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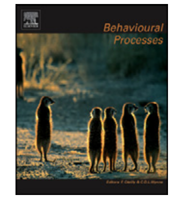

Representation of time intervals in a double bisection task: Relative or absolute?☆

Susana Maia, Armando Machado*

University of Minho, Braga, Portugal

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ABSTRACT

We examined if the representation of time intervals in a temporal discrimination task is based not only on their absolute but also on their relative durations. Six pigeons learned two temporal discriminations. In the first, red and green choices were correct following 2-s and 8-s samples, respectively. In the second, vertical and horizontal bar choices were correct following 4-s and 16-s samples, respectively. In a previous study [Zentall, T.R., Weaver, J.E., Clement, T.S., 2004. Pigeons group time intervals according to their relative duration. Psychon. Bull. Rev. 11, 113–117.], tests with 4-s samples and red/green comparisons revealed a bias for red, whereas tests with 8-s samples with vertical/horizontal comparisons revealed a bias for horizontal. These results were interpreted in terms of relative encoding of sample durations. We attempted to replicate this finding but instead of testing with only 4-s or 8-s samples, we tested with several other sample durations to obtain a psychometric function. Results were inconsistent with the relative encoding hypothesis.

1. Introduction

The present study is concerned with temporal discrimination learning which has been studied extensively using different types of symbolic matching-to-sample tasks (Roberts, 1998; Shettleworth, 1998). One such type is the temporal bisection task: Following the presentation of a sample stimulus for 1 s or 4 s, a pigeon is given a choice between two comparison stimuli, a Red (*R*) key and a Green (*G*) key. Choices of *R* are rewarded following the 1-s samples, and choices of *G* are rewarded following the 4-s samples. We represent the discrimination as follows "1 s → *R*; 4 s → *G*". During a test phase, the experimenter introduces samples with intermediate durations and records the proportion of times the animal chooses the *R* key, which we call *P*("*short*"). The curve showing how *P*("*short*") varies with sample duration is the psychometric function. It has three key features. First, as the stimulus duration increases, *P*("*short*") decreases monotonically from about 1 to about 0. Second, the point at which *P*("*short*") equals 0.5, the bisection point or point of subjective equality (PSE), occurs at, or close to, the geometric mean of the two training samples (Catania, 1970; Church and Deluty, 1977; Fetterman and Killeen, 1991; Gibbon, 1981; Platt and Davis, 1983; Stubbs, 1968). And third, for different pairs of short and long samples, but with their ratio constant, the psychometric functions superimpose when plotted in relative time, the scalar property (Church and Deluty, 1977; Gallistel, 1990; Richelle and Lejeune, 1980).

Theories and models of timing such as the Scalar Expectancy Theory (SET: Gibbon, 1977, 1981, 1991), the Behavioral Theory of Timing (BeT: Killeen and Fetterman, 1988), or the Learning-to-Time model (LeT: Machado, 1997) typically have assumed that the representation of the samples (SET) or their behavioral effects (BeT, LeT) are based exclusively on their absolute duration. However, Zentall et al. (2004) raised the hypothesis that, in temporal discrimination tasks, animals learn not only the absolute but also the relative duration of the samples (i.e., short vs. long), and that this relational learning may affect the animal's choices. According to the authors, relational learning cannot be revealed in the standard bisection task because its effects are consistent with the effects of learning the absolute sample durations. However, relational learning can be revealed in a *double* bisection task. Assume that a pigeon learns not one but two discriminations, say, "2 s → *R*, 8 s → *G*" and "4 s → Vertical (*V*) bar, 16 s → Horizontal (*H*) bar". Critically, the long duration in the first discrimination (8 s) is the geometric mean of the two durations of the second discrimination (i.e., $8\text{ s} = \sqrt{(4\text{ s} \times 16\text{ s})}$) and, similarly, the short duration in the second discrimination (4 s) is the geometric mean of the two

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* Corresponding author at: Instituto de Educação e Psicologia, Universidade do Minho, 4710 Braga, Portugal.
E-mail address: armandom@iep.uminho.pt (A. Machado).

