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RELATIVE COVER TO TARGET CUE DURATION CONTROLS TARGET RESPONDING IN THE SIGNALED RANDOM PROCEDURE

by

JAMES JOSEPH JAKUBOW

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York

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Abstract

RELATIVE COVER TO TARGET CUE DURATION CONTROLS TARGET RESPONDING IN THE SIGNALED RANDOM PROCEDURE

by

James Joseph Jakubow

Adviser: Professor Bruce Brown

Random arrangements of target conditional stimuli and unconditional stimuli result in low levels of conditioned responding to the target cue. When all unconditional stimuli in the intertrial-interval are signaled with a separate cue, the cover cue, higher levels of responding to the target conditional stimulus are observed. Assays that include a signal for the intertrial-interval unconditional stimuli are called signaled random procedures. A review of the signaled random procedure literature reveals that significantly more target cue responding is elicited when the target and cover cue durations are equal than when they are unequal. Experiment 1 was a systematic replication of an experiment by Williams (1994). In this experiment, pigeons were exposed to a 15-second target stimulus and either a 15-second or 5-second cover stimulus. Results replicated Williams' outcomes in that birds exposed to equal stimulus durations responded to the target cue significantly more than birds exposed to the unequal stimulus durations. Experiment 2 was designed as a test of this relative cue-duration effect. Four groups of pigeons were exposed to equal target and cover cue durations of 4, 12 and 36 seconds. Two more groups were exposed to unequal stimulus durations of a 12-second target cue with either a 4 or 36-second cover cue. Results confirmed the prediction that significantly more target cue responding appears when the target and cover cue durations are equal. A common-elements mechanism employing temporal and nontemporal cue elements is used to interpret the body of data in the literature. The effects of this mechanism are better predicted by competition models than by comparator models.

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Relative Cover to Target Cue Duration Controls Target Responding in the Signaled Random Procedure

The random conditioning procedure is commonly designed by dividing an experimental session into equal time units. The duration of the time unit is typically the same duration as the conditional stimuli (CS) presented during the session. A number of CSs may then be assigned randomly to time units throughout the session. Once the experimenter has decided how many CSs should occur during the session, the session duration and probability of the unconditional stimulus (US) given a CS [p(US|CS)] will determine the number of USs throughout the session. Throughout the session the p(US|CS) and the p(US|~~CS~~) are always equal. In this procedure, CSs and USs are most often presented in isolation, that is, unpaired. Probabilistically, however, a few of the stimuli may occur in close temporal proximity. Exposure to random conditioning procedures results in very little elicited responding in the presence of the CS (Rescorla & LoLordo, 1965; Rescorla 1966).

Signaled Random Procedures

If all US presentations that are not immediately preceded by the CS are signaled by another cue, the procedure is termed a signaled random procedure (Cooper, Aronson, Balsam & Gibbon, 1990; Durlach, 1982, 1983; Williams, 1994). This procedure arranges a random temporal relation between the CS and US in an identical fashion to the random control procedure. All US presentations during the intertrial interval (ITI—the period between CS presentations), however, are preceded by a second CS. Because two CSs are used in the procedure, it helps to identify each individually. The randomly presented CS (the CS bearing the random relation with the US) is often referred to as the target CS.

The second CS is typically referred to as the cover CS because it presumably reduces (covers) the effects of the USs that are not signaled by the target CS. The main interest in signaled random experiments (cover experiments) is whether responding is elicited by the target CS.

An example of a cover experiment involves an autoshaping procedure in which the subjects in one group (group Unsignaled) may be exposed to a random relation of a keylight CS (target CS) and food US. Commonly the p(US|target CS) = p(US|~~target CS~~). In this group, the USs presented in the ITI would be unsignaled by the cover CS. A second group of subjects (group Signaled) would be exposed to the same random relation of target CS and US and additionally have all USs presented during the ITI signaled by the cover CS. Results generally show that subjects in group Unsignaled do not develop substantial levels of excitatory responding to the target CS. This procedure, of course, is simply the random conditioning procedure. In comparison, however, the subjects in group Signaled do acquire responding to the target CS.

Literature Review

A systematic examination of the cover effect began with Durlach (1983). Her basic procedure involved two phases. Phase 1 contained the training of the cover CS. Phase 2 contained random arrangements of the target CS and US in which the USs presented during the ITI were either signaled or unsignaled by the cover CS. In phase 1 of Experiment 1, pigeons were exposed to 16 sessions of cover CS training. These 20-minute sessions contained 20 trials per session of a 10-s blue keylight paired with 5-s access to grain (US). The p(US|cover CS) = 1.0 and the trials were presented with a variable ITI of 60 s.

In phase 2, session duration was also 20 minutes. In this phase, birds were exposed to signaled or unsignaled random arrangements of target CS and US. This phase contained 33 sessions in which the 10-s target CS, a black "X" on a white background, was presented for 12 trials per session. The p(US|target CS) = .25. All seventeen USs presented during the ITI were signaled by the cover CS in group Signaled. In contrast, none of the USs presented during the ITI were signaled in group Unsignaled.

As measured from all birds, the results from Phase 1 showed the terminal level of the proportion of trials with a response at 78% across sessions. Results from Phase 2 showed an increase in the level of responding to the target CS in group Signaled over the 33 sessions of phase 2. Terminal level of target CS responding was equivalent to that exhibited by the cover CS. In contrast, very little responding was elicited by the target CS in group Unsignaled. Durlach explained these results in terms of the Rescorla-Wagner (1972) model. This model suggests that the cover CS competes with the context for associative value. Because, for group Signaled, US presentations were always preceded by either the cover or target CS, the context accrued little value. This arrangement allowed the target CS to accrue value slowly against this context. In contrast, the context accrues much more value in group Unsignaled because the majority of US presentations are not preceded by a discrete CS. Context conditioning, in turn, is presumed to block conditioning to the target CS.

In Experiment 1, target CS responding may have developed as a result of stimulus generalization from the keylight cover CS to the keylight target CS. In Experiment 2, three groups were exposed to an auditory (tone) cover CS and a keylight target CS. In addition, Experiment 2 also contained a forward conditioning control group [p(US|target

CS) = .25]. This group was used to compare the speed of acquisition between birds exposed to the Signaled condition and those exposed to partial reinforcement. The groups of naive birds in Experiment 2 were exposed to the same temporal parameters as in Experiment 1. The factor manipulated between experiments was the change from a keylight cover CS in Experiment 1 to a tone cover CS in Experiment 2. Results showed that the forward conditioning group acquired keypecking to the target CS more quickly and to higher levels than the other groups. No support for the visual generalization hypothesis was found, as the target CS (keylight) elicited a higher level of pecking in group Signaled (tone cover CS) than in group Unsignaled (no cover CS).

In 1990, Cooper et al. conducted experiments on the cover effect. These experiments exposed birds to conditions of different cover cue durations. Experiment 1 consisted of groups Short Cover and Long Cover. In this experiment, pigeon subjects were exposed to a 40-minute session comprised of 200 successive 12-s periods. Each session contained 20 presentations of a 12-s keylight target CSs, four of which were reinforced, which produced a p(US|target CS) = .20. Thirty-six US presentations (3-s access to grain) during the ITI also occurred during each session. Each US presented during the ITI was signaled by a 12-s cover CS (group Short) or a 48-s cover CS (group Long). The target CS was a white "X" on a black background for both groups and the cover CS was counterbalanced across groups as either a red or white key. The acquisition of responding was ascertained over 30 sessions. Results showed that pecking was elicited by both the cover and target CSs for the birds in group Short whereas pecking emerged for neither the cover nor the target CS in group Long.

Experiment 2 consisted of nearly the same parameters as in Experiment 1. Three changes were made from Experiment 1: (a) the cover CS was made a white keylight, (b) all ITI periods were filled with a red keylight, and (c) group Multiple Cover was established. Group Multiple Cover was run with the same temporal parameters as group Short Cover. The probability of a US, however, was .20 in both the presence and absence of the cover CS. Again, results showed the conditions of group Short Cover caused keypecking to emerge to both the cover and target CSs. Pecking was not observed to either stimulus for group Long Cover or group Multiple Cover.

Cooper et al. (1990) conducted experiments containing cover CS durations that were equal-to or longer-than the target CS. In a sign-tracking study using rats, Williams (1994) shortened the cover CS in comparison to the duration of the target CS. Williams used 25 rats in a 4 group between subjects design. The experiment was conducted in a converted shuttle box that contained a houselight mounted on the center ceiling and a food hopper installed in the center of the chamber. A red light was mounted on each side wall to be used as the CS in the sign-tracking test.

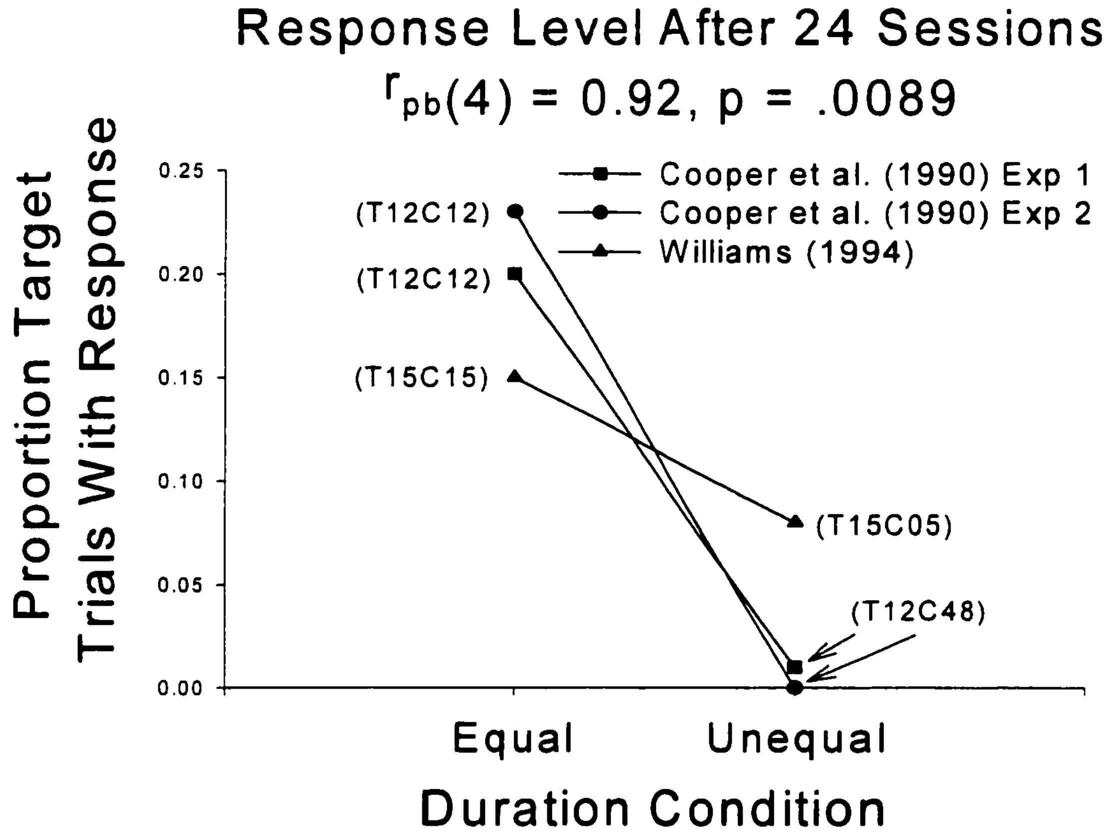
The rats were randomly assigned to groups. For all groups, the target CS consisted of a red keylight that could be lighted on either side of the shuttle chamber. When the CS was lit, the movement of the subjects toward the light was measured through a tilt floor apparatus. The cover CS was a burst of white noise of 88 dB (SPL).

All sessions contained 120 intervals that were 15 s in duration. Group CS-Only was exposed to 18 target CS presentations with a p(US|target CS) = .50 and p(US|~~target CS~~) = .50. The target CS was 15 s in duration. Group No Signal received only random arrangements of target CS and US (food pellet). The 15-s target CS occurred with a probability of .15 in each interval; and the US occurred with a p(US) =.50, yielding 60 US presentations for each session. Groups Long Signal and Short Signal were run under similar conditions as group No Signal. For group Long Signal, however, each US presented during the ITI was immediately preceded by a 15-s cover CS. For group Short Signal each US presented during the ITI was immediately preceded by a 5-s cover CS. The acquisition of sign tracking to the red light was assessed over 40 sessions.

Results showed that rats in group CS-Only developed a high level of responding within 20 sessions. This result was expected because the rats were exposed to a 50% reinforcement schedule. In contrast, group No Signal did not show a substantial level of responding. This lack of responding was also expected because group No Signal was exposed to random CS-US presentations. The results of interest came from groups Long Signal and Short Signal. Group Short Signal revealed a level of responding equivalent to that of group No Signal. Group Long Signal showed a reliable increase in sign tracking to the target CS in comparison to groups No Signal and Short Signal. Responding to the cover CS was not assessed.

The results from these experiments may appear to be unrelated, however, they can be understood with respect to a common factor—the relative duration of target and cover cues. In general, the overall pattern of results in the signaled random procedure literature show a predictive relationship between target cue responding and the temporal similarity of the target and cover cues. Figure 1 is based upon an exhaustive review of the cover effect literature. It shows the data from experiments that met the following criteria; (a) a direct comparison between equal and unequal target and cover stimulus durations was

Figure 1. The proportion of target trials with a response as a function of the similarity of stimulus duration for the target and cover cues.



conducted within a single experiment, and (b) the p(US|target CS) = p(US|~~target CS~~). The literature revealed three such experiments comprising six total groups.

Figure 1 shows the proportion of target cue trials with a response across conditions in which stimulus durations were equal or unequal. A line connects the points representing the two groups from each experiment. In all three comparisons, the level of responding is higher for the subjects exposed to the equal stimulus condition than to the unequal stimulus condition. The Cooper et al. (1990) experiments employed pigeons in an autoshaping procedure whereas Williams' (1994) experiment employed rats in an audio/visual sign-tracking task. A point-biserial test conducted on these data reveal a significant correlation between level of target cue responding and stimulus equality [$r_{pb}(4) = .92$, $p < .01$].

The effect shown in Figure 1 may be attributable to stimulus generalization based on stimulus duration. This generalization process may be characterized via a common-elements mechanism as represented by stimulus sampling models (Bush and Mosteller, 1951) or by more recent analyses in terms of stimulus elements (Rescorla and Wagner, 1972). In this kind of approach to the signaled random procedure, it is assumed that each stimulus (target and cover cue) has both a nontemporal and temporal component (e.g., color and duration), and that those components may be shared or nonshared elements of a stimulus complex. In the present example, the temporal component may serve as a common element of a stimulus compound composed of temporal and nontemporal components. In the equal stimulus condition, the probability of US presentation following the temporal duration will be highest during cover cue trials, and transfer may occur to the target cue as the duration component is common to both target and cover compound stimuli. In contrast, when the target and cover cues are of unequal durations, the target cue does not benefit from transfer based on stimulus duration. This kind of mechanism is particularly apt for Williams' (1994) procedure that employed target and cover cues from different modalities in equal or unequal durations. Results indicated that the equal-stimulus duration condition led to higher levels of target responding than its unequal-stimulus comparison group. Because Williams used cues from two different stimulus modalities, it is unlikely that target responding resulted from stimulus generalization based upon the similarity of nonshared elements of the target and cover stimuli. As Williams' study was the only one to manipulate similarity of cover and target cue duration with the use of a cover cue duration shorter than its respective target cue duration, Experiment 1 was conducted with pigeon subjects in a systematic replication of the Williams (1994) signaled random experiment.

Experiment 1

Williams' experiment employed a cover cue that was shorter than its respective target cue, unlike previous studies that used a longer cover in an unequal condition. This short cover cue manipulation, however, was conducted with rat subjects. This yielded a confound in comparing Williams' use of a short cover cue and rat subjects and Cooper et al.'s use of a long cover cue and pigeon subjects (see Figure 1). The use of pigeon subjects in the present study eliminates this confound and facilitates the comparison of results across this study and Cooper et al. (1990). Other procedural differences in the present study were intended to provide additional data. The present experiment employed a visual cover cue stimulus so that responding to the cover cue could be measured in the pigeon subjects. In Williams study, no data reflecting responding to the cover cue was available, as that study employed an auditory cover cue stimulus in an experimental chamber that was designed to measure only visual sign tracking behavior from rats. The present experiment also extended the acquisition phase from 40 sessions in Williams study to 70 sessions in the current study. Finally, the current experiment employed a reversal of conditions to assess whether the effects of the signaled random procedure were reversible.

This experiment tested the hypothesis that responding to the target cue is modulated by a common temporal stimulus that is shared between the visual components of the target and cover CSs. If this hypothesis is correct, then responding to the target cue should appear at higher levels in the group exposed to equal target and cover cue durations than in the group exposed to unequal stimulus durations. That is, responding to the target cue should be weaker in the absence of a common cue. Moreover, responding to the cover cue should also increase under the equal stimulus condition as opposed to the unequal stimulus condition.

Method

Participants

Sixteen experimentally naive pigeons maintained at 75% of their free feeding weights were used in this experiment. Eight birds were Silver Kings and eight were White Carneaux. All birds were allowed free access to grit and water in their home cages, and were fed enough grain after each experimental session to maintain their weight at the desired level. The birds were housed individually in a vivarium that maintained a 12-hour light/dark schedule.

Apparatus

All training and testing was conducted in four Lehigh Valley Electronics 3-key experimental chambers for pigeon subjects (model SEC-002). The area of the chamber occupied by the bird measured 37 cm high, 31 cm wide and 34 cm deep. The front panel contained a houselight, 3 response keys, and a food hopper. The houselight was located 1.5 cm from the top and 17 cm from the right side of the panel. It was protected by a metal covering that directed its illumination toward the ceiling.

The three response keys were located 8 cm from the top of the front panel. The center key was located 17 cm from either end of the front panel. The center points of the remaining keys were located 8.5 cm lateral to the center point of the 2.5-cm diameter center key. The hopper aperture was centrally located 6 cm directly below the center key and was 5.5 cm wide, 5 cm in height and 5 cm deep. The inside left and right walls of the hopper contained an infrared emitter/detector. These photocells were located 2.5 cm behind the front panel and 2.5 cm above the bottom of the hopper opening. The photocells were used to detect head entries into the hopper. All food deliveries were 1 s in duration from the moment the hopper photobeam was intercepted. All stimulus presentations and data collection were controlled by an IBM AT computer operating Spyder Systems CONMAN® software. All data were collected with a resolution of 100 ms. Only the center key was operational for recording responses and presenting stimuli during the experiment. Visual stimuli were presented with an IEE in-line projector (model no. 10-OK21-1820-L) mounted behind the center key of each chamber. The CSs used were a blue keylight and a white "X" on a black surround. Stimuli used for target and cover cues were counterbalanced.

