, $F(2, 6) = 16.19$, and the OTO group, $F(2, 6) = 6.69$, but not in the MTO group, $F(2, 6) = 3.24$.

Table 1 shows the percentage of trials on which the comparison stimulus associated with the short sample stimulus was chosen at each delay. These values were calculated by adding the percentage of choices of the short-associated comparison on short-sample trials and the percentage of choices of the short-associated comparison on long-sample trials and then dividing by two. Hence, a value of 50% indicates no bias to select either the short- or long-associated comparison stimulus. As can be seen in Table 1, performance on 0-s delay trials revealed no bias to choose the short-associated comparison in any of the three groups in either test. At the longer delays in each test, birds in each group revealed a tendency to choose the comparison stimulus associated with a short sample on the majority of trials. One-way ANOVAs revealed that the tendency to choose the short-associated comparison at the longest delay in each test did not differ significantly among the three groups.

Discussion

Experiment 1 provides little support for the hypothesis that an MTO sample-to-comparison mapping arrangement would result in nonanalogical coding of duration samples and, hence, would eliminate the choose-short effect. In particular, although only the MTO group failed to demonstrate a statistically reliable choose-short effect in the second

Table 1
Mean Percentages of Choices of the Comparison Stimulus Associated With the Short Sample Stimulus in Experiment 1

Group	Test 1 delay (s)			Test 2 delay (s)		
	0	5	10	0	10	20
Control	49.7	61.7	71.9 ^a	49.8	78.4 ^a	78.1 ^a
OTO	48.4	60.9	70.7	50.1	73.7 ^a	65.6
MTO	49.4	56.6	61.3	49.5	61.3	64.4 ^a

Note. OTO = one-to-one; MTO = many-to-one.
^a Significantly above 50% according to one-tailed *t* tests.

delay test, a tendency in the direction of a choose-short effect was present in that group. Moreover, the three groups did not demonstrate a statistically reliable difference in the percentage of choices of the short-associated comparison at the longest delay in either test.

The failure of the MTO mapping to eliminate, or to reduce markedly, the choose-short effect might be attributable to the fact that although the duration- and line-matching tasks were trained concurrently, acquisition in the duration task was more rapid. Therefore, some or all birds in the MTO group may have learned to use analogical codes to represent the duration samples before learning to code the line samples. Moreover, birds in the MTO group may have continued to use an analogical coding process on duration trials as they learned to code the line samples. That is, analogical coding of duration may have persisted because such a coding process (a) is a dominant form of coding of temporal samples in choice-matching procedures and (b) would continue to mediate accurate performance on duration trials. Hence, it is not surprising that associating line samples with the same comparisons as the duration samples did not strongly induce nonanalogical coding of the duration samples in Experiment 1.

Experiment 2

In Experiment 2, we used a training regimen that was designed to enhance the likelihood that duration samples would be coded nonanalogically in the MTO group. Rather than training the line and duration tasks concurrently, birds in the OTO and MTO groups were trained to a high level of accuracy with line samples before the introduction of duration samples. We anticipated that training line matching before the introduction of duration matching might be particularly likely to induce nonanalogical coding of the duration samples in the MTO group. This anticipation was based on the notion that the codes used to represent the line samples during the initial phase of training could also be used to represent the duration samples when they were introduced later in training.

To illustrate, assume that the MTO mapping specifies that the red comparison is correct after either a vertical or short sample and that the green comparison is correct after either a horizontal or long sample. During initial training involving the line samples only, birds would develop codes to mediate accurate performance on line-sample trials (e.g., *vertical* and *horizontal*, *peck red* and *peck green*, or *sample A* and *sample B*). Later in training, duration samples are introduced and are associated with the same set of comparisons as the line samples. A ready mode of acquiring accurate matching on duration trials involves associating the short sample with the code used on vertical trials and associating the long sample with the code used on horizontal trials. If this mode of coding was adopted in the MTO group, then the duration samples would not be coded in terms of perceived duration and hence would be coded nonanalogically.

Method

Subjects

Twenty-four naive, adult, Silver King pigeons were reduced to and maintained at 80% of their free-feeding weight throughout the experiment. At the time of arrival in the laboratory, 8 birds were assigned at random to each of three groups: control, OTO, and MTO. The light-dark cycle in the colony room was as specified in Experiment 1. All sessions were conducted in the morning according to the regimen specified in Experiment 1.