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durations of the first discrimination (i.e., $4\,\text{s} = \sqrt{(2\,\text{s} \times 8\,\text{s})}$). After learning, the pigeon is exposed to two types of test trials, a 4-s sample followed by a choice between *R* and *G*, and an 8-s sample followed by a choice between *V* and *H*. If the pigeon encoded only the absolute durations of the four training samples, then it should be indifferent between the comparisons on both test trials because the two test durations are at the geometric mean of the two pairs of training durations. In contrast, if the pigeon encoded also the relative durations of the training samples, then it should prefer the *R* key after the 4-s sample and the *H* key after the 8-s sample.

The reason for this relative encoding prediction is as follows. By hypothesis, during training the pigeon learns both the absolute and the relative sample durations. The latter means that in the first discrimination (2 s → *R*, 8 s → *G*) it learns that the *short* duration is associated with the *R* key and the *long* duration is associated with the *G* key, whereas in the second discrimination (4 s → *V*, 16 s → *H*) it learns that the *short* duration is associated with *V* and the *long* duration with *H*. Then on test trials, when the absolute value of the sample does not provide a basis for choice (the test durations have never been associated with any of the comparison stimuli and they are at the geometric mean of the training samples), the pigeon relies on the relative value of the sample and its association with one of the comparisons. Because 4 s was encoded as *short* during the second discrimination and *short* was associated with the *R* key during the first discrimination, the pigeon prefers the *R* over the *G* key on the first type of test trial. Similarly, because 8 s was encoded as *long* (first discrimination) and *long* was associated with the *H* key (second discrimination), the pigeon prefers *H* over *V* on the second type of test trial.

The results obtained by Zentall et al. (2004) were consistent with the relative encoding hypothesis. On tests with the 4-s samples (i.e., short sample during training), the pigeons showed a preference for *R* (also associated with short during training) over *G*, and on tests with the 8-s samples (i.e., long sample during training) they showed a preference for *H* (also associated with long during training) over *V*, although only the former result was statistically significant. The authors concluded that pigeons represent each sample not only in terms of its absolute duration, but also relative to the duration of the sample with which it is paired. Subsequently, Molet and Zentall (2008) reported similar results in humans using the arithmetic mean as the PSE.

In Zentall et al.'s (2004) study, all the analyses were based on the results of two types of test trials, each type comprising only one sample duration, the geometric mean of the training samples. Hence, we know how one point of the psychometric functions (the PSE) changed because of relational learning, but we do not know how the entire function changed. In other words, assuming Zentall et al.'s (2004) results are reliable, we know that training on the double bisection task changes the PSE of the two psychometric functions, shifting it towards longer durations in one case and towards shorter durations in the other case, but we do not know how the entire function changes. For example, does the slope of the function at the PSE also change? Are the changes in the psychometric function similar to those obtained with drugs (e.g., Meck, 1983) or with different reinforcement rates (Fetterman and Killeen, 1991)? Is it the case that the two psychometric functions no longer superimpose when plotted on a common axis? Moreover, some studies (e.g., Machado and Keen, 1999) have found that the geometric mean does not always represent well the PSE, whereas other studies (e.g., Kraemer et al., 1997) have found that the PSE is affected by the brightness or hue of the sample stimulus. For all these reasons it seemed important not only to reproduce Zentall et al.'s (2004) specific findings but also to examine how relational learning affects the entire psychometric function. Knowing how a function changes has stronger implications for theory and model building than knowing only how one of its points changes.

The main goal of the present experiment was to obtain the two psychometric functions in the double bisection task described above. After the pigeons learned the two discriminations, they were exposed to sets of test trials that included several intermediate durations, between 2 s and 8 s in one case, and between 4 s and 16 s in the other case. In an attempt to improve upon Zentall et al.'s (2004) basic procedure, two additional changes were made. First, to speed the acquisition phase, the pigeons learned the two discriminations separately and only afterwards were the two discriminations combined in the same session. In contrast, in Zentall et al.'s study, the pigeons were exposed initially to only one of the two discriminations, but after they learned it, the two discriminations were immediately combined in the same session. We also attempted to increase the salience of the trial events by increasing the intertrial interval (ITI) (from 10 s to 30 s). As reported below, these changes reduced considerably the number of sessions required to learn the double bisection task. Second, whereas Zentall et al. conducted the generalization tests under non-differential reinforcement, we conducted them in extinction.

