Pigeons group time intervals according to their relative duration

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In the present research, we asked whether pigeons tended to judge time intervals not only in terms of their absolute value but also relative to a duration from which they must be discriminated (i.e., longer or shorter). Pigeons were trained on two independent temporal discriminations. In one discrimination, sample durations of 2 and 8 sec were associated with, for example, red and green hue comparisons, respectively, and in the other discrimination, sample durations of 4 and 16 sec were associated with vertical and horizontal line comparisons, respectively. If pigeons are trained on a temporal discrimination and tested with intermediate durations, the subjective midpoint typically occurs close to the geometric mean of the two trained values. The 4- and 8-sec values were selected to be the geometric mean of the two values in the other discrimination. When a 4-sec test sample was presented with the comparisons from the 2- and 8-sec discrimination, the pigeons preferred the comparison associated with the shorter sample. Similarly, when an 8-sec test sample was presented with the comparisons from the 4- and 16-sec discrimination, the pigeons preferred the comparison associated with the longer sample. Thus, a relative grouping effect was found. That is, durations that should have produced indifferent choice were influenced by their relative durations (shorter than or longer than the alternative) during training.

Considerable research has been devoted to the study of timing in animals and in particular to the mechanisms by which animals evaluate its passage. One approach to the study of timing has been to ask whether animals can discriminate between time intervals, and if they can, what the basis of the discrimination is.

Animals' temporal discrimination learning has been examined with the use of conditional discriminations (Roberts & Church, 1978; Stubbs, 1976) in which the choice of one response alternative is reinforced following the presentation of a stimulus (e.g., a tone or a light) of one duration (e.g., 2 sec, short), whereas the choice of the other alternative is reinforced following the presentation of a stimulus of a different duration (e.g., 10 sec, long). The evidence for temporal discrimination is the extent to which the stimulus duration controls choice. If the stimulus durations are sufficiently different, animals can achieve a high level of accuracy (Meck, 1983).

Given that animals can perform the temporal discrimination at a high level, one can ask about the scaling of

the underlying psychological dimension by presenting values between the temporal durations used during training. Typically, the subjective midpoint (or point of subjective indifference) is found to occur near the geometric mean of the two training values (i.e., the square root of their product; Church & Deluty, 1977; Gibbon, 1986).

In the present experiment, we used the expected subjective midpoint of a temporal discrimination as a means of testing the hypothesis that the relative durations of the two samples in a temporal discrimination (shorter and longer) can affect the animal's judged duration of that stimulus. The rationale was as follows: Let us say that a pigeon is trained on two temporal discriminations, one in which the samples are 2 and 8 sec (with one pair of comparison stimuli) and the other in which the samples are 4 and 16 sec (with a different pair of comparison stimuli). Note that the 4-sec sample is the geometric mean of the 2- and 8-sec samples and that it is also the shorter of the two samples in its temporal discrimination (between 4 and 16 sec). Thus, if the pigeon tends to treat the 4-sec sample and the 2-sec sample similarly, then, when presented with the 4-sec sample and the comparisons that in training have been associated with the 2- and 8-sec samples, this may bias the pigeon to select the comparison associated with the shorter, 2-sec, sample. Likewise, if the pigeon tends to treat the 8-sec sample

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and the 16-sec sample similarly, then, when presented with the 8-sec sample and the comparisons that in training have been associated with the 4- and 16-sec samples, this may bias the pigeon to select the comparison associated with the longer, 16-sec, sample. Thus, in the present experiment we asked whether the relative role of a stimulus in a temporal discrimination would affect a pigeon's judgment of its value in the context of a different temporal discrimination.

Although the subjective midpoint of a temporal discrimination is typically close to the geometric mean of the two training durations, some variability has been found when the brightness or hue of the timed stimuli are manipulated (Kraemer, Brown, & Randall, 1995; Kraemer, Randall, & Brown, 1997). If we can assume that whatever deviation from the geometric mean would be similar for the 2–8 sec discrimination and the 4–16 sec discrimination, then the proposed design controls for those deviations because the proposed grouping effects would be expected to bias the pigeons to choose short on 4-sec sample test trials and to choose long on 8-sec sample test trials. Thus, the mean of the choose-short effect on 4-sec sample test trials and the choose-long effect on 8-sec sample test trials should correct for deviations of the subjective midpoint from the geometric mean (if we assume that those deviations are comparable in extent).