Apparatus and Procedure

The apparatus was the same as in Experiment 1. The birds were magazine trained and then autoshaped to peck red and green fields and horizontal and vertical lines. Training on 0-s delayed matching to sample began after each bird was pecking reliably.

Delayed-matching training. For birds in the OTO and MTO groups, training was divided into two phases, line samples only and line and duration samples. Sessions consisted of 64 trials separated by a variable intertrial interval with a mean of 20 s (range = 10–30 s). During the first 36 sessions, all trials within a session involved horizontal- and vertical-line samples. Trials were identical to those involving line samples in the first experiment. During the next 32 sessions of training, half the trials within each session involved line samples and half involved duration samples. Trials with duration samples were identical with those used in Experiment 1.

For birds in the control group, training consisted of 32 sessions, each of which consisted of 32 trials involving duration samples. Trials were identical with those used in Experiment 1.

Delay tests. Two delay tests, identical in all aspects to the delay tests conducted in Experiment 1, immediately followed the final session of training.

Results

Delayed-Matching Training

Figure 3 shows acquisition of matching to samples differing in line orientation and duration in the OTO and MTO groups. Acquisition of line matching and duration matching was similar in the two groups. A Group \times Block ANOVA was performed on the data from the first nine blocks of training, and a Group \times Block \times Sample-Type (duration and line orientation) ANOVA was performed on the data from the final eight blocks of training. These analyses revealed that neither the main effect of group nor any interactions involving the group factor were significant. Acquisition of matching to duration was similar in the control (not shown in the figure), OTO, and MTO groups. A Group (control, OTO, and MTO) \times Block ANOVA revealed that neither the main effect of group nor any interactions involving the group factor were significant.

Delay Testing

On baseline-training sessions, which were interpolated between retention-testing sessions, accuracy was consistently above 90% correct on duration-matching trials in all three groups. In the OTO and MTO groups, which received

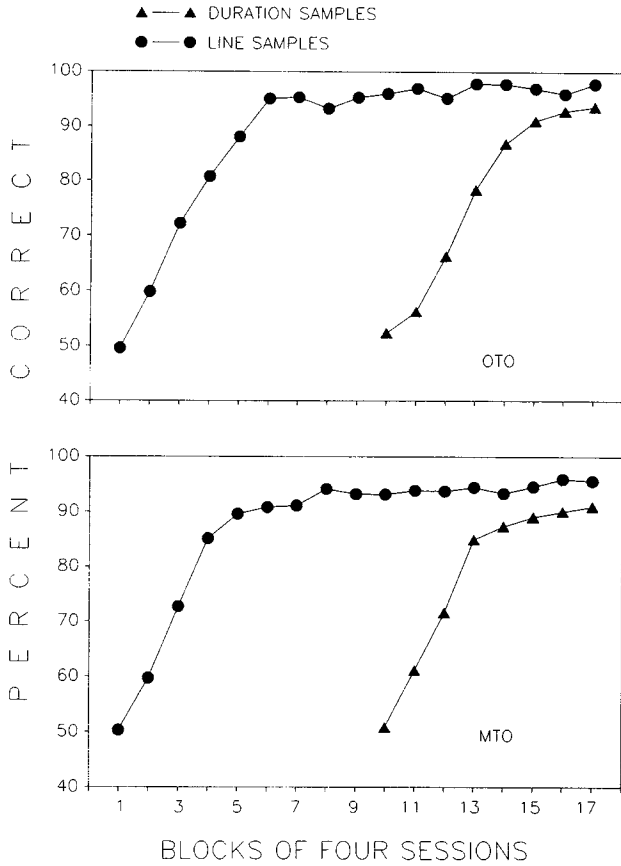


Figure 3. Percentage of correct responses on duration-sample (2-s and 10-s presentations of houselight) and line-sample (vertical and horizontal) trials as a function of blocks of four training sessions in Experiment 2. (Data from the one-to-one [OTO] group are shown in the upper portion, and those from the many-to-one [MTO] group are shown in the lower portion.)

line-matching trials in addition to duration-matching trials during baseline-training sessions, accuracy was at or above 90% correct on line-matching trials.