2. Method

2.1. Subjects

Six pigeons (*Columba livia*) maintained at 80% of their free-feeding body weight participated in the experiment. The pigeons had continued access to water and grit in their home cages where they were exposed to a 13:11-h light–dark cycle with the lights on at 8 a.m. All birds had experience in fixed interval schedules and extinction but not in temporal bisection tasks.

2.2. Apparatus

Two standard experimental chambers for pigeons from Lehigh Valley® were used. The front panel of each chamber contained three keys centered on the wall. The keys were 2.5 cm in diameter, 22 cm above the floor, and 8 cm apart, center to center. The central key could be illuminated with a white light, and the side keys could be illuminated with Red (*R*) or Green (*G*) lights or with white Horizontal (*H*) or Vertical (*V*) bars on a black background. Centered on the frontal panel, 8.5 cm below the center key and above the floor was a hopper opening measuring 6 cm × 5 cm. The birds had access to mixed grain when the hopper was raised and illuminated with a 7.5-W white light. On the back wall of the chamber another 7.5-W house light provided general illumination. An outer box equipped with a fan, which ventilated the box and helped to mask extraneous noises, enclosed the experimental chamber. A personal computer programmed in C++ controlled all experimental events and recorded the data.

2.3. Procedure

After the birds learned to peck the comparison stimuli presented on the side keys (*R*, *G*, *V*, or *H*) through autoshaping, the experiment started. It was divided into training and testing phases. During the training phase, sessions were divided into trials and the structure of a regular training trial was as follows: The center key was illuminated with white light for the sample duration (e.g., 2 s). Afterwards the center keylight was turned off and the side keys were illuminated with different colors or bars (e.g., *R* and *G*). A peck at one of these side keys turned all keylights off and, if the choice was correct, it activated the hopper for a duration that