Procedure

Magazine Training. The experiment began by training the eating response. During magazine training sessions, the experimental chambers were fitted with black wall liners and the white noise turned off. On the first food presentation, birds were permitted a 30 min latency to eat from the time the mixed grain was presented. Thereafter, training continued until eat latency decreased successively to values of 15, 5 and < 2 s. The latency requirements of 30 minutes, 15 s, 5 s and < 2 s were used with food durations of 20 s, 4 s, 2 s and 1 s, respectively. All birds were exposed to a final session of magazine training after every subject met the terminal response criterion. This criterion required the birds to have a median eat-latency of < 2 s across 51 trials of a variable time (VT) 60 s schedule during which a 1-s food US was presented. All birds successfully passed this criterion. The extra session of magazine training was conducted on the same day for all subjects. Birds were then randomly assigned to two groups with the restriction that the strain of birds (Silver King, White Carneaux) be balanced across group and chambers.

Signaled Random Procedure. The contingencies employed in the present study were identical to those of Williams (1994). The two groups in this experiment were T15C15 and T15C05. Each group name describes the duration of the target (T) and cover (C) cues in seconds. Birds assigned to group T15C15 were exposed to target and cover CS durations of 15 seconds. These birds were exposed to 30-minute sessions containing 120 15-s periods. Eighteen 15-s target CSs were presented during each session and 9 of those were immediately followed by food. Of the remaining 102 periods, 51 were scheduled to contain an ITI US presentation. All ITI USs were preceded by the 15-s cover CS. Therefore the p(US|target CS) = .50 and the p(US|~~target CS~~) = .50. Birds assigned to group T15C05 were exposed to the same set of conditions except the cover CS in this group was 5 s in duration. This 5-s cue filled the last 5-s of any 15-s period in which it was scheduled to occur. Birds were exposed to their respective conditions for 70 sessions.

Reversal of Conditions. Sessions 71-140 involved a reversal of conditions between groups. Birds in group T15C15 were exposed to the conditions of group T15C05 and birds in group T15C05 were exposed to the conditions of group T15C15. By the end of this experiment one bird from within group T15C05 died leaving n = 7 in that group.

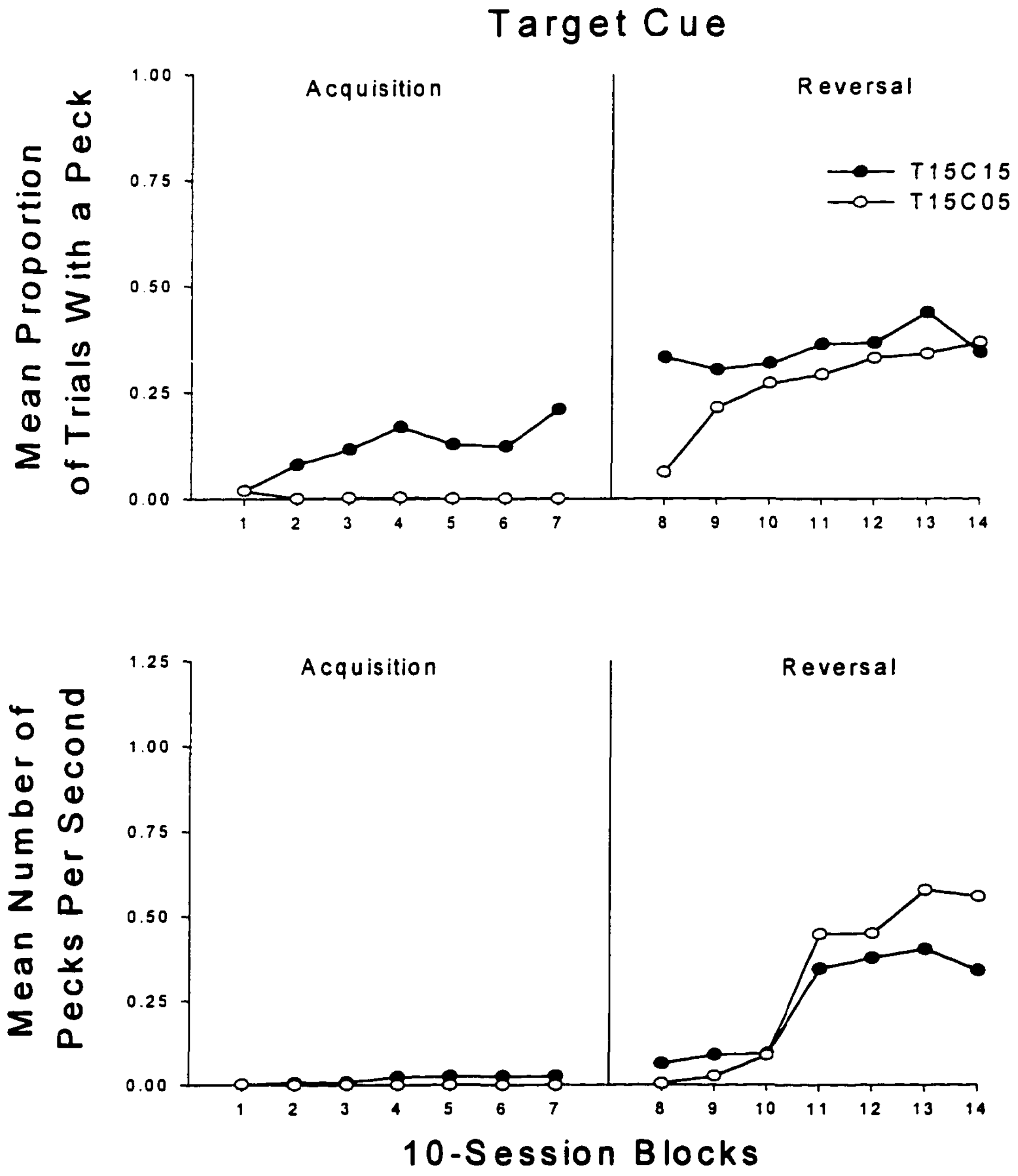
Results

The application of Pearson's Third Moment test for skewness revealed significant skewness in target and cover responding as measured by the mean of 70 sessions from each phase [Zs ≥ 1.96, ps < .05]. The presence of this skewness required the application of nonparametric statistics to assess differences across groups. The test employed was the Kruskal-Wallis H test.

Target Cue

Proportion of Trials With a Response. The results of this experiment are shown in Figures 2 and 3. Figure 2 shows the data for responding to the target stimulus. The top panel shows the group mean proportion of trials with a peck across the fourteen 10-session blocks of the experiment. Blocks 1-7 refer to the initial acquisition period and 14 refer to the reversal of conditions. This panel shows that the birds in group T15C05 responded at near zero levels throughout the 7 blocks of acquisition. Birds in group

Figure 2. The response level, proportion (top panel) or rate (bottom panel), for the target cue as a function of 10-session blocks in Experiment 1. The legend symbols refer to the treatments of groups in Phase 1 regardless of reversal condition.



T15C15 responded at higher levels than those in group T15C05 as assessed through a mean of all 7 blocks [$H(1) = 9.61$, $p < .05$]. A Kruskal-Wallis H test was also applied to the data at each block. Results reveal that group T15C15 responded at significantly higher levels than group T15C05 in blocks 4-7 [$Hs(1) > 3.84$, $ps < .05$].

Block 8 marks the beginning of the reversal phase. A Kruskal-Wallis H test was applied to the group data for the mean of blocks 8-14. The test revealed no significant difference in response level between groups [$H(1) = 1.08$, $p > .05$]. Although the graph appears to show a difference between groups on block 8, no difference was found [$H(1) < 3.84$, $p > .05$].

During the reversal phase, both groups appeared to exhibit an increase in response level in comparison to their acquisition phase response levels. A Wilcoxon Signed Ranks test for dependent measures was applied to the data for group T15C15. Results revealed a significant increase in mean response level across phases [$t(7) = 5.19$, $p < .05$]. After showing near zero levels of responding for 70 sessions, birds in group T15C05 began to respond at much higher levels to the target cue after the reversal began. A Wilcoxon Signed Ranks test for dependent measures was applied to the data for group T15C05. Results revealed a significant increase in mean response level across phases [$t(6) = 3.67$, $p < .05$].

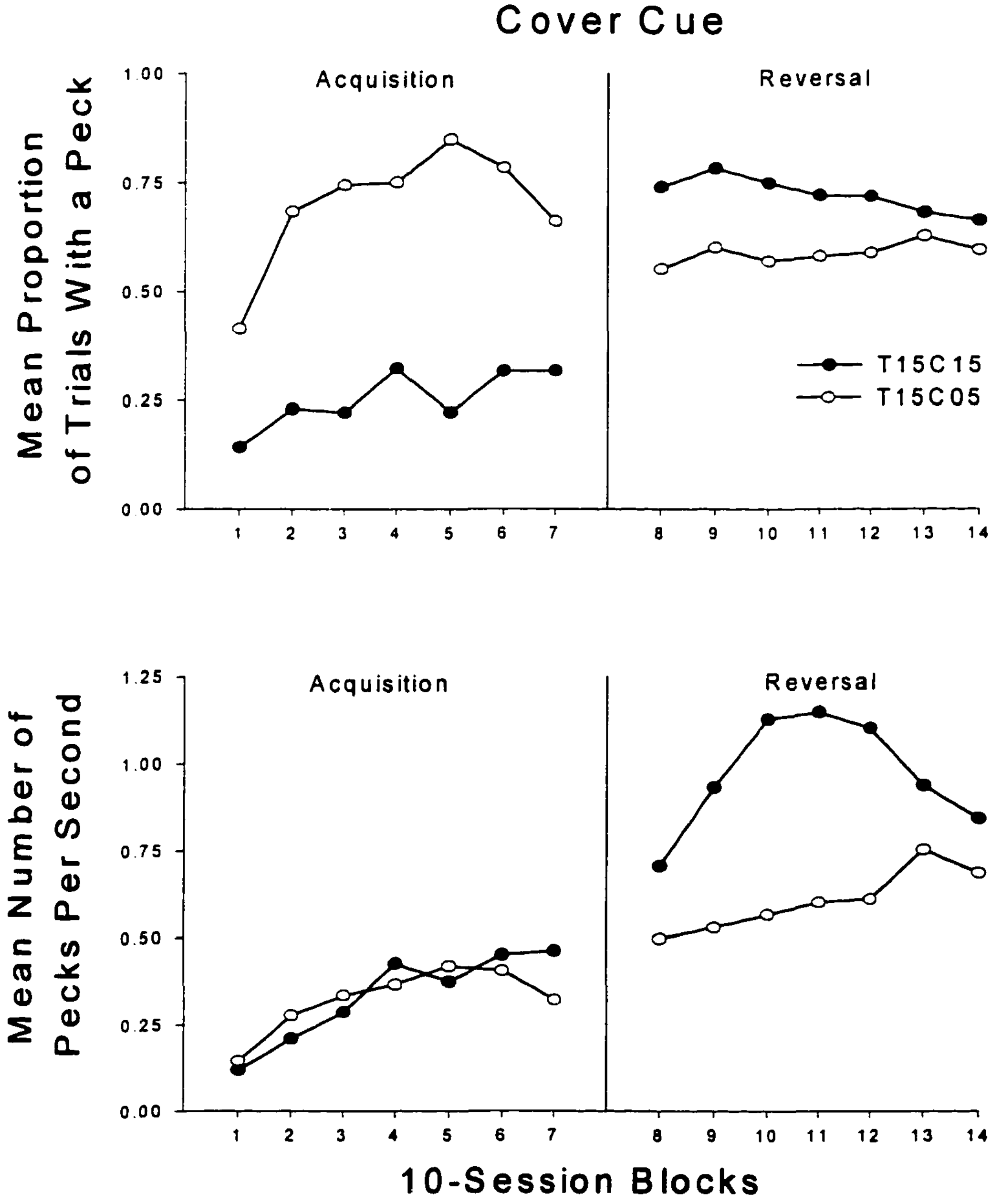
Rate of Response. The bottom panel of Figure 2 shows the mean number of pecks per second during the target cue across the fourteen 10-session blocks of the experiment. This panel reveals that group T15C15 tended to respond at a slightly higher rate than group T15C05 during the acquisition phase. A Kruskal-Wallis H test applied to the mean response rate over the 70 sessions of phase 1 revealed a significantly higher rate for group T15C15 [$H(1) = 7.70$, $p < .05$]. When this test was applied to the data for each block, it revealed that group T15C15 responded at significantly higher levels than group T15C05 in blocks 5-7 [$Hs(1) > 3.84$, $ps < .05$]. Block 8 marks the beginning of the reversal phase. A Kruskal-Wallis H test was applied to the data from each group for the mean of blocks 8-14. The test revealed no significant difference in response rate between groups [$H(1) = 0.33$, $p > .05$]. No group differences in rate of response to the target cue were found at any block throughout the reversal phase of the experiment [$Hs(1) < 3.84$, $ps > .05$].

During phase 2, both groups appeared to exhibit an increase in response level in comparison to their phase 1 response levels. A Wilcoxon Signed Ranks test for dependent measures was applied to the data for group T15C15. Results revealed a significant increase in mean response rate across phases [$t(7) = 5.19$, $p < .05$]. The same test applied to the data from group T15C05 revealed a significant increase in mean response rate across phases [$t(6) = 3.26$, $p < .05$].

Cover Cue

Proportion of Trials With a Response. Figure 3 shows the data on responding to the cover cue. The top panel shows the mean proportion of trials with a peck across the fourteen 10-session blocks of the experiment. Blocks 1-7 represent the data from the acquisition period. Blocks 8-14 represent the data from the reversal of conditions. The top panel shows that the birds in group T15C05 responded at higher levels than those in group T15C15 did throughout the acquisition phase. A Kruskal-Wallis H test applied to the mean response level across the 70 sessions of acquisition revealed that group T15C05 responded at higher levels than group T15C15 [$H(1) = 4.83$, $p < .05$]. Tests applied to

Figure 3. The response level, proportion (top panel) or rate (bottom panel), for the cover cue as a function of 10-session blocks in Experiment 1. The legend symbols refer to the treatments of groups in Phase 1 regardless of reversal condition.



each block revealed significant differences in blocks 1-6 [Hs(1) > 3.84, ps < .05] but not in block 7 [H(1) = 3.42, p = .064]. A Kruskal-Wallis H test was applied to the data from each group for the mean of blocks 8-14. The test revealed no significant difference in response level between groups [H(1) = 0.33, p > .05]. No group differences in proportion of trials with a response to the cover cue were found at any block throughout the reversal phase of the experiment [Hs(1) < 3.84, ps > .05].

During phase 2, group T15C15 appeared to exhibit an increase in response level in comparison to its phase 1 response level. A Wilcoxon Signed Ranks test for dependent measures was applied to the data for this group. Results revealed a significant increase in mean response level across phases [t(7) = 4.12, p < .05]. The same test applied to the data from group T15C05 did not reveal a significant change in response level across phases [t(6) = 2.41, p > .05].

Rate of Response. The bottom panel of Figure 3 shows the mean number of pecks per second to the cover cue across the fourteen 10-session blocks of the experiment. It reveals that both groups responded at very similar levels across blocks 1-7. A Kruskal-Wallis H test applied to the mean response rate over the 7 blocks of acquisition revealed no differences between groups [H(1) = 1.33, p > .05]. Tests applied to each block did not reveal any significant difference except for block 5 in which group T15C05 responded at a higher rate than group T15C15 [H(1) = 3.87, p = .049]. When the 7 block mean of phase 2 was assessed between groups with a Kruskal-Wallis H test no difference was revealed [H(1) = 0.85, p > .05]. No group differences in rate of response to the cover cue were found at any block throughout the reversal phase of the experiment [Hs(1) < 3.84, ps > .05]. The reversal phase appeared to produce a general increase in response level for both groups. When, however, Wilcoxon Signed Ranks tests for dependent measures was applied to the mean response rate for each group in phases 1 and 2, no significant differences were found for group T15C15 [$\underline{t}(7) = 1.14$, $\underline{p} > .05$] or group T15C05 [$\underline{t}(6) = 0.82$, $\underline{p} > .05$].

Discussion

The results from this study support the hypothesis that responding to the target cue in the signaled random procedure is affected by the similarity of stimulus durations. The higher levels of responding to the target cue in group T15C15 may indicate that a common stimulus component between the target and cover cues facilitated target cue responding (Figure 2). The presence of higher levels of cover cue responding in group T15C05 was contrary to the prediction based on common cues. Given the common element hypothesis, it was expected that a group exposed to equal stimulus durations should respond to both cues at higher levels than the group exposed to unequal stimulus durations.

The current experiment extended Williams' study in four ways, (a) it lengthened training from 40 to 70 sessions of acquisition, (b) it included a 70 session reversal phase, (c) it provided data on cover cue responding, and (d) it generalized the testing paradigm to a pigeon autoshaping procedure. The extension of the acquisition procedure from 40 to 70 sessions allowed for more opportunity for target cue responding to emerge in group T15C05. After 70 sessions of acquisition, however, substantial levels of target cue responding were not observed in this group. This result is an indication that the lack of responding was not due to a slow acquisition rate. Although it was predicted that less responding to the target cue should appear as a result of unequal stimulus duration, there is no clear reason to expect that virtually no responding to the target cue should appear in this group.

The 70-session reversal phase was used to assess whether target cue responding was reversible between phases and whether the level of target cue responding would track the duration of the cover cue. This treatment did not reveal a reversed pattern of responding to the target cue in relation to phase 1. If responding to the target cue were dependent upon the cover CS duration, then responding in group T15C15 should have decreased during the reversal phase. Instead, responding to the target cue increased in each group. This result indicates that cover CS duration alone is not the determinant of target cue responding.

This experiment also provides data regarding the behavioral control exerted by the cover cue—data not collected by Williams (1994). The cover cue exhibited a substantial difference in behavioral control between the conditions of T15C15 and T15C05. Tests revealed that group T15C05 responded at higher levels to the cover cue than did group T15C15 in phase 1. This result is consistent with familiar stimulus duration effects by virtue of the shorter CS-US interval present in group T15C05 (Gibbon, Baldock, Locurto, Gold & Terrace, 1977; Lattal, 1999).

The reversal phase controlled dissimilar effects on the cover cue in both groups. The proportion of trials response measure revealed an increase in the cover cue from its phase 1 level into the reversal phase for group T15C15. In contrast, stable performance was observed across phases for group T15C05. This difference seems to indicate that the stimulus equality effect was not a result of the increased ITI time afforded the subjects exposed to the T15C05 condition by virtue of shorter duration cover cues.

