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EFFECTS OF SIGNALED VERSUS UNSIGNALED DELAY OF REINFORCEMENT ON CHOICE

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Pigeons chose between 5-s and 15-s delay-of-reinforcement alternatives. The first key peck to satisfy the choice schedule began a delay timer, and food was delivered at the end of the interval. Key pecks during the delay interval were measured, but had no scheduled effect. In Experiment 1, signal conditions and choice schedules were varied across conditions. During unsignaled conditions, no stimulus change signaled the beginning of a delay interval. During differential and nondifferential signal conditions, offset of the choice stimuli and onset of a delay stimulus signaled the beginning of a delay interval. During differential signal conditions, different stimuli were correlated with the 5-s and 15-s delays, whereas the same stimulus appeared during both delay durations during nondifferential signal conditions. Pigeons showed similar, extreme levels of preference for the 5-s delay alternative during unsignaled and differentially signaled conditions. Preference levels were reliably lower with nondifferential signals. Experiment 2 assessed preference with two pairs of unsignaled delays in which the ratio of delays was held constant but the absolute duration was increased fourfold. No effect of absolute duration was found. The results highlight the importance of delayed primary reinforcement effects and challenge models of choice that focus solely on conditioned reinforcement.

Key words: delay of reinforcement, unsignaled delay, differentially signaled delay, nondifferentially signaled delay, choice, key peck, pigeons

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A critical variable in operant conditioning is the time between the occurrence of a response and the presentation of a reinforcer. Specifically, the duration of the delay between a response and reinforcer is believed to be inversely related to the impact of that reinforcer on future responding. However, despite general agreement regarding the importance of delay of reinforcement, attempts to understand and quantify this variable have produced diverse viewpoints.

A critical issue for understanding delayed reinforcement is specifying how its effects are related to conditioned reinforcers presented during the delay interval. In some accounts of choice, for example, the theoretical focus has been solely on conditioned reinforcement value, and the value of delayed primary reinforcement has been disregarded (e.g., Fantino, 1977; Mazur, 1997). The issue is whether delayed primary reinforcement exerts any effect independent of conditioned reinforcement, and if so, what is its nature.

One method of attempting to isolate the effects of delayed primary reinforcement, unconfounded by the effects of conditioned reinforcement, is to correlate different delays of reinforcement with the same stimulus. For example, Chung and Herrnstein (1967) darkened the entire chamber during all delay intervals. It is possible that differential conditioned reinforcement still operated in the procedure if subjects were able to learn conditional discriminations, such that the darkened chamber had different value based on which choice response it followed. It is also possible that the procedure eliminated differential conditioned reinforcement but did not remove conditioned reinforcement as a determinant of choice. That is, the stimulus change provided by the blackout may have had conditioned reinforcement properties that were equal for the two choice alternatives. The issue then posed is the rule by which the differential effects of delayed primary reinforcement and the nondifferential effects of immediate conditioned reinforcement are combined. Without knowledge of that rule, it is impossible to specify the effects of delayed primary reinforcement per se.

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A second approach to studying delayed primary reinforcement has been to have no stimulus change during the delay interval, which means that the subject is unable to discriminate that a delay-of-reinforcement interval is in effect. In some procedures (Critchfield & Lattal, 1993; Lattal & Gleeson, 1990; Lattal & Metzger, 1994), a differential-reinforcement-of-other-behavior (DRO) contingency is used in which the delay timer resets with each subsequent response. Although this ensures that the obtained delay between response and reinforcer is equivalent to the programmed delay, it also alters the response contingency. For example, many responses may go unreinforced simply because they are followed by additional responses. Thus, any effect of delay of reinforcement is confounded by changes in the schedule of reinforcement when a DRO contingency is used to study unsignaled delayed reinforcement.

An alternative to the use of the DRO schedule during the delay interval is the use of unsignaled delays of reinforcement (Williams, 1976). In this procedure, reinforcers are delivered according to a variable-interval (VI) schedule, such that completion of the VI schedule initiates a delay interval, at the end of which the reinforcer is delivered (technically referred to as a tandem VI fixed-time [FT] schedule). No stimulus change occurs during the delay interval, and responding during the interval has no scheduled effect. The disadvantage of the procedure is that the actual delays between the last response and the reinforcer are likely to be significantly shorter than the scheduled delay. Despite this problem of the obtained response–reinforcer delays being variable, Williams found that even short delays cause substantial reductions in response rate, even though the actual obtained delays were often significantly shorter than the scheduled delay value. Other researchers have also shown that even small increases in an unsignaled delay can produce an abrupt drop-off in responding (e.g., Catania & Keller, 1981; Royalty, Williams, & Fantino, 1987; Sizemore & Lattal, 1977).