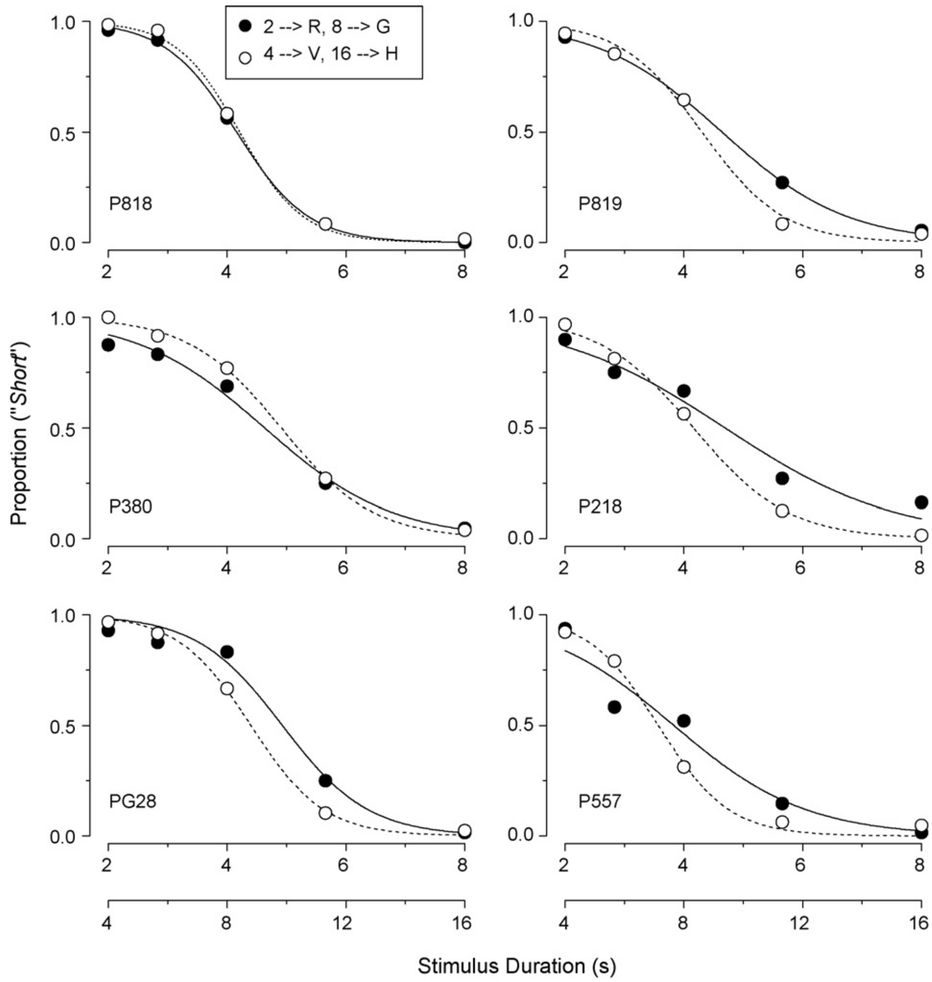

Fig. 1. The symbols show the proportion of "short" responses (*R* or *V*) as a function of sample duration. The curves are the best-fitting, two-parameter logistic functions with equation $P(t) = 1/(1 + \exp(-\lambda(t - \mu)))$, where t is the sample duration, μ is the bisection parameter or PSE, and λ is the slope parameter.

varied across pigeons from 1.3 s to 3 s in order to maintain body weight while minimizing extra-session feedings. After food, a 30-s intertrial interval followed during which the house light was illuminated. If the choice was incorrect, the ITI started immediately and the trial was repeated (correction method). If the bird made three consecutive errors, then only the correct key was illuminated during the choice phase.

Initially, the pigeons were exposed to one of the two basic discriminations, in counterbalanced order, "2 vs. 8" or "4 vs. 16". For half of the birds the assignment of keylight colors and bars to the sample durations was "2 s → *R*, 8 s → *G*" and "4 s → *V*, 16 s → *H*"; for the other half the assignment was "2 s → *V*, 8 s → *H*" and "4 s → *R*, 16 s → *G*". However, for clarity we describe the procedure and the experimental results as if all birds had the first assignment above. The two comparison stimuli were presented the same number of times on the left and right keys. Sessions ended after 96 trials, 48 with the short and 48 with the long samples.

After the birds learned the first discrimination (at least 90% correct choices for both samples, excluding repeated trials, for two consecutive sessions), they were exposed to the second discrimination. Once they learned the second discrimination, the two discriminations were combined in the same session. Of the 96 trials, 48 comprised the 2-s and 8-s durations (24 trials each) and 48 comprised the 4-s and 16-s durations (24 trials each). Training continued until the bird averaged at least 90% correct choices for two consecutive sessions on each of the four samples.

Until this point, all correct choices were reinforced and incorrect choices repeated the trial. We call these regular trials. Then, extinction trials were introduced to expose the birds to the lower rate of food that would occur during testing. Besides not ending with food (even when a choice was correct) extinction trials were not repeated even if the choice was incorrect. The number of extinction trials was set at 32 (with 64 regular trials). Each of the four samples was presented on 24 trials, 16 times as a regular trial and 8 times as an extinction trial. This phase lasted until the birds completed at least five sessions and averaged at least 90% correct choices for two consecutive sessions on each of the four sample durations.

Finally the pigeons were exposed to the testing phase for eight sessions. Each session comprised 64 regular trials (16 trials involving each of the four sample durations) and 36 generalization test trials. Two sets of logarithmically spaced durations were used during the test trials: 2.8 s, 4.0 s, and 5.7 s followed by the *R* and *G* comparison stimuli, and 5.7 s, 8.0 s, and 11.3 s followed by the *H* and *V* comparison stimuli. Each test duration was presented on six trials, three with one left–right assignment of the comparison stimuli and three with the other. Note that in each range of test durations, the intermediate duration equals the geometric mean of the training durations. Test trials were never reinforced.

