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ATTENTIONAL FACTORS IN TEMPORAL DISTORTION: THE EFFECTS OF FOOD AVAILABILITY ON RESPONSES WITHIN THE INTERVAL BISECTION TASK

by

Robert N. Johnson

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Psychology

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UTAH STATE UNIVERSITY
Logan, Utah

2013

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ABSTRACT

Attentional Factors in Temporal Distortion: The Effects of Food Availability on Responses Within the Interval Bisection Task

by

Robert N. Johnson, Master of Science

Utah State University, 2013

Major Professor: Amy L. Odum, Ph.D.
Department: Psychology

There are differences within the timing literature regarding the effects of distracter stimulus presentation within timing tasks. Whereas some researchers have found underestimation (changes in the degree of temporal stimulus control), others have found generalized disruption of timing responses. The purpose of this thesis was to determine the importance of food availability on responses within a time estimation task, using pigeons as subjects. Specifically, it was hypothesized that presenting food access following timing responses after a distracter task would produce underestimation of the target interval, relative to control conditions. Using a 2-parameter function fit to "proportion long" data from the interval bisection task, data revealed a generalized disruption effect of the distracter on timing behavior. Further analysis revealed that presentation of the food following timing responses after the distracter task reduced stimulus control within the timing task, revealing underestimation of the target interval.

These findings suggest that the causes of the differences within the timing literature may be based upon differences in procedure.

(41 pages)

PUBLIC ABSTRACT

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Time estimation is a process that underlies many complex behaviors. Accurately timed performance depends upon some biological mechanism, which may be revealed by experimental methods. There have been several proposals on the subject of the function of the timing mechanism, some of which have revealed contradictory findings regarding the effect of distraction on timing. Whereas some studies have revealed underestimation (reports of time moving more slowly than it actually is) of the target interval following distracter presentation, others have revealed generalized disruption (no meaningful evidence of timing). The purpose of the present study was to determine whether food presentation for timing responses following exposure to a distracter task would produce underestimation relative to control conditions. Pigeons were used as subjects on an interval timing task, wherein stimuli were presented for certain brief intervals, followed by presentation of side key lights, which produced food when pecked. After establishing a baseline, the task was modified to include brief access to a key light that had previously been associated with food presented during the interval to be timed. Following the interval, responses to the correct side-key produced food in one condition, and resulted in no food in the other condition. Analysis of the data revealed an overall generalized disruption in both distracter conditions, though a data-correction procedure revealed underestimation in the food-available distracter condition, relative to the no-food condition. These findings suggest that the causes of the differences between studies on timing may be based upon differences in procedure.

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CHAPTER I

INTRODUCTION

Attention to temporal cues is an important factor for many complex behaviors. Driving, cooking, and other behaviors would be more dangerous and difficult without attention to stimulus events occurring in the range of seconds to minutes. Interval-timing processes, which determine temporal behavior in the range of seconds to minutes, differ from circadian processes in several ways (Hinton & Meck, 1997). Interval timing is not necessarily linked to external events, such as tidal cycles. Also, interval timing is highly flexible, and the timing process may be stopped, restarted, or reset upon command. Finally, the interval timing process exhibits scalar variance, whereby greater intervals produce relatively greater response variability.

Divided attention and changes in neuropharmacology can distort timing. Distorted timing typically takes the form of over- or underestimation, in which the timed response occurs early or late, or reported time passage is slower or faster than objective time. Sutton and Roberts (2002) defined timing with divided attention as timing "while simultaneously engaged in another information-processing task" (p. 124). Divided attention is typically associated with delay of the timed response, or underestimation of the interval-to-be-timed. Distorted temporal responding as a function of divided attention has not been a consistent finding, however. Whereas underestimation of the target interval (i.e., responses occur too late) is sometimes reported (e.g., Lejeune, Macar, & Zakay, 1999), a loss of temporal discriminability (i.e., responses are unrelated to the temporal aspect of the task) has also been found (e.g., Sutton & Roberts, 2002; Ward &

Odum, 2007). Temporal discriminability is a term for stimulus control of temporal stimuli over responses. These latter findings suggest that distraction within the target interval leads to a reduction in stimulus control of temporal responses.

Within the timing literature, there are several procedural differences between the experiments that have resulted in systematic temporal distortions and those that have not. For example, using pigeons as subjects, Lejeune and colleagues (1999) found systematic temporal distortions when distracter probe trials sometimes resulted in food. Other experimental manipulations have included flashing stimulus lights as distracters (Ward & Odum, 2007), and probe trials that never resulted in food (Sutton & Roberts, 2002), and failed to find systematic temporal distortions. These findings suggest that the properties of the distracting stimuli and the probe trials strongly influence the probability of temporal distortions.

The purpose of this study was to determine whether distortion of temporal performance by distraction is dependent upon the reinforcing properties of the temporal task. I expected to find underestimation of the interval for trials resulting in food (cf., Lejeune et al., 1999), and loss of temporal discriminability for trials that did not result in food (cf., Sutton & Roberts, 2002).

CHAPTER II

LITERATURE REVIEW

The ability of organisms to accurately estimate short intervals—the passage of time between a few seconds and several hours—is a critical adaptation. The foraging literature reveals numerous cases of how the behaviors associated with feeding may be dependent upon adequate interval time estimation. For example, Daan and Koene (1981) found that oystercatchers in the Netherlands departed roosts at a particular time of day in order to reach feeding grounds when food access was optimal. Because lunar and tidal cycles were different for each instance of the behavior, circadian timing explanations were found to be inadequate.

