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Subjective Shortening: A Model of Pigeons' Memory for Event Duration

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Pigeons' memory for event duration was investigated using a delayed matching-to-sample procedure. When a retention interval of variable length intervened between sample and comparison stimuli, pigeons responded as though long samples had been short after retention intervals of 10 sec or more. This "choose-short" effect occurred in each subject, whether the subject was naive or experienced, whether sample durations were represented by food access or light, or whether a two- or three-choice procedure was used. A subjective-shortening model was proposed in which it was assumed that working memory of the sample duration "shortens" over the retention interval. Comparison of this memory with a stable reference memory produces the tendency to respond as though a long sample were short. Three predictions derived from the model were confirmed. First, after a long-retention interval, psychophysical functions relating probability of choosing "long" to sample duration were shifted toward longer durations. Second, stepwise increases in the retention interval produced a temporary choose-short effect, whereas stepwise decreases produced a temporary choose-long effect. Third, with extended training at a given retention interval, the choose-short and choose-long effects diminished. Only the subjective-shortening model appears to account for all of these results.

The processes of short-term, or "working," memory in animals have been the focus of considerable research during the past decade. One procedure that is widely used to study working memory in pigeons is the delayed matching-to-sample (DMTS) task. In this task, trials consist of three components: (a) presentation of a sample stimulus, (b) a delay (retention) interval, and (c) presentation of two or more comparison stimuli, one of which physically matches the sample. Choice of the matching comparison is reinforced. Because the stimuli used as the samples are alternated randomly over trials, the animal must remember which sample stimulus had been presented at the beginning of the trial in order to choose the correct comparison stimulus. One popular variation of the DMTS task is the delayed symbolic matching-to-sample (DSMTS) task. The DSMTS task is similar to the DMTS task except that the comparison stimuli do not physically match the samples; instead, the relationship between the sample and the correct comparison is arbitrary.

The most commonly used sample stimuli for pigeons have been colors or line tilts. A number of studies have shown that when the duration of these sample stimuli is increased, pigeons' matching accuracy improves (e.g., Maki & Leith, 1973; Nelson & Wasserman, 1978; Roberts, 1972; Roberts & Grant, 1974, 1976; Roitblat, 1980). This facilitatory effect of increases in sample duration has been of considerable importance for theories of working memory. For example, increases in sample duration have been postulated to improve matching accuracy by increasing the strength of a memory trace (Roberts, 1972) or by increasing the likelihood of a fully encoded representation of the sample in memory (Roitblat, 1980).

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Although considerable research has been directed at understanding the effects of sample duration on memory for the color or spatial orientation of samples, few researchers have investigated pigeons' memory of duration per se. Recently, Spetch and Wilkie (in press) found that when duration was the dimension along which pigeons discriminated the samples, accuracy was better after short samples than after long samples at long delays, a phenomenon they called the *choose-short* effect. They hypothesized that this choose-short effect might occur because pigeons' subjective representation of event duration "shortens" over the delay interval, so that the sample is remembered as being shorter than its true value after a long delay.

Because the choose-short effect reported by Spetch and Wilkie is a novel empirical phenomenon, and because little other work has been conducted on animals' memory for event duration (Church, 1980; Cohen, Calisto, & Lentz, 1981), a systematic investigation of the choose-short effect was warranted. Accordingly, Experiments 1 and 2 were designed to establish the reliability of the choose-short effect and its generality across a number of experimental parameters.

A second purpose of our investigations was to provide some support for the hypothesis that the choose-short effect is due to subjective shortening of event duration in pigeons' memory. Accordingly, a number of predictions were derived from a subjective-shortening model, and these predictions were tested in Experiments 3 and 4.

Experiment 1

The design of this experiment stemmed from Spetch and Wilkie's (in press) original demonstration of the choose-short effect. They trained pigeons under a DSMTS procedure to match short (2-sec) food access or light samples to one color of comparison stimulus and long (10-sec) food or light samples to another color of comparison stimulus. They found that when the delay between the sample and comparison stimuli was lengthened to 10 or 20 sec, each bird showed a strong tendency to choose the "short" comparison.

The purpose of the present experiment was to provide a systematic replication of this choose-short effect and to assess the stability of the effect across sessions of delay testing. In this study, naive pigeons served as subjects, and each bird was trained with only one type of sample stimulus (either food or light).

Method

Subjects

The subjects were three naive Silver King pigeons (Birds 4, 5, and 6). The birds were deprived of food until they were approximately 80% of their free-feeding weight. They were then maintained at this weight by mixed grain obtained during and after daily experimental sessions. The birds were housed in large individual home cages in which water and health grit were continuously available.

Apparatus

A BRS-Foringer PS-004 pigeon chamber was used. One wall of the chamber contained a horizontal row of three plastic pecking keys that each required a force of about .2 N to operate. Mounted behind each key was an Industrial Electronics Engineers' Series 10 stimulus projector that illuminated the keys with a uniform field of colored light. Centered below the keys was a Gerbrands G5610 solenoid-operated feeder that permitted timed access to mixed grain. Grain presentations were illuminated by a 2.8-W lamp located within the feeder. The houselight consisted of two 2.8-W lamps mounted behind a transparent plastic reflector above the pecking keys; these lamps provided a diffuse illumination of the chamber.

Control of experimental conditions and collection of the data were performed by a Data General Nova 3 computer.

Procedure

Preliminary training. During preliminary sessions, the birds were trained to eat from the raised illuminated grain feeder and then to peck the side pecking keys, which were illuminated with blue or yellow light (Birds 4 and 5) or with red or green light (Bird 6).

Baseline procedure. The baseline procedure was 0-sec DSMTS, similar to that used by Spetch and Wilkie (in press). Trials began with the presentation of a sample stimulus for either a short (2-sec) or long (10-sec) duration. For Birds 4 and 5, the sample was illumination of the houselight; for Bird 6, food access (i.e., presentation of the feeder) served as the sample. Sample offset was followed immediately (i.e., after a 0-sec delay) by illumination of the side pecking keys with two comparison stimuli. For Birds 4 and 5, the comparison stimuli were yellow and blue light; their designation as correct after short and long samples was counterbalanced across the two birds. For Bird 6 the comparison stimuli were

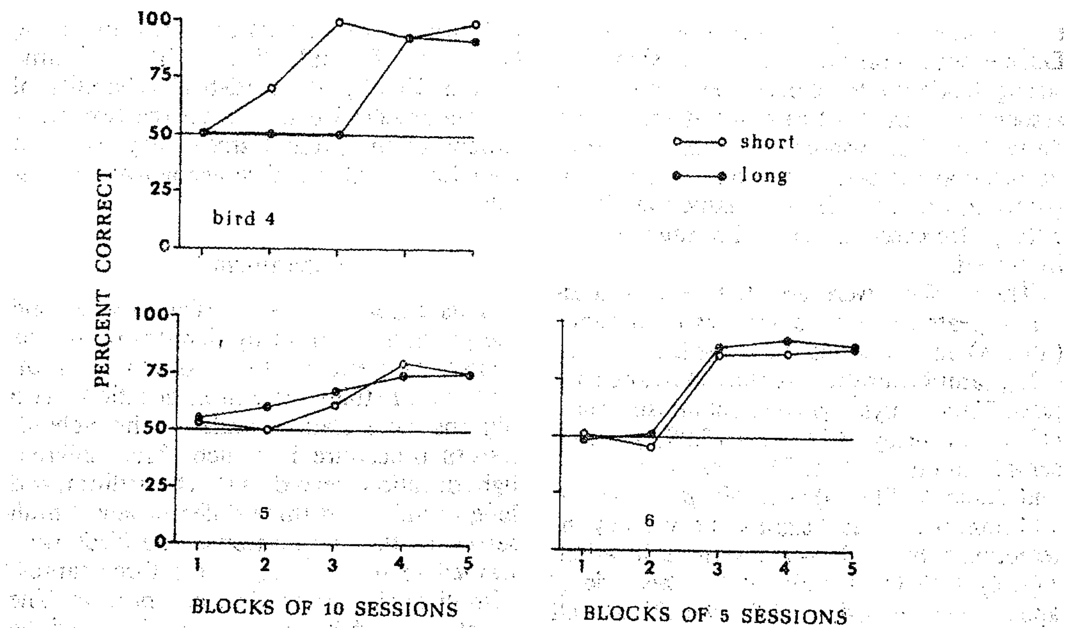

Figure 1. Percentage of correct choices after short-duration (open circles) and long-duration (closed circles) samples during baseline training for birds in Experiment 1.