During retention-testing sessions, only duration samples were used, and retention functions on short-sample and long-sample trials in each group during each delay test are shown in Figure 4. In the control and OTO groups, the retention functions are asymmetrical; accuracy declined more rapidly on trials initiated by a long sample than on trials initiated by a short sample. However, the retention functions are symmetrical in the MTO group; accuracy declined at an equivalent rate on trials initiated by short and long samples.

A Group \times Sample-Duration \times Delay ANOVA performed on the percentage of correct responses in the first delay test revealed significant main effects of sample duration, $F(1, 21) = 8.70$, and delay, $F(2, 42) = 231.75$. The only other significant term was the Sample-Duration \times Delay interaction, $F(2, 42) = 4.65$. Sample-Duration \times Delay ANOVAs were also performed on the data from each group separately. The Sample-Duration \times Delay interaction revealed a significant choose-short effect in the control, $F(2,$

14) = 3.89, and OTO, $F(2, 14) = 3.78$, groups but not in the MTO group ($F < 1$).

An identical series of ANOVAs was performed on the percentage of correct responses in the second delay test. The ANOVA that included data from all three groups again revealed significant main effects of sample duration, $F(1, 21) = 10.13$, and delay, $F(2, 42) = 218.38$, and a significant Sample-Duration \times Delay interaction, $F(2, 42) = 6.27$. Separate Sample-Duration \times Delay ANOVAs revealed a reliable choose-short effect in the control group, $F(2, 14) = 4.54$, and the OTO group, $F(2, 14) = 4.06$, but not in the MTO group ($F < 1$).

Table 2 shows the percentage of choices of the comparison stimulus associated with the short sample at each delay. Both the control and OTO groups showed a tendency to select the short-associated comparison on the majority of trials at the two longer delays in each test. In contrast, the MTO group was equally likely to select the short- and long-associated comparison at each delay in each test. One-way ANOVAs revealed that the tendency to choose the short-associated comparison at the longest delay in each test

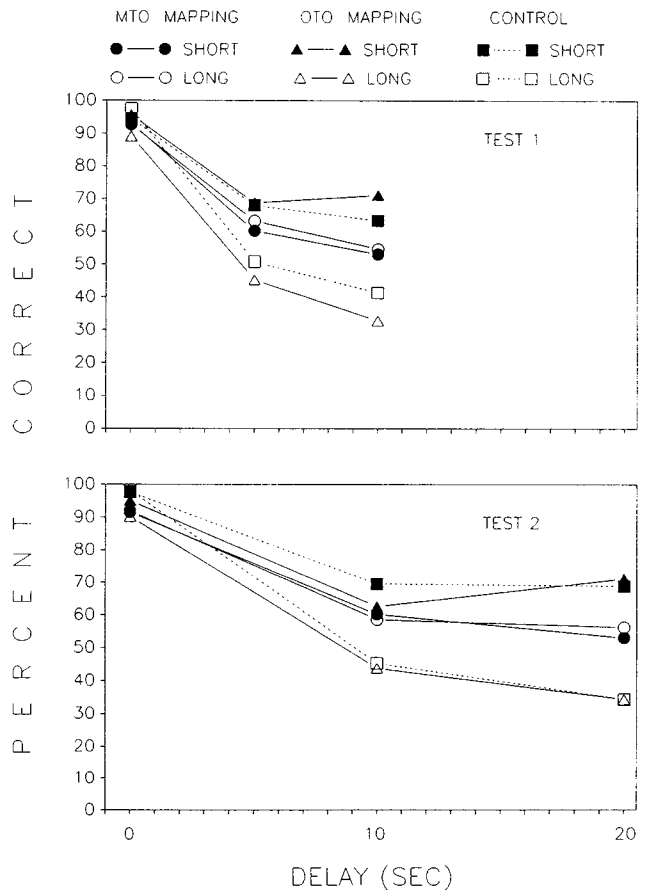


Figure 4. Percentage of correct responses on trials initiated by a short (2-s) and long (10-s) sample in each group as a function of delay in Experiment 2. (Data from the first test [delays of 0, 5, and 10 s] are shown in the upper portion, and those from the second test [delays of 0, 10, and 20 s] are shown in the lower portion. MTO = many-to-one; OTO = one-to-one.)