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3. Results

3.1. Training

All pigeons learned the basic discriminations. The first discrimination was learned after 17.7 sessions on average (range: 10–39) and the second discrimination was learned after 9.8 sessions on average (range: 7–14). The total number of sessions required to learn the two discriminations separately and then combined in the same session averaged 56 (range: 22–92). To put these numbers in perspective, consider that in Zentall et al.'s (2004) study, the pigeons required on average 42.5 sessions to learn the first discrimination and 185.5 sessions to learn the two discriminations when they were combined.

With respect to the number of sessions required to reach criterion, there were no statistically significant differences between the "2 vs. 8" and "4 vs. 16" discriminations ($F(1, 10) = 1.76$, ns), or between the two sets of comparison stimuli (colors vs. bars: $F(1, 10) = 0.9$, ns).

3.2. Testing

Fig. 1 shows the individual results on the two types of tests, "2 vs. 8" and "4 vs. 16". The lines through the data points are the two-parameter logistic curves that best fit the data. Four findings are noteworthy. First, on both types of test trials, *P*("*short*") decreased monotonically with signal duration. Second, the two curves overlapped clearly only in one case (see bird P818); in the other five cases, the curve for the "4 vs. 16" discrimination was steeper than the curve for the "2 vs. 8" discrimination. These two findings were corroborated by a repeated-measures ANOVA with two factors, test duration and discrimination task. The ANOVA yielded a strong effect of duration ($F(4, 20) = 234.6$, $p < 0.0001$), no effect of discrimination task ($F(1, 5) = 0.39$, ns), and an effect of the interaction between the two factors ($F(4, 20) = 5.06$, $p < 0.05$). The interaction effect expresses the difference in steepness between the two functions.

Third, the geometric mean of the training stimuli did not always predict the bisection point. In fact, if 0.5 was the true probability of choosing "short" when the test duration equaled the geometric mean, then the 95% confidence interval for *P*("*short*") would range from 0.358 to 0.641 (normal approximation to the binomial). Of the 12 cases, only 4 were within that interval.

Fourth, these findings are also illustrated by the logistic curves which accounted always for more than 95% of the variance in the data (mean $\omega^2 = 99\%$). A *t*-test for related samples revealed a significant difference between the slopes of the two functions ($\lambda_{\text{“2 vs. 8”}} = 1.09$; $\lambda_{\text{“4 vs. 16”}} = 1.53$; $t(5) = 5.04$, $p = 0.004$) but not between their PSEs ($\mu_{\text{“2 vs. 8”}} = 4.5$; $\mu_{\text{“4 vs. 16”}} = 4.3$; $t(5) = 1.69$, ns).

To summarize our findings and compare them with Zentall et al.'s (2004) findings, Fig. 2 shows the average data (circles), the curves obtained by averaging the individual logistic curves, and the two average test results reported by Zentall et al. (triangles). When the *R* and *G* comparisons were presented after the 4-s samples, the two studies yielded consistent results, a preference for *R* – *P*("*short*") = 0.74 (Zentall et al.) and 0.65 (present study). But when the *V* and *H* comparisons were presented after the 8-s samples, the two studies did not yield consistent results. Whereas Zentall et al. found a slight preference for *H* (*P*("*short*") = 0.45), we found a slight preference for *V* (*P*("*short*") = 0.59).

Fig. 3 shows how preferences for *R* and *V* changed during testing. Each data point in the figure shows the average over two test sessions of the difference, *D*, between the number of trials the pigeon chose *R* after 4-s samples (call it #*R*) and the number of trials the pigeon chose *V* after 8-s samples (call it #*V*), that is, *D* = #*R* − #*V*. The