red and green. The left–right location of the comparison stimuli on the two pecking keys was varied randomly across trials. A peck at the correct comparison produced a 5-sec grain reinforcer, followed by a 30-sec intertrial interval (ITI), whereas a peck at the incorrect comparison terminated the trial and produced the ITI. There were approximately 60 trials in each session. Each subject was trained under this procedure until matching accuracy appeared stable and asymptotic (50 sessions for Birds 4 and 5; 25 sessions for Bird 6).

Delay manipulations. Following baseline training, the birds received several sessions (40 for Birds 4 and 5; 20 for Bird 6) in which a variable delay procedure was in effect, with 0-sec delays occurring on a random half of the trials, and 5- and 20-sec delays occurring equally often on the remaining trials.

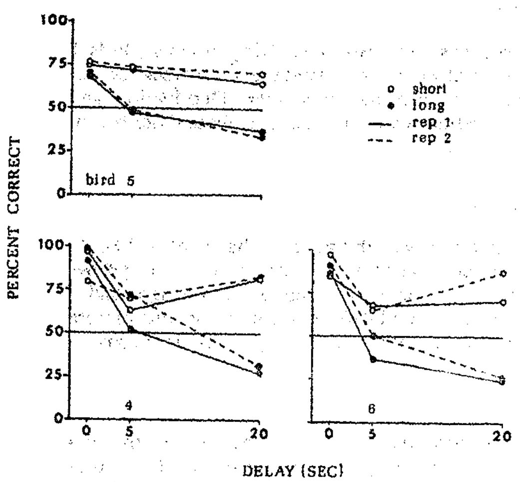

Figure 2. Percentage correct after short-duration (open circles) and long-duration (closed circles) samples at the three delays during the first half (solid lines) and the second half (dashed lines) of the delay-manipulation phase in Experiment 1.

Results

Acquisition

Figure 1 shows the birds' matching accuracy after short and long samples during baseline training. Bird 4 sometimes was more accurate after short samples, whereas Birds 5 and 6 were slightly more accurate after long samples. However, these differences were minimal at the end of acquisition. Thus, there was no systematic tendency for the birds to choose the short comparison stimulus during acquisition.

Delay Manipulations

Figure 2 shows matching accuracy after short and long samples at the three delays. These data are displayed as two replications, which correspond to the first and the second half of the total number of sessions in which the variable delay procedure was in effect. During both replications the birds showed a strong tendency to choose the comparison associated with short samples at the 20-sec delay. This choose-short effect was not as pronounced at the 5-sec delay and was not apparent at the 0-sec delay. Finally, overall accuracy decreased as the delay interval was increased.

These effects were assessed using a four-way repeated measures analysis of variance (ANOVA) on choice accuracy; the factors were delay, sample duration, replications, and subjects. This analysis yielded significant main effects for delay, $F(2, 4) = 15.99$, $p < .05$, sample duration, $F(1, 2) = 90.11$, $p < .05$, and subjects $F(2, 4) = 15.49$, $p < .051$. In addition, there was a significant two-way interaction between delay and sample duration, $F(2, 4) = 18.18$, $p < .05$, and between delay and subjects, $F(4, 4) = 16.95$, $p < .05$, as well as a significant three-way interaction between delay, sample duration, and subjects, $F(4, 4) = 7.58$, $p < .05$. No other effects were significant.

The effects of delay and sample duration were analyzed further by a posteriori pairwise comparisons (Newman–Keuls, $p = .05$). These analyses showed that accuracy after long samples was significantly lower after a 20-sec delay than after a 0-sec or 5-sec delay, whereas accuracy after short samples did not change significantly over the three delays. Furthermore, accuracy was greater after short samples than after long samples at the 20-sec delay but not at the 0-sec or 5-sec delays; during both replications, this effect was significant for each bird. Thus, each bird showed a reliable choose-short effect at the 20-sec delay that was stable across the two replications.

Discussion

These results replicate and extend Spetch and Wilkie's (in press) findings in three ways. First, they demonstrate that the tendency to choose the short comparison at long delays (i.e., the choose-short effect) does not depend on the subjects' having extensive training in duration-discrimination tasks. Second, in this experiment, each subject was exposed to only one type of sample stimulus (either food or light). Thus, the choose-short effect was not specific to a more complex task involving both types of sample stimuli within the same session. Finally, the statistical reliability of the choose-short effect across the two replications in the present study suggested that the effect is stable and robust across test sessions.

Experiment 2

This experiment was designed to extend the previous findings by demonstrating the choose-short effect with a procedure that involved more than two sample durations. Two pigeons were trained under a three-choice DSMTS procedure in which three different light durations served as short, medium, and long samples and three different key stimuli served as the comparisons. The birds were trained to match each of the three sample stimuli to the appropriate comparison. The effect of the delay interval on choice of the three comparisons after each sample duration (short, medium, and long) was then examined. With this procedure, a choose-short effect would be reflected by a selective increase in incorrect choices to the short comparison and a decrease in correct choices to both the medium and the long comparisons.

Method

Subjects

The subjects were two Silver King pigeons (Birds 1 and 2), each of which had served previously in a number of duration-discrimination studies. Deprivation and housing conditions were the same as those described in Experiment 1.

Apparatus

The apparatus was the same as that used in Experiment 1 except that three different stimuli (red, yellow, and green light for Bird 1; red and green light and a white rectangle on a black background for Bird 2) were presented on the three pecking keys as comparisons.

Procedure

Baseline procedure. Each trial began with the presentation of a houselight sample for one of three durations: 2 sec (short), 6 sec (medium), or 14 sec (long). Immediately following termination of the sample (0-sec delay), the three pecking keys were illuminated with the three comparison stimuli. The particular comparison stimuli that were correct after each sample duration varied across the birds. For Bird 1, choices of red after short,

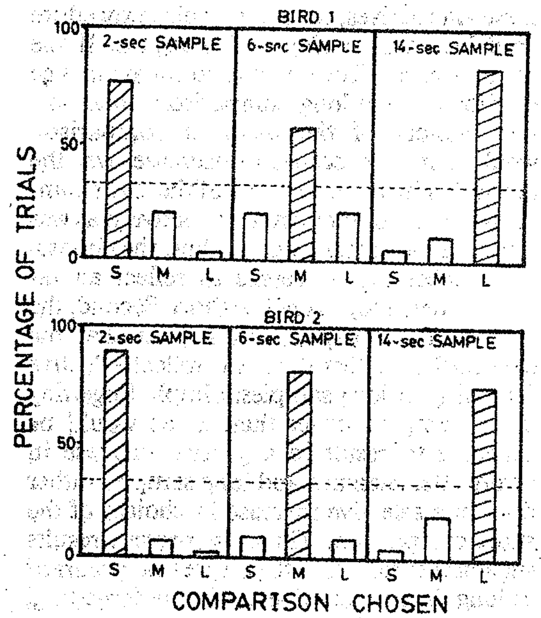

Figure 3. Percentage of trials on which birds chose the "short" (S), "medium" (M), or "long" (L) comparison stimulus after each of the three sample durations during the last 10 sessions of baseline training in Experiment 2. Slashed bars represent correct choices; the dashed line indicates chance level (33%) for a three-choice procedure.

yellow after medium, and green after long were designated correct; for Bird 2, the correct choices were green after short, the rectangle after medium, and red after long. Correct choices were reinforced with 4-sec access to grain followed by a 30-sec ITI; incorrect choices terminated the trial and initiated the ITI. The order of presentation for the three samples and the six possible key arrangements of the comparison stimuli was determined randomly. Bird 1 received 50 sessions and Bird 2 received 30 sessions of baseline training.