METHOD

Subjects

The subjects were 6 White Carneaux pigeons, purchased as retired breeders (5–8 years old) from the Palmetto Pigeon Plant (Sumter, SC). The pigeons were maintained at 80% of their free-feeding body weights throughout the experiment and were caged individually with grit and water available in the home cage. The pigeons were maintained on a 12:12-h, light:dark cycle. All pigeons had previously served in an unrelated study involving simple simultaneous discriminations.

Apparatus

The experiment was conducted in a BRS/LVE (Laurel, MD) sound-attenuating pigeon test chamber. Three horizontally aligned rectangular response keys (2.5 cm high $\times$ 3.0 cm wide) were mounted on the response panel and were separated from each other by 1.0 cm. Mounted behind each response key was a 12-stimulus in-line projector (Industrial Electronics Engineering, Series 10, Van Nuys, CA, with No. 1820 G. E. lamps) that projected a white field on the center key. Red and green hues (Kodak Wratten Filters Nos. 26, 60, respectively), and three white vertical lines (2.4 cm long, 0.3 cm wide, and 0.3 cm apart) and three white horizontal lines (on a black background) could be projected on the side keys. A house-light located at the center of the chamber ceiling provided general illumination. A rear-mounted grain feeder was horizontally centered on the response panel midway between the pecking keys and the floor of the chamber. Reinforcement consisted of 1.5-sec access to Purina Pro Grains. White noise and an exhaust fan masked extraneous noise. The experiment was controlled by a microcomputer located in an adjoining room.

Procedure

Phase 1 training. During the pretraining session, all pigeons were shaped to peck the red, green, vertical, and horizontal stimuli on the left and right keys for access to the grain feeder. Training

began on the following session. Each trial began with illumination of the white center key. The center key remained illuminated for either 4 or 16 sec for 4 of the pigeons and for 2 or 8 sec for the remaining pigeons. At the end of the interval, the center key was turned off and the side keys were illuminated. For half of the subjects in each group, the comparison stimuli were vertical and horizontal lines. The vertical lines were correct following the shorter sample; the horizontal lines were correct following the longer sample. For the remaining subjects in each group, the comparison stimuli were red and green hues. Red was correct following the shorter sample; green was correct following the longer sample. A single peck to either comparison turned off the comparisons. If a choice was correct, it provided the pigeon with reinforcement and started a 10-sec intertrial interval during which the house light was illuminated. If a choice was incorrect, it started the intertrial interval with no reinforcement.

There were 96 trials in each session, 48 with short samples and 48 with long samples. After 20 sessions of training with a noncorrection procedure, all pigeons were given correction training. During correction training, all trials on which an incorrect comparison choice was made were repeated (up to five times). For purposes of calculating choice accuracy, performance on only the first presentation of each trial was counted. All pigeons were trained to a criterion of 90% correct for both short- and long-sample trials for two consecutive sessions.

Phase 2 training. Once criterion was reached, the second temporal discrimination was introduced. Half of the trials were the same as during Phase 1. For the pigeons originally trained with 4- and 16-sec samples, the remaining trials involved 2- and 8-sec samples and the other pair of comparison stimuli. For the pigeons originally trained with 2- and 8-sec samples, the remaining training trials began with 4- and 16-sec samples and the other pair of comparison stimuli. Phase 2 training continued for each pigeon until it reached a criterion of 21 out of 24 correct trials for each of the four sample durations for two consecutive sessions. Correction training was used throughout Phase 2.

Testing. There were eight test sessions. Each session consisted of 64 trials that were a continuation of Phase 2 training (16 trials involving each of the four sample durations) and 32 test trials. On half of the test trials in each session, the 4-sec sample was presented with the comparisons that had been associated with the 2- and 8-sec samples during training, and on the remaining test trials in each session, the 8-sec sample was presented with the comparisons that had been associated with the 4- and 16-sec samples during training. Reinforcement was provided on a random 50% of the test trials regardless of which comparison was chosen.

