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Behavioral Theory of Timing Applied to a DRL-Limited Hold Procedure

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## Abstract

The behavioral theory of timing (Killeen & Fetterman, 1988) holds that animals use behavioral tasks, called adjunctive behaviors, to aid them in timing intervals. Several studies have supported this theory, however the majority of these studies have been correlational. The present study used an experimental approach to manipulate the presence of adjunctive behavior. Rats responded on two DRL limited-hold procedures in which subjects must wait a certain time interval before responding; early responses were not reinforced and reset the clock. In addition, the animal had a specific interval of time in which to make a response; late responses were not reinforced and also reset the clock. The opportunity for adjunctive behavior was manipulated with a chew block which was provided for half of the sessions. The results show that the presence of the chew block did not have an effect on timing ability. In fact very little chewing occurred, and when chewing did occur it interfered with timing ability. This violates the predictions of BeT that chewing would improve timing ability. However, the low rates of chewing show that perhaps this is not an appropriate test for BeT. In addition, it is possible that other adjunctive behaviors were occurring during the experimental sessions. Future studies should include more subjects, run more sessions, and examine all behavior during each session.

## Author Note

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## Behavioral Theory of Timing

### Applied to a DRL-Limited Hold Procedure

Traditional behavior analyses concentrated on the strengthening of reflex behavior. Skinner (1938), for example, described operant conditioning in animals using a modified version of the law of effect: When a response is followed by a reinforcer, the rate of a response will increase. Pavlov (1927) described classical conditioning as a process by which a new reflex is formed from components of an existing reflex. An association is formed between a conditioned stimulus and a response when the conditioned stimulus is paired with the unconditioned stimulus. According to Pavlov, temporal contiguity, or the appearance of the conditioned stimulus immediately before the unconditioned stimulus, is the necessary component for classical conditioning to occur. Both classical and operant conditioning thus involve the formation of a new reflex or strengthening of an old reflex.

In both classical and operant conditioning, time is clearly an important factor. In operant conditioning, the response must be followed in time by a reinforcer, and the length of delay affects behavior (Skinner, 1938). Similarly, in classical conditioning the unconditioned stimulus must precede the conditioned stimulus. In both accounts timing is necessary for associations to be formed across time, yet neither Skinner nor Pavlov had much interest in how animals time intervals.

Discovering how animals keep track of time is an important question, regardless of the lack of attention paid to it in early behavioral psychology. For example, animals need to have a concept of time for foraging. Animals need to know the times of day that are best for prey and the times of year that produce certain vegetation. Similarly, timing

is important for predator avoidance; animals need to be sensitive to the times of day when predators are most likely to be hunting. In addition, migration patterns depend on the time of year as well as other factors (Shettleworth, 1998).

Research indicates that animals are able to time both short intervals (measured in seconds and minutes) and long intervals (measured in hours to months). Long intervals are timed by endogenous circadian rhythms, which allow animals to synchronize behavior with day and night. An internal pacemaker controls these daily behavioral rhythms. This pacemaker runs independently of the environment, but it requires continual cues from the environment, such as light and temperature, to keep behavior synchronized (Shettleworth, 1998). Timing short intervals, however, requires different mechanisms than adjusting daily activity to circadian rhythms.

Several studies suggest that animals are able to time short intervals. Pavlov (1927) found that dogs trained with a three minute whistle predicting weak acid placed in the dog's mouth salivated most during the last minute of the whistle. Similarly, Roberts (1981) used the peak procedure to display the timing abilities of pigeons. In this procedure, pigeons were reinforced for the first peck made 20 seconds after the illumination of a pecking key. Roberts found that pigeons pecked faster as the time for reinforcement approached. During empty trials in which the signal stayed on longer than usual but no food was given, pigeons pecked the most around the usual time of reinforcement.