Delay manipulations. The variable delay procedure was initiated following baseline training. On a randomly determined half of the trials in each session the delay was 0 sec; on the remaining trials a delay of 5 sec or 10 sec occurred, each with an equal probability. All other aspects of the procedure were unchanged. Both birds were tested for 20 sessions.

Results

Baseline Performance

Figure 3 shows the percentage of trials on which the birds chose the short, medium, or long comparison keys after each sample duration during the last 10 sessions of baseline training. Each bird was well above chance level (33.3%) in choosing the correct comparison after each sample duration. Moreover, after short and long samples, more errors occurred to the medium comparison, whereas after medium samples, the errors were equally likely to be a choice of the short or long comparisons. Thus, both birds' choice of the comparison stimuli clearly was controlled by the sample duration.

Delay Manipulations

Choices of the three comparison stimuli after each sample duration at the three delays are shown in Figure 4. Data from all 20 sessions are included. Several features of these data should be noted. First, after both the medium and long samples, choice of the correct comparison decreased over the delays, whereas after the short samples, choice of the correct comparison did not change greatly over the delay. Second, after medium samples, choice of the short comparison increased at the 10-sec delay, whereas choice of the long comparison did not change substantially at any of the delays. Third, after

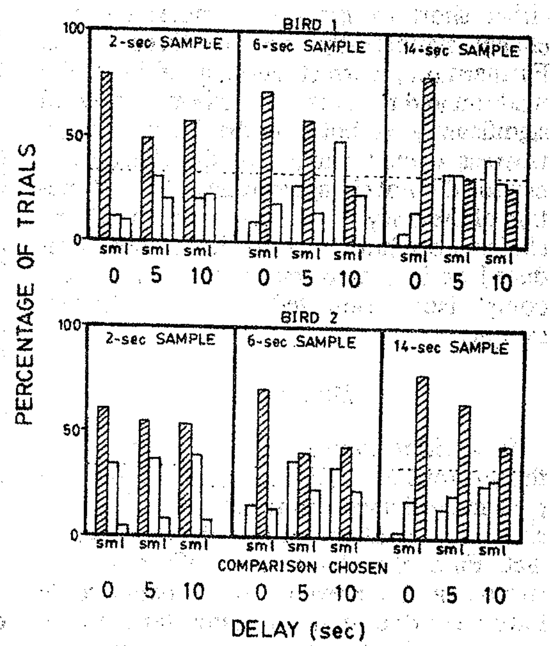

Figure 4. Percentage of trials on which the birds chose the "short" (S), "medium" (M), or "long" (L) comparison after each of the three sample durations at the 0-, 5-, and 10-sec delays in Experiment 2. The dashed line indicates chance level (33%) for a three-choice procedure.

long samples, choice of the short comparison increased at the 10-sec delay.

These results were confirmed by three, three-way repeated measures ANOVAs of choices of the short, medium, and long comparisons; the factors were delay, sample duration, and subjects. The analysis of choices of the short comparison revealed a significant main effect for sample duration, $F(2, 2) = 46.08$, $p < .05$. No other effects were significant. The analysis of choices of the medium comparison showed a significant Sample Duration × Delay interaction, $F(4, 4) = 14.02$, $p < .05$, but no other significant effects. Similarly, the analysis of choices of the long comparisons showed a significant Sample Duration × Delay interaction, $F(4, 4) = 7.65$, $p < .05$, and no other significant effects.

Subsequent a posteriori comparisons (Newman-Keuls, $p = .05$) showed that incorrect choices of the short comparison after both medium and long samples occurred more often at the 10-sec delay than at the 0-sec delay, whereas incorrect choices of the medium comparison after either short or long samples and of the long comparison after either short or medium samples did not change significantly over the three delays. Furthermore, correct choices of both the medium and the long comparisons decreased significantly at both of the longer delays, whereas correct choices to the short comparison did not change significantly as a function of the delay. Thus, even under this three-choice procedure, increases in the delay produced an increased tendency to choose the comparison associated with the shortest sample.

Discussion

In addition to extending the generality of the previous findings to a new procedure, the present results seem to argue against two possible interpretations of the choose-short effect. First, the choose-short effect demonstrated in the previous experiments could have been due to an increased tendency to avoid choosing the "long" comparison rather than to an increased tendency to choose the short comparisons. Although the two-choice procedure of the previous studies did not provide any means of distinguishing between these alternatives, the three-choice procedure used here was useful in this regard. If the choose-short effect was due to an avoidance of choosing the long comparison, then correct choices of the medium comparison would not be expected to decrease over the delay, and incorrect choices of the short comparison should not increase selectively, as was found in the present study. Thus, the choose-short effect indeed seems to reflect an increased tendency to choose short. Second, the results of this experiment suggest that the choose-short effect does not reflect selective forgetting of long samples: Simple forgetting of all samples longer than 2 sec would be expected to result in a general increase in errors after medium and long samples rather than in a selective increase in choices of the short comparison. Thus, the present results suggest that not all of the errors that occurred at long delays were due to simple forgetting; at least some of these errors seemed to reflect the tendency to choose short.

Experiment 3

The results of the first two experiments demonstrated that the choose-short effect is a robust and reliable phenomenon in pigeons. Furthermore, the results suggested that the choose-short effect is not due to an avoidance of choosing the long comparison or to a selective forgetting of long samples. Thus far the results seem to be consistent with the subjective-shortening interpretation offered by Spetch and Wilkie (in press)—that is, that the subjective representation of sample duration shortens in pigeons' working memory as a function of time.

Although there is a paucity of research on the processes of animals' memory for event durations, one recent study conducted by Church (1980) is relevant to the subjective-shortening view proposed here. Church studied rats' memory for event durations using a right–left lever-choice procedure and found no evidence of a choose-short effect at short delays: With delay increases of up to 8 sec, accuracy decreased approximately equally after the short and long signals. The rats did, however, show a choose-short tendency after a 32-sec delay, but because they also showed this tendency when no signal had been presented. Church concluded that these results were due to biased guessing rather than to a process of subjective shortening.

To investigate this issue further, Church conducted a second experiment in which he compared the point of subjective equality (PSE) across delay intervals of 0 to 8 sec. This PSE was thought to represent the sample duration that produces an internal representation that is halfway between the long and short training durations. Church reasoned that if the subjective sample durations shorten over the delay, a longer sample duration would be required to maintain a probability of .5 of choosing long. That is, the psychophysical functions relating probability of choosing "long" to sample duration should shift to the right, and the PSE should shift toward longer durations as the delay interval is increased. Church found that the psychophysical function was flattened but did not shift to the right, and the PSE did not change as a function of the delay. He therefore concluded that the subjective duration of the signal did not shorten over the delay. However, in this study Church did not test any delays longer than 8 sec. Thus, it is not known whether the 32-sec delay, which produced a choose-short effect in his first study, would produce a shift in the PSE.