RESULTS

Phase 1 Training

The pigeons reached criterion in Phase 1 involving a single temporal discrimination (either 2- and 8-sec samples or 4- and 16-sec samples) in an average of 42.5 sessions. The discrimination involving 4- and 16-sec samples was significantly easier to acquire (30.0 sessions) than the discrimination involving 2- and 8-sec samples (67.5 sessions) [$F(1,4) = 12.79, p < .05$].

Phase 2 Training

The pigeons reached criterion in Phase 2 involving both temporal discriminations in an average of 185.5 sessions. Although once again the discrimination involving 4- and 16-sec samples was easier to acquire (158.0 sessions) than the discrimination involving 2- and

8-sec samples (258.5 sessions), because of considerable variability among pigeons, the difference was not statistically reliable ($F < 1$). It should be noted that the difference in sessions to criterion between Phases 1 and 2 was due in part to the fact that the pigeons received only half as many trials per session on the second discrimination during Phase 2 as they received on the first discrimination during Phase 1. However, the comparison of problem difficulty within a phase is not biased by this difference in number of training trials per session between the two phases of training.

Testing

Relative duration. To obtain an adequate sample of test trial performance, the 4-sec sample test trials were pooled over the test sessions and were subjected to a t test. On 4-sec sample test trials, the mean choice of the comparison that in training was associated with the short 2-sec sample was 73.8%, a difference from chance (50%) that was statistically significant [$t(5) = 4.13, p < .01$, two-tailed]. Given 128 test trials with an a priori probability correct of 50%, the 95% confidence interval is $50\% \pm 7\%$. All 6 pigeons exceeded the upper limit of that range. The data from the 4-sec sample test trials for individual subjects appear in Figure 1 over the label "Chs Short."

On 8-sec sample test trials, the mean choice of the comparison that in training was associated with the long 16-sec

sample was 55.5%, a difference from chance that was not statistically significant [$t(5) = 0.85$]. However, it should be noted that on 8-sec sample test trials, all but 1 subject showed a preference for the comparison associated with the long 16-sec sample. Only 4 of the 6 pigeons had scores that exceeded the confidence interval (43%–57%). The data from the 8-sec sample test trials for individual subjects appear in Figure 1 over the label "Chs Long."

As was mentioned in the introduction, the geometric mean of the durations or the discriminative subjective midpoint provides a reasonable approximation of the subjective midpoint of the training values. However, it was also noted that empirical findings have often differed from that theoretical figure (Kraemer et al., 1995; Kraemer et al., 1997). It was suggested earlier that a better estimate of the unbiased effect of the manipulation represented by the present study would be the mean of the 4-sec choose-short effect and 8-sec choose-long effect because the expected grouping effect for the two kinds of test trial should be in the opposite direction. That is, if the bias were to *reduce* the relational choose-long effect for the longer 8-sec sample (because the actual subjective midpoint was somewhat higher than 8 sec), then it should also *increase* the relational choose-short effect for the shorter 4-sec sample (because the actual subjective midpoint should also be somewhat higher than 4 sec). To test for the mean grouping effect of training on the test samples, the test data involving the two

Figure 1. Percent choice of relative duration for individual subjects. *Choose short* (Chs Short) represents percent choice of the comparison associated in training with the 2-sec sample on 4-sec sample test trials. *Choose long* (Chs Long) represents percent choice of the comparison associated in training with the 16-sec sample on 8-sec sample test trials. *Combined* represents the average of the choose-long and choose-short effects and corrects for the deviation of the subjective midpoint from the geometric mean of the training durations. The shaded bars in each set represent data from the 2 pigeons that were first trained on the 2- and 8-sec sample durations and then trained on the 4- and 16-sec sample durations. The white bars in each set represent data from the 4 pigeons that were first trained on the 4- and 16-sec sample durations and then trained on the 2- and 8-sec sample durations. The black bar in each set represents the mean percent choice of the relative duration for the 6 subjects for each data set.

test trial types were combined for each subject and were subjected to a *t* test. The mean choice of the comparison associated with the 2-sec sample on 4-sec sample trials and the comparison associated with the 16-sec sample on 8-sec sample trials (64.7%) was significantly different from chance [$t(5) = 3.96, p < .05$, two-tailed]. Thus, the magnitude of the relational learning effect was 64.7% (or 14.7% above chance). Furthermore, the average percent choice of the relative duration (4-sec sample and 8-sec sample test trials combined) was greater than 50% for each of the 6 subjects in the experiment. When the data from 4-sec test trials and 8-sec test trials were combined (256 trials), the test data from all 6 of the pigeons exceeded the 95% confidence interval of 45%–55%. The data from the combined 4-sec sample and 8-sec sample test trials for individual subjects appear in Figure 1 over the label "Combined."