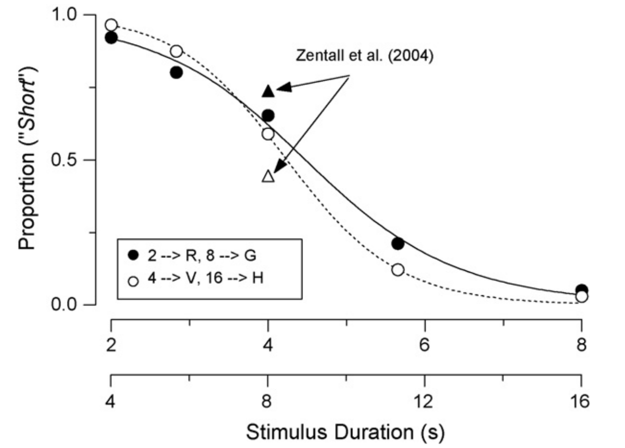

Fig. 2. The symbols show the average proportion of "short" responses (*R* or *V*) as a function of sample duration. The curves show the average of the best-fitting logistic curves shown in Fig. 1. The triangles show the average proportions obtained in Zentall et al.'s (2004) study. Filled triangle = $P(R|t = 4\text{ s})$; unfilled triangle = $P(V|t = 8\text{ s})$.

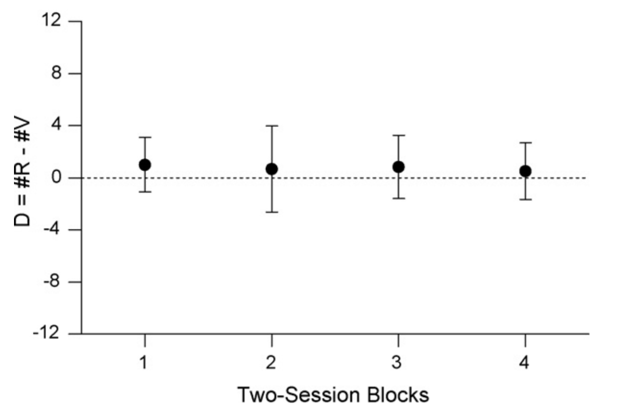

Fig. 3. Average across pigeons of the difference (*D*) between the number of trials in which *R* was preferred to *G* after 4-s samples (#*R*) and the number of trials in which *V* was preferred to *H* after 8-s samples (#*V*). Each two-session block comprised 12 test trials of each type. The vertical bars show the 95% confidence intervals for the mean of *D*.

relative encoding hypothesis implies that on average *D* > 0, whereas the null hypothesis implies *D* = 0. The vertical bars in the figure show the 95% confidence intervals for *D*.

The figure shows that *D* did not differ appreciably from 0 in any block of sessions. A rank-based, repeated-measures ANOVA (Meddis, 1984) with Block as one factor and *R*/*V* choice as another factor, yielded no significant effects of either factor or their interaction[1] (Block: $Z_1 = 0.19$, $p = 0.435$; *R*/*V*: $Z_1 = 1.37$, $p = 0.09$; Block × *R*/*V*: $Z_1 = 0.34$, $p = 0.37$).

4. Discussion

The purpose of the present experiment was to examine Zentall et al.'s (2004) hypothesis that, when animals learn a temporal discrimination, their judgment of time intervals is based not only on their absolute durations but also on their relative durations (short vs. long). To that end, six pigeons learned the temporal dis-

[1] The ANOVA by ranks used specific hypotheses with the following sets of orthogonal contrasts, λ: Block: $\lambda_i = +2, +1, -1, -2$ for blocks 1, 2, 3, and 4, respectively; *R*/*V*: $\lambda = +1$ for *R* and $\lambda = -1$ for *V*; and $\lambda_i = +2, +1, -1, -2, -2, -1, +1, +2$, for the combination of the four blocks and two choices (i.e., Block 1, *R* = +2, Block 2, *R* = +1, . . ., and Block 4, *V* = +2). See Meddis (1984), pp. 299–329.

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criminations "2 s → *R*, 8 s → *G*" and "4 s → *V*, 16 s → *H*". Then, during generalization tests, their preference for *R* over *G* was assessed following samples that ranged from 2 s to 8 s, and preference for *V* over *H* was assessed following samples that ranged from 4 s to 16 s. Tests with sample durations corresponding to the geometric means of the training stimuli allowed us to replicate Zentall et al.'s (2004) study, and tests with intermediate sample durations allowed us to obtain the psychometric function.