The present experiment was designed to provide support for the subjective-shortening hypothesis by showing that a long delay will produce a rightward shift in the psychophysical function relating probability of choosing "long" to sample duration and a shift in the PSE to a longer value. In this study, pigeons were trained under a DSMTS procedure with 2- and 10-sec samples and then tested with various sample durations after delays of 0, 5, and 20 sec. Psychophysical functions relating probability of choosing long to sample duration were then determined, and the PSE was calculated for each delay. A rightward shift in the functions and a significant increase in the value of the PSE with increases in the delay would provide support for the subjective-shortening hypothesis.

Method

Subjects and Apparatus

Subjects and apparatus were the same as those used in Experiment 2.

Procedure

Baseline sessions. Each bird was exposed to a few baseline sessions that were similar to the delay-manipulation sessions of Experiment 1 except that correct choices were reinforced with a probability of .75. Light durations served as the samples, and the comparison stimuli were blue and yellow keylights, with their designation as correct after short and long samples counterbalanced across the two birds. As in Experiment 1, 0-sec delays occurred on half of the trials, and 5- and 20-sec delays occurred equally often on the remaining trials.

Generalization testing: Series 1. The procedure used in this condition was similar to that used in the baseline sessions, except that within each session, generalization-test trials occurred with a probability of .25. On these test trials, the light sample was presented for one of three test durations: 4 sec, 6 sec, or 8 sec, each occurring with an equal probability. Following the delay, the usual comparison stimuli were presented. A peck to either of the comparison keys terminated the trial and was recorded but never reinforced. On the remaining 75% of the trials, one of the usual 2- and 10-sec samples was presented, each with an equal probability, and correct choices were reinforced with a probability of .75. These intermittent reinforcement contingencies were sufficient to maintain responding on all trials throughout the experiment. Both birds were tested under this condition for 30 sessions.

Generalization testing: Series 2. The procedure used in this condition was identical to that used for Series 1, except that the test durations of the samples in this series were 6 sec, 14 sec, and 18 sec. Both birds were tested for 30 sessions under this condition.

Results

Figure 5 shows the mean probability of responses to the "long" comparison as a function of sample duration at each of the three delay intervals for the two series. The delay interval had two marked effects on these functions. First, increases in the delay produced a rightward shift in the function; the sample duration at which the birds began to choose "long" on over half of the trials was much longer after a 20-sec delay than after a 0-sec or 5-sec delay. Second, it is also clear that increases in the delay produced a substantial flattening of the psychophysical functions. Nevertheless, responding was not independent of sample duration at any of the delays, as indicated by significant ($p < .05$) positive correlations between sample duration and probability of choosing long (Bird 1: 0-sec delay, $r = .87$; 5-sec delay, $r = .73$; 20-sec delay, $r = .86$; Bird 2: 0-sec delay, $r = .79$; 5-sec delay, $r = .80$; 20-sec delay, $r = .79$).

The rightward shift in the psychophysical functions was corroborated by an analysis of

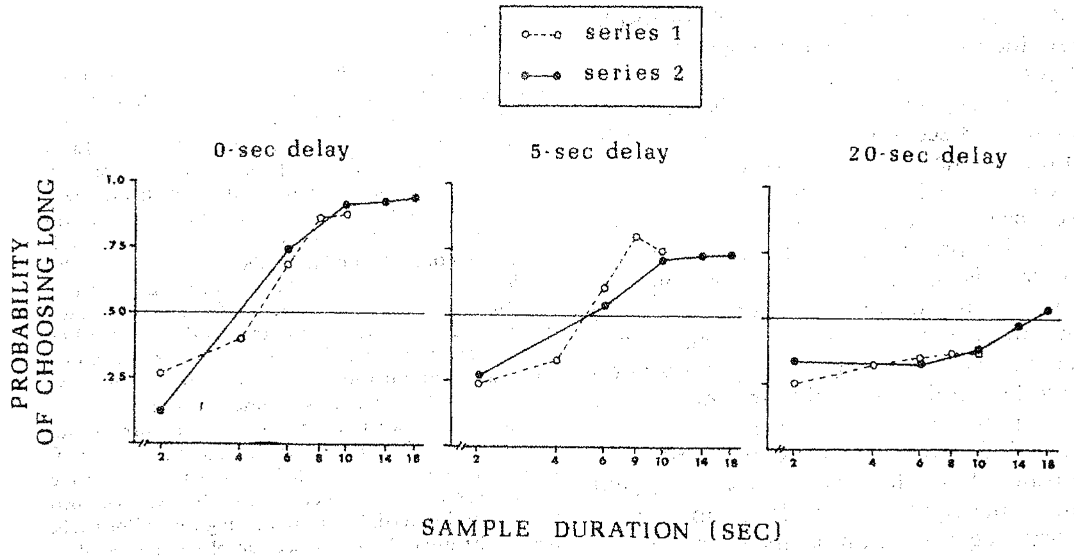

Figure 5. Mean probability of a response to the "long" comparison as a function of sample duration for the three delays during Series 1 (open circles) and Series 2 (closed circles) of generalization testing in Experiment 3.

the PSE at each delay. The PSE was estimated in the following way. First, a linear regression equation relating the probability of a "long" response to sample duration was calculated by the method of least squares for each bird during each series and at each delay. Second, these equations were used to find the sample duration at each delay that corresponded to a probability of .5 of a "long" response, which represents the estimated PSE (cf. Church, 1980). At the 0-, 5-, and 20-sec delays, respectively, the estimated PSE for Bird 1 was 4.8 sec, 5.8 sec, and 17.6 sec during Series 1, and 5.4 sec, 3.9 sec, and 20.6 sec during Series 2. For Bird 2, the estimated PSE with the 0-, 5-, and 20-sec delays, respectively, was 4.4 sec, 5.1 sec, and 20.6 sec during Series 1, and 4.5 sec, 7.6 sec, and 10.8 sec during Series 2.

A two-way repeated measures ANOVA performed on the PSE data revealed a significant main effect of delay, $F(2, 2) = 33.8$, $p < .05$, but not of series, $F(1, 1) = .64$, $p > .05$, or subjects, $F(1, 2) = .76$, $p > .05$. None of the interactions were significant. Subsequent a posteriori comparisons (Newman–Keuls, $p = .05$) confirmed that the PSE was significantly longer at the 20-sec delay than at either the 0-sec or the 5-sec delay.

Discussion

The results of Experiment 3 provide some support for the view that the subjective duration of events in pigeons' memory shortens over a delay. After a 20-sec delay, a longer sample duration was required before the birds chose "long" with a probability of .5 or greater. This effect of increases in the delay on the psychophysical function was also reflected by a significant shift in the PSE toward a longer value. After a 20-sec delay, the sample duration that the birds treated as being halfway between short and long (i.e., the PSE) had increased, suggesting that the subjective-sample durations had decreased.

Although these results support the subjective-shortening hypothesis, it should be noted that some features of these data may be consistent with other interpretations. For example, at the 20-sec delay, the psychophysical function was substantially flattened, suggesting some general loss of stimulus control. This result seems to be consistent with a general forgetting, or biased-guessing, interpretation (cf. Church, 1980). Nevertheless, the correlations between sample duration and probability of choosing "long" were significantly positive, even at the 20-sec delay, indicating a reliable degree of stimulus control by sample duration. Thus, general forgetting or biased guessing does not appear to account for the entire pattern of results.

Experiment 4

The results of the first three experiments are consistent with the view that the subjective representation of event duration in pigeons' memory shortens as a function of time. In the present experiment, a more detailed model of this subjective-shortening process is described and tested.