The temporal generalization hypothesis suggests that groups exposed to equal stimulus durations should respond at higher levels to both cues in comparison to a group exposed to unequal stimulus durations. It follows that a positive correlation between responding to the target and cover cues for birds in group T15C15 should exist. To test this possibility, a correlation of each birds mean-target-cue response level vs. mean-cover-cue response level was conducted for both rate and proportion-of-trials-responded-to. The results from these tests did not reveal any significant correlations [group T15C05, $\underline{rs}(5) \leq 0.75$, $\underline{ps} > .05$; group T15C15, $\underline{rs}(6) \leq 0.38$, $\underline{ps} > .05$]. Experiment 2 provided a further opportunity to test the generalization hypothesis by examination of the correlation across groups.

Experiment 2

Higher levels of target cue responding were observed in the equal stimulus duration conditions of Experiment 1, Williams (1994) and Experiments 1 and 2 of Cooper et al. (1990). In contrast, less responding was seen to the target cue in all unequal stimulus-duration conditions in those experiments regardless of whether the cover was shorter or longer than its target cue. The possibility that responding to the target cue is modulated by the relative durations of target and cover cues is tested in this experiment.

Previous experiments have lengthened (Cooper et al., 1990) or shortened (Experiment 1; Williams, 1994) the cover cue duration relative to a 12-15 s target cue. Because these experiments varied in ways in addition to relative cue duration (e.g., species, experimental chamber, stimulus modality, etc.), an evaluation of relative target cue duration to cover cue duration in controlling target cue responding was undertaken in the present study.

The experiment was conducted by establishing groups of pigeons that were exposed to equal or unequal cue durations. Three groups of birds were exposed to equal stimulus durations of 4, 12 and 36 s cues. Two more groups were exposed to unequal stimulus durations of a 12-s target cue and a 4-s cover cue, or a 12-s target cue and a 36-s cover cue. The present design may be understood as a selected portion of a target duration by cover duration (3 x 3) matrix. The five cells selected from the matrix were intended to permit conclusions regarding the similarity of target and cover cue duration apart from the effect of absolute stimulus duration. First, unequal conditions (12-s target with 4-s cover and 12-s target with 36 s cover) were selected to examine the effects of both an increase and decrease in cover cue duration relative to an equal stimulus duration group (12-s target with 12-s cover). Second, possible effects of the absolute durations of cover cues in the unequal groups are assessed by the inclusion of the control groups (4-s target with 4 s cover and 36-s target with 36-s cover) for which the target and cover cue durations are equal, and equivalent to the cover cue durations in the unequal groups. If the relative temporal duration of target and cover cues controls the level of target cue responding, then groups exposed to the three conditions with equal target and cover cue durations should produce higher levels of responding to the target cue than groups exposed to unequal durations.

A cover cue pretraining phase similar to that of Durlach (1983) was instituted in Experiment 2 due to the higher levels of target cue responding observed in previous experiments in comparison to Experiment 1 of this study (shown in Figures 1 and 2). This pretraining phase was used to establish the cover cue as an effective cue for US presentations in an attempt to increase the level of responding to the target cue.

Method

Participants

Thirty experimentally naive pigeons (15 Silver King, 15 White Carneaux) obtained from the Palmetto Pigeon Plant, Sumter, South Carolina, were used. The birds were housed individually and exposed to a 12-hour light/dark schedule. All birds were allowed free access to grit and water in their home cages and were maintained at 75% of their free feeding weights.

Apparatus

This experiment employed five Lehigh Valley 3-key experimental chambers (model SEC-002) identical to those used in Experiment 1. The control of inputs and outputs from these chambers was performed by MED-Associates MED-PC® system software employing a data resolution of 10 ms. The two stimuli used for the target and cover cues were a blue keylight and a white "X" on a black surround. All birds received the white "X" cue as the target CS and the blue light as the cover CS.

Procedure

Magazine Training. After achieving their 75% free-feeding weights, all birds were exposed to the same magazine training protocol as in Experiment 1. This procedure involved progressively decreasing the latency criterion for a bird to eat from the hopper while also decreasing the duration of each hopper exposure. Latency requirements of 30 minutes, 15 s, 5 s and less than 2 s were used with food durations of 20 s, 4 s, 2 s and 1 s, respectively. After magazine training was completed, birds were randomly assigned to each of 6 groups.

Group Assignment. All groups were formed through the random assignment of birds into one of six conditions. Each condition manipulated the absolute durations of cues while holding constant their relative temporal relations. The six groups created were T04C04, T12C04, T12C12, T12C12D, T12C36 and T36C36. As in Experiment 1, each group name describes the duration in seconds of the target (e.g., T12) and cover (e.g., C36) cues for that group. For four groups, target and cover cue durations were equal. Group T12C12D, however, contained a unique trial distribution protocol that controlled for inter-US interval differences between groups T12C12 and T12C36. For all groups, one trial could begin immediately after another had finished. In contrast, group T12C12D employed a 24 s trial-free period after each target CS presentations. This trial distribution constraint maintained the same target-cover trial distributions as in group T12C36 (24 s delay + 12 s cover cue = 36 s) and made more similar the US-US intervals between groups (Jenkins, Barnes and Barrera, 1981). Furthermore, it also kept the target and cover cues equal in duration as in group T12C12.

Block Procedure. Counterbalancing between groups and running-times per day could not be performed on a daily basis due to the unequal number of groups and chambers, 6 and 5 respectively. For this reason, all birds in a group were run at the same time of day. The time of day, however, changed in a systematic fashion across sessions. The process used resulted in a 12-day running cycle. Running times required that all groups be ranked 1 (first group to run that day) through 6 (last group to run that day) for the first day in a cycle. On days 2, 4, 6, 8, 10, and 12 of a cycle, ranks 1-2, 3-4, and 5-6 were reversed from the running rank of the previous day. On days 1, 3, 5, 7, 9 and 11 of a cycle, ranks 2-3 and 4-5 were reversed from their previous days ranks. This manner of changing the running-time-of-day kept constant the exposure any group received to a particular running time over a 12-session cycle. The experiment was conducted over 7 cycles comprising 84 sessions.

Limited Hold Procedure. In contrast to Experiment 1, all US presentations throughout Experiment 2 contained a 10-s limited-hold. If a bird did not eat during a US presentation within 10 s of its onset, the hopper was lowered and the session proceeded. This constraint was added owing to the number of observed instances of birds not eating grain during Experiment 1. Results from the 10-s limited-hold procedure for USs showed a high level of photocell beam breaks during all food presentations. During the cover cue pretraining phase the mean percentage of photocell beam breaks across all 6 groups for all 12 sessions of pretraining was 100%. During the signaled random procedure, the mean percentage of photocell beam breaks was 99.99% across all 6 groups for all 84 sessions of training. No percentage differences existed between groups or the type of cue preceding the US (target vs. cover).

Cover Cue Pretraining. After the groups were formed, all birds were exposed to a cover cue pretraining procedure. Birds in each group were exposed to the same cover cue durations for which they were scheduled during the training phase of the experiment. All cover cue presentations were immediately followed by 1-s access to grain. As in Experiment 1, the 1-s period was determined from the point at which the bird's head breaks the infrared photobeam in the hopper.

The ITI was created from a list of 20 values that comprised a mean duration 10 times longer than the cover cue duration. The shortest value in the list was equal to the cover cue duration. Another 18 values were added to that list. Each of these values was an increasing multiple of the cover cue duration. One more ITI value was added which was equal to the mean of the distribution. Groups exposed to 4-s cover cue durations (T04C04, T12C04) were exposed to ITI values equal to the following set (4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 40, 44, 48, 52, 56, 60, 64, 68, 72, 76). This constraint on trial distributions held constant the relative temporal relations between cue presentations across groups. All birds were exposed to this procedure for 12 sessions thereby completing one block cycle.

Signaled Random Procedure. Following cover cue pretraining, all birds were exposed to the signaled random procedure. Each session of the signaled random procedure was comprised of 250 time-base periods. For each group, the time base was equal to the duration of the target cue for that group (e.g., group T12C04 was exposed to a 12-s time base). Among the 250 time base periods, birds were exposed to 184 CS-free periods (ITI), 46 cover cues and 20 target cues. For group T12C04, which was exposed to a cover cue duration shorter than its time base, an 8 s period of no CS (ITI) preceded the presence of each cover cue. For group T12C36, which was exposed to a cover cue duration longer than its time base, a reduction in ITI periods was used to maintain a session duration equal to that of the other groups exposed to a 12 s time base (T12C04, T12C12, T12C12D). Events for group T12C36 were therefore programmed with 92 ITI periods. The order of an event (e.g., target cues) within a session was randomly selected without replacement using a probability equal to its relative probability among all unselected events within the session. Four of the 20 target cues were followed by food [p(US|target) = .20]. All of the 46 cover cue presentations were followed by food [p(US|cover) = 1.0]. The experiment was conducted over 84 sessions comprising seven block cycles.

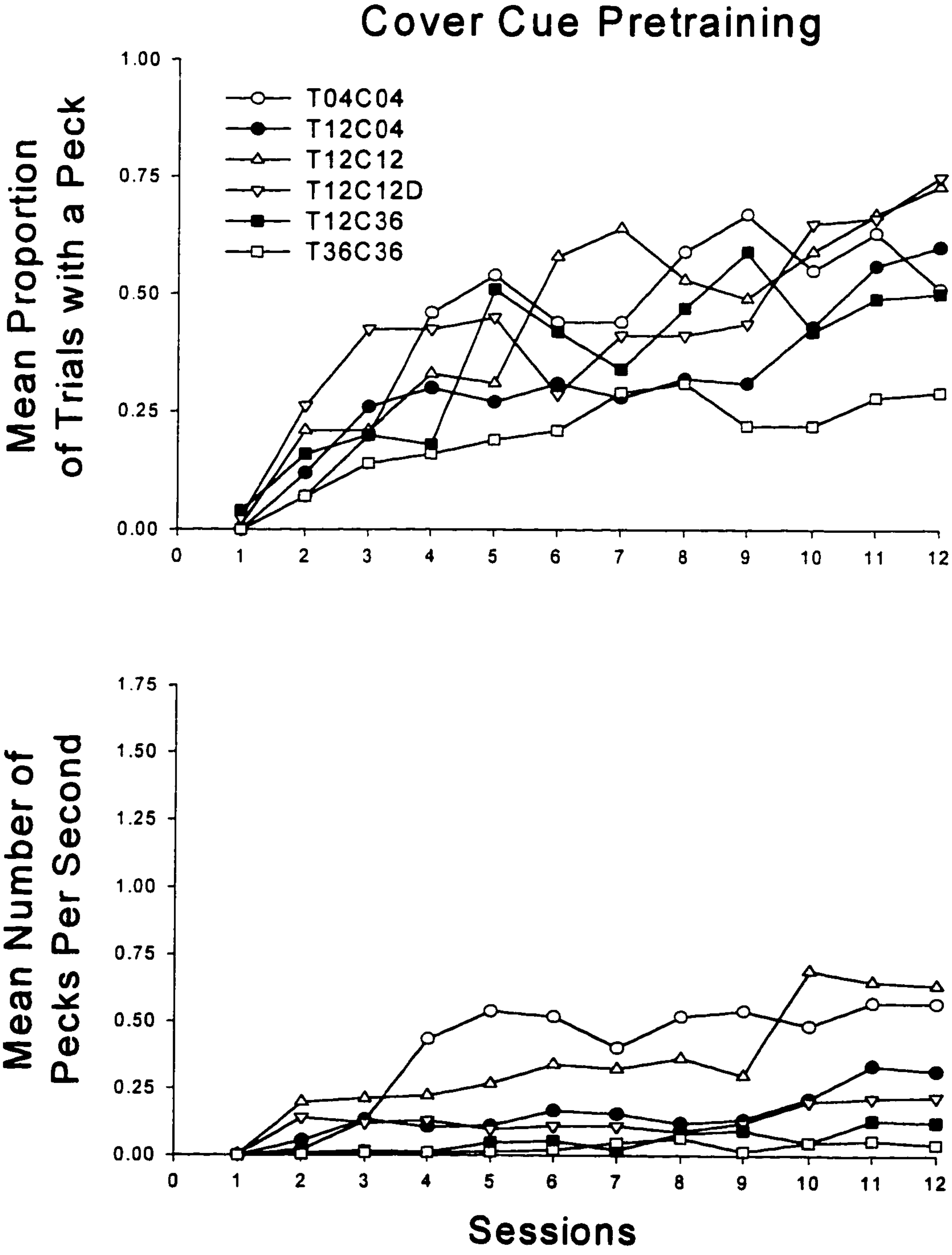
Results

Cover Cue Pretraining

Proportion of Trials With a Response. Figure 4 shows the results from cover cue pretraining. The top panel shows the mean proportion of trials with a peck across the 12-sessions of pretraining. The data indicate a consistent increase in response level across the 12 sessions. Moreover, all groups responded at comparable levels throughout this phase of training. A mixed-design analysis of variance (ANOVA) was applied to the data using sessions and groups as factors. The test revealed a significant main effect of sessions [$F(11, 48) = 3.80$, $p < .05$] but not of groups [$F(5, 24) = 0.50$, $p > .05$] and no sessions X group interaction [$F(55, 216) = 1.34$, $p > .05$]. Tukey post-hoc tests applied to the sessions factor revealed a difference between sessions 1-3 and sessions 5-12.

Rate. The bottom panel shows the mean number of pecks per second during cover cue pretraining. The data reveal a wide range of response levels across groups. A mixed design ANOVA was applied to the data using sessions and groups as factors. The analysis yielded results very similar to those from the proportion data. A significant main effect of sessions [$F(11, 48) = 2.99$, $p < .05$] was found. There was, however, no group [$F(5, 24) = 1.25$, $p > .05$] or sessions X group interaction [$F(55, 216) = 1.31$, $p > .05$]. Tukey post-hoc tests applied to the mean response level for all groups over sessions revealed an overall increase in response level from sessions 1-3 to sessions 10-12.

Figure 4. The response levels, proportion (top panel) or rate (bottom panel), of the six experimental groups during the 12 sessions of cover cue pretraining in Experiment 2.



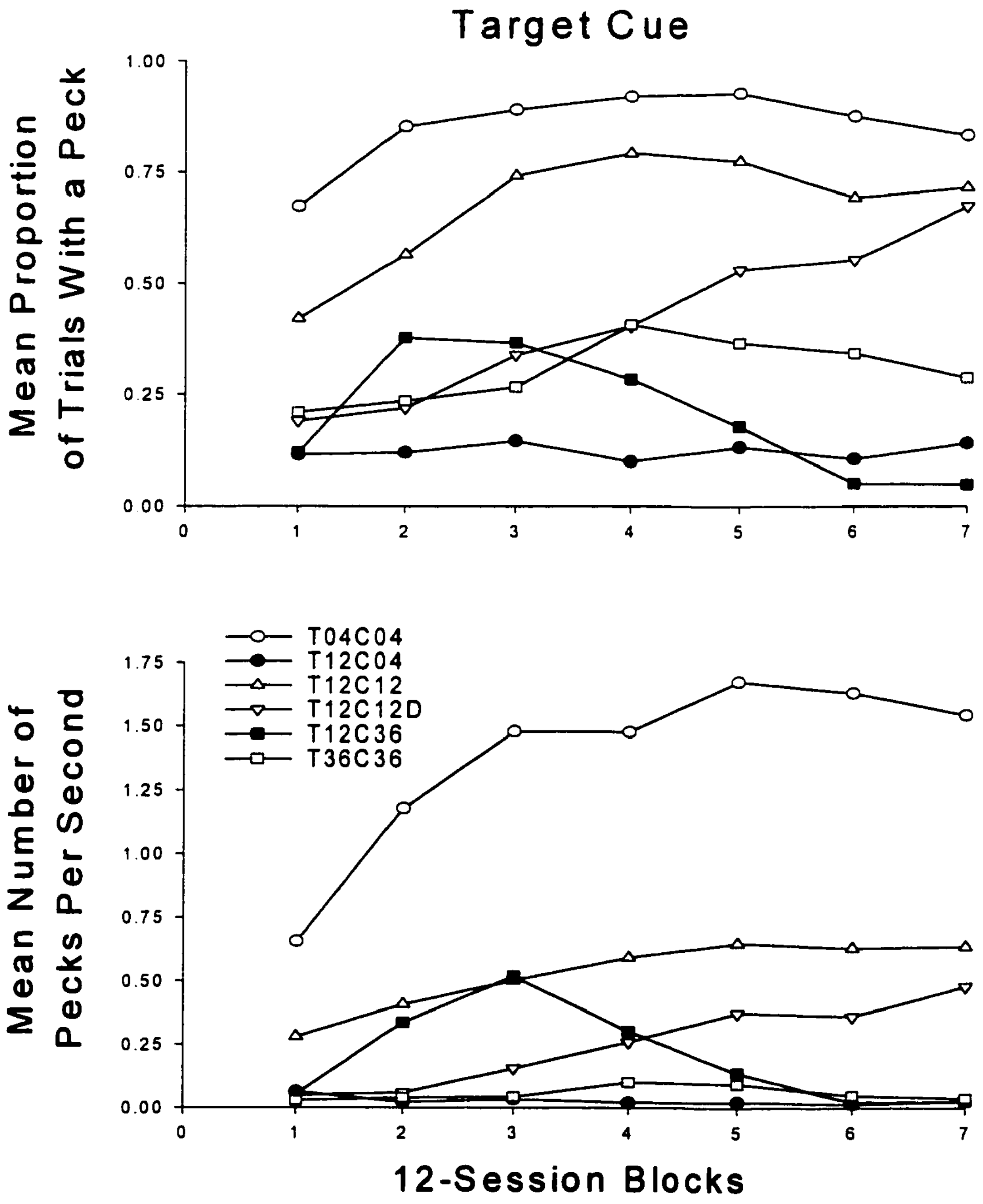
Target Responding in the Signaled Random Procedure

Proportion of Trials With a Response. The application of Pearson's Third Moment test for skewness revealed a significant skew in both target and cover responding [$Zs \geq 1.96$, $ps < .05$]. Therefore these data were submitted to nonparametric Kruskal-Wallis H tests to assess differences across groups. The analyses were conducted by applying a Kruskal-Wallis H test to the mean response measure across all seven blocks of acquisition (84 sessions). The H tests were then applied to each of the 15 pairwise comparisons among the 6 groups in each block. A description of all tests conducted on the target cue data is presented in Appendix A. Summaries of the findings from those tests are presented in Table 1.