Previous studies of unsignaled delayed reinforcement have been limited to single-response situations. This is unfortunate because it is possible that sensitivity to reinforcement delay may be quite different in single-response and choice situations. One might expect that unsignaled delays in a choice situation might negatively affect behavior not only because subjects may not discriminate the response–reinforcer contingencies but also because there is the opportunity to mistakenly associate the wrong response with a reinforcer. In short, one might expect more confusion to be engendered by unsignaled delays in a choice procedure.

It is also possible, however, that a choice procedure may prove to be more informative in analyzing the effects of primary reinforcement. For example, Catania (1963) compared the effects of reinforcer magnitude in single-schedule and concurrent-schedule procedures. He found no systematic effect in the single-schedule procedure, but the concurrent-schedule procedure showed a linear relation between response rate and reinforcer duration. Thus, a variable that seems to have a limited effect in single-response procedures may have a larger and more consistent effect in concurrent procedures.

The present work extended the study of unsignaled delays to a concurrent-schedule procedure in which choice alternatives are associated with different unsignaled delays of reinforcement. Given that unsignaled delays produce major decrements in responding in single-schedule situations, the issue was whether the relative value of the different delays is maintained in a choice situation or whether responding becomes erratic.

In addition, Experiment 1 compared the unsignaled delay procedure to procedures in which differential signals were correlated with the different delays (similar to concurrent chains), and to procedures in which a nondifferential signal was used, such that the delays contingent on both choice alternatives were signaled by the same stimulus. In the case of nondifferential signals, if the value of each alternative is a combination of delayed primary reinforcement plus common conditioned reinforcement, then preference for the shorter delay alternative may be attenuated relative to the unsignaled condition (which presumably has only delayed primary reinforcement as a determinant of choice). In comparing the differentially signaled and unsignaled conditions, it is of interest to ask whether adding differential conditioned reinforcement enhances the relative value of delayed primary reinforcement.

Table 1

Order of conditions and number of sessions conducted in each condition.

Choice schedule	Signal contingency	Order of condition/sessions to stability					
		T1	T2	T3	T4	B1	B2
FR 1	Unsignaled	1/18	1/18	4/22	7/18	4/18	7/18
VI 30	Unsignaled	2/19	2/30	6/23	8/30	6/30	8/18
Stubbs–Pliskoff	Unsignaled	3/18	3/30	5/21	9/30	5/30	9/26
FR 1	Nondifferential	4/27	7/18	1/18	1/18	7/25	4/18
Stubbs–Pliskoff	Nondifferential	5/18	9/20	3/19	3/30	9/20	5/20
VI 30	Nondifferential	6/25	8/22	2/20	2/20	8/18	6/30
FR 1	Differential	7/18	4/18	7/18	4/18	1/18	1/18
VI 30	Differential	8/18	6/18	8/18	6/19	2/18	2/27
Stubbs–Pliskoff	Differential	9/20	5/18	9/18	5/20	3/24	3/18
Stubbs–Pliskoff (rev.)	Unsignaled	10/30	10/26	10/28	10/32	10/35	10/22
VI 60	Unsignaled	11/19	11/19	12/18	13/19	12/30	13/30
VI 60	Nondifferential	12/18	13/18	11/18	11/19	13/21	12/26
VI 60	Differential	13/18	12/19	13/20	12/22	11/19	11/18

EXPERIMENT 1

Method

Subjects

The subjects were 6 adult White Carneau pigeons. Each had previously participated in studies of behavioral contrast; none had prior experience with concurrent-chains procedures. Mixed grain available during, and when necessary, following experimental sessions maintained the pigeons at approximately 85% of their free-feeding weights. The birds were housed in individual cages with water and grit freely available.