The subjective-shortening model is based on the idea that the processes of working (i.e., short-term) memory interact with the processes of reference (i.e., long-term) memory (cf. Honig, 1978). According to the model, a reference memory of the sample durations and their associations with the comparison stimuli is established during initial training at a 0-sec delay. This reference memory, once established, remains relatively stable within and between trials provided that a substantial proportion of the trials consist of the delay used during initial training (e.g., 0-sec). On the other hand, the working memory of the sample undergoes a systematic change within the trial whenever there is a delay greater than 0 sec between the sample and comparison stimuli: The remembered duration of the sample shortens over the delay. It is the discrepancy between the reference memory of the sample and the working memory of the sample that produces the choose-short effect: As the working memory of the long sample shortens, it becomes more similar to the reference memory of the short sample, thereby producing a tendency to respond as though a long sample was short.

It is clear from the model that the appearance of a stable choose-short effect depends on the stability of the reference memory established during initial training. The reference memory of original training should remain relatively stable with a variable delay procedure, such as that used in the first three experiments, because a substantial proportion of the trials still contained the 0-sec delay used in original training. Consequently, the discrepancy between the reference memory of the sample and the working memory of the sample after a long delay should be maintained over test sessions.

According to the model, a stepwise delay procedure, in which the delay is changed to a value that remains constant on all trials for several sessions, should produce results different from those obtained with the variable delay procedure. When the delay is manipulated in a stepwise fashion, the reference memory should not remain stable over the delay manipulation phase because 0-sec delays are not interspersed with the longer delays. Instead, a new reference memory should develop gradually at each delay that is based on the working memory of the samples at that delay. As a result, the discrepancy between the working memory and the reference memory of the samples should diminish as a function of training at each delay. Thus, it can be predicted from the model that stepwise increases in the delay should produce a temporary choose-short effect, and with extended training at the delay this choose-short effect should diminish. It can also be predicted from the model that stepwise decreases in the delay should produce a temporary choose-long effect. The choose-long effect should occur because once a reference memory has been established at a long delay, a subsequent decrease in the delay would result in a temporary discrepancy between working memory and reference memory that is opposite to that produced by increases in the delay.

Thus, the major purpose of Experiment 4 was to test three predictions derived from the subjective-shortening model concerning the outcome of stepwise manipulations in the delay: (a) Increases in the delay should lead to an initial choose-short effect, (b) decreases in the delay should produce an initial choose-long effect, and (c) with extended training at a given delay, these choose-short and choose-long effects should diminish. Empirical confirmation of these predictions would provide strong support for the subjective-shortening model.

A secondary purpose of Experiment 4 was to replicate Church's (1980) finding that animals tend to choose "short" when no sample is presented (i.e., on 0-sec sample tests).

Method

Subjects

Five naive adult Silver King pigeons (Birds 7, 8, 9, 10, and 11) served as the subjects. Deprivation and housing conditions were the same as those described for subjects in Experiment 1.

Apparatus

The test chamber for Birds 7, 8, and 9 was identical to that described in Experiment 1. For Birds 10 and 11, a BRS/LVE 132-02 light-proof, sound-attenuating test chamber was used. One wall of this chamber contained a horizontal array of three pecking keys, each equipped with a microswitch to sense pecks of about .2 N or greater. An Industrial Electronics Engineers' Series 10 stimulus projector was mounted behind each key; these illuminated the center key with a uniform field of yellow light or with a white square on a dark background, and the side keys with a uniform field of either red or green light. A BRS/LVE 114-10 grain feeder containing a 2.8-W lamp was mounted below the center key.

Procedure

Preliminary training. During a few preliminary sessions, each bird was trained to eat from the raised illuminated grain feeder and then trained to peck the center key when illuminated with yellow light and the side keys when illuminated with either red or green light.

Baseline condition (0-sec DSMTS). A variation of the DSMTS procedure, similar to that described in Experiment 1, was used. In this experiment, trials began with the presentation of a yellow light on the center pecking key; the first peck to this key terminated the yellow light and produced the sample stimulus, which lasted for either a short (2-sec) or long (10-sec) duration. For Birds 10 and 11, the sample stimulus was the presence on the center key of a white square on a dark background, whereas for Birds 7, 8, and 9 the sample stimulus was illumination of the houselight. Immediately (0 sec) following the offset of the sample, the side keys were illuminated with red and green light, which served as the comparison stimuli. For Birds 10 and 11, the red comparison was designated as correct after short samples and the green comparison after long samples; for Birds 7, 8, and 9, green was designated correct after short samples and red after long samples. A peck to the correct comparison terminated both comparisons and produced 3-sec access to grain followed by a 30-sec ITI; pecks to the incorrect comparison terminated the trial and initiated the ITI. The presentation of the short and long samples and the arrangement of the red and green comparisons on the side keys occurred in a mixed and counterbalanced order over trials in each session.

Each bird was trained under this condition until matching accuracy was well above chance and appeared to be stable. Accordingly, Birds 7, 8, 9, 10, and 11 were exposed to this condition for 24, 18, 18, 36, and 24 sessions, respectively.

Delay manipulations. During this condition, all aspects of the procedure, including the reinforcement contingencies, were the same as during baseline except that the delay between the sample and comparison stimuli was manipulated over blocks of several sessions. For each bird, the delay manipulations were conducted in three consecutive phases.

Phase 1: Increases in the delay. During this phase, the delay was increased for several sessions to 5 sec, then to 10 sec and/or to 20 sec. Birds 7, 8, and 10 were tested at all three of these delays, whereas Bird 9 was tested only at the 5- and 20-sec delays, and Bird 11 was tested only at the 5- and 10-sec delays. Birds 7, 8, 9, 10, and 11 were tested at the 5-sec delay for 21, 21, 21, 24, and 27 sessions, respectively. Birds 7, 8, 10, and 11 were tested at the 10-sec delay for 15, 12, 12, and 33 sessions, respectively, and Birds 7, 8, 9, and 10 were tested at the 20-sec delay for 18, 21, 12, and 18 sessions, respectively.

Phase 2: Decreases in the delay. During this phase, the delay first was decreased from 10 sec (Bird 11) or from 20 sec (Birds 7, 8, 9, and 10) to 5 sec for several sessions. Subsequently, the delay was decreased to 0 sec for several sessions. Birds 7, 8, 9, 10, and 11 were tested at the 5-sec delay for 6, 6, 9, 9, and 12 sessions, respectively, and at the 0-sec delay for 6, 6, 6, 6, and 9 sessions, respectively.

Phase 3: Replication of the increases in the delay. Following exposure to the 0-sec delay in Phase 2, the delay was increased again to 5 sec for six sessions (Bird 8) or three sessions (Birds 7, 9, 10, and 11). For Bird 8, the delay subsequently was increased once again to 20 sec for three additional sessions.

0-sec sample tests. To assess the birds' choice tendencies in the absence of a sample, each bird was administered three 0-sec sample test sessions following the delay-manipulation phases. During these test sessions, the comparison stimuli were presented at the beginning of each trial without being preceded by a sample stimulus; the birds' choice of the comparison stimuli, which had been designated as correct for short and long samples throughout the experiment, was recorded, and the peck terminated the trial without reinforcement. Each of the three 0-sec sample test sessions was separated by a baseline (0-sec delay) session.

Results

The results of this experiment confirmed each of the predictions derived from the subjective-shortening model. During the first session following an increase in the delay to 5 sec, 10 sec, or 20 sec, the birds showed a consistent choose-short effect, whereas during the first session following a decrease in the delay to 5 sec, the birds showed a choose-long effect. In addition, with extended training at each delay, these choose-short and choose-long effects diminished. Finally, the present results replicated those of Church (1980) in finding a choose-short tendency on 0-sec sample tests. These results are discussed in detail in the following sections.