Table 2
Mean Percentages of Choices of the Comparison Stimulus Associated With the Short Sample Stimulus in Experiment 2

Group	Test 1 delay (s)			Test 2 delay (s)		
	0	5	10	0	10	20
Control	48.5	58.6	61.0 ^a	49.8	62.1	67.2 ^a
OTO	53.3	61.8 ^a	69.2 ^a	52.4	59.4 ^a	68.4 ^a
MTO	50.2	48.5	49.2	49.8	50.8	48.4

Note. OTO = one-to-one; MTO = many-to-one.

^a Significantly above 50% according to one-tailed *t* tests.

differed significantly among the three groups, $F(2, 21) = 4.55$ at the 10-s delay in Test 1, and $F(2, 21) = 3.45$ at the 20-s delay in Test 2. One-tailed *t* tests were used for further evaluation of between-group differences in the tendency to choose the short-associated comparison at the longest delay in each test. In both cases (i.e., 10-s delay in Test 1 and 20-s delay in Test 2), the control and OTO groups did not differ reliably, $t(14) = 1.04$ and 0.13 in Tests 1 and 2, respectively, and each group demonstrated a significantly higher percentage of short-associated choices than did the MTO group, $t(14) = 2.01$ and 3.02 for control versus MTO and OTO versus MTO in Test 1, respectively, and $t(14) = 2.26$ and 2.39 for control versus MTO and OTO versus MTO in Test 2, respectively.

Discussion

The MTO training regimen used in the present experiment eliminated entirely the tendency of pigeons to select the comparison stimulus associated with the short sample at longer delays. The finding that the OTO training regimen did not affect the magnitude of the choose-short effect reveals that the MTO mapping, rather than mere prior experience with a task involving line-orientation samples, was responsible for the elimination of the choose-short effect.

On the basis of the logic outlined in the introduction to this article, we conclude that birds in the OTO and control groups coded the duration samples analogically and assessed duration retrospectively at the time of comparison choice. However, we believe that birds in the MTO group developed a single, nonanalogical common code to represent the line and duration samples that were associated with the same comparison stimulus.

Experiment 3

In the first two experiments, we used both nontemporal and temporal samples to create an MTO sample-to-comparison mapping arrangement. In Experiment 3, we used two pairs of duration samples (short and long keylight and short and long houselight) to create two variations of an MTO sample-to-comparison mapping arrangement. The primary purpose of Experiment 3 was to determine whether either of these MTO mappings involving only temporal samples would induce nonanalogical common coding of duration samples.

The design involved four samples, defined by the factorial combination of duration (2 s and 10 s) and carrier of duration (houselight and keylight). In the inconsistent group, the sample-to-comparison mapping arrangement specified that one comparison (e.g., red) was correct following either a short presentation of one carrier (e.g., 2-s houselight) or a long presentation of the alternative carrier (e.g., 10-s keylight). The alternative comparison (green in the present example) was correct following either of the remaining two samples (10-s houselight and 2-s keylight in the present example). In the consistent group, the samples and comparisons were the same as in the inconsistent group, but the sample-to-comparison mapping arrangement differed. Specifically, the two short samples (2-s houselight and 2-s keylight) were associated with one comparison stimulus (e.g., red), and the two long samples (10-s houselight and 10-s keylight) were associated with the alternative comparison stimulus (green in the present example).

In the inconsistent group, both the type of carrier (houselight or keylight) and the duration are relevant aspects of sample presentation. This fact produces a basic commonality between the inconsistent group and the MTO groups of the preceding experiments: A common-coding process, whether sample derived (*sample A* and *sample B*) or prospective (*peck red* and *peck green*), reduces the number of required codes from four to two. An additional advantage of common coding, unique to the mapping arrangement used in the inconsistent group, is a reduction in the complexity of the codes. In the absence of common coding, accurate performance would require use of bidimensional codes in which information about both duration and carrier is preserved in each of the codes. Common coding, whether sample derived or prospective, requires unidimensional codes. Honig and Thompson's (1982, p. 279) suggestion that the coding process that requires less information will operate leads to the expectation of nonanalogical common coding in the inconsistent group.