Apparatus

Six experimental chambers (32 cm long by 27 cm wide by 29 cm high) were housed in wooden enclosures. Three response keys, 2 cm in diameter and 5 cm apart, were arranged horizontally, 20 cm from the chamber floor. IEE projectors mounted behind each key were used to project color fields onto the keys. The food-hopper aperture was 10.5 cm below the center response key and was illuminated with a white light during food presentations. A white houselight was located in the rear left corner of the ceiling and was continuously illuminated for the session duration. An AT-compatible computer with Turbo Pascal® software was used to arrange stimuli and record responses.

Procedure

Each session consisted of 60 trials, half of which were choice trials and half of which were forced-exposure trials. During choice trials, red and green keylights were simultaneously presented on the left and right response keys. Across blocks of four trials, each stimulus appeared an equal number of times on each side key. The delay of reinforcement was 5 s for one stimulus and 15 s for the other, with the assignment of delays to stimulus colors counterbalanced across subjects. During forced-exposure trials only one stimulus (and corresponding delay) was presented. Each block of four consecutive trials consisted of two forced-exposure trials (one short delay and one long delay) and two choice trials. The order of these trials within each block was randomly determined. All trials terminated with reinforcer delivery, which consisted of 3-s access to grain. Initiation of the next trial immediately followed reinforcement. Conditions differed depending on the choice schedule that initiated the delay period and the presence or absence of stimuli during the delays. Table 1 shows the order of each condition and the number of sessions conducted in each condition for each subject.

Choice schedules. Four different types of choice schedules were employed in different conditions. One schedule was a fixed-ratio (FR) 1 schedule in which the first response to either choice stimulus initiated the associated delay period. The second schedule was a VI 30-s schedule. All VI values were selected from a Fleshler and Hoffman (1962) progression of 10 intervals. Interval values for each trial were randomly selected, with the limitation that all values were used before they all again became available for selection. The VI 30-s schedule was programmed so that a single timer counted each interval, and after an interval elapsed, the first response to either choice stimulus initiated the associated delay. The third choice schedule was similar to the procedure reported by Stubbs and Pliskoff (1969) and is hereafter referred to as the Stubbs–Pliskoff condition. A single VI 30-s schedule operated as described above, but only one of the choice alternatives was operative on each trial (although both stimuli were present). Of every four choice trials, the 5-s delay was operative in two trials and the 15-s delay was operative in two trials. The fourth schedule was a concurrent VI 60-s VI 60-s schedule. The VI 60-s timer operated independently on each alternative. However, once a delay was initiated, the remaining time from the unselected alternative was saved and reinstituted following reinforcement.

In all conditions, once a choice response was effective (i.e., it initiated a delay), further responding was recorded but had no effect for the remainder of the trial.

Signal contingencies. Three different signal contingencies were employed in different conditions. In the unsignaled conditions, the red and green choice stimuli were always present except during reinforcer delivery. In the nondifferential signal conditions, the initiation of a delay caused the two choice stimuli to go dark and the center keylight to be illuminated with a horizontal line, which remained until the delivery of food. In the differential signal conditions, the initiation of the delay caused the two choice stimuli to go dark and the center keylight to be illuminated with the same color as the selected choice stimulus.

Preference and stability. Preference for the short delay was measured by calculating choice proportions as the number of choice responses on the short alternative divided by the number of choice responses for both alternatives. Choice responses did not include any responses from forced-exposure trials or delay periods. A total of 12 different conditions were studied. Each condition was continued for a minimum of 18 sessions. After the minimum number of sessions (and for each session thereafter), the nine preceding sessions were separated into blocks of three sessions. Preference was considered stable when the means (M) of the choice proportions within each block did not differ by more than .05 and showed neither an upward trend ($M_1 < M_2 < M_3$) nor a downward trend ($M_1 > M_2 > M_3$). If stability was not reached after 30 sessions, the next condition was instituted in the following session. The mean level of preference in each condition was determined by averaging choice proportions for the last nine sessions in each condition. After the first nine conditions had been completed, the Stubbs–Pliskoff/unsignaled condition was replicated with the choice stimulus assignments reversed for each subject. This replication condition was conducted exactly as the previous conditions, except that the maximum number of sessions was increased to 35. The stimulus assignments were returned to the original configuration for the conditions following this replication condition.