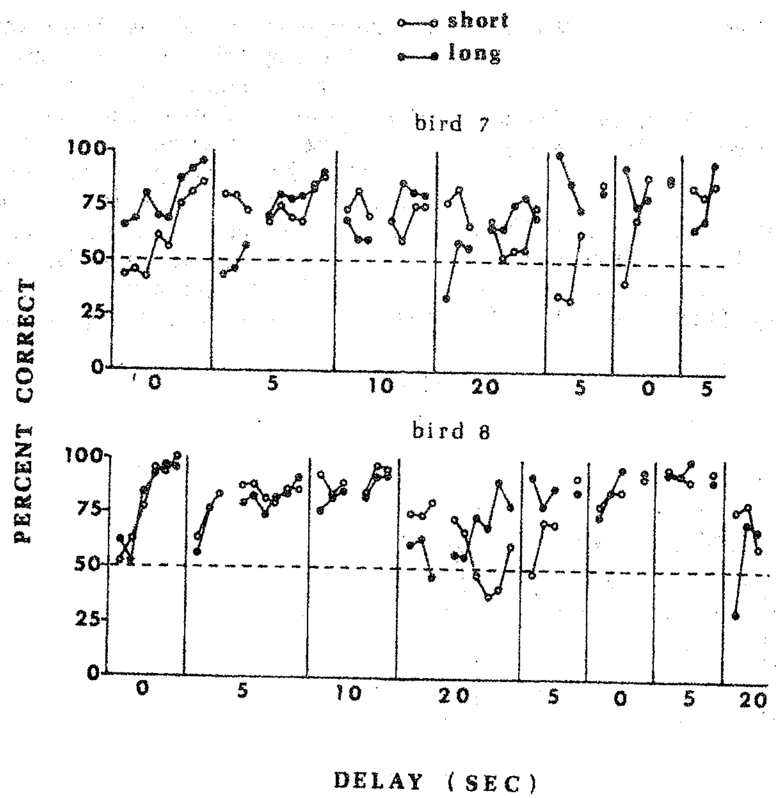

Figure 6. Percentage correct after short- and long-duration samples during blocks of three consecutive sessions of Experiment 4 and during the first three individual sessions after each change in the delay (indicated by the solid vertical lines) for Birds 7 and 8.

Choose-Short and Choose-Long Effects

The percentage of correct choices after short and long samples is shown in Figures 6 and 7 for each bird in blocks of three consecutive sessions, except for the first three sessions after each delay change, which are shown individually to facilitate detection of the initial choose-short and choose-long effects. Each increase in the delay resulted in an initial choose-short effect, whereas a decrease in the delay led to an initial choose-long effect. Figure 8 shows the mean percentages of all the birds' correct choices after short and long samples during the first session after each delay change in the three phases. Clearly, during Phases 1 and 3 (increases in the delay), accuracy was higher after short samples than after long samples, whereas during Phase 2 (decreases in the delay), accuracy was higher after long than after short samples.

A priori one-tailed dependent t tests, comparing accuracy after short and long samples, were conducted on the data shown in Figure 9. These analyses revealed that accuracy after short samples was significantly greater than accuracy after long samples during the first session following each delay increase in Phase 1: 5-sec delay, $t(4) = 4.41$, $p < .01$; 10-sec delay, $t(3) = 2.68, p < .05$; 20-sec delay, $t(3) = 3.4, p < .05$. This was also true following the second delay increase to 5 sec in Phase 3: $t(4) = 3.67$, $p < .05$. In contrast, accuracy after short samples was significantly lower than accuracy after long samples during the first session following a decrease in the delay to 5 sec in Phase 2: $t(4) = 2.67, p < .05$. The lower accuracy after short samples at the 0-

sec delay in Phase 2 was not statistically significant, $t(4) = 1.19$.

Decreases in the Choose-Short and Choose-Long Effects With Extended Training at a Given Delay

The choose-short and choose-long effects that were present after the delay changes tended to diminish with extended exposure to each of the delays (Figures 6 and 7). To test the significance of this change with extended training, "choice ratios" were calculated using the data from the first and last blocks of three sessions at each delay in Phase 1 and Phase 2. These ratios were calculated by dividing the percentage of correct choices after short samples by the sum of the percentage of correct choices after both short and long samples. Thus, ratios of greater than .5 indicate higher accuracy after short samples (i.e., a choose-short effect), and ratios of

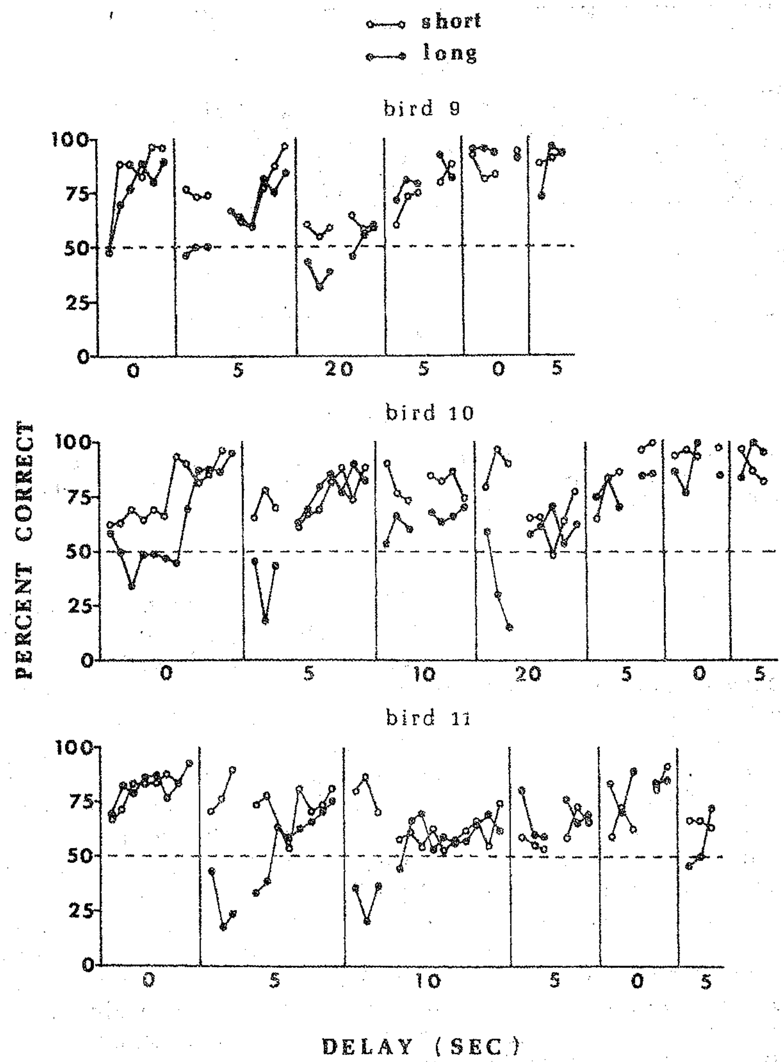

Figure 7. Percentage correct after short- and long-duration samples during blocks of three consecutive sessions of Experiment 4 and during the first three individual sessions after each change in the delay (indicated by the solid vertical lines) for Birds 9, 10, and 11.