According to the relative encoding hypothesis, *R* should be preferred to *G* after 4-s samples for two reasons: (a) The sample's absolute duration would not bias choice toward *R* or *G* because it equals the geometric mean of the training samples and, in simple bisection tasks, the geometric mean is the PSE (or at least is near the PSE); (b) however, the sample's relative duration would bias the pigeon toward *R* because, according to the hypothesis, 4-s samples were encoded as *short* during to the second discrimination, and *short* was associated with *R* during the first discrimination. Hence, from (a) and (b) it follows that *R* will be preferred to *G* after 4-s samples (i.e., *P*("*short*") > 0.5). The relational hypothesis predicts also that *H* should be preferred to *V* following 8-s samples. The two reasons for this prediction are that (a) whereas the sample's absolute duration would not bias choice, (b) the sample's relative duration would bias choice toward *H* because 8-s samples were encoded as *long* during to the first discrimination and *long* was associated with *H* during the second discrimination. It follows from (a) and (b) that *V*, the key associated with the shorter duration, should be the least-preferred key after 8 s-samples (i.e., *P*("*short*") < 0.5).

Our results showed a small bias for *R* after 4-s samples, but no bias against *V* after 8-s samples. In fact, contrary to the relative encoding hypothesis, there were more choices of *V* than *H*. In any case, the average preferences for *R* and *V* were almost identical. We conclude that the present experiment did not replicate the relative encoding effect observed by Zentall et al. (2004).

The difference in results between the present study and Zentall et al.'s (2004) study could be due to the procedural differences between them, namely, the ITI duration (10 s vs. 30 s), the training sequence (training in one and then in both discriminations vs. training in one, then in another, and only then in both discriminations), the contingencies of reinforcement during the generalization tests (non-differential reinforcement vs. extinction), and the introduction of novel sample durations during testing (i.e., 2.8 s, 5.7 s, and 11.3 s). The first two aimed at increasing the speed of acquisition and it seemed they succeeded, for the average number of sessions needed to learn the two discriminations was reduced considerably (from 185.5 to 56). It is hard to see how lengthening the ITI and training the discriminations separately before combining them in the same session could have eliminated the relative encoding effect.

The third difference, however, potentially could account for the data as follows. The relative encoding effect (i.e., preference for *R* over *G* after 4-s samples is stronger than preference for *V* over *H* after 8-s samples) may be present at the end of training, but evolve during the test sessions in different directions according to the test contingencies. Non-differential reinforcement on the test trials would amplify or maintain the difference in preference, whereas extinction would reduce it to 0. Although we do not know whether the relative encoding effect in Zentall et al.'s (2004) study varied across test sessions, Fig. 3 shows that in the present study it did not. We conclude there was no evidence of the relative encoding effect at any moment during the test phase.

The fourth difference was pointed out by one reviewer who suggested that the novel sample durations used during testing could have attenuated the relative encoding effect. To understand the account, consider the 2.8-s and 5.7-s samples used to obtain the "2 vs. 8" psychometric function. Because 2.8 s is close to 2 s, and 5.7 s is close to 8 s, stimulus generalization could have led the pigeons to choose between the *R* and *G* keys on the basis of the sample's absolute duration. In addition, the tendency to choose on the basis of absolute duration could then have generalized to the critical sample of 4 s, obscuring the choose-short effect predicted by the relative encoding hypothesis. A similar argument applied to the 5.7-s and 11.3-s samples could explain why the critical sample of 8 s would not have yielded the choose-long effect predicted by the hypothesis. To summarize, by stimulus generalization the novel samples (2.8 s, 5.7 s, and 11.3 s) would strengthen choice based on absolute durations, which would then generalize to the critical samples of 4 s and 8 s and thus attenuate or eliminate the relative encoding effect.