Figure 5 shows responding during the target cue across the seven 12-session blocks of training. The top panel of this figure shows the mean proportion of trials with a peck. Groups exposed to equal stimulus durations are represented with open symbols. Groups exposed to unequal stimulus conditions are represented by filled symbols. Figure 5 indicates that groups with equal target cue and cover cue durations exhibited higher levels of responding than groups with unequal target cue and cover cue durations. This pattern emerged across session blocks. The data revealed a significant difference in the proportion of trials responded to across all groups as the mean of 84 sessions [$H(5) = 17.39$, $p < .05$].

Group effects were assessed separately in the first block (1) and the last block (7) in order to evaluate the change in performance across session blocks. A Kruskal-Wallis H test applied to all groups from block 1 did not reveal a significant effect [$H(5) = 10.87$,

Figure 5. The response level, proportion (top panel) or rate (bottom panel), for the target cue as a function of 12-session blocks in Experiment 2 for all six groups. Open symbols represent groups with equal target and cover cue durations. Closed symbols represent groups with unequal stimulus durations.



$p = .053$]. Tests between each group at block 1 revealed a significantly higher level of the proportion of trials responded to for group T04C04 over groups T12C04, T12C12 and T12C36.

Block 7 revealed a different pattern of results than block 1. A Kruskal-Wallis H test applied to all groups in block 7 revealed a significant effect [$H(5) = 17.37$, $p < .05$]. Tests between each group at block 7 revealed a significantly higher level of the proportion of trials responded to for group T04C04 over groups T12C04, T12C36 and T36C36. Group T12C12 also responded at a significantly higher than group T12C04, T12C36 and T36C36. Group T36C36 responded at a significantly higher level than group T12C36. The greater number of differences observed on block 7 than on block 1 indicates emerging differences among groups across the seven blocks of training. The development of differences between groups may also be seen by observing the significant differences in Table 1.

Rate. The bottom panel of Figure 5 shows the mean pecks per second for target cue responding across the 84 sessions of acquisition. The data reveal a significant difference in the responses per second elicited by the target cue across groups as measured by the mean of 84 sessions [$H(5) = 16.89$, $p < .05$]. The Kruskal-Wallis H test applied to all groups from block 1 revealed a significant effect [$H(5) = 12.42$, $p < .05$]. Tests between each group revealed a significantly higher level of response rate for group T04C04 over groups T12C04, T12C12D, T12C36 and T36C36.

Block 7 reveals a different pattern of effects than block 1. A Kruskal-Wallis H test applied to the data of block 7 revealed a significant group effect [$H(5) = 18.36$, $p < .05$]. Tests on pairs of groups revealed a significantly higher level of response rate for group T04C04 over groups T12C04, T12C12D, T12C36 and T36C36. Group T12C12 also responded at a significantly higher level than group T12C04, T12C36 and T36C36. Block 7 reveals more differences between groups than block 1. This result indicates emerging differences across the seven blocks of training. Overall, the pattern of results of Figure 5 reveals higher levels of responding by groups exposed to equal stimulus durations rather than unequal stimulus durations. The pattern of differences emerging between groups may be observed in Table 2.

Performance at the End of Training. Figure 6 shows the mean level of responding during the target cue for sessions 61-84 (blocks 6 and 7). Blocks 6 and 7 were combined due to the similarity of performance across groups on these blocks. That similarity can be observed in Tables 1 and 2. The top panel of this figure shows the mean proportion of trials with a peck. The bottom panel shows the mean number of pecks per second. This graph shows the differences between equal-stimulus groups (white bars) and unequal stimulus groups (black bars).

The mean proportion of trials with a response (top panel) shows that all equal-stimulus groups responded on a higher proportion of trials than their unequal-stimulus comparison groups. A Kruskal-Wallis H test applied to the mean of blocks 6 and 7 revealed a significant overall effect [$H(5) = 19.31$, $p < .05$]. Comparisons among individual groups showed that group T04C04 responded on more trials than group T12C04, T12C36 and T36C36 [$Hs(1) \geq 5.77$, $ps < .05$]. Group T12C04 responded on fewer trials than groups T12C12 and T12C12D [$Hs(1) \geq 3.93$, $ps < .05$]. Group T12C12

Figure 6. The response level, proportion (top panel) or rate (bottom panel), for the target cue in Experiment 2 for all six groups in sessions 61-84. Open bars represent groups with equal target and cover cue durations. Closed bars represent groups with unequal stimulus durations.

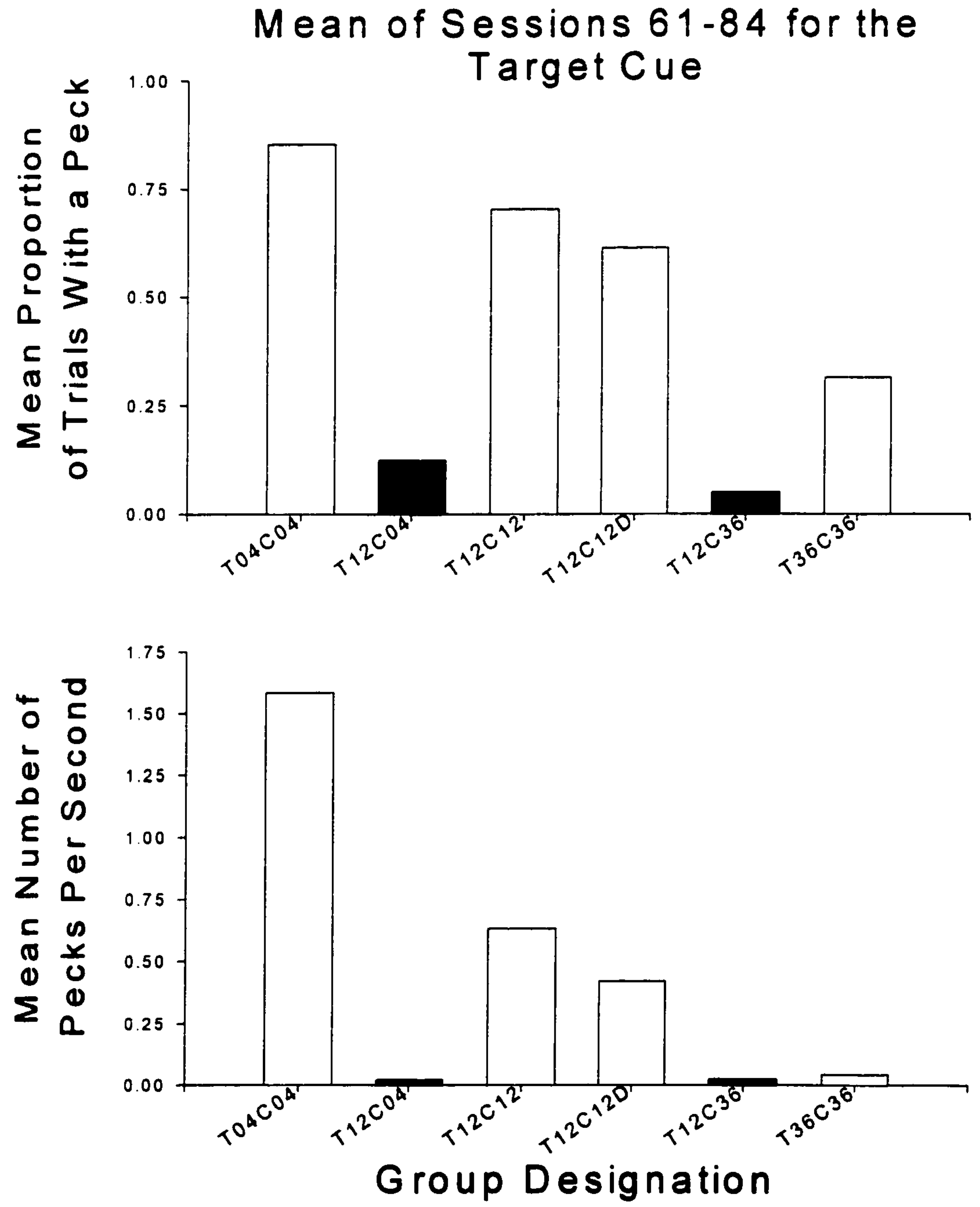


Table 1

Kruskal-Wallis H Test Results for the 15 Pairwise-Comparisons at Each of the Seven Blocks of Signaled-Random Acquisition in Experiment 2 with the Proportion of Target Trials with a Response as the Dependent Measure

	Session Block						
Groups Compared	1	2	3	4	5	6	7
T04C04/T12C04	>	>	>	>	>	>	>
T04C04/T12C12	.	.	.	.	.	.	.
T04C04/T12C12D	>	>	>	>	>	.	.
T04C04/T12C36	>	.	.	>	>	>	>
T04C04/T36C36	.	>	>	.	>	>	>
T12C04/T12C12	.	<	<	<	<	<	<
T12C04/T12C12D	.	.	.	.	.	.	.
T12C04/T12C36	.	.	.	.	.	.	.
T12C04/T36C36	.	.	.	.	.	.	.
T12C12/T12C12D	.	.	>	>	.	.	.
T12C12/T12C36	.	.	.	>	>	>	>
T12C12/T36C36	.	.	>	.	.	.	>

(table 1 continues)

	Session Block						
Groups Compared	1	2	3	4	5	6	7
T12C12D/T12C36	.	.	.	.	.	>	.
T12C12D/T36C36	.	.	.	.	.	.	.
T12C36/T36C36	.	.	.	.	.	<	<

All comparisons in this table were assessed through Kruskal-Wallis H tests. The greater-than (>) and less-than (<) signs in the table reflect a statistically significant difference between the two groups named in the left column of the table. The > and < signs should be read as though they were placed in between the two group names to indicate the order of the group means. A period "." indicates no statistically significant difference was found.

Table 2

Kruskal-Wallis H Test Results for the 15 Pairwise-Comparisons at Each of the 7 Blocks of Signaled-Random Acquisition in Experiment 2 With the Responses Per Second to the Target Cue as the Dependent Measure

	Session Block						
Groups Compared	1	2	3	4	5	6	7
T04C04/T12C04	>	>	>	>	>	>	>
T04C04/T12C12	.	.	>	.	>	>	.
T04C04/T12C12D	>	>	>	>	>	>	>
T04C04/T12C36	>	.	.	>	>	>	>
T04C04/T36C36	>	>	>	>	>	>	>
T12C04/T12C12	.	<	<	<	<	<	<
T12C04/T12C12D	.	.	.	.	.	<	.
T12C04/T12C36	.	.	.	.	.	.	.
T12C04/T36C36	.	.	.	.	.	.	.
T12C12/T12C12D	.	.	.	.	.	.	.
T12C12/T12C36	.	.	.	.	.	>	>
T12C12/T36C36	.	>	>	.	>	>	>

(table 2 continues)

Groups Compared	Session Block 1	2	3	4	5	6	7
T12C12D/T12C36	.	.	.	.	.	.	.
T12C12D/T36C36	.	.	.	.	.	.	.
T12C36/T36C36	.	.	.	.	.	.	.

All comparisons in this table were assessed through Kruskal-Wallis H tests. The greater-than (>) and less-than (<) signs in the table reflect a statistically significant difference between the two groups named in the left column of the table. The > and < signs should be read as though they were placed in between the two group names to indicate the order of the group means. A period "." indicates no statistically significant difference was found.

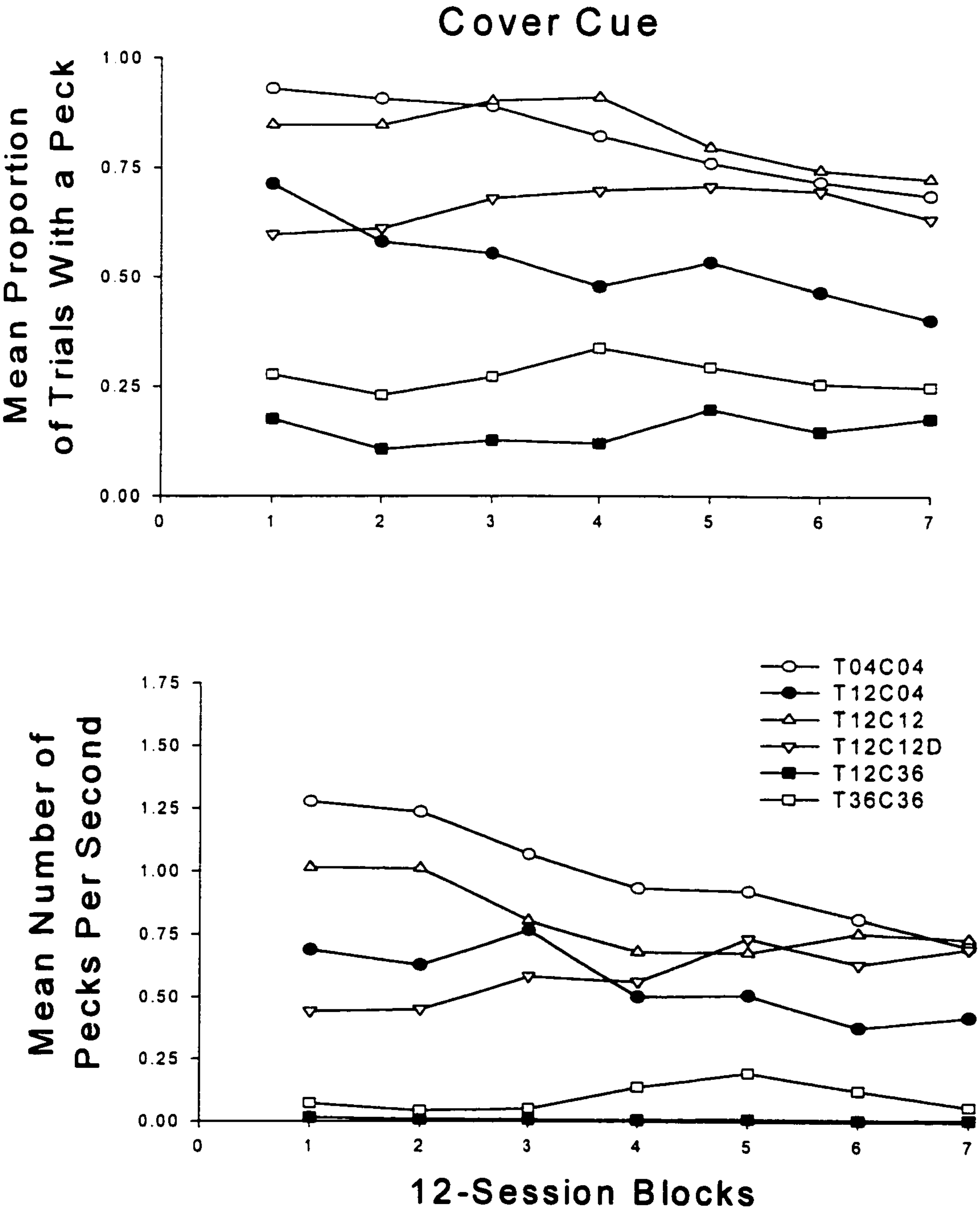
responded on a higher proportion of trials than groups T12C36 and T36C36 [$\underline{Hs}(1) \geq 3.93$, $\underline{ps} < .05$]. Group T12C12D responded on more trials than group T12C36 [$\underline{H}(1) = 5.77$, $\underline{p} < .05$] and group T12C36 responded on fewer trials than group T36C36 [$\underline{H}(1) = 4.81$, $\underline{p} < .05$].

Kruskal-Wallis H tests applied to the mean responses per second (bottom panel) show a significant effect when comparing the differences among all six groups [$\underline{H}(5) = 19.68$, $\underline{p} < .05$]. Tests applied to individual groups reveals a higher rate of responding for group T04C04 over all other groups except T12C12 [$\underline{Hs}(1) = 6.81$, $\underline{ps} < .05$]. Group T12C04 responded at a significantly lower rate than groups T12C12 and T12C12D [$\underline{Hs}(1) \geq 3.93$, $\underline{p} < .05$]. Group T12C12 responded at a higher rate than groups T12C36 and T36C36 [$\underline{Hs}(1) = 4.81$, $\underline{ps} < .05$]. Group T12C12D responded at a higher rate than group T12C36 [$\underline{H}(1) = 3.93$, $\underline{p} < .05$]. No difference was found between groups T12C36 and T36C36.

Cover Cue Responding in the Signaled Random Procedure

Proportion of Trials With a Response. Figure 7 shows responding during the cover cue across the seven 12-session blocks of training. The top panel of this figure shows the mean proportion of trials with a peck. Groups exposed to equal stimulus durations are represented with open symbols. Groups exposed to unequal stimulus conditions are represented by filled symbols. The data do not reveal differences in the proportion of cover trials responded to across all groups as measured by the mean of 84 sessions [$\underline{H}(5) = 10.86$, $\underline{p} = .054$]. Substantial between group differences early in this phase appeared to diminish with continued training. This change in pattern of responding was evaluated with separate analyses in blocks 1 and 7.

Figure 7. The response level, proportion (top panel) or rate (bottom panel), for the cover cue in Experiment 2 for all six groups. Open symbols represent groups with equal target and cover cue durations. Closed symbols represent groups with unequal stimulus durations.



A Kruskal-Wallis H test applied to all groups in block 1 revealed a significant effect for the proportion of trials responded to between groups [$H(5) = 12.46$, $p < .05$]. Tests on pairs of groups revealed a significantly higher level of the proportion of trials responded to for group T04C04 over groups T12C04 and T12C36. Group T12C04 also responded at a significantly higher level than group T12C36. Additionally, the level for group T12C12 exceeded that for groups T12C36 and T36C36. These results are in contrast to those of block 7.

A Kruskal-Wallis H test applied to all groups from block 7 did not reveal a significant effect [$H(5) = 8.26$, $p > .05$]. Tests between each group indicated a significantly higher level of the proportion of trials responded to for group T04C04 over group T12C36. Group T12C12 also responded significantly higher than group T12C36. The overall pattern from cover cue responding indicates that more differences between groups were present during block 1 than during block 7. These results are opposite those of target cue responding in which group differences emerged over sessions.

Rate. The bottom panel of Figure 7 shows the mean number of pecks per second for cover cue responding across the seven 12-session blocks of training. The data reveal a significant effect across all groups as the mean of 84 sessions [$H(5) = 14.66$, $p < .05$]. An assessment for emerging differences between groups across the seven 12-session blocks was evaluated with separate analyses in blocks 1 and 7.