In the consistent group, in which only duration is relevant, accurate performance could be mediated by nonanalogical common coding that is either prospective or sample derived, as is the case in the inconsistent group. However, two additional common-coding processes could mediate accurate performance, one nonanalogical and the other analogical. The additional nonanalogical common-coding process, referred to as *retrospective and categorical coding*, is a sample-derived, common-coding process in which the sample-derived code is not related arbitrarily to the physical properties of the samples. In this coding process, each of the two 2-s samples would be coded as short and each of the two 10-s samples would be coded as long.

In the analogical common-coding process, each of the four samples would be represented analogically as one of two values (e.g., the number of pulses generated by an internal pacemaker during sample presentation), corresponding to either a 2-s or a 10-s duration. The efficiency of the analogical common-coding process in mediating accurate performance is directly related to the extent to which perceived duration is independent of the carrier (houselight or keylight). A recent finding by Wilkie (1987) revealed that

perceived duration is not necessarily independent of the carrier. In particular, Wilkie found that bright events are perceived as longer than equivalent durations of dim events. Because our houselight was brighter than our keylight, analogical representations of equivalent durations of houselight and keylight might not be identical. Consequently, an analogical common-coding process might not be particularly effective.

Method

Subjects

Sixteen naive, adult, Silver King pigeons were reduced to and maintained at 80% of their free-feeding weight throughout the experiment. At the time of arrival in the laboratory, 8 birds were assigned at random to each of two groups: inconsistent and consistent. The light-dark cycle in the colony room was as specified in Experiment 1. All sessions were conducted in the morning, according to the regimen specified in Experiment 1.

Apparatus and Procedure

The apparatus was the same as that used in Experiments 1 and 2. The birds were magazine trained and then autoshaped to peck red and green fields. Training on 0-s delayed matching to sample began after each bird was pecking reliably.

Delayed-matching training. Sessions consisted of 48 trials separated by an intertrial interval of 20 s. Each trial began with the illumination of the center key by the preparatory stimulus (a black dot on a white ground). The preparatory stimulus was terminated by a single peck or, in the absence of a peck, terminated after 5 s. Termination of the preparatory stimulus was followed immediately by onset of an overhead houselight on half of the trials and by onset of a white X on a black ground on the center key on the other half of the trials. The durations of the houselight and keylight were short (2 s), or long (10 s), equally often. Which sample was presented on any particular trial was determined randomly each session, with the restriction that each of the four samples (2-s houselight, 10-s houselight, 2-s keylight, and 10-s keylight) was presented 12 times. Termination of the sample was followed immediately (0-s delay) by illumination of the two side keys, one with red light and the other with green light. Position of the correct comparison stimulus was balanced within sample type. A single peck on either comparison stimulus terminated both comparison stimuli. If the correct comparison was pecked, a 4-s presentation of grain occurred as reinforcement. If the incorrect comparison was pecked, the trial terminated without reinforcement, and 4 s was added to the intertrial interval.

For the 8 birds assigned to the consistent group, one comparison stimulus (red for 4 birds and green for 4 birds) was correct on both types of short-sample trials (2-s houselight or 2-s keylight), and the alternative comparison stimulus was correct on both types of long-sample trials (10-s houselight or 10-s keylight). For the 8 birds assigned to the inconsistent group, one comparison stimulus (red for 4 birds and green for 4 birds) was correct given a short presentation of houselight or a long presentation of keylight (2-s houselight or 10-s keylight), and the alternative comparison stimulus was correct given a long presentation of houselight or a short presentation of keylight (10-s houselight or 2-s keylight). Each bird received 88 sessions of training.

Delay test. Retention testing began on the day following the end of training. Retention-testing sessions were identical with training sessions except that 16 trials were added; eight involved

a 5-s delay interpolated between the termination of the sample and the onset of the comparison stimuli, and eight involved a 10-s delay interpolated between the termination of the sample and the onset of the comparison stimuli. The contingencies on 5-s and 10-s delay trials were identical with those on 0-s delay trials. Each of the four types of samples was presented on two of the trials at each of the two longer delays, once with the correct comparison on the right and once with the correct comparison on the left. The order in which the different trial types appeared was determined randomly each session.