Although we cannot rule the idea that results during testing may vary with the test samples (e.g., their number and specific durations), we believe the foregoing account is implausible. First, it does not explain why stimulus generalization strengthens the absolute and not the relative decision rule. In fact, with equal plausibility one could defend the opposite argument: Because 2.8 s is close to 2 s and 5.7 s is close to 8 s, stimulus generalization could have led the pigeons to choose on the basis of the sample's relative duration, which would then generalize to the 4-s samples and thereby strengthen the relative encoding effect. Second, and more generally, the account tacitly assumes some form of competition between two decision rules, one based on absolute durations and the other based on relative durations, but it remains silent about the competition mechanism. Without a modicum of explicitness concerning such mechanism, the relative encoding hypothesis may be hard or even impossible to test.

While we wait for future studies to identify the necessary and sufficient conditions of the relative encoding effect in double bisection tasks, we note that, given what is currently known about *simple* bisection tasks (e.g., Gallistel, 1990; Richelle and Lejeune, 1980; Roberts, 1998; Shettleworth, 1998), our findings are not particularly unusual or surprising. The two discriminations were well learned, and the generalization tests yielded orderly psychometric functions with their characteristic sigmoid shape and PSE close to the geometric mean of the training stimuli. These results are consistent with current models of timing, which assume that the representation of the samples (SET) or their behavioral effects (BeT, LeT) is based exclusively on absolute durations.

Moreover, in agreement with previous studies using *double* bisection tasks (Machado and Keen, 1999; see also Arantes, 2008; Arantes and Machado, 2008; Oliveira and Machado, 2008), our results also showed that the two psychometric functions superimposed for one pigeon, but the "4 vs. 16" function was steeper than the "2 vs. 8" function for five pigeons. This result is consistent only with LeT. We show next how LeT accounts for the key aspects of our results.

In the spirit of its predecessor, BeT (Killeen and Fetterman, 1988), LeT assumes that a series of behavioral states mediate temporal discrimination. During training, these states become differentially coupled with the operant responses, increasing the coupling by means of reinforcement, and decreasing it by means of extinction. Finally, choice depends on which states are the most active at the moment of choice (itself a function of sample duration) and on the degree of the coupling between those states and the available responses (for further details and mathematical analysis, see Arantes and Machado, 2008; Machado and Keen, 1999; Machado and Pata, 2005).

Using three free parameters to fit simultaneously the two psychometric functions of each pigeon, the model accounted for an appreciable percentage of the data variance (mean $\omega^2 = 94\%$, range = 77–99%). Fig. 4 re-plots the average data from the present study as well as the average of the model's individual fits. Although the two curves do not fit the data as well as the "theory-free" logis-

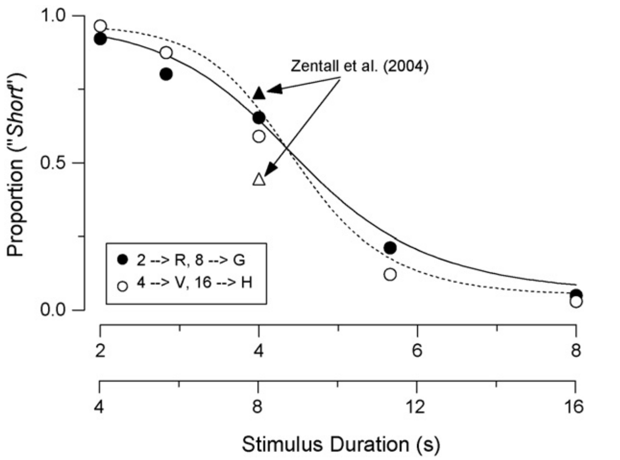

Fig. 4. The symbols show the average proportion of "short" responses (*R* or *V*) as a function of sample duration. The curves show the average of the individual curves generated by the Learning-to-Time (LeT) model.

tic functions (see Figs. 1 and 2), the model clearly reproduces the key aspects of the data, including the steeper slope of the "4 s vs. 16 s" function, the PSE slightly above the geometric mean on both discriminations, and the similarity of the probabilities of choosing *R* after 4-s samples and *V* after 8-s samples. This last aspect shows that, consistent with our data, the LeT model does not predict the relative encoding effect.

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