Order of training. Some of the pigeons were trained with 2- and 8-sec sample discrimination first. When tested with the 4-sec sample, these pigeons chose the comparison associated with the 2-sec sample on 61.8% of the trials. When tested with the 8-sec sample, they chose the comparison associated with the 16-sec sample on 63.6% of the trials. The remaining pigeons were trained on the 4- and 16-sec sample discrimination first. When these pigeons were tested with the 4-sec sample, they chose the comparison associated with the 2-sec sample on 79.9% of the trials, whereas when they were tested with the 8-sec sample, they chose the comparison associated with the 16-sec sample on 51.4% of the trials. Thus, the effect of training on the longer pair of samples first was negligible for the 2- and 4-sec samples, but it appeared to reduce the grouping effect on the 8- and 16-sec samples. A two-way analysis of variance performed on these data with order (trained with shorter samples first or with the longer samples first) and test sample (4-sec or 8-sec sample) as variables indicated that neither the main effect of order ($F < 1$) nor the effect of test sample [$F(1,4) = 2.33$] was statistically significant. Similarly, the interaction between group and test sample was not statistically significant [$F(1,4) = 3.04$].

DISCUSSION

The purpose of the present experiment was to determine whether pigeons that acquire a temporal discrimination learn to group samples according to whether they are the short or the long samples within their training pair. The strategy was to train the pigeons on two temporal discriminations in which the longer sample from the 2-sec/8-sec discrimination represented the geometric mean of the 4-sec/16-sec discrimination, and the shorter sample from the 4-sec/16-sec discrimination represented the geometric mean of the 2-sec/8-sec discrimination. When the 4-sec sample was presented with the comparison stimuli from the 2-sec/8-sec discrimination, the resulting preference for the comparison associated with the 2-sec sample in training suggested that the 4-sec

sample was also represented as the short sample. Similarly when the 8-sec sample was presented with the comparison stimuli from the 4-sec/16-sec discrimination, the resulting preference for the comparison associated with the 16-sec sample in training suggested that the 8-sec sample was also represented as the long sample.

Three possible mechanisms can be proposed to account for this finding. First, it is possible that the pigeons used their own behavior to mediate comparison choice. Machado and Keen (1999) trained pigeons on two temporal discriminations, one involving the discrimination between samples of 1 and 4 sec, the other, the discrimination between samples of 4 and 16 sec. They found that most of their pigeons began pecking the sample after it had been presented for more than 1 sec, but they stopped pecking after about 6 sec. Thus, in training they could use their pecking behavior to direct comparison choice. If they had not been pecking when the sample went off, they would choose the comparison associated with a 1-sec or a 16-sec sample. However, if they had been pecking when the sample went off, they would choose whichever comparison was present that was associated with the 4-sec sample. To determine the basis for comparison choice, Machado and Keen presented the pigeons with special test trials on which the duration of the sample was varied and novel combinations of the comparison stimuli were presented. When the pigeons were given a choice between the 1-sec associated comparison and the 4-sec associated comparison (which during training was always presented with the 16-sec associated sample), the pigeons produced a U-shaped choice function. That is, they chose the 1-sec associated comparison when the sample was short (1 sec) and the 4-sec associated comparison when the sample was longer (4 sec), but they also showed some tendency to choose the 1-sec associated comparison when the sample was very long (16 sec). Their choice of the 1-sec associated comparison on long sample trials can be attributed to the fact that their behavior on short and on very long sample trials was more similar than it was to their behavior on 4-sec sample trials. A similar but smaller effect was found when the pigeons were given a choice between the 16-sec associated comparison and the 4-sec associated comparison (which during training was always presented with the 1-sec associated sample). That is, the pigeons chose the comparison associated with the 4-sec sample most when the sample was 4 sec long, and they chose it less when the sample was 1 or 2 sec long.