RESULTS

The data for each subject, for the last nine sessions of each condition, are presented in detail in Appendix A. The preference results are summarized in Figure 1, which shows the mean choice proportion for each condition (for the Stubbs–Pliskoff/unsignaled condition, only the first assessment of preference is shown). Both the unsignaled and differential signal conditions produced similar, high levels of preference. Averaged across the different choice schedules, choice proportions for the unsignaled and differential signal conditions were .87 and .91, respectively. The slightly higher mean level of preference in the differential signal conditions occurred with each of the choice schedules studied, and ranged from .03 to .06. Of the possible 24 individual-subject comparisons of the signal effects (6 subjects $\times$ 4 choice schedules), differential signals produced the highest choice proportions in 14 comparisons, and the unsignaled conditions produced the highest choice proportions in five (the differential signal and unsignaled conditions produced the same choice proportions in four comparisons). The Stubbs–Pliskoff/unsignaled condition was replicated following a stimulus reversal. The mean choice proportion of the reversal condition was slightly lower (.74) than the first assessment of preference (.81).

Preference was, on average, significantly re-

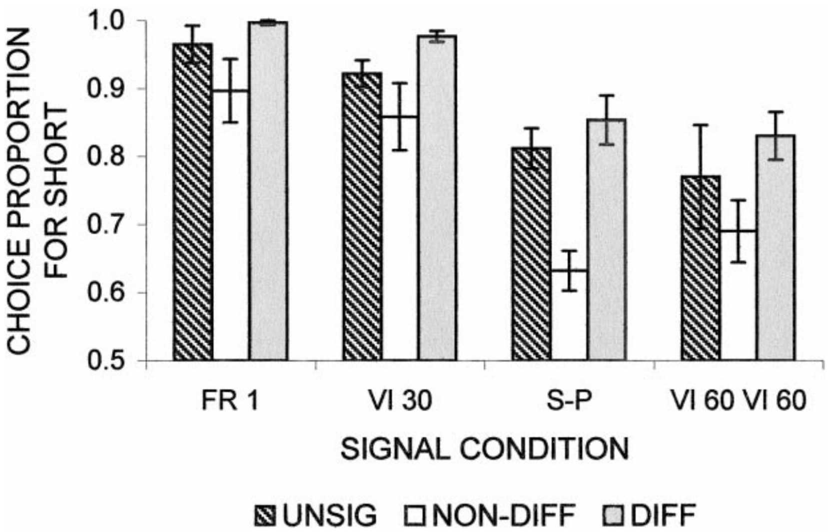

Fig. 1. Choice proportions in each of the 12 conditions, averaged across pigeons. Conditions differed depending on the choice schedule that initiated the delay (FR 1, VI 30 s, Stubbs–Pliskoff, or concurrent VI 60 s VI 60 s) and the presence or absence of stimuli during the delays (unsignaled, nondifferential signals, and differential signals). Error bars represent ±1 *SE*.

duced in the nondifferential signal conditions (overall mean of .77), particularly when the Stubbs–Pliskoff choice schedule was employed (mean choice proportion was .63). Of the 24 individual-subject comparisons, the nondifferential signal condition produced the highest level of preference only once.

FR 1 choice schedules produced the most extreme preference (overall mean choice proportion of .95), although the VI 30-s schedule was only slightly lower (.92). This small difference occurred with each of the three different signal contingencies, and ranged from .02 to .05. On an individual level, the FR 1 condition produced higher levels of preference for 13 of 18 possible comparisons (6 subjects × 3 signal conditions). Preference was lowest when Stubbs–Pliskoff and concurrent VI 60-s VI 60-s choice schedules were used: .77 and .76, respectively.

A two-factor (Choice Schedule × Signal Condition) within-subject analysis of variance (ANOVA) was performed on the choice proportions presented in Appendix A (not including the Stubbs–Pliskoff reversal condition). The main effects of choice schedule, $F(3, 15) = 18.01$, $p < .01$, and signal condition, $F(2, 10) = 12.65$, $p < .01$, were significant. The interaction was not significant, $F(6, 30) = .87$, $p > .10$. Post hoc comparisons (Bonferroni adjustment for multiple comparisons, $\alpha = .05$) were conducted on each of the main effects. The Stubbs–Pliskoff choice schedule was significantly different from both the FR 1 and VI 30-s schedules, and the VI 30-s schedule was significantly different from the VI 60-s schedule. Also, nondifferential signals differed significantly from differential signals. No other differences were obtained.