Similarly, humans use interval timing to accomplish many tasks that are not clearly associated with circadian processes. For example, a driver's decision to brake or not when approaching a yellow traffic light is related to the amount of time the yield signal has been visible. Estimates of the seconds between the occurrence of the yellow light and the red stop signal that follows cannot reasonably be based on circadian processes. Some interval timing process that allows for estimation at the seconds-to-minutes level must surely exist. Temporal estimation may be measurably disrupted in terms of overestimation, underestimation, or loss of stimulus control. Overestimation describes a tendency to report time as moving at a faster rate than it really is. Although overestimation has been found with some verbal reporting methods with human subjects (Johnson & Hutchens, 2008; Rai, 1973), and neuropharmacological manipulations with rats (methamphetamine—Matell, Bateson, & Meck, 2006; ethanol—Meck, 2007), it is

not typically found when intervals are disrupted by distracting stimuli. Underestimation describes a tendency to report time as moving at a slower rate than it really is, and is a frequently reported effect of haloperidol administration (see Cheng, Hakak, & Meck, 2007, for a comprehensive review), or disruption by distracting stimuli for rats (Aum, Brown, & Hemmes, 2004, 2007; Brown, Richer, & Doyère, 2007; Buhusi & Meck, 2006) or pigeons (Buhusi, Paskalis, & Cerutti, 2006; Lejeune et al., 1999). Finally, a loss of temporal discriminability may occur when disrupted temporal responses do not clearly represent over- or underestimation, and display decreased stimulus control. Loss of temporal discriminability has been reported with disruption by distracting stimuli (Sutton & Roberts, 2002; Ward & Odum, 2007) and neuropharmacological effects (e.g., morphine: Odum & Schaal, 2000; d-amphetamine: Odum & Ward, 2007) for pigeons.

Although the influence of distracting stimuli on timing has been examined in several studies, a clear picture of the effect of distraction on time estimation has not been forthcoming. Whereas some studies have found specific temporal distortions (Aum et al., 2004; Buhusi & Meck, 2006; Lejeune et al., 1999), other studies have found a loss of temporal discriminability as a function of stimulus presentation (Sutton & Roberts, 2002; Ward & Odum, 2007). These inconsistent findings pose a problem for general statements regarding timing, as the effect of divided attention on time estimation should be predictable.

The Interval Bisection Task

The interval bisection task is a classic temporal estimation procedure, related to

the matching-to-sample paradigm. Relatively long or short sample intervals are presented, and following the sample, a response to a corresponding “long” or “short” key or lever (side or color differentiated) results in food. For example, Stubbs (1968) instituted a task whereby pigeons would receive food for responses to keys corresponding to 1- or 10-s sample presentations. Following the 1-s sample, pecking the green key light (“short” response) resulted in 5-s access to food, whereas pecking the red key light (“long” response) resulted in 60-s blackout. Likewise, following the 10-s sample, the “long” response resulted in food, and the “short” response resulted in blackout. When Stubbs introduced intermediate samples of 2- to 9-s in addition to the 1- and 10-s endpoints, the proportion of long responses resembled a sigmoidal generalization gradient, similar to that shown in Figure 1; with the lowest percentage of long responses following 1-s samples, and the greatest percentage of long responses following 10-s samples.

The psychometric function produced by the proportion of long responses may be analyzed to determine sources of error and the possibility of temporal distortion. Blough (1996) manipulated sample color in a symbolic matching-to-sample task, in which pigeons pecked comparison keys according to whether the sample resembled endpoints on a spectrum. Blough found that manipulation of stimulus duration resulted in changes in slope, or variance, while manipulation of the retention interval between sample and comparison presentations resulted in lowered range of the psychometric function. These effects may be equated to changes in stimulus sensitivity and control, respectively. Blough further suggested that alterations in the mean of the distribution result from bias,

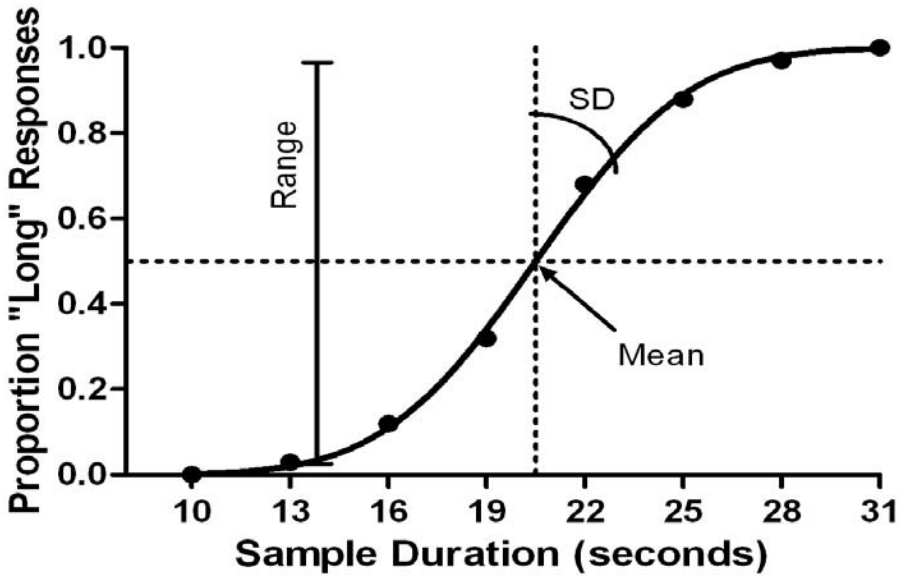


Figure 1. Hypothetical distribution of the proportion of long responses as a function of sample duration fitted with a Gaussian cumulative function showing placement of the range, slope, and mean for the proportion of long responses as a function of sample duration.