These examples suggest that animals are able to time intervals, but it is not clear exactly how animals accomplish this. There are different theories to explain how animals time both short and long intervals. Theories to explain short term timing include the

scalar expectancy theory (Church & Kirkpatrick, 2001; Gibbon, 1977) and the behavioral theory of timing (Killeen & Fetterman, 1988). Both theories describe an internal pacemaker to help keep track of time; however, the two theories are very different with regard to their hypothesis of the mechanisms animals use to time intervals. The scalar expectancy theory, for example, proposes that cognitive constructs help the animal time intervals, while the behavioral theory of timing states that it is the animal's behavior which allows the animal to keep track of time.

### Scalar Expectancy Theory

One leading theory of how animals time intervals is the scalar expectancy theory (Church & Kirkpatrick, 2001; Gibbon, 1977). The first assumption of this theory is that timing is "scalar," which refers to an empirical property in which the error in timing remains a constant fraction of the absolute interval. For example, if an animal was on a schedule in which it had to press a bar after 30 seconds had elapsed, the animal's responses would form a normal curve with a standard deviation, or error. Assuming that the standard deviation is six seconds, the error then is one-fifth of the interval. If the interval was then increased to 60 seconds, the scalar property of timing would predict that the standard deviation, or error, would be 12 seconds, because this is again one-fifth of the interval being timed. Therefore the fraction of error to absolute interval remains constant despite changes in the length of the interval. Several studies have supported this scalar property of timing (e.g. Roberts, 1981).

In addition to assuming that timing is scalar, this theory proposes three cognitive constructs that animals use to time intervals. These constructs are assumed to be structures in the brain, but the specific structures or pathways have not yet been

identified. The three constructs are a pacemaker, an accumulator, and a comparator.

The first construct, the pacemaker, measures time by pulsing at a high, steady rate (Machado & Keen, 1999). This pacemaker can be stopped and restarted like a stopwatch at the beginning and end of each interval being timed (Roberts, 1981).

The second construct, an accumulator, collects the number of pacemaker pulses that have occurred since a signal or stimulus. The signal or stimulus acts as a “switch”, determining whether or not the pulses reach an accumulator. For example, in a situation where an animal must respond thirty seconds after a light appears, the light acts as this stimulus, starting the pacemaker and switching the accumulator “on.” The perception of time since an event is represented by the number of pulses in the accumulator (Machado & Keen, 1999; Shettleworth, 1998).

The third and final construct of the scalar expectancy theory is the comparator, which compares current time to remembered time. More specifically, the comparator compares the total number of pulses in the accumulator to a value previously stored in memory. This comparator determines whether or not the animal responds and works in an “all-or-nothing” way. For example, during peak procedures, an animal does not increase its rate of responding gradually as the time for reinforcement approaches. Instead, the animal switches suddenly from a very low rate of responding to a very high rate. The animal keeps this high rate until reinforcement is received, then switches again to a very low rate of responding (Church & Kirkpatrick, 2001; Shettleworth, 1998). Once a reinforcer is obtained, the accumulator is cleared and the process starts over.

Support for the scalar property of timing has been found by Roberts (1981) in his peak procedure. Roberts found that when pigeons were reinforced for pecking 20

seconds after the illumination of a pecking key, a normal curve developed with the peak at 20 seconds. He found that if he increased the interval to 40 seconds, a normal curve again developed with a peak at 40 seconds. He found that the standard deviations for both curves were a constant fraction, despite changes in the length of the interval. This supports the assumption of the scalar expectancy theory that time is scalar.

Despite the support of the scalar property of timing, several studies have disagreed with the idea of the scalar expectancy theory that the pacemaker is steady. Bizo and White (1995b), for example, found that the pacemaker rate often varied with the rate of reinforcement. Many other studies have replicated those findings (e.g. Fetterman & Killeen, 1995; Machado & Keen, 1999; Mazur, 2002). The variable speed of the pacemaker is described by the behavioral theory of timing, but not the scalar expectancy theory.