A Kruskal-Wallis H test applied to all groups from block 1 revealed a significant effect for the responses per second measure [$H(5) = 17.86$, $p < .05$]. Tests on pairs of groups revealed a significantly higher level of response rate for group T04C04 over

Table 3

Kruskal-Wallis H Test Results for the 15 Pairwise-Comparisons at Each of the Seven Blocks of Signaled-Random Acquisition in Experiment 2 with the Proportion of Cover Trials with a Response as the Dependent Measure

	Session Block						
Groups Compared	1	2	3	4	5	6	7
T04C04/T12C04	>	>	.	>	.	.	.
T04C04/T12C12	.	.	.	.	.	.	.
T04C04/T12C12D	.	.	.	.	.	.	.
T04C04/T12C36	>	>	>	>	>	>	>
T04C04/T36C36	.	.	.	.	.	.	.
T12C04/T12C12	.	.	.	<	.	.	.
T12C04/T12C12D	.	.	.	.	.	.	.
T12C04/T12C36	>	.	.	.	.	.	.
T12C04/T36C36	.	.	.	.	.	.	.
T12C12/T12C12D	.	.	.	.	.	.	.
T12C12/T12C36	>	>	>	>	>	>	>
T12C12/T36C36	>	>	.	.	.	>	.

(table 3 continues)

	Session Block						
Groups Compared	1	2	3	4	5	6	7
T12C12D/T12C36	.	.	.	.	.	.	.
T12C12D/T36C36	.	.	.	.	.	.	.
T12C36/T36C36	.	.	.	.	.	.	.

All comparisons in this table were assessed through Kruskal-Wallis H tests. The greater-than (>) and less-than (<) signs in the table reflect a statistically significant difference between the two groups named in the left column of the table. The > and < signs should be read as though they were placed in between the two group names to indicate the order of the group means. A period "." indicates no statistically significant difference was found.

Table 4

Kruskal-Wallis H Test Results for the 15 Pairwise-Comparisons at Each of the Seven Blocks of Signaled-Random Acquisition in Experiment 2 With the Responses Per Second to the Cover Cue as the Dependent Measure

	Session Block						
Groups Compared	1	2	3	4	5	6	7
T04C04/T12C04	.	.	.	.	.	.	.
T04C04/T12C12	.	.	.	.	.	.	.
T04C04/T12C12D	.	.	.	.	.	.	.
T04C04/T12C36	>	>	>	>	>	>	>
T04C04/T36C36	>	>	>	>	>	>	>
T12C04/T12C12	.	.	.	.	.	.	.
T12C04/T12C12D	.	.	.	.	.	.	.
T12C04/T12C36	>	>	>	.	>	>	>
T12C04/T36C36	>	.	.	.	.	.	.
T12C12/T12C12D	.	.	.	.	.	.	.
T12C12/T12C36	>	>	>	>	>	>	>
T12C12/T36C36	>	>	>	>	.	>	>

(table 4 continues)

Groups Compared	Session Block 1	2	3	4	5	6	7
T12C12D/T12C36	.	.	.	.	.	.	.
T12C12D/T36C36	.	.	.	.	.	.	.
T12C36/T36C36	.	.	.	.	.	.	.

All comparisons in this table were assessed through Kruskal-Wallis H tests. The greater-than (>) and less-than (<) signs in the table reflect a statistically significant difference between the two groups named in the left column of the table. The > and < signs should be read as though they were placed in between the two group names to indicate the order of the group means. A period "." indicates no statistically significant difference was found.

groups T12C36 and T36C36. Groups T12C04 and T12C12 responded with a significantly higher response rate than groups T12C36 and T36C36. The pattern of these results is similar to those of block 7.

A Kruskal-Wallis H test applied to all groups from block 7 revealed a significant effect in the responses per second measure [$H(5) = 14.02$, $p < .05$]. Tests on pairs of groups revealed a significantly higher level of response rate for group T04C04 over groups T12C36 and T36C36. Group T12C04 also responded at a significantly higher response rate than group T12C36, and group T12C12 responded with a significantly higher response rate than groups T12C36 and T36C36.

Block 1 Cover Cue Responding. Nonparametric Wilcoxon Signed Ranks tests were applied to the change from the mean of the 12 session cover cue pretraining phase to the mean of the first 12 session block of the signaled random procedure. The test revealed an increase in the proportion of trials with a response for groups T04C04, T12C04 and T12C12 [$ts(4) \geq 4.24$, $ps < .05$]. When the Wilcoxon tests were applied to the responses per second measure for the same period, an increase in the response rate was observed for groups T04C04, T12C04 and T12C12 [$ts(4) \geq 4.24$, $ps < .05$]. Compare Figures 4 and 7 to view this change. Overall, Figure 7 reveals an increasing unification of all group means across the 84 sessions of the signaled random procedure.

Performance at the End of Training. Figure 8 shows responding during the cover cue for sessions 61-84 (blocks 6 and 7) at the end of the signaled random acquisition phase. Blocks 6 and 7 were combined due to the similarity of performance across groups that can be observed in Tables 3 and 4. The top panel of this figure shows the mean proportion of trials with a peck. The bottom panel shows the mean pecks per second.

This graph shows the differences between the equal-stimulus groups (white bars) and unequal stimulus groups (black bars).

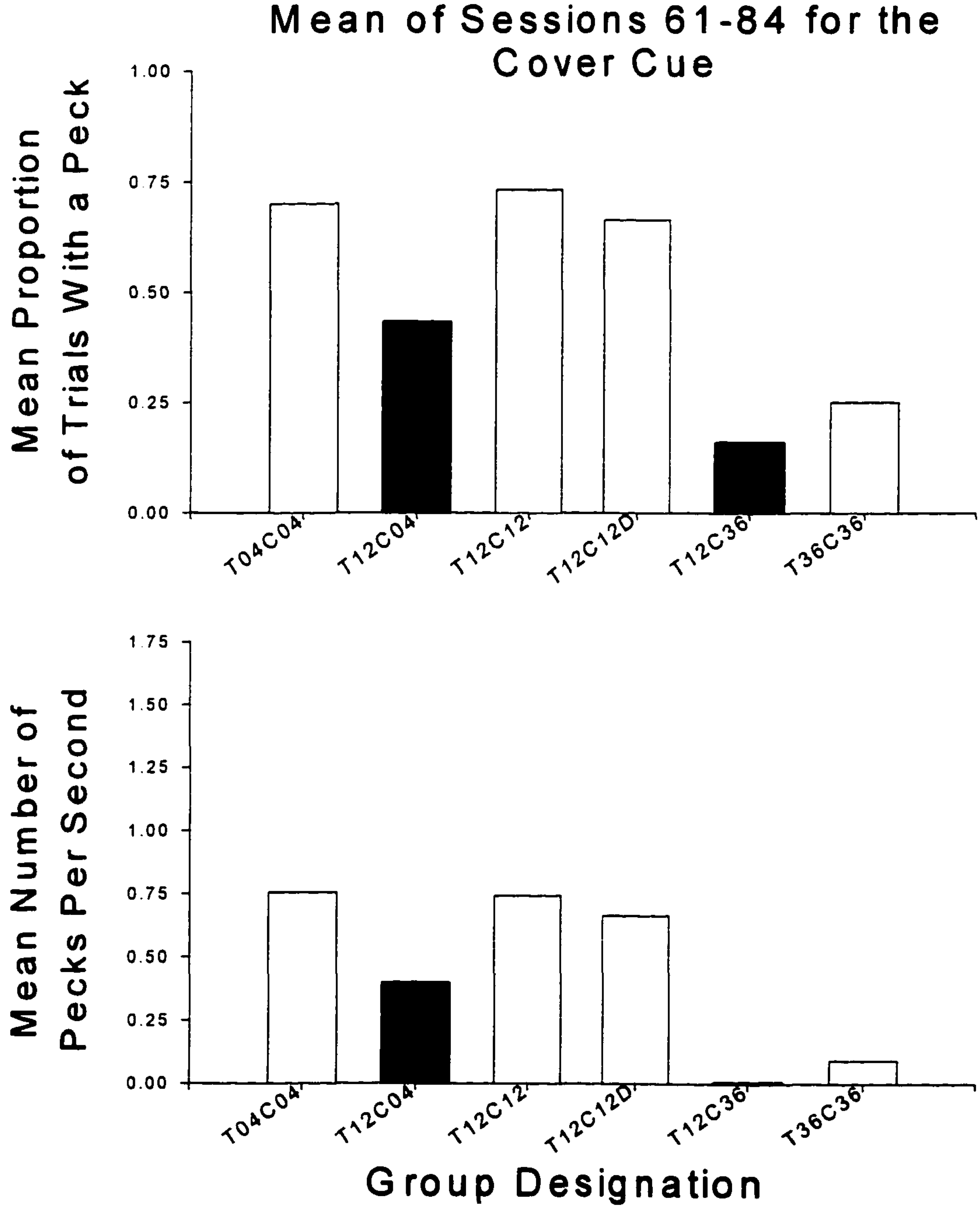
The mean proportion of trials with a response (top panel) does not reveal a significant difference when comparing all 6 groups together [$H(5) = 9.18$, $p > .05$]. Individual Kruskal-Wallis H tests reveal three significant differences across groups. Tests revealed that group T04C04 responded on a higher proportion of trials than group T12C36 [$H(1) = 4.81$, $p < .05$]. Group T12C12 responded on a higher proportion of trials than groups T12C36 and T36C36 [$Hs(1) \geq 3.93$, $ps < .05$]. These three differences existed in block 1 with two additional effects; group T04C04 responded on a higher proportion of trials than group T12C04 and group T12C04 responded on a higher proportion of trials than group T12C36.

The mean number of responses per second (bottom panel) reveals a significant difference among all six groups when compared together [$H(5) = 13.77$, $p < .05$]. Individual Kruskal-Wallis H tests reveal five significant differences across groups. Tests revealed that group T04C04 responded on more trials than groups T12C36 and T36C36 [$Hs(1) \geq 4.84$, $ps < .05$]. Group T12C04 responded on more trials than group T12C36 [$H(1) = 4.81$, $p < .05$] and group T12C12 responded on more trials than groups T12C36 and T36C36 [$Hs(1) \geq 3.96$, $ps < .05$]. All these differences existed in block 1. Block 1 additionally revealed a higher response rate for group T12C04 over group T36C36.

Target and Cover Response Correlation

A Pearson product-moment correlation coefficient was calculated between target and cover cue responding for all six groups. The test employed the mean level of target and cover cue responding for each group across the 84 sessions of the signaled random

Figure 8. The response level, proportion (top panel) or rate (bottom panel), for the cover cue in Experiment 2 for all six groups in sessions 61-84. Open bars represent groups with equal target and cover cue durations. Closed bars represent groups with unequal stimulus durations.



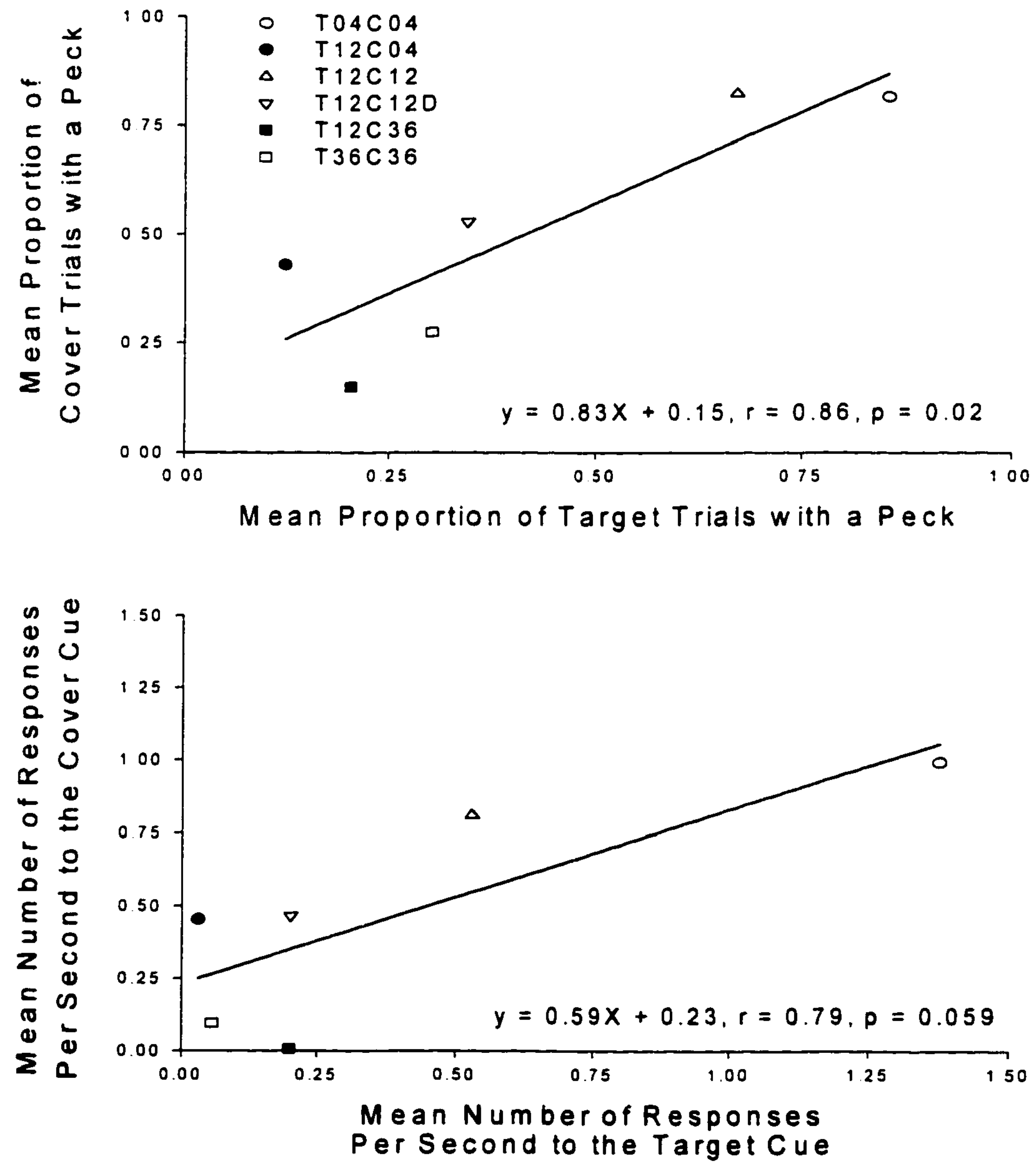
procedure. A significant correlation was found between the levels of responding to the target and cover cues as measured by the proportion of trials with a response [$r(4) = .86$, $p < .05$]. In contrast, the responses per second dependent measure did not reveal significance [$r(4) = .79$, $p = .059$]. These data may be seen in Figure 9. The top panel shows the data represented as the mean proportion of trials with a response. The bottom panel shows the data represented as rate. Both panels of this figure show the linear regression equation describing the relationship between responding to the target and cover cues.

Discussion

The present experiment showed that higher target cue response levels appeared under conditions of equal stimulus durations in comparison to unequal stimulus durations. Experiment 2 thus replicated Cooper et al. (1990), Williams (1994), and the results of Experiment 1 of the present study. Groups T04C04, T12C12, T12C12D and T36C36 all responded on a higher proportion of trials than did groups T12C04 and T12C36. Overall, these data indicate that outcomes from the signaled random procedure may be influenced by the relative duration of target and cover cues.

The current experiment (a) extended the signaled random procedure to include equal stimulus conditions of 4 and 36 s durations, (b) extended and replicated the effects of stimulus equality on the target cue to durations of 4, 12 and 36 s, and (c) lengthened the duration of the acquisition phase from 70 sessions in Experiment 1 to 84 sessions in the current experiment. The extension of the acquisition phase to 84 sessions provided further evidence that responding controlled by the target cue appears at substantial levels only when groups are exposed to equal stimulus durations. It also suggests that if

Figure 9. A correlation between the 84-session means of cover cue responding to target cue responding as represented by the proportion of trials with a response (top panel) and responses per second (bottom panel) dependent measures. Each panel shows the linear regression line and the equation that represents it. Open symbols represent groups with equal target and cover cue durations. Closed symbols represent groups with unequal stimulus durations.



substantial levels of responding to the target cue are ever to be measured under these conditions in groups T12C04 and T12C36, at least 84 sessions of training will be required. Experiments 1 and 2 showed that high levels of responding developed only after substantial amounts of training. This effect may account for the apparent absence of a duration similarity effect in Jenkins, Barnes and Barrera (1981, Experiment 11) that employed only 10 sessions of training.

Results from Experiment 2 are in line with the common temporal stimulus element hypothesis. This hypothesis suggests that responding to the target cue is modulated by a common temporal stimulus that is shared by the visual components of the target and cover CSs in the equal stimulus groups. It suggests that responding to the target and cover cues should appear at higher levels in equal stimulus groups than in unequal stimulus groups. If a common stimulus element increases responding to the target cue then this element should have the same effect on the cover cue. Therefore, groups exposed to equal stimulus durations should reveal a positive correlation between levels of target and cover cue responding. A positive correlation between response levels on target and cover cues over the 84 sessions of the training phase was obtained for proportion of trials with a response. The data from Experiment 1 did not reveal evidence of this correlational relationship for either the proportion of trials or the rate measure. The analysis of Experiment 2, however, was based upon response levels for six groups of birds, as opposed to two groups in Experiment 1: for which assessing a correlation would be more difficult.

Responding controlled by the cover cue was compared between the cover cue pretraining phase and the first block of the signaled random procedure. Results revealed that groups T04C04, T12C04 and T12C12 all showed higher levels of responding to the cover cue after the beginning of the signaled random procedure. This effect, however, did not appear in all groups. Groups T12C12D, T12C36 and T36C36 did not show a significant increase in responding.

Responding to the target cue was examined within the first block of the signaled random procedure. This test assessed whether responding in block 1 could be attributed to the transfer of control by the previously trained cover cue. The data did not indicate substantial amounts of transfer of responding to the target cue during the first 12-session block (see Figure 5 and Table 1). Responding to the target cue clearly emerged from low levels within block 1 and over the 84 sessions of training for groups exposed to equal target and cover cue durations.

Throughout the cover-cue-pretraining phase, equal stimulus groups (T04C04, T12C12, T12C12D and T36C36) exhibited equivalent levels of performance during acquisition as assessed by the proportion of trials measure. The similarity of performance across groups is predicted by the relative temporal analyses of Gibbon et al. (1977). In two experiments, Gibbon et al. (1977) showed that pigeons exhibited an equal speed of response acquisition when they were exposed to equal relative-trial-structures (mean ITI/mean trial duration = I/T), as were used in Experiment 2.