or the report of a substantially greater number of samples resembling one endpoint relative to the other. Figure 1 shows how changes in slope, range, and mean of the function relate to the psychophysical distribution. McClure, Saulsgiver, and Wynne (2005) note that Blough's analysis may be applied to interval bisection data, providing an interpretation of changes in mean in terms of the bisection point at which a particular interval may be categorized as "long" half of the time. Directional changes in the bisection point, then, may be equated to over- or underestimation of the sample interval.

Procedural Factors

One reason for the inconsistency of findings when temporal responses undergo disruption may be procedural. Lejeune and colleagues (1999) found underestimation of

the target interval as a function of disruptor task presentation. Using three pigeons as subjects, baseline was established with interval endpoints of 10-s (short) and 40-s (long). Intermediate samples of 20- and 25-s durations were included following training on the 10- and 40-s endpoints. In separate sessions, a variable ratio (VR; Ferster & Skinner, 1957) schedule of reinforcement was implemented, which provided food for every 5 pecks on average to a blue key light. Over the course of ten 100-trial test sessions, the VR 5 task was available during the interval-to-be-timed 3-s after sample onset (early condition) for approximately half of the trials. Food was available for appropriate temporal responses following VR presentation 50% of the time. Probe trials produced modest underestimation relative to baseline.

Temporal stimulus control may be lost when a stimulus within the interval-to-be-timed comes to signal that responses during that trial will not result in food, as may be the case when non-reinforced probe trials are used. For example, Sutton and Roberts (2002) used distracter probe trials within the sample interval as part of an investigation into information processing effects on timing. In Experiment 3, the experimenters inserted probe trials in which food was not available for responses corresponding to sample length into one of every four blocks of trials, and a house light was on. As a distracting stimulus, the house lights failed to produce underestimation relative to baseline, and resulted in a decreased range of the psychophysical function. The experimenters attributed their findings to the possibility that the house light came to signal that no food was available for appropriate responses, resulting in less sample stimulus control, but no directional effect on estimation.

The experiments by Lejeune and colleagues (1999) and Sutton and Roberts (2002) were different in several ways. For example, Lejeune and colleagues used four sample durations, the longest differing from the shortest by 30 s. Sutton and Roberts used relatively briefer sample durations (2, 3, 4.5, 6.7 and 10 s). Lejeune and colleagues used white noise as the sample duration, and Sutton and Roberts used the house light. Finally, Lejeune and colleagues implemented probe trials in which food was sometimes available for appropriate timing responses following the VR task presentation. Food was never available for appropriate timing responses following disrupter presentation within Sutton and Roberts' preparation. As yet, however, no studies have specifically investigated whether a disruptive stimulus, as opposed to a distracting task, can result in underestimation when food is available.

As the availability of food is a clear difference between studies that have reported distortions and those that have not, food availability was manipulated in the current experiment. Given previous findings, it was expected that the use of a disruptive task during the interval-to-be-timed would decrease attention to the interval bisection task and result in underestimation (e.g., Lejeune et al., 1999). Furthermore, distracter trials that resulted in food for accurate performance were expected to result in underestimation relative to trials that did not result in food (e.g., Sutton & Roberts, 2002). Additionally, it was expected that presentation of a disrupter stimulus would reduce temporal stimulus control relative to baseline when food was not available for correct responses, due to reduced attention to choice keys within the interval bisection preparation.

Statement of the Problem

Manipulation of distracter presentation within time estimation tasks has had differing results. Whereas some studies have found evidence for underestimation as a function of distraction, others have found loss of stimulus control. Alterations of a single variable, such as attention to the temporal estimation task, should have consistent effects on response patterns. That such patterns are not consistent over several studies suggests that procedural differences may play a role in observed outcomes. Therefore, the purpose of this study was to manipulate food availability for probe trials to determine the effects of these procedural differences on the attentional properties of temporal responding.

CHAPTER III

METHODS

Subjects

Eight homing pigeons served as subjects. All eight had prior experience in unrelated operant procedures. Subjects were housed in a temperature- and light- (12 light hours: 12 dark hours) controlled colony and maintained at approximately 80% ad libitum weight. All experimental procedures were conducted at approximately the same time every day.

Apparatus

Eight BRS/LVE operant chambers housed within sound-attenuating chambers were used. The dimensions of these chambers were 30.7-cm long, 35-cm wide, and 35.8-cm high. The front panel in each chamber featured three translucent keys, and each key was 2.6 cm in diameter, 24.6 cm from the floor, and could be lit from behind with white, turquoise, red, green, blue, and yellow light. Each key required a force of 0.10 N or more to record responses. The house light (28 V, 1.1 W) was centered at the top of the chamber, 4.4 cm above the center key. Pigeon chow pellets were obtained at a rectangular opening 9 cm below the center light, when the hopper was presented and lit with white light. House and stimulus lights were off during hopper presentations.