#### Behavioral Theory of Timing

A second theory that explains how animals time intervals is the behavioral theory of timing (BeT) developed by Killeen and Fetterman (1988). Like the scalar expectancy theory, the behavioral theory of timing also assumes that timing is scalar. Instead of using cognitive constructs to explain timing, however, this theory holds that adjunctive behaviors mediate timing. When an animal is on a time-based reinforcement schedule such as a fixed interval schedule, the animal often displays repetitive behaviors, such as grooming and pacing, between reinforcers due to schedule constraints (Keehn & Stoyanov, 1986). These behaviors are often called adjunctive behaviors (Falk, 1971, 1977). Animals show these behaviors even on fixed reinforcement schedules, which do not rely on behavior during the interval (Shettleworth, 1998). Therefore, these behaviors

occur even though they appear to show no contribution to survival (Falk, 1971). After an animal receives reinforcement, the animal often performs behaviors not related to feeding such as grooming and pacing, which are called interim behaviors. As the interval progresses and the time for reinforcement approaches, behaviors related to feeding, such as gnawing or pecking, often occur. These behaviors have been called terminal behaviors (Killeen & Fetterman, 1988; Staddon & Simmelhag, 1971).

According to BeT, as the animal moves from one adjunctive behavior to another, the animal is progressing through a series of internal states (Shettleworth, 1998). The occurrence of a stimulus starts the sequence of these internal states. The states are correlated with the adjunctive behaviors, but the states vary in duration, so that a single adjunctive behavior may be correlated with multiple states, or multiple behaviors may be correlated with one state (Bizo & White, 1995a; Killeen & Fetterman, 1993).

These internal states are hypothetical constructs that classify behaviors according to the order in which they occur. Empirical evidence has shown that behaviors do follow a particular pattern following reinforcement. The literature on these internal states came from Skinner's classic superstition paper (Skinner, 1948). Skinner found that pigeons displayed specific patterns of behavior, such as pecking or grooming, during the interval between reinforcers, even when reinforcement was independent of the pigeon's behavior. Staddon and Simmelhag (1971) later expanded on Skinner's work and found that some behaviors, the interim behaviors noted previously, had a high probability of occurrence immediately after reinforcement. Other behaviors, terminal behaviors, had a high probability of occurrence immediately preceding reinforcement. Staddon and Simmelhag among others (e.g. Timberlake & Lucas, 1985) have called these patterns of behavior

*behavioral states.*

The behavioral states themselves constitute the perceptual representation of time (Church & Kirkpatrick, 2001). In timing experiments in which an animal is interrupted during an adjunctive behavior, such as grooming, and must respond whether the interval is short or long, the animal will make whichever response has been most associated with reinforcement during that specific behavior (Killeen & Fetterman, 1988). For example, if a pigeon is reinforced for pecking 30 seconds after a light appears, the animal will learn to peck during the behavioral state associated with that time.

Transitions between states of adjunctive behaviors are caused by pulses from an internal pacemaker similar to the pacemaker described by the scalar expectancy theory (Killeen & Fetterman, 1988). There is no accumulation process in this pacemaker as in the scalar expectancy theory. In BeT time is represented by the current state of adjunctive behavior, not the number of pulses in an accumulator (Church & Kirkpatrick, 2001). In BeT the speed of the pacemaker is not steady (Killeen, Hall, & Bizo, 1999). Instead the speed depends on the speed of reinforcement, so as the rate of reinforcement increases, so does the speed of the pacemaker (Bizo & White, 1995b; Fetterman & Killeen, 1995; Mazur, 2002).

Many studies have supported the behavioral theory of timing (Fetterman & Killeen, 1995; Richelle & Lejeune, 1980). Fetterman and Killeen, for example, found that increasing and decreasing the rate of reinforcement produced changes in the timing of adjunctive behaviors, as BeT predicted. Other studies also found that the pacemaker rate depends on the rate of reinforcement, which means that the animal progresses through the behavioral states at a faster rate when the rate of reinforcement is increased

(Bizo & White, 1995a; Lejeune, Cornet, Ferreira, & Wearden, 1998; Morgan, Killeen, & Fetterman, 1993). Another study found that animals are able to respond more accurately to reinforcement schedules when adjunctive behaviors are performed. When adjunctive behaviors are disrupted, timing ability is also disrupted (Richelle & Lejeune, 1980).