Each bird received eight sessions of retention testing. Each of retention-testing sessions 2-8 was preceded by two baseline-training sessions identical in all aspects with those used during delayed-matching training.

Results

Delayed-Matching Training

Acquisition of delayed matching in each group is shown in Figure 5. Acquisition in the two groups was similar. Accuracy was higher on houselight trials than on keylight

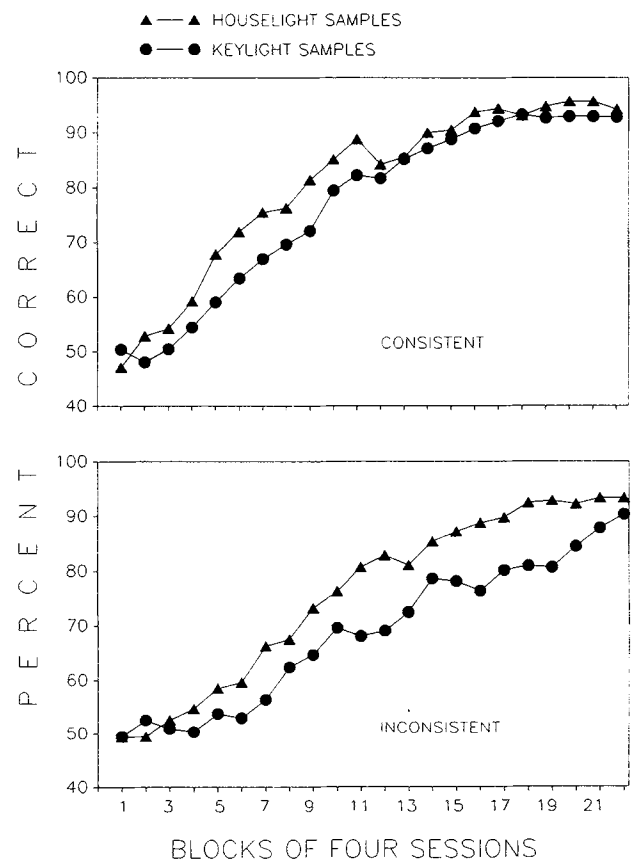


Figure 5. Percentage of correct responses on houselight-sample (2-s and 10-s presentations of houselight) and keylight-sample (2-s and 10-s presentations of keylight) trials as a function of blocks of four training sessions in Experiment 3. (Data from the consistent group are shown in the upper portion, and those from the inconsistent group are shown in the lower portion.)

trials during a large majority of the training blocks. However, asymptotic levels of performance were similar on houselight and keylight trials. A Group (inconsistent and consistent) \times Block \times Carrier (keylight and houselight) ANOVA revealed that neither the main effect of group nor any interactions involving the group factor were significant. Although the main effect of carrier was significant, $F(1, 14) = 10.98$, rate of acquisition of matching was not affected by carrier, Block \times Carrier interaction, $F(21, 294) = 1.53$.

Delay Test

On baseline-training sessions, which were interpolated between retention-testing sessions, accuracy remained consistently above 90% correct in both groups. Retention functions on short-sample and long-sample trials in each group are shown in Figure 6. Neither group demonstrated any tendency to choose the comparison stimulus associated with a short sample stimulus at the longer delays; at the 5-s delay, accuracy on long-sample trials was slightly higher than on short-sample trials, and at the 10-s delay, accuracy on short- and long-sample trials was equivalent. The percentage of choices of the comparison stimulus associated with the short sample, shown in Table 3, revealed no tendency to choose the short-associated comparison at longer delays.