As noted earlier, because half of all trials were forced-exposure trials, subjects frequently experienced the contingencies associated with the long delay to food even if choice behavior indicated an exclusive preference for the short delay to food. This ensured that no more than 75% of the total obtained reinforcement could come from one alternative. This constraint did not appear to attenuate the preference levels, because both the FR 1 and VI 30-s schedules produced extreme preference for the short delay to food. Figure 2 contrasts the proportion of reinforcers obtained from the short alternative (only including reinforcers from choice trials) with the proportion of responses to the short alternative. The FR 1 schedule, of course, requires that the proportions be identical. The Stubbs–Pliskoff choice schedule forces the subjects to collect an equal number of reinforcers from each alternative, so the reinforcer proportion is constant at .5 for the three signal conditions. The concurrent VI 60-s VI

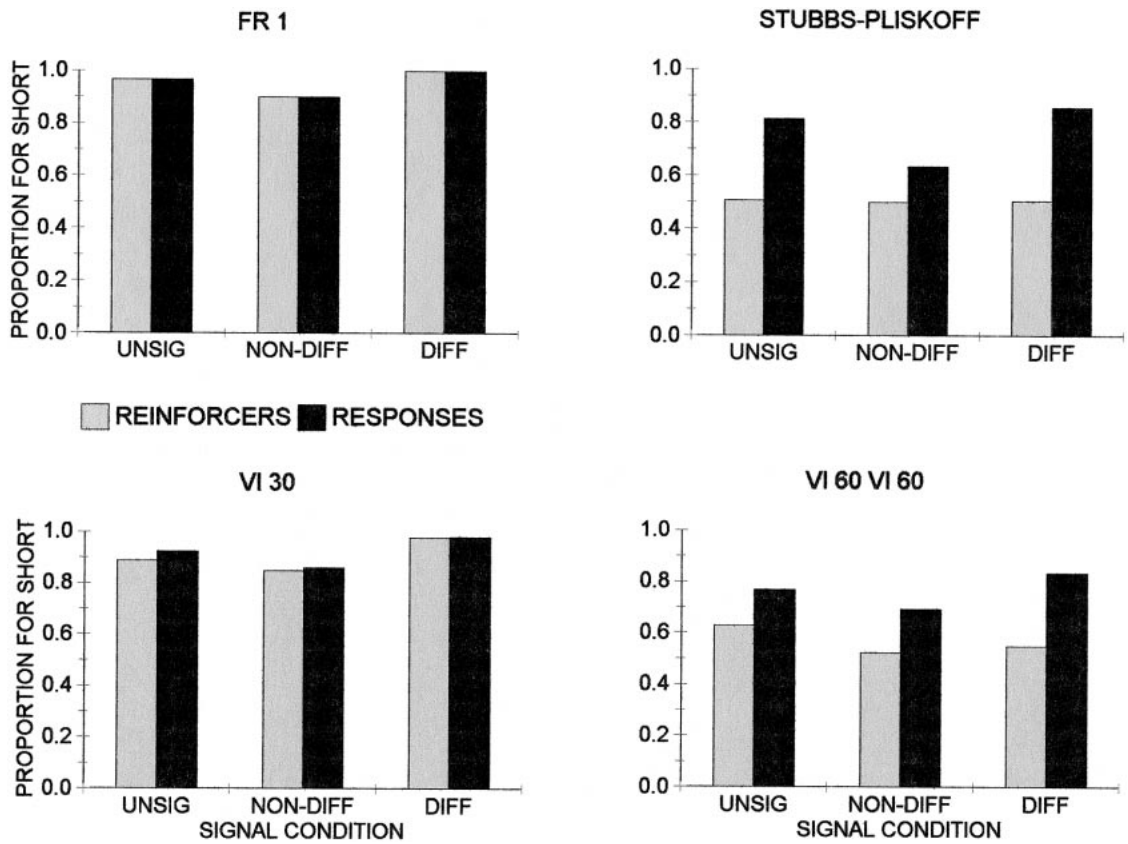

Fig. 2. Proportion of reinforcers obtained from the short delay alternative (including reinforcers only from choice trials) and the proportion of responses to the short delay alternative (during the choice phase). Each graph presents data from a particular choice schedule (FR 1, VI 30 s, Stubbs–Pliskoff, or concurrent VI 60 s VI 60 s), and for each of the signal conditions (unsignaled, nondifferential signals, and differential signals).