Although some studies do support BeT, there are also several studies that found problems with this theory. Richelle and Lejeune (1980) found that adjunctive behaviors do not always occur during reinforcement schedules. On the other hand, adjunctive behaviors often occur when the animal is not timing. McIntire, Lundervold, Calmes, Jones, & Allard (1983) also found problems with BeT. These researchers built an apparatus with multiple chambers where rats could perform different adjunctive behaviors. They found that blocking some of the chambers did not create a difference in timing. In addition, Bizo and White (1997) found that the pacemaker period increased with increases in trial duration, despite the constancy of the rate of reinforcement. Finally, though Fetterman, Killeen, & Hall (1998) did find that presence of adjunctive behavior aided timing, the study was only correlational. In order to determine the accuracy of BeT, studies need to be done that are not correlational. Also, behavior needs to be coded to determine whether the animal is engaging in adjunctive behaviors to determine if these behaviors are aiding timing abilities.

Both scalar expectancy theory and the behavioral theory of timing are leading theories in how animals time intervals. While both theories hold that timing is scalar, the scalar expectancy theory does not account for the difference in pacemaker rate depending on the rate of reinforcement (i.e. Bizo & White, 1995b; Fetterman & Killeen, 1995). In addition, the scalar expectancy theory does not consider the effect of adjunctive behavior

on timing ability. The behavioral theory of timing, however, does include both the flexibility of the pacemaker (i.e. Morgan et al., 1993) and the role of adjunctive behaviors in timing (Richelle & Lejeune, 1980).

#### Previous Research at Illinois Wesleyan University

Previous research in our lab has performed experimental manipulation of adjunctive behaviors. The hypothesis of this research was that animals would time intervals with more accuracy if explicit items known to promote adjunctive behaviors were available (Minnich, O'Neill, Norris, & Dougan, 2003). In this study, rats were trained using a differential reinforcement of low rates (DRL) schedule in which rats must wait a certain number of seconds to respond before receiving reinforcement. Early responses reset the clock. This research also includes a limited hold after the interval - the rats had to make a response within a specific number of seconds after the interval ended. The rats were trained both with a chew block and without a chew block, with the intention that the chew block would lead to the adjunctive behavior of chewing. The chew block was chosen because it could be manipulated easily; the researchers could provide the chew block for some sessions and remove it for others.

The results of this research were that the presence of the chew block had no effect on the number of correct, or reinforced, responses. However, the rats made slightly more late responses (after the limited hold) when the chew block was present, suggesting that the presence of the chew block was possibly a distracter for the rats. It is not known whether the animals actually engaged in chewing when the chew block was present, so it cannot be determined whether adjunctive behaviors directly influenced timing.

The current study attempts to examine the occurrences of early and late responses

in conditions with and without a chew block. The first hypothesis is that when the chew block is present, the animal will engage in chewing. The second hypothesis is that rats will show fewer early and late responses when engaging in adjunctive behavior (chewing) than when not engaging in adjunctive behavior (not chewing). This hypothesis contradicts the earlier findings that rats in the chew block condition made slightly more late responses. However, the previous research did not code that the animals were engaging in the adjunctive behavior, chewing, when the chew block was present. The behavioral theory of timing predicts that when the chew block is present, the rats will engage in chewing and make more accurate (reinforced) responses. The scalar expectancy theory would predict that the chew block would have no effect on the responses.

## Method

### *Subjects*

The subjects were six experimentally naïve rats that were obtained from the breeding colony at Illinois Wesleyan University. The subjects were kept in individual cages with free access to water. The rats were divided into two squads, each consisting of three rats.

### *Apparatus*

The apparatus used was the same apparatus used in other studies in this lab (e.g. Campbell & Dougan, 1995). Three identical standard operant conditioning units were used for conditioning (BRS/LVE Model RTC-028). The chamber measured 30 cm in length, 26.5 cm in height, and 24 cm in width. The front and back walls of the chamber were made of stainless steel, and the two side walls and ceiling were made of Plexiglas.

The floor was made up of metal bars, and the chamber was illuminated by a 5-W houselight centered in the front wall, 1 cm from the ceiling.