Procedure

Shaping to peck lit keys was not necessary, as these pigeons had already been exposed to operant procedures.

Training and Baseline Phases

Every other day, for 52 days, four pigeons were trained on the interval bisection task with 10- and 31-s endpoints. The session began with the house light lit for 5-s, followed by the trial-ready center key being lit turquoise. A single peck to the turquoise key light turned off the turquoise center key, and turned on the center sample key light (see Table 1 for counterbalancing assignments). The sample was presented for 10- or 31-s, following which, the center key was turned off, and the side choice keys were lit. Pecking on the left key turned off the side key lights and resulted a 2-s hopper presentation following 10-s sample duration presentations, and pecking the right key turned off the side key lights and resulted in a 2-s hopper presentation following 31-s sample duration presentations. The house light was lit for a 5-s period following food presentation, after which the house light was turned off and the turquoise center trial-ready key light was lit again. Pecking on the left key following the 31-s sample duration presentation, or pecking the right key following the 10-s sample duration presentation lit the house light for 7 s, after which the house light was turned off and the turquoise center trial-ready key light was lit again. The period between the lighting of the trial-ready key light and the end of the 5- or 7-s house light presentation following a choice represented 1 trial. A session was comprised of 32 interval bisection trials.

Table 1

Counterbalancing Key Light Color Assignments and Disrupter Order

	Bird number			
Variable	367, 38	49876, 9178	1188, 3060	216, 1821
Key assignment				
Trial ready	Turquoise	Turquoise	White	White
Sample	Red	Blue	Red	Blue
Choice	Yellow	Green	Yellow	Green
RR	Green	Yellow	Green	Yellow
Disruptor order				
With food first	367	49876	1188	216
Without food first	38	9178	3060	1821

After 40 sessions of 10- and 31-s endpoint sample duration training, performance remained at chance for the majority of the birds, so the sample duration endpoints were reduced to 4- and 10-s and correction procedures were implemented. Under correction procedures, an incorrect choice (pecking the "short" key following a 10-s sample duration, or the "long" following a 4-s sample duration) resulted in the repetition of the previous trial until the correct response was made. Intermediate sample durations were inserted in the following individual pairs: 5- and 9-s, 6- and 8-s, and 6.5- and 7.5-s, every 20 sessions until all baseline sample durations were included. After 20 sessions with all baseline sample durations included on correction, correction was removed. Twenty sessions following the removal of correction, the proportion of food availability associated with intermediate sample durations was reduced to 0.8, 0.6, and 0.5 over the course of 45 sessions.

During the course of establishing baseline, two birds died and were replaced, and four more birds were added to the experiment. The six new birds also had previous experience with operant procedures, so no pretraining was necessary. Training for the new six birds was briefer, as they experienced only the 4- and 10-s sample duration endpoints. Each of the new six birds experienced 35 sessions of endpoint training prior to insertion of intermediate sample durations. Intermediate sample durations were inserted as above, but a pair was inserted every five days instead of every 20. After the insertion of the final pair of intermediate sample durations, the probability of food presentation following accurate responses during intermediate sample duration trials was reduced from 1.0 to .8, .6, and .5, as above, over the course of 15 sessions. For all eight birds, once the probability for food presentation was reduced to .5, the number of trials was increased to 64 per session and measurement of baseline temporal responding began. The baseline phase consisted of 20 sessions of 64 trials prior to each disrupter phase. Nineteen sessions of correction were required for one subject following a disrupter phase, due to severe side bias, but was not required for any of the other subjects throughout the remainder of the experiment.

RR Training

Beginning the day after the first session with the interval bisection task, and every other day throughout 30 to 54 of the initial training days of the experiment, pigeons responded on a task that was later introduced as a disrupter. Pigeons pecked a key for a .5 probability of 2-s access to food (random ratio [RR] 2; Lattal, 1991; see Table 1 for key color counterbalancing). The location of the lit key (right or left) varied randomly across

trials during these sessions. The house light remained extinguished throughout these sessions. Sessions finished after 40 trials. After 30 to 54 days, RR training sessions occurred every 5 days, except the day prior to, during, and following disrupter phases.

Experimental Manipulations

Two experimental conditions were implemented to determine the effects of food availability on performance within the temporal estimation task. These conditions included probe trials in which food became available for responses corresponding with sample length (with food) and probe trials in which food is unavailable regardless of responses following the sample (without food). Previous findings suggest that temporal responses may become habituated to the disrupter task (Lejeune et al., 1999), so the number of probe trials was limited to eight per session. Furthermore, each experimental manipulation was in effect for 10 sessions, and was separated from other experimental manipulations by 20 sessions of the baseline interval bisection task and three sessions of RR2 training. Order of manipulation presentation was counterbalanced across pigeon as shown in Table 1.

Disruption with Food

To determine the effect of food availability following distracter probe trials on temporal distortion or stimulus control within the interval bisection task, 10 interval bisection sessions were modified to include eight probe distracter trials in each session. Each probe trial replaced one equivalent sample in each 8-trial block outlined above. Therefore, each sample duration was presented in seven normal trials and one probe trial.

During probe trials, a single side key light, color-associated with the previously trained RR 2, acted as a distracter stimulus. Responses to the distracter resulted in food access as determined by the RR 2 contingency outlined above, though only responses within the first 1-s of presentation resulted in 2-s access to food with a .5 probability. This restriction was meant to ensure that food access, if obtained, did not extend beyond the sample duration. Which side key was lit was randomly determined from trial to trial. The color of the key light when activated corresponded with the color of the stimulus light associated with the previously trained RR 2 contingency outlined above.