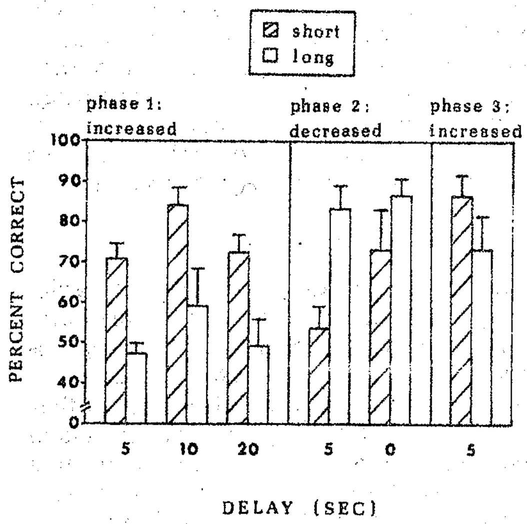

Figure 8. Mean percentage (± SE_M) of correct choices after short-duration (slashed bars) and long-duration (open bars) samples during the first session after each delay change in Experiment 4.

less than .5 indicate higher accuracy after long samples (i.e., a choose-long effect). A decrease in the choose-short effect over training therefore would be reflected in a decrease in the choice ratio, whereas a decrease in the choose-long effect over training would result in an increase in the choice ratio.

For all except the 10-sec delay in Phase 1, the prediction that the choose-short and choose-long effects would diminish with extended training was confirmed by one-tailed, dependent-measures t tests comparing the choice ratios for the first and last block of three sessions. During Phase 1 (delay increases), the choice ratio decreased significantly from the first to the last block of sessions at the 5-sec delay (first $M = .626$, last $M = .510$), $t(4) < .05$, and at the 20-sec delay (first $M = .625$, last $M = .502$), $t(3) = 6.28$, $p < .01$, which indicated that the choose-short effect diminished as a function of training. At the 10-sec delay, the choice ratio also decreased, but the difference was not significant (first $M = .589$, last $M = .515$), $t(3) = 2.21$. During Phase 2 (delay decreases), the choice ratio increased significantly from the first to the last block of sessions at both the 5-sec delay (first $M = .440$, last $M = .515$), $t(4) = 4.17$, $p < .01$, and the 0-sec delay (first $M = .476$, last $M = .511$), $t(4) = 2.61$, $p < .05$, which indicated that the choose-long effect diminished as a function of training.

0-Sec Sample Tests

Figure 9 shows the percentage of trials on which the birds chose the short comparison during the three 0-sec sample tests. All birds showed a consistent tendency to choose the short comparison in the absence of the sample.

The results of a dependent t test (two-tailed) of the mean percentage of "short" and "long" choices confirmed that the birds chose "short" significantly more often than they chose "long" during these 0-sec sample tests, $t(41) = 5.17$, $p < .05$.

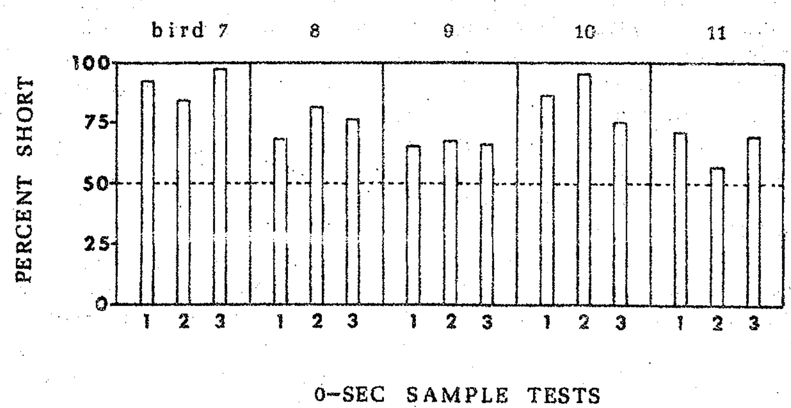

Figure 9. Percentage of trials in which the birds chose "short" during the three 0-sec sample tests in Experiment 4.

Discussion

Each of the predictions derived from the subjective-shortening model was confirmed. First, each stepwise increase in the delay led to an initial choose-short effect. Second, a decrease in the delay to 5 sec led to an initial choose-long effect. Third, these choose-short and choose-long effects diminished as a function of training at each delay. The empirical confirmation of these predictions provides strong support for the subjective-shortening model.

The results of Experiment 4 also replicate Church's (1980) finding that animals tend to choose "short" in the absence of a sample. Although this result could be attributed to biased guessing (Church, 1980), it can also be interpreted easily within the context of the subjective-shortening model. This model assumes that choices are based on a comparison between the working memory of the sample and its representation in reference memory. It is possible that the absence of a sample in working memory is perceived as being more similar to the reference memory of a short sample than a long sample. Thus, a tendency to choose "short" after no sample might be due to temporal generalization: Animals might treat a 0-sec sample more like "short" than like "long."

The present results also illustrate the importance of procedural variables in the study of working memory. The stepwise procedure used in Experiment 4 clearly produced different outcomes from those obtained with the variable-delay procedure used in the previous studies. Furthermore, with the stepwise procedure, performance at a given delay was different during initial sessions than during later sessions: The choose-short and choose-long effects were pronounced during the first few sessions at a new delay but disappeared after extended training at that delay. These results suggest that the use of only one type of delay-manipulation procedure or the practice of reporting only data from the last few sessions at each delay could lead to erroneous conclusions about the phenomena of working memory. Cohen, Calisto, and Lentz (1981), in a recent study of pigeons' memory for event duration, found no systematic differences between accuracy after short and long samples. It is interesting to note, however, that Cohen et al. used only a stepwise delay procedure and presented only mean data from a large number of trials at each delay. Thus, any choose-short or choose-long effects would have been obscured by their methods of delay manipulation and data presentation.

General Discussion

Spetch and Wilkie (in press), in an earlier study of pigeon's memory for sample duration, found that after a long delay pigeons tended to respond as though a long-duration sample had been short, a phenomenon they called the *choose-short* effect. The results of the present experiments demonstrated that the choose-short effect is not an anomalous outcome of the particular experimental parameters used in Spetch and Wilkie's original study. In the present investigations, the choose short effect occurred reliably and was not specific to a particular subject history (naive or experienced), to a particular set of comparison stimuli (colors or forms), to a particular choice procedure (two-choice or three-choice), to a particular type of sample stimulus (food access or light), or to a particular delay-manipulation procedure (variable or stepwise). Thus, the choose-short effect appears to be a reliable and general phenomenon.

The choose-short effect does not appear to be due to simple, nonmemorial factors such as biased guessing (cf. Church, 1980). Although biased guessing could account for the results of the first two experiments and possibly those of Experiment 3, the results of Experiment 4 are problematic for a guessing interpretation of the choose-short effect: It is not clear why guesses should be biased toward "short" after the delay is increased, become progressively less biased during extended exposure to a given delay, and then be biased toward "long" after the delay is decreased.

To account for the choose-short effect, Spetch and Wilkie (in press) hypothesized that the remembered duration of the samples might shorten over the delay, making long-duration samples seem more like short samples. A subjective-shortening model, based on this view of memory for event duration, was developed in the present investigations. According to the model, a reference memory of the sample durations and their association with the comparison stimuli is established during initial training. This reference memory remains relatively stable within and between trials provided that a substantial proportion of the trials consist of the delay at which the animals originally were trained. On the other hand, a working memory of the sample undergoes a systematic change within the trial when there is a delay between the sample and comparison stimuli: The remembered duration of the sample shortens over the delay. It is the discrepancy between the reference memory of the sample and the shortened working memory of the sample that produces the choose-short effect. In a variable delay procedure that includes trials containing the 0-sec delay, reference memory should be relatively stable, and the discrepancy between reference memory and working memory at long delays should be maintained over test sessions. The stable choose-short effect shown in the first two experiments was consistent with this model.