60-s choice schedule also was effective in equating the obtained number of reinforcers for the two alternatives. Choice proportions were more extreme than the reinforcer proportions in all of the Stubbs–Pliskoff and concurrent VI 60-s VI 60-s conditions for every pigeon.

Figure 3 shows the mean rate of responding during each signal condition with VI 30-s, Stubbs–Pliskoff, and concurrent VI 60-s VI 60-s choice schedules. The unsignaled condition usually produced the lowest response rates. The overall mean number of responses per minute to the short and long choice stimuli during the choice period were 15 and 2, respectively. The overall mean number of responses per minute to the short and long stimuli during the delay (the choice stimuli were present during both the choice and delay periods) were 12 and 5, respectively. The difference in responding to the two stimuli was smaller during the delay than during the choice phase. This result was most prominent with the Stubbs–Pliskoff and concurrent VI 60-s VI 60-s choice schedules. For example, the mean relative rates of responding (short responses divided by the sum of short and long responses, averaged across birds) for the choice and delay periods, respectively, were .94 and .93 for the VI 30-s condition, .81 and .65 for the Stubbs–Pliskoff condition, and .78 and .66 for the concurrent VI 60-s VI 60-s condition.

The differential signal condition (Figure 3) produced relatively high response rates, particularly to the stimuli associated with the short delay. Overall mean number of responses per minute were 49 and 7 to the short and long choice stimuli and 76 and 6 to the short and long delay stimuli, respectively. By com-