Disruption Without Food

Disrupter sessions without food were as disrupter sessions with food, except that food was never available for responses following a disrupter trial.

Model Fitting

The proportion of long responses during baseline and disruption performance were analyzed in Graphpad Prism 5.0a using a 2-parameter function (e.g., Odum, 2002);

$$\text{Proportion long} = \frac{1}{1+(t/T_{50})^{-\varepsilon}},$$

where the proportion of long responses is plotted as a function of sample duration t; T_{50} is the point at which the proportion of long responses = 0.5, or the mean of the function; and ε is the standard deviation, or slope, which indexes the sensitivity (precision) of timing. Changes in the T_{50} are theoretically related to the subjective passage of time. A decrease in T_{50} relative to baseline would indicate overestimation, and an increase in T_{50} relative to baseline would indicate underestimation. Equation 1 was used to fit data for

individual and group performance. The range was computed by subtracting the proportion of long responses at the 4-s sample duration from the proportion of long responses at the 10-s sample duration for each set of baseline and disruption trials analyzed.

Normalization of Proportion Long Data

Previous research (McClure et al., 2005) has shown that changes in the range of proportion of long responses can result in artifactual changes in the T_{50} and ε of the function. These artifactual changes to the T_{50} and ε may influence interpretation of the effects of a manipulation, indicating under- or overestimation of the timed interval or a change in the sensitivity instead of a reduction in stimulus control. An established normalization procedure removes the effect of range on T_{50} and ε (e.g., Odum & Ward, 2007). To eliminate any artifactual effect of the range on T_{50} and ε, the proportion of long responses were normalized so that the proportion of long response at the 4-s sample duration was subtracted from the obtained proportion of long responses for each of the "short" sample durations (i.e., 5-, 6-, and 6.5-s), with the constraint that the result could not be less than 0. The difference between the proportion of long responses at the 10-s sample duration and 1.0 was added to the obtained proportion of long responses for each of the "long" sample durations (i.e., 7.5-, 8-, and 9-s), with the constraint that the result could not be greater than 1.0.

Dependent Measures

The proportion of long responses for baseline and disrupter sessions was

normalized. As described above, 20 baseline sessions were followed by 10 daily disrupter sessions. Disrupter sessions consisted of a single RR2 presentation during a stimulus duration presentation per block of eight interval bisection trials. For purposes of meaningful comparison between baseline and disrupter sessions, eight trials from each of 10 baseline sessions for each subject were selected according to a list generated by MED PC in a manner identical to that used to select trials for disrupter presentation.

Responses per minute during disrupter presentation, rate of hopper presentations during the disrupter, and latency to peck trial-ready and choice keys for selected baseline and disrupter trials were also analyzed. Responses per minute were computed by dividing the total number of RR key responses in the session by the total time the RR stimulus was presented, minus feeder time. Latency to peck the trial-ready and choice keys was defined as the number of seconds between the presentation of the trial-ready or choice key lights and the first peck.

Data Analysis

Two-way repeated measures ANOVAs (food availability x disrupter presentation) were performed on $T_{50,}$ ε, and the Range for the selected baseline data and disruption data. Planned *t*-test comparisons were performed for mean $T_{50,}$ ε, and the range between baseline and with and without food disrupter conditions. Responses per minute to the RR key, and the total number of hopper presentations during RR presentation for with and Without Food disrupter presentations were also compared using paired-samples *t* test. Friedman's nonparametric analyses of the baseline and with and without food disrupter

condition medians of latency to peck trial-ready and choice keys were performed. Baseline and with and without food disrupter condition goodness of fit (R^2) for Equation 1 medians were also analyzed using Friedman's nonparametric analysis. Alpha = .05 was used to determine significance for all inferential tests.

CHAPTER IV

RESULTS

Primary Measures and Model Fit

Figure 2 shows the mean proportion of long responses as a function of sample duration and trial type (with food presentation at top and without food presentation on the bottom) with normalized performance on the left and nonnormalized performance on the right. For normalized and nonnormalized baseline data (unfilled circles), there is a