In contrast, level of performance diverged across the equal stimulus groups during the signaled random procedure. An analysis of the mean proportion of trials with a response across sessions 61-84 revealed that groups T04C04 and T12C12 responded at higher levels than group T36C36. An analysis of the proportion of cover trials responded to revealed that group T12C12 responded on more trials than group T36C36. If responding to the target and cover cues were controlled only by the relative temporal relations among stimuli in the session (e.g., trial durations, ITI) then all target and cover response levels should be equivalent for all equal stimulus groups. That is, groups with equal relative trial structures. This prediction, however, is based on analyses of speed of acquisition. The differences in performance levels between groups in the present study were observed after an initial response-acquisition-phase was complete. These results, then, are theoretically consistent with Gibbon et al.'s (1977) analyses, if level of maintained responding is not predicted by the I/T ratio. Data that support this possibility come from a study by Gibbon, Farrell, Locurto, Duncan & Terrace (1980). In that experiment, Gibbon et al. (1980) reported that equal I/T durations do not accurately predict the level of post-acquisition responding. The present data may reflect differences in response level based upon factors that influence maintained levels of performance.

An overview of Tables 1 and 2, and Figure 5 shows the development of differences between groups in the proportion and rate measures for the target cue. As session-blocks proceed, there is a wider dispersion of group means. Groups exposed to equal stimulus durations (T04C04, T12C12, T12C12D and T36C36) show increases in responding to the target cue. In contrast, groups exposed to unequal stimulus durations (T12C04, T12C36) continue to respond at relatively low levels in comparison to their equal stimulus counterparts. An overview of Tables 3 and 4, and Figure 7 shows that group differences in responding to the cover cue are more prevalent in the earlier blocks and decrease as training progresses—an effect opposite that of the target cue. While a common-elements mechanism anticipates a positive correlation between response levels to target and cover cues during training, it does not readily accommodate the divergence in response patterns for these cues as training progressed. An implication of that divergence is that factors in addition to common stimulus elements may have influenced performance changes across blocks.

General Discussion

The findings of two experiments demonstrated that (a) birds exposed to equal target and cover cue durations showed significantly more target cue responding than birds exposed to unequal target and cover cue durations, (b) the experiments extended the acquisition procedure from 40 sessions in Williams (1994) and Cooper et al. (1990) to 84 sessions in Experiment 2, (c) the experiments extended the application of the signaled random procedure to equal stimulus durations of 4 and 36 s, (d) Experiment 1 revealed a reversal of conditions does not reverse the level of target cue responding, (e) both experiments replicated the equal stimulus condition of Cooper et al. (1990) and the equal and unequal stimulus conditions of Williams (1994).

Taken together, the results from the present experiments are consistent with previous findings in the literature. Moreover, they are consistent with the present analysis of target cue responding in terms of a stimulus equality effect. The results from signaled random experiments have primarily been explained though the operations of two families of theories, the comparator and competition families. Models from each family accurately predict the results of a wide range of experimental operations in the conditioning literature. Currently, however, no specific model from either family has been able to capture the majority of behavioral outcomes of the signaled random procedure. The following section describes a few of the models frequently cited in the literature. These models were selected owing to their predictive competence under a wide range of experimental operations. The potential of these models to accurately predict the outcomes of the stimulus equality effect in the signaled random procedure is then examined.

Competition Models

Rescorla and Wagner. The Rescorla-Wagner theory (1972) may currently be considered the prototypical competition theory. This model assumes that learning, represented as the associative value accruing to the CS, V, is restricted to an absolute range and that learning rate diminishes with increasing V. The Rescorla-Wagner model is expressed as:

$$\Delta V = \alpha\beta(\lambda - V_{tot}) \tag{1}$$

The equation states that the increment in the total value accruing to a stimulus on any trial, ΔV, is a function of the learning rate parameters of the CS, α, and US, β. These values are multiplied by the difference between the total amount of value which can accrue to the CS, λ, and the amount of value already acquired by it, V_{tot}. The value of V_{tot} is equal to the sum of the associative values of all stimuli (e.g., stimuli A, B...n) present during a trial and can be represented by

$$V_{tot} = V_A + V_B + \ldots + V_n \tag{2}$$

The Rescorla-Wagner model has had substantial success in addressing many different areas of learning and conditioning. These areas include, but are not limited to, the acquisition and extinction of responding, generalization and discrimination, blocking, overshadowing and CS-US contingencies. Successes and failures of the model have been reviewed by Miller, Barnet and Grahame (1995).

The Rescorla-Wagner model predicts response acquisition by estimating the value accruing to the CS and contextual cues each time they are associated with the US. Value is decremented each time these stimuli are presented in the absence of the US. The CS and context may both accrue value when the CS is forwardly paired with the US in a standard delay-conditioning procedure. During the ITI, when the CS and US are absent, however, the subject is exposed to the context without the US. This results in a decrement in value to the context. In contrast, no reduction in value to the CS occurs because it is not present. When, again, the CS and US are both presented, the CS and context both accrue value. This cycle of incrementing CS and contextual value followed by decrementing contextual value alone, proceeds throughout the session. Eventually, the CS will gain all the associative value supported by the US due to the CS-US contingency. The context, therefore, will have none. In the random control procedure, the context is frequently associated with unpaired USs. Accordingly, the context develops a high level of value and the value of the CS approaches zero. Consequently, responding to the CS will not develop due to its inability to effectively compete with the strong context.

In the equal stimulus condition of the signaled random procedure, the cover CS is forwardly paired with the otherwise unpaired USs of the random procedure. The Rescorla-Wagner model predicts that cover CS rapidly gains associative value because there is a strong contingent relationship between the cover CS and US. Consequently, the context is unable to gain associative value and remains relatively neutral. Competition between the partially reinforced target CS and the weak context allows the target CS to gain value slowly.

Thus, when the Rescorla-Wagner model is applied to the equal stimulus condition of the signaled random procedure, it accurately predicts that target cue responding will develop. In contrast, when the model is applied to conditions in which the cover cue duration is shorter or longer than the target cue duration, it fails to accurately predict that less responding will be controlled by the target cue. Rather, the model predicts that the level of target cue responding will be inversely related to cover cue duration because longer cover cues acquire less associative value than shorter cover cues. This failure of the model to accurately predict the outcomes of the stimulus-equality effect from the signaled random procedure can be alleviated by applying a common-elements generalization analysis. When the model is applied using temporal cues as shared or nonshared components of the target and cover cues, more accurate predictions about responding to the target cue can be made for the equal and unequal stimulus conditions. Equal stimulus groups contain a common temporal element between the target and cover cues. Unequal stimulus groups do not contain a common temporal element. This common-elements approach to generalization has been pursued by Rescorla (1976).

The application of the Rescorla-Wagner (1972) model to the study of generalization suggests that cues control generalized responding to the extent that they contain common elements. Rescorla argued that when two cues, a high-frequency tone and a low-frequency tone for instance, are both reinforced, a common element between them is also reinforced. The common element was assumed to exist because both cues are on the same stimulus dimension. The two tones constitute an AX+/BX+ paradigm. The X element in these pairs refers to the common auditory elements shared by both A and B. The conceptualization of generalization through common elements suggests that cues that generalize to one another may also show additive or competitive effects. One outcome of these assumptions is that value accruing to a previously trained compound (e.g., AX) can be gained more rapidly by reinforcing an alternate compound, BX, than by further training on AX. If the AX+ compound is trained to asymptote, both the A and X components should each contain a portion of all the associative value attributable to λ. By reinforcing the BX compound after AX is at asymptote, increases in value to the AX compound should be seen due to the increase in value attributed to the shared X component. Moreover, this common-elements approach suggests that keeping minimal the amount of value accruing to the X component should result in greater increases in value to the AX compound when the BX compound is later reinforced. The value of X may be minimized by using a pretraining discrimination procedure. Subjects may first be exposed to an AX+/BX- discrimination procedure. During the training, most value will accrue to the A component, the X component will remain relatively neutral and the B component will become inhibitory. When the BX compound is later reinforced, the X component has a high capacity to accrue value and therefore the AX+ compound should increase in value substantially.

Rescorla (1976) tested this hypothesis using a conditioned suppression paradigm. In Experiment 1, all rats were trained to respond on a variable interval 120-s (VI 120-s) schedule of food delivery. Four groups were then created with seven rats each. A discrimination procedure was presented to all rats over a 7-day period, followed by a training phase in which cue A or B was reinforced. Finally, an extinction test with cue A was conducted. Groups were labeled in terms of their discrimination-phase cues and their subsequent training-phase cues: positive cues, negative cue/training cue. In each discrimination session all rats were exposed to two presentations of a 120-s high-frequency tone (1800 Hz; cue A) followed by footshock. Four exposures of a nonreinforced cue were intermixed among those trials. For two critical groups, A+, B-/A+ and A+, B-/B+, the negative cue was a low-frequency tone (250 Hz; cue B) interrupted at a rate of once per second. For groups A+, C-/A+ and A+, C-/B+ the negative cue was the houselight flashing at a rate of twice per second (cue C).

All rats were then exposed to forward conditioning of the high tone or the low tone for two sessions. Rats in groups A+, B-/A+ and A+, C-/A+ were exposed to four trials per session of the 120-s high tone followed by footshock. Rats in group A+, B-/B+ and A+, C-/B+ were exposed to four trials of the 120-s low tone followed by footshock.

All rats were then exposed to the extinction test for four days in which the nonreinforced high-frequency tone was presented during the VI 120-s schedule of food delivery. The data were assessed as suppression ratios of the form CS/(CS + BL), where the rate of food maintained bar pressing during the high tone is represented by CS and the rate of bar pressing in the 120-s period immediately preceding the tone is represented by BL.

Results showed that the high tone controlled a strong degree of suppression for all rats during discrimination training. In contrast, the low tone and the light did not control substantial suppression in any group. The subsequent conditioning phase revealed almost complete suppression to the high and low frequency tones when they were both followed by footshock. The effect of main interest was tested in the last phase that exposed all rats to extinction trials of the high tone during the VI 120-s schedule of food delivery. Results showed that those rats in group A+, B-/B+ exhibited the greatest levels of suppression over the four sessions of extinction testing. All other groups revealed equivalent levels of suppression that were lower than that of group A+, B-/B+.

This experiment found support for a common-elements hypothesis. The strongest suppression to cue A was present in a group exposed to extra reinforcement of a cue containing an associatively neutral common-element, B. Less suppression was measured in groups exposed to extra reinforcement of the previously reinforced cue, A, or groups that were exposed to discrimination training of the light cue, C, that did not contain a common element with the high tone. The strongest suppression was present observed in A+, B-/B+ was attributed to conditioning of a cue (low frequency tone, B+) containing a common auditory element with the high tone. That training permitted the common element to accrue additional value. In contrast, no additional value accrued to the auditory element of the high tone in group A+, B-/A+ beyond that acquired during discrimination training. For groups exposed to initial discrimination training with a light (A+, C-/A+ and A+, C-/B+), effects of A+ and B+ training were similar, but weaker as predicted.

Rescorla's (1976) application of the Rescorla-Wagner model of a common-elements approach to generalization can be applied to the signaled random procedure. Under the equal stimulus conditions, the presence of the target (A), cover (B), and temporal (X) cues serve as an AX+/BX+ conditioning paradigm. The nontemporal stimulus components of the target and cover cues serve as components A and B, respectively. The common temporal duration serves as the X element. This common element is reinforced more frequently than components A or B because both AX and BX are followed by USs. The common temporal element, X, should facilitate learning about

A, the target cue, and therefore result in more responding to it. The unequal stimulus conditions are comprised of an AX+/BY+ condition. Because no common temporal element exists, cues A and B should contain the same level of associative value as their corresponding temporal components, X and Y respectively. Computer simulations of this common-elements approach accurately predict a number of outcomes from Experiments 1 and 2.

Computer simulations of the signaled random procedure were conducted by using the parameter-values from the Rescorla-Wagner (1972) model. The learning rate parameter-value, α, of temporal and nontemporal CS components was equal to .50 and the α value for the background was equal to .10. The learning rate parameter-value for the US, β, was equal to .10 and the β value during nonreinforced trials was equal to .05. Estimations of V from this model were calculated with a λ value equal to 100. Simulations calculated changes in value by using a time base period equal to the smallest CS value within an experimental condition. This metric was used because equal and unequal stimulus conditions inherently contain stimuli of different durations.

The simulation of Experiment 1 was conducted by using the same random selection-without-replacement trial structure that the birds were exposed to in that experiment. For instance, in Experiment 1, each session presented trial events to the birds across three blocks. Each block contained 17 ITI events, 17 cover trials, three nonreinforced target trials and three reinforced target trials, for a total of 40 events per block. The computer simulations of Experiment 1 followed this same procedure. Estimates of V for each of the CSs in phase 2 started were equal to the values of V for each cue at the end of phase 1. The runs of each phase were conducted across 70 simulated sessions.

Simulations of Experiment 2 were also conducted by using the same random selection-without-replacement process that the birds were exposed to in that experiment. These events were 184 ITI events, 46 cover trials, 16 nonreinforced target trials and four reinforced target trials for a total of 250 session events. Simulations of Experiments 1 and 2 were conducted three times each because the random trial structure of the runs allowed slightly different results to occur from the same parameter values. A mean estimate of V_{tot} was then obtained.

Estimations of V for the nontemporal and temporal elements were made within each simulation. Results showed that the total associative value was equivalent for the equal and unequal stimulus conditions when the nontemporal and temporal target-cue elements were summed together. This outcome is the result of exposing the target cue stimulus-complex to the same overall contingency to reinforcement regardless of whether cues are shared or unshared. The temporal element of the target cue, however, is observed to accurately predict the results of the stimulus equality effect.

Reinforced cover cue trials within the equal stimulus condition are the most frequently occurring trial type within the session. While the nontemporal and temporal elements of the cover cue complex accrue value on every trial, the target cue complex is reinforced on a partial schedule. The values of the shared temporal and the nontemporal elements of the target cue increase to their asymptotic levels. Once these asymptotic levels are reached, the more frequently reinforced shared-temporal element effectively competes with the less frequently reinforced nontemporal element of the target cue. This process causes the nontemporal target cue element to lose value as the shared temporal cue gains value. After many trials, the nontemporal target cue component loses value to near neutral levels. In contrast, the shared temporal cue contains most of the excitatory value of the target cue complex.

Within the unequal stimulus conditions, the target cue will not gain in associative value as the cover cue is reinforced because there is no shared temporal element. Moreover, the associative value accruing to the target cue will be equally shared by its temporal and nontemporal elements. The asymptotic level, however, will be the same as in the equal stimulus condition because the p(US|target CS) is identical in the equal and unequal stimulus conditions.

This competitive common-elements approach predicts the differences in levels of responding to the target cue between the equal and unequal stimulus conditions of Experiments 1 and 2, Cooper et al. (1990) and Williams (1994). Moreover, the model predicts that more responding to the target CS will appear whenever a shared element exists between the target and cover cues. The increase in response level to the target cue in group T15C15 across phases 1 to 2 was also predicted by the Rescorla-Wagner model. In addition, this model predicted that target cue acquisition would be slower and less robust during the signaled random procedure than during a procedure containing the same p(US|target CS) but no cover CSs or unsignaled USs—standard autoshaping. This result has been verified by Williams (1994) in a comparison between groups CS-Only and Long Signal. Accurate predictions about the differences in levels of responding to the cover cue in phase 1 of Experiment 1 were also made.

The increase in responding to the cover cue in group T15C15 across phases 1 to 2 of Experiment 1 was also accurately predicted. In contrast, levels of responding to the cover cue were not accurately predicted in phase 2 of that experiment. The model accurately predicted that the level of responding to the cover cue for group T12C36 would be lower than all other groups in Experiment 2. It, however, inaccurately predicted that group T12C04 would show the highest levels of responding to the cover cue and that all equal-stimulus groups would show equivalent response levels intermediate to groups T12C04 and T12C36 (see Figure 7). Mean estimates of value for elements A, B and X are presented in Table 5.

Alternative accounts of generalization that may be applied to the signaled random procedure come from Blough (1975, 1983) and Pearce (1987). These accounts were developed from the same mathematical basis as the Rescorla-Wagner (1972) model. These models represent learning functions created from learning rate parameters of the CS and US that result in an asymptotic level of learning controlled by the strength of the US. Each model, however, was modified to better account for empirical findings that the Rescorla-Wagner model could not explain. Because their assumptions are modified from the Rescorla-Wagner model, they each make predictions about responding that the others do not. For instance, Blough developed a model that accounts for operant responding while Pearce continued Rescorla and Wagner's tradition of explaining Pavlovian conditioning.

Blough. A model that makes predictions similar to those of the Rescorla-Wagner (1972) model comes from Blough (1975, 1983). The mathematical basis of Blough's model is a modified version of the Rescorla-Wagner (1972) model. It, however, was

Table 5

Values of the Nontemporal Target Element, A, Nontemporal Cover Element, B, and Temporal Element, X, for Experiments 1 and 2 as Predicted by the Rescorla-Wagner (1972) Model.

Experiment 1

Phase 1

Group	A	B	X_A	X_B	X_C
T15C05	16.3	50.0	16.3	50.0	.
T15C15	4.6	25.8	.	.	30.4

Phase 2

Group	A	B	X_A	X_B	X_C
T15C05	18.7	42.4	.	.	11.1
T15C15	1.9	63.0	27.7	37.2	.

(table 5 continues)

Experiment 2

Cover Cue Pretraining

Group	A	B	X_A	X_B	X_C
T04C04	.	50.0	.	50.0	.
T12C04	.	50.0	.	50.0	.
T12C12	.	50.0	.	50.0	.
T12C12D	.	50.0	.	50.0	.
T12C36	.	50.0	.	50.0	.
T36C36	.	50.0	.	50.0	.

Signaled Random Procedure

Group	A	B	X_A	X_B	X_C
T04C04	-9.1	32.3	.	.	23.2
T12C04	6.9	50.0	6.9	50.0	.
T12C12	-9.1	32.3	.	.	23.2
T12C12D	-8.7	31.1	.	.	22.4
T12C36	6.6	12.7	6.6	12.7	.
T36C36	-9.1	32.3	.	.	23.2

(table 5 continues)

Column headings A, B refer to the nontemporal elements of the target and cover cues respectively. Column headings X_A, X_B refer to the estimated values of the temporal elements associated with cues A, B. Column heading X_C refers to the value associated with the common temporal element from an equal-stimulus condition. A "." in place of a data point means no value was estimated for that cue.

modified to accurately predict the outcomes of dimensional stimulus contrast experiments. The Rescorla-Wagner model fails to predict accurately the results of those experiments. Dimensional stimulus contrast is the term applied to the increase in responding to S+ stimuli approximating an S- stimulus from the same stimulus dimension in an operant discrimination experiment. If a pigeon is exposed to equal response-reinforcer contingencies in the presence of eleven stimuli equally spaced along a stimulus dimension, then equal rates of responding will be observed in the presence of all those stimuli. If the centermost stimulus, the sixth ordinal stimulus, is no longer reinforced, an increase in the rate of operant responding to minimally the fifth and seventh stimuli will be observed. This increase in responding is greatest to the stimuli most similar to the S- (ordinal stimuli five and seven) and the effect wanes as the stimuli become disparate from the S- (e.g., third, fourth and eighth, ninth stimuli). The increase in responding is often referred to as "shoulders." The development of these "shoulders" cannot be explained by behavioral contrast because the increase in responding is specific to a limited stimulus set. Behavioral contrast theory suggests that responding should increase in the presence of all other reinforced stimuli.