A Group \times Carrier \times Sample-Duration \times Delay ANOVA revealed significant main effects of group, $F(1, 14) = 5.45$, reflecting higher accuracy in the consistent group (73.2%) than in the inconsistent group (67.6%), and delay, $F(2, 28) = 179.18$. The only other significant term was the Sample-Duration \times Delay interaction, $F(2, 28) = 3.96$, reflecting the finding that accuracy on long- and short-sample trials was approximately equivalent at the 0-s and 10-s delays and was

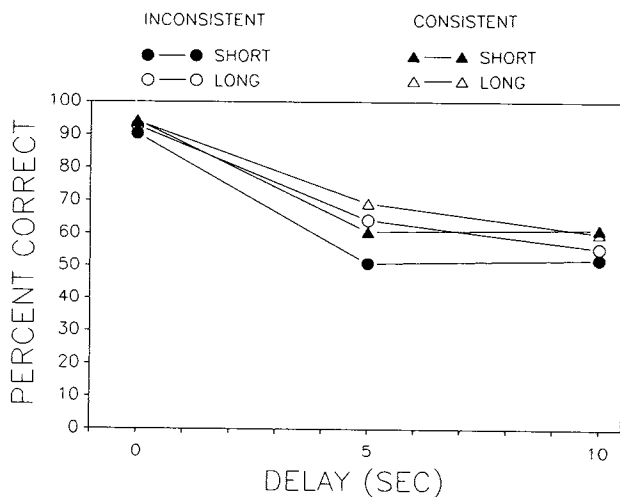


Figure 6. Percentage of correct responses by the consistent and inconsistent groups on trials initiated by a short (2-s presentation of houselight or keylight) and long (10-s presentation of houselight or keylight) sample in each group as a function of delay in Experiment 3.

Table 3

Mean Percentages of Choices of the Comparison Stimulus Associated With the Short Sample Stimulus in Experiment 3

Group	Delay (s)		
	0	5	10
Consistent	50.2	45.7	50.6
Inconsistent	48.9	43.4	47.9

Note. No mean was significantly greater than 50% according to one-tailed t tests.

10.9 percentage points higher on long-sample trials than on short-sample trials at the 5-s delay.

Discussion

Experiment 3 revealed that both of the MTO mapping arrangements eliminated the choose-short effect. We interpret this result as revealing that the MTO mappings induced some form of nonanalogical common coding of the duration samples.

Recently, Bowers and Richards (1990) conducted a delay test using pigeons that had been trained in a procedure similar to that used in the consistent group described earlier. As in the present study, no evidence of a choose-short effect was obtained, a result Bowers and Richards interpreted as reflecting prospective coding. However, Spetch and Wilkie (1982) obtained a choose-short effect at longer delays in pigeons trained in an MTO procedure involving consistent mapping, suggesting that their pigeons coded the samples analogically.

Spetch and Wilkie (1982) used food access and light as carriers rather than houselight and keylight as in our Experiment 3 or red and green keylights as in Bowers and Richards's (1990) experiment. This fact may be important, because duration discrimination is acquired considerably more quickly on trials in which the carrier for duration is food than on trials in which the carrier is houselight (see Spetch & Wilkie, 1981). The differential rates of acquisition on food access versus light trials may have resulted in Spetch and Wilkie's nominal MTO task functioning as two independent OTO tasks. If so, analogical coding, and, hence, the choose-short effect, would be anticipated. In Experiment 3, rate of acquisition was not significantly affected by carrier, and this may have increased the probability that the nominal MTO task was also functionally an MTO task. Although Bowers and Richards did not report acquisition data separately as a function of carrier, it is unlikely that the color of the keylight had any marked effect on rate of acquisition.

Therefore, analogical coding may result if a temporal component of an MTO mapping is learned more quickly than the second component of the MTO mapping (as in our Experiment 1; see also Spetch & Wilkie, 1982). However, nonanalogical coding may result if the two components are learned simultaneously (as in our Experiment 3; see also Bowers & Richards, 1990) or if the nontemporal component is learned before the temporal component (as in our Experiment 2).

General Discussion

In the present experiments, we examined a set of interrelated hypotheses concerning the processes involved in representing and remembering events of different durations in pigeons. These assumptions are that, in a choice-matching task involving samples of different durations, (a) the samples are normally coded retrospectively and analogically; (b) a process of subjective shortening of remembered duration operates during a retention interval if, and only if, samples are coded retrospectively and analogically; (c) the choose-short effect is caused by a process of subjective shortening; and (d) the coding of samples differing in duration is a flexible, controlled process, in that such samples are coded nonanalogically under conditions in which such a coding process is either more efficient or less demanding, or both, than is an analogical coding process.