The front wall contained response bars, which were each 5 cm from the floor and 3 cm from the side wall nearest the bar. The bars were retractable, and when extended, they projected 2.5 cm into the chamber with width of 3 cm. When the bars were retracted, they were flush with the front wall. Only the left bar was used in the present experiment. Three cue-lights (red, white, and green) were located 5 cm above each bar. Each of the individual lights were 2 cm apart (center to center). None of the cue-lights were used for this experiment. On the front wall a food cup extended 1.5 cm into the chamber. This food cup was located 11 cm from the right wall and 2 cm from the floor. In addition, the apparatus was enclosed in a sound-attenuating chamber.

All programming of experimental events and all data collection was arranged by an IBM<sup>®</sup> PC compatible computer, connected to a MED Associates<sup>®</sup> interface and running MED-PC<sup>®</sup> software. The computer and interface were located in an adjacent room.

### *Procedure*

All rats were maintained at 80% of their free-feeding body-weights. The rats were trained individually to bar press for food pellet reinforcement in one of three traditional Skinner boxes, with each individual rat placed in the same box for every session. After the shaping process was completed, the rats were divided into two squads (each consisting of three rats) and run on one of two schedules following a DRL-limited hold procedure – DRL 10, LH 5 and DRL 5, LH 5. The DRL (differential reinforcement of low rates) schedule is one during which the rats must wait a specific time period before

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responding. Early responses were not reinforced and reset the clock. The limited hold (LH) part of the procedure places a restriction on the amount of time each rat has to make a response. For example, on a DRL 5, LH 5 schedule, the rat must wait 5 seconds before responding, after which the rat only has a 5 second window in which to make a response. Responses made during the initial period (5 or 10 seconds) were recorded as *early* and reset the clock. Responses made after the initial period but before the hold expired were recorded as *reinforced* and were reinforced with a food pellet. Responses made after both the initial period and the hold expired were recorded as *late*.

Each rat was run for a total of 40 sessions, each 30 minutes in length. Squad 1 was placed on a DRL 10, LH 5 schedule for the first 20 sessions, with half of the sessions randomly receiving a chew block such that no more than 2 consecutive sessions were the same. Squad 2 was placed on a DRL 5, LH 5 schedule for the first 20 sessions with half of the sessions also randomly receiving a chew block. For the remaining 20 sessions, each squad switched to the other schedule (see table 1). This was done to see if the length of the schedule had an effect on accurate timing behavior. The rats were run once per day around the same time each day. Since the computer program controlled the schedule and recorded the responses as *early*, *reinforced*, or *late*, inter-observer reliability was not an issue.

This study is different from the previous research in that behavior during the experimental sessions was coded to determine if the rats were engaging in adjunctive behavior. For the last three days of each schedule, behavior during the sessions was recorded using a video camera. Chewing behavior was then coded by the author to determine the length of time each rat spent chewing during each session in which the

chew block was present.

### Results

One rat was dropped from the study because it consistently failed to press the bar throughout both schedules. This left a total of five rats.

The total number of responses for each rat in each session was divided into three categories: early, reinforced, and late responses. *Early* responses occurred before the initial time period (5 or 10 seconds) had expired. These responses served to reset the clock. *Reinforced* responses occurred after the initial time period had expired, but before the hold expired. These responses were reinforced with a food pellet, after which a new interval started. Finally, *late* responses occurred after the initial interval and after the hold period. These responses were not reinforced and served to reset the clock.

The average numbers of early, reinforced, and late responses are presented in Table 2, expressed as both absolute numbers and percentages of the total number of responses. As shown in Table 2, the presence of the chew block did not have a clear effect on the number of early, reinforced, and late responses. However, there was an apparent effect of schedule, with subjects making more responses on the DRL 5 schedule as compared to the DRL 10 schedule. The subjects also made a greater percentage of reinforced responses and a smaller percentage of early and late responses on the DRL 5 schedule compared to the DRL 10 schedule.