In the present experiment, pigeons were trained with 2- and 8-sec samples and with 4- and 16-sec samples. If the pigeons had started pecking after about 6 sec, they could have used the absence of pecking as a cue to choose the 2- or 4-sec associated comparison and pecking as a cue to choose the 8- or 16-sec comparison. Then on test trials, they would have chosen the 2-sec associated comparison when the 4-sec sample had been presented, and they would have chosen the 16-sec associated comparison when the 8-sec sample had been presented. Unfor-

tunately, sample-peck data were not taken, but even if they had been taken and had not shown this pattern, sample pecking is only one form of differential behavior that could have controlled comparison choice.

Another mechanism that could have influenced comparison choice on test trials was the contrast between the two sample durations associated with the same comparisons (see Flaherty, 1996). To understand how this mechanism might work, first assume that the two samples presented with the same comparisons appear to be more different from each other than they would otherwise be (e.g., $2 - a$ and $8 + b$; $4 - c$ and $16 + d$). Then, on test trials, when the 8-sec sample is presented with comparisons associated with 4- and 16-sec samples (the subjective midpoint for which is presumably 8 sec), the pigeons should treat the $8 + b$ sample as having a value somewhat higher than 8 sec and the pigeons should tend to choose the long sample associated comparison. Similarly, the 4-sec sample would take on a value of $4 - c$ and when on test trials it is presented with the comparisons previously associated with the 2- and 8-sec samples, it should have a value somewhat lower than the presumed subjective midpoint of 4 sec, and the pigeons should tend to choose the short sample associated comparison.

Third, it is possible that the pigeons represented the samples as relative values depending on the comparison choice available. Thus, in addition to their absolute value, pigeons may represent each of the samples relative to the other (i.e., 4 sec is the longer of 2 and 4 sec, whereas 8 sec is the shorter of 8 and 16 sec). Then, on test trials involving the geometric mean of the samples from original training, when the absolute value of the sample does not provide a basis for comparison choice, pigeons may use the relative value of the sample in making their choice.

Whatever the mechanism used by pigeons to group the short (2- and 4-sec) and the long (8- and 16-sec) samples, the present research suggests that there is an interaction between samples associated with different comparisons. This conclusion is consistent with a similar conclusion reached by Zentall and Clement (2002), who manipulated sample frequency rather than sample duration.

REFERENCES

- CHURCH, R. M., & DELUTY, M. Z. (1977). Bisection of temporal intervals. *Journal of Experimental Psychology: Animal Behavior Processes*, **3**, 216-228.
- FLAHERTY, C. F. (1996). *Incentive relativity*. New York: Cambridge University Press.
- GIBBON, J. (1986). The structure of subjective time: How time flies. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 20, pp. 105-135). San Diego: Academic Press.
- KRAEMER, P. J., BROWN, R. W., & RANDALL, C. K. (1995). Signal intensity and duration estimation in rats. *Behavioural Processes*, **34**, 265-268.
- KRAEMER, P. J., RANDALL, C. K., & BROWN, R. W. (1997). The influence of stimulus attributes on duration matching-to-sample in pigeons. *Animal Learning & Behavior*, **25**, 148-157.
- MACHADO, A., & KEEN, R. (1999). Learning to time (LeT) or scalar expectancy theory (SET)? A critical test of two models of timing. *Psychological Science*, **10**, 285-290.
- MECK, W. H. (1983). Selective adjustment of the speed of internal clock and memory processes. *Journal of Experimental Psychology: Animal Behavior Processes*, **9**, 171-201.
- ROBERTS, S., & CHURCH, R. M. (1978). Control of an internal clock. *Journal of Experimental Psychology: Animal Behavior Processes*, **4**, 311-337.
- STUBBS, D. A. (1976). Scaling of stimulus duration by pigeons. *Journal of the Experimental Analysis of Behavior*, **26**, 15-25.
- ZENTALL, T. R., & CLEMENT, T. S. (2002). Memory mechanisms in pigeons: Evidence of base-rate neglect. *Journal of Experimental Psychology: Animal Behavior Processes*, **28**, 111-115.

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