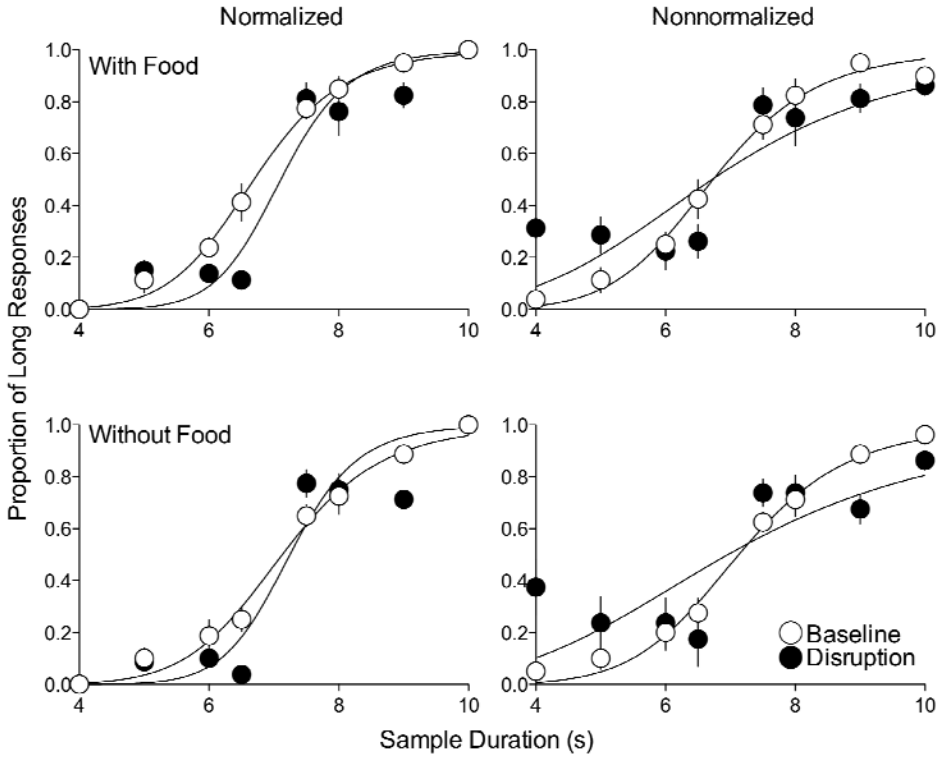


Figure 2. Mean proportion of long responses as a function of sample duration for trials with food available (top panel) and not available (bottom panel) following disrupter presentation. Filled circles represent responses following disrupter presentation and unfilled circles represent performance during baseline. The left panel shows normalized data (with the endpoint range set to 1.0) and the right panel shows nonnormalized data, with freely varying endpoint range.

smooth, sigmoidal increase in the proportion of long responses as a function of sample duration, so that the highest proportion of long responses tend to occur after samples longer than the 7-s arithmetic mean, and the lowest proportion tends to occur after samples shorter than 7-s. However, performance during non-normalized disruption performance is visibly different, with a clear reduction in the range (distance between proportion of long responses at the endpoints; see Figure 2, right side) relative to baseline.

Nonnormalized Measures and Parameters

The mean T_{50}, ε, and range for nonnormalized proportion of long responses are shown in Table 2. A two-way repeated-measures ANOVA did not reveal significant differences between disrupter types or baseline for $T_{50,}$ which shows that directional shifts were not detected in the non-normalized data set. There was no main effect of disrupter presentation on T_{50}, $F(1,7) = 0.26$, $p = .62$. There was no main effect of disrupter type on T_{50}, $F(1,7) = 2.80$, $p = .14$. Finally, the interaction of disrupter type and disrupter presentation, $F(1,7) = 0.87$, $p = .38$, was not significant, which shows that T_{50} did not vary differentially by the two factors.

A two-way repeated-measures ANOVA for ε revealed no main effect of disrupter presentation, $F(1,7) = 0.39$, $p = .55$, which shows that sensitivity was not affected by introduction of disrupter trials. There was no main effect of disrupter type on ε, $F(1,7) = 0.02$, $p = .89$, which shows that sensitivity of timing was not affected by food availability. Finally, the interaction of disrupter type and disrupter presentation was not significant,

Table 2

Descriptive Statistics for Nonnormalized and Normalized T_{50}, ε, and Range by Condition

	Nonnormalized				Normalized			
	Baseline		Disruption		Baseline		Disruption	
Condition	*M*	SEM	*M*	SEM	*M*	SEM	*M*	SEM
With food parameters and range								
T_{50}	6.58	0.14	6.42	0.63	6.68	0.15	7.17	0.13
ε	8.77	0.55	8.34	2.43	11.94	2.46	36.57	21.06
Range	0.86	0.03	0.55	0.11	—	—	—	—
Without food parameters and range								
T_{50}	7.06	0.13	6.44	0.94	7.08	0.11	7.32	0.11
ε	9.89	1.67	7.82	2.89	10.65	1.87	27.59	10.63
Range	0.91	0.04	0.49	0.12	—	—	—	—

$F(1,7) = 0.19$, $p = .67$), which shows that sensitivity did not vary differentially by the two factors.

A two-way repeated-measures ANOVA for the range revealed a significant main effect of disrupter presentation, $F(1,7) = 14.38$, $p < .01$, which shows that stimulus control for timing behavior was affected by disrupter presentations. There was no main effect of disrupter type on the range, $F(1,7) = 0.08$, $p = .93$, though, showing that there was no differential effect of food availability on stimulus control. Finally, the interaction for disrupter presentation and disrupter type was also not significant, $F(1,7) = 1.73$, $p = .23$), which shows that stimulus control did not very differentially by the two factors. Paired *t* tests revealed significant differences between mean range for baseline and

disruption with food: $t(7) = 2.78$, $p = .03$; and Without Food: $t(7) = 4.27$, $p < .01$; but differences between baselines, $t(7) = 1.00$, $p = .35$, and disruption types, $t(7) = 0.59$, $p = .57$, were not significant. These findings show that disrupter presentation reduced stimulus control relative to baseline.

Medians and 25th and 75th quartiles for goodness of fit (R^2) are shown in Table 3. A Friedman nonparametric ANOVA revealed a significant effect of median goodness of fit (R^2) between the baseline and disrupter conditions, $\chi^2(3) = 12.75$, $p < .01$. Wilcoxon analyses revealed this to be an effect of reduced R^2 in disruption relative to baseline performance, with significant differences between baseline and disruption With Food R^2 ($z = 2.52$, $p = .01$), and Without Food: ($z = 2.10$, $p = .04$). There were no significant differences for the goodness of fit for Equation 1 between baselines ($z = 0.84$, $p = .40$) or disruption types ($z = 0.98$, $p = .40$).