A two-way within-subjects ANOVA (DRL schedule X chew block condition) was performed to further analyze the results in Table 2. The analysis yielded a significant effect of DRL Value ( $F[1,4] = 42.36, p < .05$ ). There was no significant effect of chew block ( $F[1,4] = 0.01, p > .05$ ) and no significant interaction ( $F[1,4] = 0.19, p > .05$ ).

Figure 1 shows the percentage of reinforced responses for days 1 through 10 for each schedule and condition. As shown in Figure 1, the data forms a learning curve for each schedule and condition, that is, the percentage of reinforced responses increased over the 10 days. However, there are no clear differences in percentages of reinforced responses for the chew block and no chew block conditions. There is a difference, however, in the learning curves for the DRL 5 schedule as compared to the DRL 10 schedule, with the percentage of reinforced responses on the DRL 5 schedule consistently higher than on the DRL 10 schedule. The results presented in figure 1 are consistent with the ANOVA results described above.

Table 3 shows the average rates of chewing for the chew block condition for each DRL schedule. During the sessions with the chew block, the rats did very little chewing overall, spending less than 10% of the session chewing. Two rats did perform a large amount of chewing during the DRL 10 schedule. Interestingly, these rats were *below* the average for reinforced responses, showing that chewing on the chew block did not improve their performance and may have in fact interfered with performance.

## Discussion

The present study tested a prediction of the behavioral theory of timing by examining the effects of adjunctive behavior on DRL performance. Rats were exposed to four experimental conditions: DRL 5 with a chew block, DRL 5 without a chew block, DRL 10 with a chew block, and DRL 10 without a chew block. The behavioral theory of timing predicted that the rats would make more accurate or reinforced responses when the chew block was present.

The presence of the chew block did not have a significant effect on the percentage of early, reinforced, or late responses. There was a significant effect of schedule, with rats making more reinforced responses on the DRL 5 schedule as compared to the DRL 10 schedule. There was no significant interaction between the condition of chewing and the schedule. In addition, the rats engaged in very little chewing when the chew block was present. The chewing that did occur was negatively associated with performance. That is, rats who chewed the block most were below average in their reinforced responses. This suggests that chewing may have hindered performance.

The present findings violate the behavioral theory of timing, which predicts that adjunctive behavior will aid performance. There are several possible reasons for these results. One explanation is that the behavioral theory of timing is in fact inaccurate and adjunctive behaviors do not aid timing ability. This conclusion is supported by two aspects: the overall failure to find a significant effect of the chew block on timing ability, plus the finding that the rats who did chew were below average in reinforced responses. However, many other studies have shown the behavioral theory of timing to be accurate in explaining timing abilities (e.g. Bizo & White, 1995a; Fetterman & Killeen, 1995). For example, Richelle and Lejeune (1980) found not only that animals responded more efficiently to schedules when adjunctive behaviors were preformed, but also that disruption of adjunctive behaviors disrupted timing abilities. Given the support for BeT found in other studies, perhaps there is another explanation for the results of the present study.

A second possible explanation for the results is that this not an appropriate test for BeT because the rats did not chew when the chew block was present. Although all rats

chewed on the block to some extent, chewing rates were lower than we anticipated. Since there were such low rates of chewing, the manipulation did not really work. This explanation would suggest that the behavioral theory of timing could well be correct, but we were not able to test it directly because the rats failed to chew on the chew block. It remains ironic that the two rats that did chew performed poorly during those sessions, but with such low rates of chewing overall, it is difficult to make assumptions.

Another possibility is that perhaps BeT is correct, but the rats were performing other adjunctive behaviors during the session, such as grooming or pacing. Since we only measured chewing behavior, it is unclear whether other behaviors were occurring during the sessions. If other adjunctive behaviors were occurring, this could explain the lack of significant differences between the chew block and no chew block conditions. Because sessions were videotaped, it is possible to go back and code the sessions for other adjunctive behaviors such as grooming or pacing.