Experiment 3 provided further support for the subjective-shortening model by showing that the sample duration that birds treated as halfway between short and long was shifted to a longer value after a 20-sec delay. This finding was consistent with the idea that after a long delay, the working memory of the sample duration had shortened.

Experiment 4, however, provided the most stringent test of the subjective-shortening model. This experiment tested a number of predictions derived from the model concerning the outcome of stepwise manipulations of the delay. The pivotal aspect of the model from which the predictions were derived was the interplay between working memory and reference memory. According to the model, the stability of a previously established reference memory depends on the proportion of trials that consist of the delay used during the initial training. When the delay is changed in a stepwise fashion to a new value, the reference memory of original training should not be maintained. Instead, a new reference memory based on the working memory of the samples at that delay should develop, and the discrepancy between the working memory and the reference memory should diminish. Moreover, once a reference memory has been established at a long delay, a subsequent decrease in the delay should produce a temporary discrepancy between working memory and reference memory that is in the opposite direction to that produced by an increase in the delay.

Thus, it was predicted that stepwise increases in the delay would produce a temporary choose-short effect and that after extended training at a given delay the choose-short effect would diminish. Furthermore, stepwise decreases in the delay would produce a temporary choose-long effect, which also would diminish after extended training at a given delay. Each of these predictions was confirmed by the results of Experiment 4. Because this pattern of results could not have been predicted simply on the basis of the previous experiments, which had revealed only a stable choose-short effect, this experiment represented the most rigorous test of the predictive power of the subjective-shortening model.

The concept of subjective shortening in memory is not entirely new (cf. Frankenhaeuser, 1959; James, 1890; Ornstein, 1969). For example, Frankenhaeuser (1959) believed that memory of a time interval depended on retention of the stimulus events that filled the interval; if any of these stimuli were forgotten, the interval itself would be remembered as being shorter. In support of this view, Frankenhaeuser reported that human subjects' estimates of past time were consistently smaller than the present time estimates on which they were based. Furthermore, she reported that "a close correspondence was found between amount of time retained and number of stimuli retained" (Frankenhaeuser, 1959, p. 121).

The idea that memory of time undergoes systematic change or distortion has also been discussed in relation to a phenomenon reported in the human psychophysical literature called the *time-order error* (cf. Allan, 1979). When two stimuli longer than 1 sec and of equal duration are presented successively, subjects often judge the first stimulus as shorter than the second (e.g., Hellstrom, 1977). Köhler (1923) suggested that this error might occur because the second stimulus is being compared to a "faded" trace of the first stimulus, leading to an underestimation of the first stimulus.

The idea that remembered durations may shorten over time has also been mentioned in the animal memory literature (Church, 1980; Honig, 1981). Church (1980) discussed the idea of subjective shortening in terms of a gradual resetting of an "internal clock." However, he failed to find evidence for such a mechanism (Church, 1980). Honig (1981) mentioned the possibility that the remembered duration of prior stimuli might be "foreshortened." He suggested that this process of foreshortening might not have been observed in Church's study because the rats may have solved the task by remembering a coded response decision rather than the duration of the stimulus.

The subjective-shortening model may be similar in some respects to trace-decay theory (e.g., Roberts & Grant, 1976). For example, both views assume that memory is retrospective rather than prospective (cf. Honig & Thompson, in press). In fact, one might equate the two views by conceptualizing the process of subjective shortening as the decay of a sample trace along the duration dimension. Nevertheless, the subjective-shortening model differs from the trace-decay theory of Roberts and Grant (1976) in so far as it emphasizes the importance of an interactive relationship between reference memory and working memory.

It is important to note that the subjective-shortening model proposed in the present investigations is an attempt to describe the processes involved in memory for event duration rather than an attempt to explain the specific mechanisms responsible for subjective shortening. There are several possible mechanisms that could produce subjective shortening, such as the gradual resetting of an internal clock (cf. Church, 1980), the decay of a stimulus trace along the time dimension (cf. Roberts & Grant, 1976), or the forgetting of events that fill the interval (cf. Frankenhaeuser, 1959; James, 1890; Ornstein, 1969). The subjective-shortening model, as it is presently formulated, does not specify which, if any, of these possible mechanisms may underlie the subjective-shortening process.

Finally, the two-process framework of the subjective-shortening model, which emphasizes the relationship between working memory and reference memory, may have general utility for the development of models of memory processes in animals. The two-process framework is derived from the idea that performance on a working memory task is determined not only by the processes of working memory but also by the content of reference memory (Honig, 1978, 1981). Changes in reference memory may affect performance on a working memory task, and changes in working memory may gradually alter the content of reference memory. This interactive, two-process framework was an essential aspect of the subjective-shortening model; without it, many of the results of Experiment 4 would not have been predicted. Thus, an awareness of the ways in which reference memory and working memory may interact might facilitate the development of more viable models of memory in animals.

References

Allan, L. G. The perception of time. *Perception & Psychophysics*, 1979, *26*, 340–354.

Church, R. M. Short-term memory for time intervals. *Learning and Motivation*, 1980, *11*, 208–219.

Cohen, S. L., Calisto, G., & Lentz, B. E. Comparisons of sample stimuli in delayed symbolic matching-to-sample: Some results and implications. *The Psychological Record*, 1981, *31*, 77–93.

Frankenhaeuser, M. *Estimation of time*. Stockholm, Sweden: Almquist & Wiksel, 1959.

Hellstrom, A. Time-errors are perceptual. *Psychological Research*, 1977, *39*, 345–388.

Honig, W. K. Studies of working memory in the pigeon. In S. H. Hulse, H. Fowler, & W. K. Honig (Eds.), *Cognitive processes in animal behavior*. Hillsdale, N.J.: Erlbaum, 1978.

Honig, W. K. Working memory and the temporal map. In N. E. Spear & R. R. Miller (Eds.), *Information processing in animals: Memory mechanisms*. Hillsdale, N.J.: Erlbaum, 1981.

Honig, W. K., & Thompson, R. K. R. Retrospective and prospective processing in animal working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 16). New York: Academic Press, in press.

James, W. *The principles of psychology*. New York: Holt, 1890.

Köhler, W. Zur theorie des Suksessiuvergleichs und der Zeitfehler. *Psychologie Forschung*, 1923, *4*, 115–175.

Maki, W. S., Jr., & Leith, C. R. Shared attention in pigeons. *Journal of the Experimental Analysis of Behavior*, 1973, *19*, 345–349.

Nelson, K. R., & Wasserman, E. A. Temporal factors influencing the pigeon's successive matching-to-sample performance: Sample duration, intertrial interval, and retention interval. *Journal of the Experimental Analysis of Behavior*, 1978, *30*, 153–162.

Ornstein, R. E. *On the experience of time*. London: Penguin, 1969.

Roberts, W. A. Short-term memory in the pigeon: Effects of repetition and spacing. *Journal of Experimental Psychology*, 1972, *94*, 74–83.

Roberts, W. A., & Grant, D. S. Short-term memory in the pigeon with presentation time precisely controlled. *Learning and Motivation*, 1974, *5*, 393–408.

Roberts, W. A., & Grant, D. S. Studies of short-term memory in the pigeon using delayed matching to sample. In D. L. Medin, W. A. Roberts & R. T. Davis (Eds.), *Processes of animal memory*. Hillsdale, N.J.: Erlbaum, 1976.

Roitblat, H. L. Codes and coding processes in pigeon short-term memory. *Animal Learning & Behavior*, 1980, *8*, 341–351.

Spetch, M. L., & Wilkie, D. M. A systematic bias in pigeons' memory for food and light durations. *Behaviour Analysis Letters*, in press.

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