Normalized Measures and Parameters

The mean T_{50}, ε, and range for normalized proportion of long responses are shown in Table 2. A two-way repeated-measures ANOVA revealed significant differences

Table 3

Descriptive Statistics for Nonnormalized and Normalized Goodness of Fit by Condition

	Nonnormalized				Normalized			
	Baseline		Disruption		Baseline		Disruption	
Goodness of fit	Med	25th/75th	Med	25th/75th	Med	25th/75th	Med	25th/75th
With food R^2	0.54	0.50/0.60	0.24	0.11/0.45	0.54	0.51/0.65	0.52	0.51/0.63
Without food R^2	0.49	0.36/0.63	0.20	0.06/0.46	0.53	0.45/0.63	0.54	0.52/0.62

between disrupter types and baseline for $T_{50.}$ There was a significant main effect for disrupter presentation on T_{50}, $F(1,7) = 21.17$, $p < .01$, which means that the disrupter presentation resulted in a rightward shift of the timing function. There was also a significant main effect for disrupter type on T_{50}, $F(1,7) = 6.56$, $p = .04$, showing that manipulation of food availability produced a rightward shift in the function relative to the without food disrupter condition. Finally, the interaction of disrupter type and disrupter presentation on T_{50}, $F(1,7) = 1.16$, $p = .32$, was not significant, which shows that T_{50} did not vary differentially by the two factors. Planned *t* test comparisons on T_{50} for the normalized data showed that the means for baseline T_{50} differed from disruption in the with food condition, $t(7) = 3.82$, $p < .01$. Comparisons of T_{50} for baseline and disruption without food, $t(7) = 1.53$, $p = .17$; baselines, $t(7) = 2.08$, $p = .07$; and disrupter types, $t(7) = 1.31$, $p = .23$, were not significantly different. Overall, these findings show that food availability in a context of disruption caused underestimation of the interval to be timed to occur.

A two-way repeated-measures ANOVA for ε revealed no main effect of disrupter presentation, $F(1,7) = 3.01$, $p = .13$, which shows that sensitivity was not affected by introduction of disrupter trials. There was no main effect of disrupter type on ε, $F(1,7) = 0.17$, $p = .69$, which shows that sensitivity of timing was not affected by food availability. Finally, the interaction of disrupter type and disrupter presentation on ε, was not significant $F(1,7) = 0.09$, $p = .77$, which shows that sensitivity did not vary differentially by the two factors.

Medians and 25th and 75th quartiles for goodness of fit (R^2) are shown in Table 4.

Table 4

Medians and 25th and 75th Quartiles of Latency to Peck Trial-Ready or Choice Stimuli by Condition

	With food		Without food	
Condition	Trial-ready	Choice	Trial-ready	Choice
Baseline				
Median	2.41	3.05	2.05	2.99
$25^{th}/75^{th}$	1.07/6.84	2.53/4.12	1.07/5.23	2.54/4.20
Disruption				
Median	2.19	3.14	2.07	2.89
$25^{th}/75^{th}$	1.21/5.48	2.51/4.16	1.06/5.00	2.49/4.03

A Friedman nonparametric ANOVA did not reveal significant differences between median goodness of fit (R^2) for Equation 1 for the baseline and disrupter conditions ($\chi^2(3) = 2.55$, $p = .47$). This shows that normalization improved the degree of fit of Equation 1 to the proportion of long response data.

Latencies

Table 4 shows median seconds between stimulus presentation and pecking for trial-ready and comparison keys. Latencies were fairly stable across conditions. Friedman ANOVAs for latencies did not reveal significant differences between baseline and disrupter sessions latencies to peck (trial-ready: $\chi^2(3) = 4.42$, $p = .22$, choice: $\chi^2(3) = 6.13$, $p = .10$).

Response and Food Presentation Rates

Responses per minute during RR disrupter presentation for each disrupter condition was fairly stable across the with food (M = 63.80, SEM = 8.59) and without food (M = 55.83, SEM = 6.40) conditions; a paired t test did not show significant differences between disrupter conditions on response rates during RR stimulus presentation, $t(18) = 1.14$, $p = .27$.

Total number of hopper presentations per session during RR disrupter presentation for each disrupter condition was fairly stable across the with food (M = 0.72, SEM = .09) and without food (M = 0.69, SEM = 0.12) conditions; a paired t test did not show significant differences between disrupter conditions on number of hopper presentations, $t(9) = 0.23$, $p = .82$.

CHAPTER V

DISCUSSION

The purpose of this study was to determine whether the availability of food following the presentation of a disrupter stimulus affects the performance of pigeons in the interval bisection procedure. The lighting of food-associated disrupter keys during the sample duration of probe sessions reduced the accuracy of responses during the choice phase, so that the range of the psychophysical function was reduced. Normalization of the data to account for a reduction in range revealed a shift in the mean of the function relative to baseline for the condition in which food was available for accurate performance following disrupter presentation. This shift in the mean of the function was not present in the condition where food was not available following disrupter presentation. These findings show that pigeons underestimated the passage of time when food was available for accurate responses, but stimulus control of timing behavior was reduced in both the with food and without food disrupter conditions.