A fourth explanation of the results is that the experiment might not have gone on long enough. At the peak of the learning curve, rats were receiving reinforcement for only fifty to sixty percent of their responses on the DRL 5 schedule, and even less for the DRL 10 schedule. Since percentage of reinforced responses was still increasing at the end of the study, it may have continued to increase if the experiment was extended. Perhaps additional sessions are needed before the adjunctive behaviors influence timing abilities. It is also possible that more sessions are necessary before substantial adjunctive behavior would develop. Future research should conduct more sessions to determine if adjunctive behavior develops.

Also, it is possible that the choice of a DRL schedule with a limited hold is

problematic for this study. The limited hold makes reinforcement much more difficult for the rats, and in some cases pressing behavior extinguished and needed to be reshaped. As noted above, one subject was dropped from the study as a result of this. The task was particularly difficult for rats starting on the DRL 10 schedule. The difficulty of the task, combined with the extinction of responses, may have disrupted behavior to an extent that it was impossible to test the theory.

In addition to the difficulty of the DRL schedule, we may have in fact used the wrong DRL values. Rats on the DRL 5 schedule did not have enough time to chew if they were to receive the maximum amount of reinforcement per session. Once the rat successfully pressed the bar and received reinforcement, eating the food pellet took several seconds. Once the rat finished eating the pellet, it was time to press the bar again. Future studies should either use different values for the DRL schedule to allow more time to chew, or use a different task altogether to make it easier for the rats to gain reinforcement.

Finally, the random alternation between chew block and no chew block conditions may have inhibited timing as well as the development of chewing behavior. Richelle and Lejeune (1980) found that disruptions in adjunctive behavior also disrupted timing ability. It is possible that by alternating chew block conditions with no chew block conditions the adjunctive behavior, and therefore timing ability, was disrupted. Perhaps it would have been better to present the chew block for a large number of consecutive trials instead of randomizing chew block sessions. Future studies should examine this by presenting the chew block for several consecutive sessions to determine if this affects timing ability.

It would be tempting to say that because BeT is not supported by the results of the present study, SET is supported instead. However, this conclusion would be premature for several reasons. First, as previously noted, the results do not clearly oppose or confirm BeT. Instead it is possible that this was not an appropriate test for BeT. Second, because SET makes no predictions about adjunctive behavior, the present experiments are not directly relevant to SET. Therefore, it is not appropriate to assume that SET is supported by these results.

There are several possible directions for future research. First, studies should include more subjects. One limitation of this study is the small sample size used, especially since one rat was dropped from the study. However, small sample sizes are common in behavioral work, so this is probably not the only necessary change. Another limitation is that the present study was only run for 40 sessions. As mentioned previously, rats were only reinforced for fifty to sixty percent of their responses at the end of the study, and this percentage was still increasing. By extending the experiment it would be possible to determine whether the rats continued to become more accurate in timing as the experiment progressed. Also, additional sessions might show that the presence of the chew block does influence timing ability. Therefore, future studies should include more experimental sessions to determine if this makes a difference in the influence of adjunctive behaviors.

Future research may also want to use easier tasks, such as the DRL without the limited hold, since the present task was too difficult for rats to time. In addition, future studies should progress more slowly in order to avoid extinction. Future research might want to use a task without a reset component, such as a fixed interval schedule, in order

to ensure that the rats receive reinforcement.

Another recommendation for future research is that all behavior, not just the chewing behavior, be coded. It is possible that other adjunctive behaviors occurred during this study, but since we only coded the length of chewing behavior, this cannot be determined. Future research should examine all behavior during sessions to determine if other adjunctive behaviors are occurring.

A final suggestion for future research is that a large number of chew block sessions be run consecutively to determine if this aids not only the development of adjunctive behavior but subsequently timing ability. The random alternation between chew block and no chew block conditions in this study could have disrupted timing ability, as suggested by Richelle and Lejeune (1980). Therefore, it would be interesting to see if making chew block conditions consecutive would produce different results.

In summary, the results of the present study are in opposition to the predictions of BeT that adjunctive behaviors mediate timing. When the rats did perform the desired adjunctive behavior, chewing, their performance was possibly hindered. However, since chewing occurred at such low rates, it is difficult to determine the accuracy of BeT. Future studies should include more subjects and run more sessions. In addition, suggestions for future research include examining all behavior during each session as well as running chew block sessions consecutively to determine the effects of this manipulation on timing ability.