Blough's (1975) model predicts the presence of these "shoulders." It does so by revealing that any two stimuli in close approximation on a stimulus dimension show larger differences in behavioral control when one functions as an S+ and the other an S-. Blough accounts mathematically for this effect through a generalization factor. The role of this generalization factor is to control the amount of value accruing to the stimuli approximating the S+. The nearer the cues are on a stimulus dimension the more value they accrue. The reinforced cue will accrue the most value of any stimuli on the trial. The process for calculating this generalization can be seen in this equation.

$$V_A = \sum_{i=1}^{n} \gamma A_i v_i \qquad (3)$$

This equation states that the associative value of stimulus A, V_A, is a function of all stimuli, $(i = 1 \ldots n)$, that are activated by stimulus A. The total associative strength of all those activated elements, v_i, is combined through a weighted generalization factor, γ_{Ai}. This generalization factor weights all similar stimuli according to a normal distribution that uses the reinforced stimulus as its mean. Changes in associative strength across trials can then be assessed using the following equation.

$$\Delta v_i = \gamma_{Ai} \beta(\lambda - V_A) \qquad (4)$$

This equation states that the change in associative value for each stimulus element, Δv_i, during a reinforced trial follows an increasing negatively-accelerated function. The weighted generalization factor for stimulus A, γ_{Ai}, is multiplied with the learning rate parameter for each trial, β. The learning rate parameter represents a larger value when $(\lambda\text{-}V_A)$ is positive in comparison to when $(\lambda\text{-}V_A)$ is negative. Consistent with the Rescorla-Wagner (1972) model, the value of β is always between 0-1.0. The values of λ and V_A represent the asymptotic associative strength attributable to the reinforcer and the total associative strength accrued through previous trials, respectively.

The Blough (1975) model predicts the outcomes of the signaled random procedure equally as well as the Rescorla-Wagner (1972) model. Blough's formulation predicts that the target cue will control more responding under the conditions of equal target and cover cue durations. Moreover, it predicts slow acquisition to the target cue within a signaled random procedure. Because the Blough (1975) model was designed to account for stimulus generalization, it may have a predictive advantage under a different set of experimental operations than those presented from the signaled random procedure literature. The Blough model predicts a systematic decrement in responding to the target cue when the degree of stimulus duration inequality is systematically changed across groups. A group exposed to equal target and cover cue durations is predicted to show a high level of responding to the target cue. In contrast, groups exposed to systematically greater differences between target and cover cue durations are predicted to show systematically less responding to the target cue. The Rescorla-Wagner model does not predict a systematic decrement across groups because it only changes the associative value of a cue when it is present during a trial. The Rescorla-Wagner model maintains that there is no common stimulus element between a 10-s target cue and a 12-s cover cue. The Blough model, however, will increase the associative value of the cue it is near on the same stimulus dimension. More specifically, the Blough model will allow a subset of elements from a stimulus to accrue value if they reside within the bounds of the normal density function of γ. Whether such generalization decrement to the target cue would occur, however, remains to be established experimentally.

Pearce. An alternative account of stimulus generalization comes from Pearce (1987). Pearce's theory of generalization assumes that animals contain a memory buffer that is always full from the stimuli currently being experienced. Whenever a US is presented, the whole complex of stimuli in the memory buffer functions as the CS for that US. Therefore, contextual stimuli are combined with the CSs as part of the total CS complex. This stimulus complex is then stored in the subject's long-term-memory

(LTM). If the stimulus complex changes and another US is presented, then the new stimulus complex functions as a distinct CS from the old CS. For instance, if a pigeon is exposed to a red keylight followed by grain access in an autoshaping trial, the contextual stimuli also serve as part of the CS complex. If the intensity of the houselight in the chamber, a contextual stimulus, dims across the session, then the subject will always be presented with a distinct CS complex. For each trial, the reinforced CS complex is compared with the contents of the CS representation in LTM. The degree of similarity between the current CS complex and the CS representation determine the amount to which the stimulus elements accrue value.

Pearce argues that generalization between stimuli is partially determined by the proportion of common elements that each stimulus shares in the memory buffer. This level of similarity is then affected by the level of associative value of the reinforced cue. The manner in which generalization is calculated is seen in the following equation.

$$e_X = {}_AS_X \cdot E_A \qquad (5)$$

This equation states that the level of generalization to X, e_X, is a product of the similarity between stimuli A and X, ${}_AS_X$, and the total associative value of A, E_A. To determine the degree of generalization between cues, e, a measure of similarity between cues and associative strength must first be calculated. Estimates of stimulus similarity may be calculated with the following equation.

$$ {}_AS_X = \frac{P_{com}}{P_{\Sigma A}} \cdot \frac{P_{com}}{P_{\Sigma X}} \qquad (6)$$

This equation states that similarity between stimuli A and X, ${}_AS_X$, is partially estimated from the perceived intensity of common elements in the memory buffer that are shared between the cues, P_{com}. That value is divided by the perceived intensity of those elements in the memory buffer from each CS when presented alone, $P_{\Sigma A}$ and $P_{\Sigma X}$. The estimate of similarity gives larger values whenever P_{com} is large. The associative strength of each cue is estimated from an equation based upon the Rescorla-Wagner (1972) model. Associative value, E, is estimated as follows:

$$\Delta E = \beta(\lambda - \overline{E}) \qquad (7)$$

This equation states that the change in associative value on any trial, ΔE, is estimated from the US learning rate parameter, β, the asymptotic level of associative value that can accrue to the CS, λ, and the total associative strength already accrued by the stimulus, $\overline{E}$. This equation produces estimates of associative value for all cue elements that are similar to those produced by the Rescorla-Wagner model. The sum of the associative values for all the elements of a cue multiplied by the similarity between cues is what ultimately determines the associative value reflecting learning to the target cue in this model (equation 5).

The application of Pearce's model to the signaled random procedure results in correct predictions about responding to the target cue when the target and cover cue stimuli are equal or unequal in duration. In the equal stimulus condition, the temporal and nontemporal elements of the target and cover cues increase in associative value because they are all followed by USs. Moreover, the contiguous relationship between the CSs and USs increases the amount of space in the memory buffer that is occupied by CS representations. Because all CSs are presented for the same duration and within the same context, the temporal element of the CSs and the contextual configuration occupy a large proportion of the memory buffer. The contextual and temporal common elements in memory increase the overall level of similarity between the target and cover cues. This similarity and the frequently reinforced nontemporal element of the cover cue result in higher estimations of associative value for the target cue than when the target and cover cues are unequal durations. When the target and cover cues are of unequal durations, the cues share nominally only the context as a common element. This situation results in less similarity between cues and therefore lower estimations of associative value for the target cue.

The three models presented above represent theories that postulate the mechanisms of shared associative value and competition between cues. The common-elements analysis of learning is critically important for these models to accurately predict the outcomes of the signaled random procedure. Not all theories, however, share these assumptions about learning. The comparator family of theories suggests that responding is best understood through the relative relationships of events within the session. The comparator theories argue that behavior is better understood by examining these relative relationships apart from the previously discussed competitive mechanisms. The following section describes three comparator models that each uses a different set of events to predict behavior change.

Comparator Theories

Gibbon and Balsam. Scalar Expectancy Theory (SET) is a prototypical example of a comparator theory (Gibbon & Balsam, 1981). It was designed to account for the speed of acquisition of conditioned responding. That responding is based upon the relative strengths of the CS and context. According to SET, the CS and context control expectancy for USs independently. The control of responding during the CS, in turn, is the result of a ratio-comparison between the expectancy for US presentations during the

CS versus the expectancy for US presentations in the context. Expectancy in the CS is inversely related to the trial duration, T, defined as the mean CS duration that occurs prior to the US. Expectancy in the context is inversely related to the cycle duration, C, defined as the mean delay between USs. Thus the expectancy ratio, r, is expressed as follows:

$$r = \frac{C}{T} \tag{8}$$

Therefore, the C/T ratio reflects the relative delay to the US in the presence of context and trial cues, respectively.

The calculation of cycle and trial may be performed as follows. Assume that the US is presented on a variable time 60-s schedule and that p(US|CS) = .50, and that CS duration is 10 seconds. The mean time between US presentations, C, would be 60 s. Trial time, T, would be equal to 20 s because, on average, two CS presentations must occur before any CS is followed by a US. That is, the value of T is the product of CS duration and the inverse of p(US|CS). Dividing C by T (60 by 20), an expectancy ratio of 3 is obtained.

In the Gibbon and Balsam (1981) model, acquisition speed is directly related to the C/T ratio. Based on empirical work, the form of the relation between number of trials to acquisition (N) and the C/T ratio is a power function. The function obtained by Gibbon and Balsam (1981) is expressed as follows:

$$N = 260.6\ (C / T)^{-.8294} \tag{9}$$

With a C/T ratio equal to 3, it will take 105 CS presentations (N) before any 3-out-of-4 trials in a row will elicit responding—a response measure used because it fit the data well. As derived through empirical investigations, the expectancy for the US during the

CS must be approximately twice that of the context before responding will be elicited by the CS (Gibbon & Balsam, 1981). The mechanism of action of SET is therefore based upon the development of expectancy for US presentations during the trial and the interval separating US presentations.

If SET were applied to the random control procedure then a mean duration between each US presentation, C, would be compared with the mean duration of all CS presentations between each CS-US pair, T. Because the random control procedure arranges p(US|CS) = p(US|~~CS~~), it follows that mean delay from US to US and from CS to US will be identical, and that r will equal 1. When r equals 1, it is below the empirically derived limit for responding to develop. This calculation suggests that the expectations for US events are equal throughout the session regardless of whether the CS is present or not.

The Gibbon-Balsam model makes predictions about the speed of response acquisition based upon the C/T comparison. In the signaled random procedure, the target C/T ratio always equals 1 because the temporal structure of the signaled random procedure is identical to that of the random procedure. Regardless of the relative relationship of the target to cover cue durations, the C/T ratio will equal 1. If this model predicts the same C/T ratio for all groups, it therefore fails to make differential predictions between them. Consequently, SET cannot make accurate predictions regarding the signaled random procedure. A modified version of SET was later developed that was intended to make more accurate predictions when applied to the signaled random procedure.

Cooper, Aronson, Balsam and Gibbon. Cooper, Aronson, Balsam and Gibbon (1990) developed the deletion comparator version of SET in an attempt to combat the predictive failure of the Gibbon-Balsam model. This model suggests that the appropriate calculation of cycle duration for the target CS is equal to the target CS duration plus the ITI time that does not include any period occupied by the cover CS or its US. This calculation differs from that of standard C/T ratios, as it removes all session time that contains any other reinforced stimulus. Because it also removes signaled USs, this metric increases cycle duration and therefore predicts more responding than the standard calculation.

To illustrate, assume an experimental session is comprised of 100 10-s time-base periods (1000 s). Assume further that the p(US|CS) = p(US|~~CS~~) =.50 for the target cue and that each session contains 20 target CSs and 40 cover CSs. A calculation of the Gibbon-Balsam C/T ratio reveals that US presentations occur with a mean interval of 20 s (1000 s session ÷ 50 USs = 20 s). The mean trial intervals are also 20 s (10 s target CS ÷ .50 probability = 20 s). Hence, the standard C/T ratio for the session reveals a value of 1 (C/T = 20/20 = 1). In the deletion comparator model, all time associated with alternative cues and their USs must be subtracted from the session duration. Subtracting all cover cue time from the session yields a total session duration of 600 s [1000 s session – (40 cover cues X 10 s duration) = 600 s]. Recalculation of mean cycle time for the session now gives a value of 60 [600 s ÷ 10 USs = 60 s]. Recalculation of mean trial duration gives the same value as before, 20. Calculation of the deletion comparator C/T ratio now gives a value of 3 (C/T = 60/20 = 3).

Removal of session time would not increase cycle duration in the standard SET calculation. In this model, however, the US paired with the alternative cue is also deleted. The removal of alternative USs increases cycle duration. Cycle duration, therefore, increases most dramatically when a short alternative CS is deleted. This increase in cycle duration occurs because less time is eliminated from the total session in comparison to a longer CS, and this increases the proportion of ITI time in the session. This relative increase in ITI time increases the value of the cycle. The increased cycle time suggests that the deletion comparator model would predict more target cue responding under conditions with a cover cue shorter than the target cue in comparison to when the cover and target cues are equal durations. The empirical findings of Williams (1994) and Experiments 1 and 2 of this manuscript present data counter to that prediction.

The preceding scalar expectancy and deletion-comparator models were designed to explain behavior with respect to the relative temporal intervals within sessions. The following model is an exception in this manner. It explains behavior change with respect to the relative CS→US and context→US relationships within a session.

Miller and Matzel. Miller and Matzel (1988) identified the mechanism of contiguity between CS to US as well as context to US as factors in controlling behavior change. This model maintains that contiguity is both necessary and sufficient for the acquisition of learning. Three associations are assumed to developed during each CS→US pairing. The first is the association between the CS and US. Contiguous pairings of the CS and US result in learning about that relation. The second association results from the pairing of any stimuli present during a CS→US trial with the CS itself. Those cues present contiguously with the CS serve as comparator stimuli. Comparator stimuli function as local contextual stimuli. They are frequently identified as the stimuli that comprise the context itself, however, they may be punctate stimuli that occur coincident with the CS. In such instances, the more salient stimulus functions as the CS and the remaining stimuli function as the comparator stimuli. The third association is between the contextual stimuli and the US. This last association works in concert with the CS-to-contextual-stimulus association to modulate the level to which CS→US learning is expressed.

Responding on any trial is ultimately determined by a comparison between the representation of the US controlled by the CS and the representation of the US controlled by the comparator stimuli. The CS elicits a representation of the US after CS→US pairings. Learning is reflected in the degree to which the CS elicits the US representation. The expression of that learning, however, is modulated by the remaining two associations. It is assumed that learning is a direct function of the CS→US relation and an inverse function of the associations between the CS to comparator stimuli and the comparator stimuli to US.

Contiguous forward target-CS→US pairings results in a CS that elicits a strong US representation. Responding to the target CS develops because it controls a stronger US representation than the combined effects of the remaining two associations. In contrast, the added presence of unsignaled USs during the ITI results in stronger US representations by the comparator stimuli. This change produces a less favorable comparison between the two US representations. The less favorable comparison results in less target-CS responding. When cover cues precede all those unsignaled USs, the comparator stimuli again control a weak US representation in comparison to the target

CS. The presence of the cover stimuli result in strong US representations elicited by the cover cues. The reduction in control by the comparator stimuli allows the target CS learning to be expressed. This model suggests that high levels of target responding should always appear when USs presented during the ITI are preceded with a cover cue in the signaled random procedure. This prediction, however, is counter to the results of experiments that show substantial levels of responding to the target cue only when the stimulus durations are equal.

Although the three comparator-theories described above do not accurately predict the stimulus equality effect (Experiment 2), they do help clarify another finding from the literature. The following section describes how a comparison between CS duration and intertrial interval give accurate predictions about the level of responding to the target cue in the signaled random procedure.

Relative Intertrial Interval Time. The intertrial interval to trial time ratio (I/T) has been used to examine the relative temporal mechanisms of behavior. It has been used to predict the onset of autoshaped keypeck acquisition with pigeons (Gibbon et al., 1977), magazine approach acquisition with rats (Lattal, 1999) and the postacquisition response levels of conditioned suppression with rats (Coleman, Hemmes & Brown, 1986). The following section shows it can also accurately predict the postacquisition response levels to the target and cover cues in the signaled random procedure.

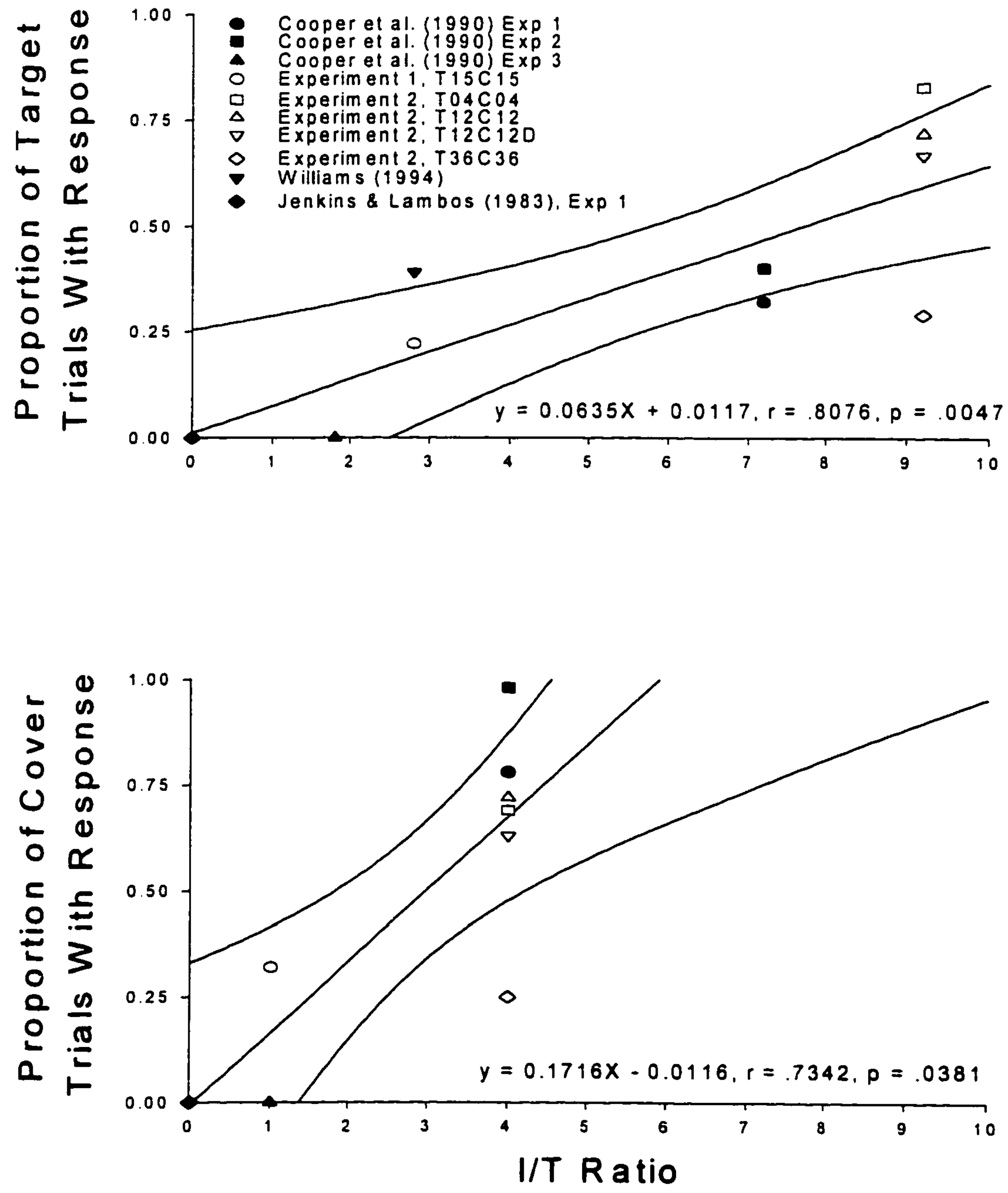
When the I/T ratio is applied to the signaled random procedure, it may be calculated for the target cue and cover cue. The I/T ratio for the target cue may be calculated as the sum of all intertrial-interval time (non-CS, non-US time) divided by the sum of all target CS periods. The I/T ratio for the cover cue may be calculated as the sum of all intertrial-interval time (non-CS, non-US time) divided by the sum of all cover CS periods. In either case, the value of the ITI would be the same and only the value of the total CS time would change. The predictive capacity of this metric can be seen in Figure 10.