In the timing literature, reports of underestimation of the interval-to-be-timed as a function of disrupter presentation have been countered by reports of loss of temporal stimulus control. For example, Lejeune and colleagues (1999) disrupted temporal performance in an interval bisection task by presenting the opportunity to respond on a variable-ratio schedule of reinforcement during the interval-to-be-timed. They found that disrupter presentation caused underestimation of the interval-to-be-timed relative to baseline measurements. Sutton and Roberts (2002) examined the effect of the presentation of a house light during the interval-to-be-timed and found loss of temporal

stimulus control.

The difference between studies that report underestimation as a function of disrupter presentation and those that report loss of stimulus control may be procedural, in the availability of food for appropriate responses within the disrupter trial. For example, Lejeune and colleagues sometimes made food available for correct temporal responses following disrupter presentation, whereas food was never available in the disrupter trials reported by Sutton and Roberts.

When food is available for correct timing responses within an interval bisection preparation, attention to the comparisons may be increased, thereby increasing the likelihood that a temporal distortion, if present, would produce measurably different behavior. The purpose of this study was to manipulate food availability for appropriate responses following disrupter presentations.

Presentation of the disrupter stimulus was expected to cause underestimation of the interval-to-be-timed in the with food condition. When food was available for accurate responses following the presentation of the RR stimulus, temporal stimulus control was generally lost. Loss of temporal stimulus control obscured the presence of a rightward shift of the timing function, however, as normalization of the proportion of long responses for during disruption with food revealed a modest rightward shift of T_{50} relative to baseline.

Presentation of the disrupter stimulus was expected to cause a loss of temporal stimulus control in the without food disrupter condition. Disrupter presentation resulted in loss of stimulus control in both with and without food disrupter conditions.

Normalization of the proportion of long responses for the without food disrupter condition did not reveal any shift of T_{50} relative to baseline, which supports the hypothesis that food unavailability following disrupter presentation would reduce stimulus control without accompanying distortion of the timing process.

Presentation of the disrupter stimulus reduced the range of the proportion of long responses relative to baseline. Reduction of the range as a function of disrupter presentation has been reported previously in similar circumstances (Sutton & Roberts, 2002; Ward & Odum, 2007) and is generally considered loss of temporal stimulus control. Both with food and without food disrupter sessions produced relatively equal reductions in the range. Reductions in the range can affect interpretation of timing, so data were normalized.

The normalized proportion of long responses revealed that the availability of food in disrupter sessions produced a slight rightward shift relative to baseline. Shifts in the proportion of long response data as a function of disrupter stimulus presentation have been previously reported (Lejeune et al., 1999), and are considered examples of underestimation. Underestimation in the current experiment only occurred during the disrupter sessions in which food was available for accurate responses following the disrupter presentation, as predicted by the hypothesis. Disrupter presentations may stop, reset, or restart timing processes, but the interval bisection procedure allows separation of attention to the temporal cue from attention to the choice, which is necessary for that distortion to be measured. In this experiment, attention to the choice keys was manipulated by making food available for correct responses following disrupter

presentation. The results of the present experiment imply that the choice of pecking "long" or "short" is dependent upon an attentional process, whereby a temporal response is based upon whether it has been associated with a biologically salient event (i.e., food). If food is not paired with accurate performance in a context of disruption, loss of stimulus control is a likely outcome. However, if food is associated with accurate performance in a context of disruption, the duration of the stimulus presentation may inform a temporal decision more clearly.

Due to potentially artifactual effects of range on T_{50} and ε, a normalization procedure was implemented on the proportion "long" response data. McClure and colleagues (2005) studied the effects of *d*-amphetamine on pigeon behavior within the interval bisection task. Using a four-parameter model, they found dose-dependent reductions in the range of the proportion of short and long responses, but no systematic effect on the mean of the function. Two-parameter analyses of proportion "long" data, however, revealed an apparent leftward shift as a function of dose, due to an inability to account for the effect of range. To reduce any artifactual effects on T_{50} and ε, Odum and Ward (2007) instituted the normalization procedure described in the present experiment when examining the effects of *d*-amphetamine administration on pigeons within two versions of the interval bisection task.

A normalization procedure to reduce artifactual effects of range on T_{50} and ε was not performed by Lejeune and colleagues (1999) or Sutton and Roberts (2002). Lejeune and colleagues found that the placement of a VR task within probe sample intervals produced underestimation relative to baseline. The Wilcoxon test was used to compare

baseline and disruption percentage “long” response data for each individual bird. Wilcoxon analysis revealed a tendency to peck “short” where differences between baseline and disruption conditions were significant at the 10-, 20-, and 25-s sample intervals (the three shortest), but not at the longest (40 s). Sutton and Roberts (2002) found that house light presentation reduced the range of the proportion of “long” responses during probe trials. An ANOVA revealed an interaction between sample duration and condition,and a *t* test on the slope of a regression revealed a significant difference.

Limitations of the current study include the lack of the manipulation of disrupter placement and longer disrupter presentation and food availability during disruption. Lejeune and colleagues (1999) manipulated disrupter placement within probe trials, with the hypothesis that relatively late disrupter presentation produced more shifts in attention relative to early presentation, causing greater timing distortion. Manipulation of placement was not included in the current experiment due to the necessity of relatively brief sample durations and food availability. Training longer sample durations could facilitate manipulation of disrupter placement, which would be informative regarding the effect of compounding shifts of attention on timing.

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