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Table 1

*Schedule of Sessions for Each Squad*

Day	Squad 1		Squad 2	
	Schedule	Condition	Schedule	Condition
1-20	DRL 10 LH 5	Chewblock on 10 trials, randomly determined	DRL 5 LH 5	Chewblock on 10 trials, randomly determined
21-40	DRL 5 LH 5	Chewblock on 10 trials, randomly determined	DRL 10 LH 5	Chewblock on 10 trials, randomly determined

Table 2

*Average Number of Early, Reinforced, and Late Responses Expressed as Raw Totals and as Percentages*

DRL Value	Chew			No Chew		
	Early	Reinforced	Late	Early	Reinforced	Late
5	128.5 (42%)	157.9 (56%)	6.4 (2%)	115.7 (41%)	163.9 (56%)	5.3 (2%)
10	66.1 (60%)	47.3 (29%)	5.8 (11%)	67.0 (63%)	43.8 (28%)	5.3 (9%)

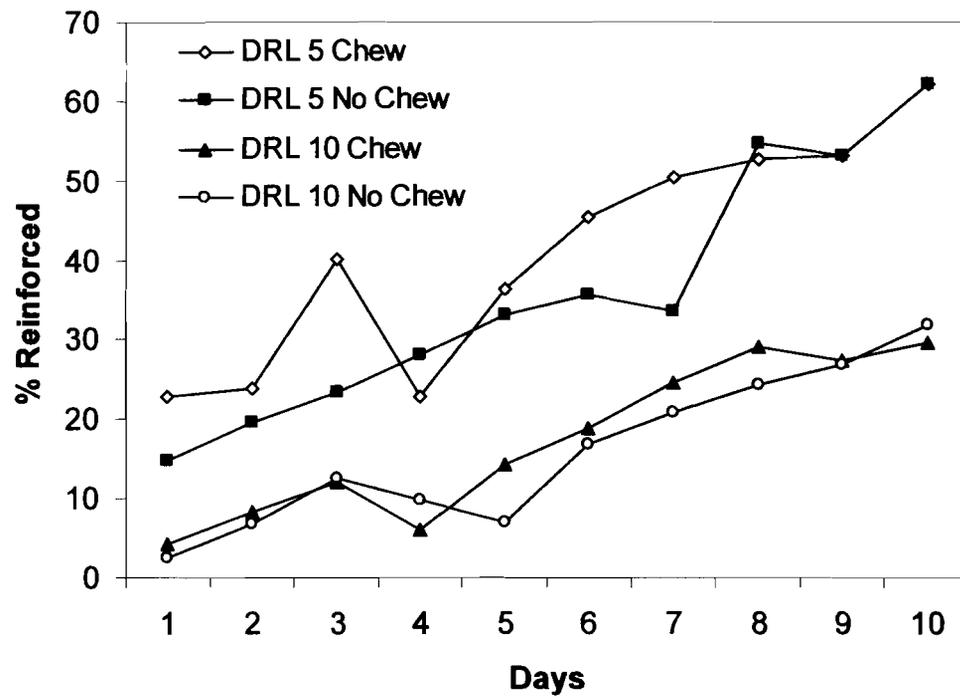


Figure 1. Percentage of responses reinforced during days 1 through 10 for each schedule and condition.

Table 3

*Average Amount of Time Spent Chewing on the Chew Block, Expressed in Seconds Per Session and Percentage of Session Length*

Subject	DRL 5			DRL 10		
	Seconds Chewing	Percentage Chewing	Percent Reinforced	Seconds Chewing	Percentage Chewing	Percent Reinforced
1	50	2.8	55	525	29.2	4
2	12	0.7	59	10	0.6	0
3	72	4	65	301	16.7	19
4	59	3.3	61	13	0.7	68
5	27	1.5	70	15	0.8	56
Mean	44	2.5	62	173	9.6	29