Figure 10 shows the proportion of trials with a response as a function of I/T ratio. The data values presented from each experiment were the final values collected and presented graphically for that study. The data contained in this graph come from all experiments in the signaled-random procedure literature that contained a C/T = 1, p(US|target CS) = p(US|~~target CS~~) as well as equal target and cover cue durations (Cooper et al., 1990; Jenkins & Lambos, 1983; Williams, 1994; Experiments 1 and 2 of the current study). The top panel shows the relationship for the target cue and the bottom panel shows the relationship for the cover cue. Each panel shows the linear regression line (straight line), its equation and the Pearson correlation coefficient. Both panels reveal significant correlations between I/T ratio and postacquisition response levels. These data are shown within the 95% confidence intervals (curved lines).

These figures show that I/T ratio is a good predictor of postacquisition response levels to the target and cover cues within the equal stimulus conditions of the signaled random procedure. The graphs reveal that the I/T ratio is positively correlated with response level to the target and cover cues. Correlations between I/T ratio and response rate (responses/second) for the target or cover cues did not reveal statistically significant effects.

Both panels of Figure 10 show that a condition employing a C/T ratio of 1 may contain various I/T ratios within a signaled random schedule. In contrast, single CS

Figure 10. The proportion of target trials (top panel) and cover trials (bottom panel) with a response as a function of the I/T ratio across experiments. The I/T ratio was calculated as the total ITI (non-target CS, non-cover CS) time divided by the total target-CS time. The curved lines represent the 95% confidence interval estimated from the linear regression line.



procedures (standard delay conditioning procedures) confound the relationship between I/T and C/T ratios. The factors that can produce a constant C/T ratio with one of many I/T ratios become clarified when examining the temporal structure of a session. In all signaled random schedules, the p(US|CS) = p(US|$\overline{\text{CS}}$) and C/T = 1. The I/T ratio, however, is free to vary based upon three factors. Those factors are probability of reinforcement for the target cue, session duration and total target CSs per session. These three factors and their effects on I/T ratio are shown in Table 6.

Table 6 shows examples of how these three factors can modulate the I/T ratio. Each section shows how the designated factor influences I/T ratios when it is manipulated while the remaining two factors are held constant. Each example uses a 10-s time base and 10-s target and cover CS durations. The outcomes from these examples show how decreasing the probability of reinforcement for the target cue, decreasing the number of target CSs per session and increasing session duration all increase the relative I/T ratio while keeping the p(US|CS) = p(US|$\overline{\text{CS}}$) and the C/T ratio at 1. These factors indicate the importance of the signaled random procedure for attempts to dissociate C/T and I/T effects on acquisition and maintained performance of conditioned responding.

Conclusions

The General Discussion section reviewed the applicability of explanations from competition and comparator models to the results from the signaled random procedure. Overall, the competition models make more accurate predictions regarding responding to the target and cover cues in the signaled random procedure. The superiority of the competition models over comparator models in this assay is attributable to the theoretical mechanisms employed by each. Competition models are assumed to operate through a mechanism in which stimulus elements that accrue associative strength are shared among CSs. In contrast, comparator models are assumed to function through the comparison of independent stimulus events. An appraisal of these models suggests that ones that assume the sharing of common stimulus elements between CSs support accurate assessments of behavior. Because this shared-element process is common among competition models, they are more likely to predict the experimental results of the signaled random procedure than comparator models that do not contain such assumptions. It should be noted that the success of a competition account of the data depends upon strong control of behavior by the common temporal element of the target and cover cues.

In contrast, comparator models correctly predict postacquisition response levels as a function of I/T ratio. The competition models fail to make this prediction. This failure, as well, appears to be a function of the models' proposed theoretical mechanisms. Overall, this indicates that the results from signaled random procedure experiments are based on a combination of factors operating through disparate mechanisms.

Table 6

The p(US|target CS), Session Duration and Total Target CSs Per Session Change the Relative Intertrial-Interval to Trial Time Ratio (I/T) during the Signaled Random Procedure

p(US|target CS)	Total 10 s Time Base Units	Total 10 s CSs	Total ITI USs	Total ITI (s)	C/T	I/T
p(US|target CS)*						
.80	100	10	72	180	1	1.8
.60	100	10	54	360	1	3.6
.40	100	10	36	540	1	5.4
.20	100	10	18	720	1	7.2
Session Duration*						
.60	50	10	24	160	1	1.6
.60	100	10	54	360	1	3.6
.60	200	10	114	760	1	7.6
.60	400	10	234	1560	1	15.6

(table 6 continues)

p(US|target CS)	Total 10 s Time Base Units	Total 10 s CSs	Total ITI USs	Total ITI (s)	C/T	I/T
Total CSs Per Session*						
.50	100	8	46	460	1	57.5
.50	100	6	47	470	1	78.3
.50	100	4	48	480	1	120
.50	100	2	49	490	1	245

*Indicates the manipulated factor. The three factors of interest, probability of reinforcement for the target cue, session duration and total target CSs per session are represented in each section of the table. Within each section, one of the three variables changes while the other two remain constant. In all instances, time base periods and target CSs are 10 s in duration. When the p(US|target CS) is manipulated it is assumed that the p(US|cover CS) = 1.0.

Appendix A

Target Cue Responding

Proportion of Trials With a Response. Figure 5 shows responding during the target cue across the seven 12-session blocks of training. The top panel of this figure shows the mean proportion of trials with a peck. The data reveal a significant effect across all groups as the mean of 84 sessions [$H(5) = 17.39$. $p < .05$]. The Kruskal-Wallis H test applied to all groups from block 1 reveals a nonsignificant effect [$H(5) = 10.87$, $p = .053$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over groups T12C04, T12C12D and T12C36.

A Kruskal-Wallis H test applied to all groups from block 2 reveals a significant effect [$H(5) = 11.97$, $p < .05$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over groups T12C04, T12C12D and T36C36. Group T12C12 also responded significantly higher than group T12C04.

A Kruskal-Wallis H test applied to all groups from block 3 reveals a significant effect [$H(5) = 14.34$, $p < .05$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over groups T12C04, T12C12D and T36C36. Group T12C12 also responded significantly higher than group T12C04, T12C12D and T36C36.

A Kruskal-Wallis H test applied to all groups from block 4 reveals a significant effect [$H(5) = 15.11$, $p < .05$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over groups T12C04, T12C12D and T12C36. Group T12C12 also responded significantly higher than group T12C04, T12C12D and T12C36.

A Kruskal-Wallis H test applied to all groups from block 5 reveals a significant effect [$H(5) = 16.22$, $p < .05$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over groups T12C04, T12C12D, T12C36 and T36C36. Group T12C12 also responded significantly higher than group T12C04 and T12C36.

A Kruskal-Wallis H test applied to all groups from block 6 reveals a significant effect [$H(5) = 17.95$, $p < .05$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over groups T12C04, T12C36 and T36C36. Group T12C12 also responded significantly higher than group T12C04 and T12C36. Groups T12C12D and T36C36 responded significantly higher than group T12C36.

A Kruskal-Wallis H test applied to all groups from block 7 reveals a significant effect [$H(5) = 17.37$, $p < .05$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over groups T12C04, T12C36 and T36C36. Group T12C12 also responded significantly higher than group T12C04, T12C36 and T36C36. Group T36C36 responded significantly higher than group T12C36.

Rate. The bottom panel of Figure 5 shows the mean number of pecks per second for target cue responding across the 84 sessions of acquisition. The data reveal a significant effect across all groups as the mean of 84 sessions [$H(5) = 16.89$, $p < .05$]. The Kruskal-Wallis H test applied to all groups from block 1 reveals a significant effect

[$H(5) = 12.42$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over groups T12C04, T12C12D, T12C36 and T36C36.

A Kruskal-Wallis H test applied to all groups from block 2 reveals a significant effect [$H(5) = 14.85$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over groups T12C04, T12C12D and T36C36. Group T12C12 also responded significantly higher than groups T12C04 and T36C36.

A Kruskal-Wallis H test applied to all groups from block 3 reveals a significant effect [$H(5) = 14.28$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over groups T12C04, T12C12, T12C12D and T36C36. Group T12C12 also responded significantly higher than group T12C04 and T36C36.

A Kruskal-Wallis H test applied to all groups from block 4 reveals a significant effect [$H(5) = 14.58$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over groups T12C04, T12C12D, T12C36 and T36C36. Group T12C12 also responded significantly higher than group T12C04.

A Kruskal-Wallis H test applied to all groups from block 5 reveals a significant effect [$H(5) = 17.88$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over all other groups. Group T12C12 also responded significantly higher than group T12C04 and T36C36.

A Kruskal-Wallis H test applied to all groups from block 6 reveals a significant effect [$H(5) = 19.11$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over all other groups. Group T12C12 also responded significantly higher than group T12C04, T12C36 and T36C36.

A Kruskal-Wallis H test applied to all groups from block 7 reveals a significant effect [$H(5) = 18.36$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over groups T12C04, T12C12D, T12C36 and T36C36. Group T12C12 also responded significantly higher than group T12C04, T12C36 and T36C36.

Appendix B

Cover Cue Responding

Proportion of Trials With a Response. Figure 7 shows responding during the cover cue across the seven 12-session blocks of training. The top panel of this figure shows the mean proportion of trials with a peck. The data reveal a nonsignificant effect across all groups as the mean of 84 sessions [$H(5) = 10.86$, $p = .054$]. The Kruskal-Wallis H test applied to all groups from block 1 reveals a significant effect [$H(5) = 12.46$, $p < .05$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over groups T12C04 and T12C36. Group T12C04 also responded significantly higher in proportion than group T12C36. Group T12C12 responded significantly higher than groups T12C36 and T36C36.

A Kruskal-Wallis H test applied to all groups from block 2 reveals a significant effect [$H(5) = 12.04$, $p < .05$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over groups T12C04 and T12C36. Group T12C12 also responded significantly higher than groups T12C36 and T36C36.

A Kruskal-Wallis H test applied to all groups from block 3 reveals a significant effect [$H(5) = 10.10$, $p < .05$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over group T12C36. Group T12C12 also responded significantly higher than group T12C36.

A Kruskal-Wallis H test applied to all groups from block 4 reveals a significant effect [$H(5) = 12.20$, $p < .05$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over groups T12C04 and

T12C36. Group T12C12 also responded significantly higher than group T12C04 and T12C36.

A Kruskal-Wallis H test applied to all groups from block 5 reveals a nonsignificant effect [$H(5) = 8.25$, $p > .05$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over group T12C36. Group T12C12 also responded significantly higher than group T12C36.

A Kruskal-Wallis H test applied to all groups from block 6 reveals a nonsignificant effect [$H(5) = 9.46$, $p > .05$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over group T12C36. Group T12C12 also responded significantly higher than groups T12C36 and T36C36.

A Kruskal-Wallis H test applied to all groups from block 7 reveals a nonsignificant effect [$H(5) = 8.26$, $p > .05$]. Tests between each group reveal a significantly higher level of the proportion of trials responded to for group T04C04 over group T12C36. Group T12C12 also responded significantly higher than group T12C36.

Rate. The bottom panel of Figure 7 shows the mean number of pecks per second for cover cue responding across the 84 sessions of acquisition. The data reveal a significant effect across all groups as the mean of 84 sessions [$H(5) = 14.66$, $p < .05$]. A Kruskal-Wallis H test applied to all groups from block 1 reveals a significant effect [$H(5) = 17.86$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over groups T12C36 and T36C36. Groups T12C04 and T12C12 responded significantly higher than both groups T12C36 and T36C36.

A Kruskal-Wallis H test applied to all groups from block 2 reveals a significant effect [$H(5) = 16.34$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over groups T12C36 and T36C36. Group T12C04 responded significantly higher than group T12C36. Group T12C12 responded significantly higher than groups T12C36 and T36C36.

A Kruskal-Wallis H test applied to all groups from block 3 reveals a significant effect [$H(5) = 14.71$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over groups T12C36 and T36C36. Group T12C04 also responded significantly higher than group T12C36. Group T12C12 responded significantly higher than groups T12C36 and T36C36.

A Kruskal-Wallis H test applied to all groups from block 4 reveals a significant effect [$H(5) = 12.38$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over groups T12C36 and T36C36. Group T12C12 also responded significantly higher than groups T12C36 and T36C36.

A Kruskal-Wallis H test applied to all groups from block 5 reveals a significant effect [$H(5) = 12.42$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over groups T12C36 and T36C36. Group T12C04 and T12C12 also responded significantly higher than group T12C36.

A Kruskal-Wallis H test applied to all groups from block 6 reveals a significant effect [$H(5) = 13.25$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over groups T12C36 and T36C36. Group T12C04 also responded significantly higher than group T12C36. Group T12C12 responded significantly higher than groups T12C36 and T36C36.

A Kruskal-Wallis H test applied to all groups from block 7 reveals a significant effect [$H(5) = 14.02$, $p < .05$]. Tests between each group reveal a significantly higher level of response rate for group T04C04 over groups T12C36 and T36C36. Group T12C04 also responded significantly higher than group T12C36. Group T12C12 responded significantly higher than groups T12C36 and T36C36.

References

Blough, D. S. (1975). Steady state data and a quantitative model of operant generalization and discrimination. Journal of the Experimental Analysis of Behavior, 104, 3-21.

Blough, D. S. (1983). Alternative accounts of dimensional stimulus control. In M. L. Commons, R. J. Herrnstein & A. R. Wagner (Eds.), Quantitative analyses of behavior: Discriminative processes (pp. 59-72). Cambridge, MA: Ballinger.

Bush, R. R., & Mosteller, F. (1951). A model for stimulus generalization and discrimination. Psychological Review, 58, 413-423.

Coleman, D. A., Hemmes, N. H. & Brown, B. L. (1986). Relative durations of conditioned stimulus and intertrial interval in conditioned suppression. Journal of the Experimental Analysis of Behavior, 46, 51-66.

Cooper, L. D., Aronson, L., Balsam, P. D., & Gibbon, J. (1990). Duration of signals for intertrial reinforcement and nonreinforcement in random control procedures. Journal of Experimental Psychology: Animal Behavior Processes, 16, 14-26.

Durlach, P. J. (1982). Pavlovian learning and performance when a CS and US are uncorrelated. In M. Commons, R. J. Herrnstein & A. R. Wagner (Eds.), Quantitative analysis of behavior: Acquisition (pp. 173-193). Cambridge, MA: Ballinger.

Durlach, P. J. (1983). Effect of signaling intertrial unconditioned stimuli in autoshaping. Journal of Experimental Psychology: Animal Behavior Processes, 9, 374-389.

Gibbon, J., Baldock, M. D., Locurto, C., Gold, L., & Terrace, H. S. (1977). Trial and intertrial durations in autoshaping. Journal of Experimental Psychology: Animal Behavior Processes, 3, 264-284.

Gibbon, J., & Balsam, P. (1981). Spreading association in time. In C.M. Locurto, H. S. Terrace and J. Gibbon (Eds.), Autoshaping and conditioning theory (pp. 219-253). N.Y.: Academic Press.

Gibbon, J., Farrell, L., Locurto, C. M., Duncan, H. J., & Terrace, H. S. (1980). Partial reinforcement in autoshaping with pigeons. Animal Learning and Behavior, 8, 45-59.

Jenkins, H. M., Barnes, R. A., & Barrera, F. J. (1981). Why autoshaping depends on trial spacing. In C. M. Locurto, H. S. Terrace, & J. G. Gibbon (Eds.), Autoshaping and conditioning theory (pp. 255-284). N.Y.: Academic Press.

Jenkins, H. M., & Lambos, W. A. (1983). Tests of two explanations of response elimination by noncontingent reinforcement. Animal Learning and Behavior, 11, 302-308.

Lattal, K. M. (1999). Trial and intertrial durations in Pavlovian conditioning: Issues of learning and performance. Journal of Experimental Psychology: Animal Behavior Processes, 25, 433-450.

Miller, R. R., Barnet, R. C., & Grahame, N. J. (1995). Assessment of the Rescorla-Wagner model. Psychological Bulletin, 117, 363-386.

Miller, R. R., & Matzel, L. D. (1988). The comparator hypothesis: A response rule for the expression of associations. In G. H. Bower (Ed.), The psychology of learning and motivation (Vol. 22, pp. 51-92). San Diego, CA: Academic Press.

Pearce, J. M. (1987). A model for stimulus generalization in Pavlovian conditioning. Psychological Review, 94, 61-73.

Rescorla, R. A. (1966). Predictability and number of pairings in Pavlovian fear conditioning. Psychonomic Science, 4, 383-384.

Rescorla, R. A. (1976). Stimulus generalization: Some predictions from a model of Pavlovian conditioning. Journal of Experimental Psychology: Animal Behavior Processes, 2, 88-96.

Rescorla, R. A., & LoLordo, V. M. (1965). Inhibition of avoidance behavior. Journal of Comparative and Physiological Psychology, 59, 406-412.

Rescorla, R. A., & Wagner, A. R. (1972). In A. Black and W.F. Prokasy (Eds.), Classical Conditioning II: Current research and theory (pp. 64-99). New York: Appleton-Century-Crofts.

Williams, B. A. (1994). Contingency theory and the effect of the duration of signals for noncontingent reinforcement. Psychonomic Bulletin and Review, 1, 111-114.