We evaluated these assumptions by using various MTO sample-to-comparison mapping arrangements in which a nonanalogical common-coding process appeared, on logical grounds, to be either more efficient or less demanding, or both, than an analogical coding process. The finding that each of three MTO mapping arrangements can eliminate the choose-short effect is consistent with the assumptions noted earlier.

Throughout this article, we have argued, as have others (e.g., Urcuioli et al., 1989; Zentall et al., 1991), that MTO mapping arrangements encourage some form of common coding in which samples associated with the same correct comparison are represented by a single code. A reviewer of an earlier version of this article suggested, however, that nonanalogical coding in the present experiments might reflect the number of symbolic matching problems used (i.e., those in which there is not a physical match between the sample and correct comparison), rather than the MTO sample-to-comparison mapping ratio. Notice that each group that revealed evidence of nonanalogical coding of duration (the MTO group in Experiment 2 and the consistent and inconsistent groups in Experiment 3) was trained with two symbolic matching problems. However, each group that revealed evidence of analogical coding of duration (the control and OTO groups in Experiments 1 and 2) was trained in only one symbolic matching problem. In the OTO groups, the second matching problem was identity matching, in which the sample and correct comparison were physically similar.

Although it is thus possible that the number of symbolic-matching problems, rather than the sample-to-comparison mapping ratio, was critical to the present findings, we view this possibility as unlikely. The view that MTO mappings encourage common sample-coding has intuitive appeal, in that such a coding process would reduce the number of codes required to mediate accurate performance. Our intuition, however, provides no rationale for why identity-matching problems would encourage, and symbolic-matching problems would discourage, retrospective and analogical coding. Moreover, matching to duration samples is a symbolic-matching task. Hence, if symbolic-matching

problems discourage retrospective and analogical coding, then why do pigeons that are trained to match duration samples only (e.g., the control groups in our experiments) code those samples retrospectively and analogically? Finally, although the MTO mappings used in our experiments each involved two symbolic-matching tasks, other researchers have obtained evidence for common coding of nontemporal samples even though only one of the two matching problems involved in the MTO mapping was symbolic (e.g., Urcuioli et al., 1989; Zentall et al., 1991).

The significance of our findings is not predicated on whether the catalyst for nonanalogical coding of duration was the MTO mapping or the use of multiple symbolic-matching problems. Although it is clearly important to determine which variable (or variables) results in nonanalogical coding of duration, the fact that evidence for analogical and nonanalogical coding of duration samples was obtained reveals that coding processes in pigeons are flexible and responsive to task demands.

Both Kraemer et al. (1985) and Killeen and Fetterman (1988) offered accounts in which they maintained that the choose-short effect arises from processes other than analogical coding and subjective shortening. According to Kraemer et al. (1985), pigeons normally code event duration nonanalogically in terms of either retrospective-categorical codes (*short* and *long*) or prospective codes (*peck red* and *peck green*). The choose-short effect is held to arise because (a) the code activated by a sample presentation is unlikely to be remembered throughout a long delay; and (b) in the absence of an active code at testing, processes of stimulus generalization result in the pigeon being more likely to behave in accord with the contingencies of a short-sample trial than in accord with the contingencies of a long-sample trial.

According to Killeen and Fetterman's (1988) behavioral theory of timing, onset of a sample in a matching task involving samples of different durations initiates a series of behavioral states that change probabilistically as a function of time in the presence of the sample. Choice between the comparison stimuli is held to be controlled by the behavioral state present at the time of choice. To account for the choose-short effect, Killeen and Fetterman assumed that during a delay interval the behavioral state tends to shift toward the state that is normally present after a short sample.

As formulated at present, neither Kraemer et al.'s (1985) nor Killeen and Fetterman's (1988) theory anticipated that the choose-short effect would be affected by (a) the assessment task (choice vs. successive matching) used (Grant & Spetch, 1991) or (b) the sample-to-comparison mapping arrangement used in a choice task (as shown by the present results). This is not to say, of course, that an adequate account of the present results and those of Grant and Spetch (1991) is necessarily beyond the scope of either or both of these interpretations. At the least, however, these alternative theories of the choose-short effect will require elaboration to accommodate the present results and those of Grant and Spetch (1991).

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