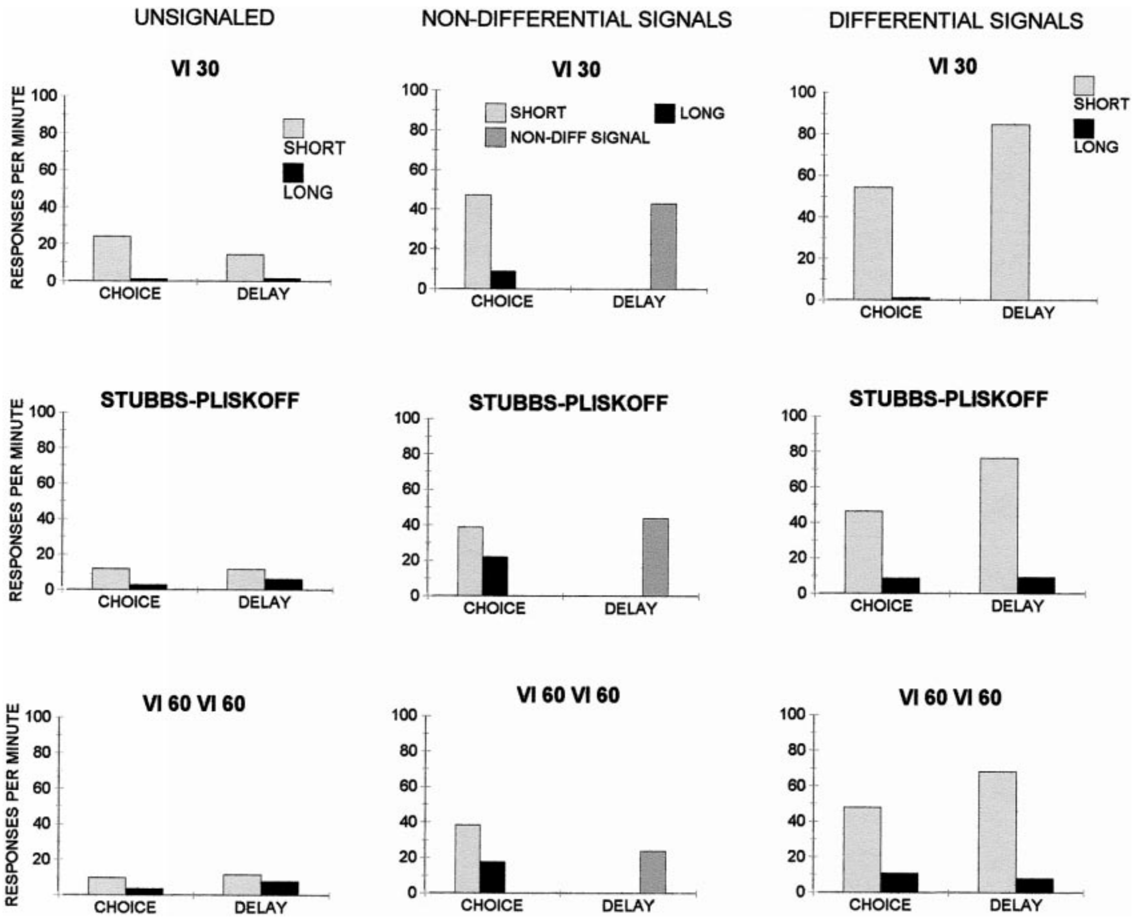

Fig. 3. Rates of responding during the choice and delay periods during each of the signal conditions. Both choice stimuli were always present during the unsignaled conditions (left graphs). Therefore, response rate during the delay measures the rate of responding that occurred to the short and long choice stimuli while both were present. The same delay stimulus was always presented during each short and long delay when nondifferential signals (center graphs) were used; therefore, the same rate of responding is indicated for both types of trials. Because the differential signal condition (right graphs) presented different stimuli during the short and long delays, the rate of responding indicated was measured separately for the short and long delays.

parison, the nondifferential signal conditions produced higher levels of responding to the long choice stimulus than was the case under the unsignaled or differential signal conditions, and moderate levels of responding during the delay. The overall mean number of responses per minute to the short and long choice stimuli were 41 and 16, respectively. The same delay stimulus was presented during both short and long delay periods, and pecks were not recorded separately depending on the duration of the delay. The overall mean number of responses per minute during the delays was 37.

Figure 4 shows the mean interreinforcement interval (IRI) for each condition. Because of the extreme preference for the short delay alternative when the choice schedule was FR 1, the mean time to reinforcement was quite short, and did not appear to vary with the signal contingency (overall mean IRI was 10 s). The other three choice schedules (VI 30 s, Stubbs–Pliskoff, and concurrent VI 60 s VI 60 s) are similar in that the programmed duration of the choice phase averaged 30 s. These schedules produced very similar IRIs when nondifferential and differential signals were used. However, the mean time to reinforcement increased slightly with the concurrent VI 60-s VI 60-s choice sched-

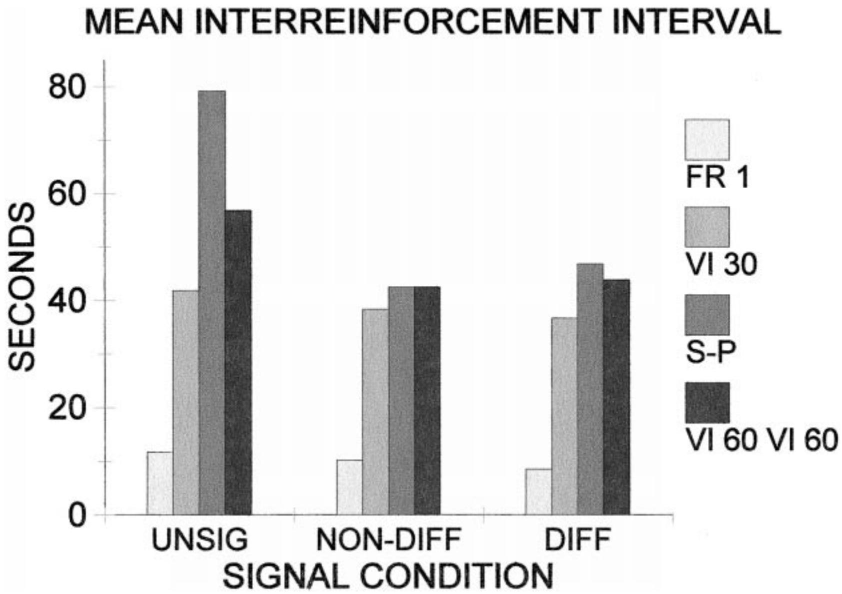

Fig. 4. Mean IRI for each choice schedule (FR 1, VI 30 s, Stubbs–Pliskoff, or concurrent VI 60 s VI 60 s) and signal condition (unsignaled, nondifferential signals, and differential signals).

ule and increased sharply with the Stubbs–Pliskoff choice schedule when no signals were provided during the delay.

Discussion

The major findings of Experiment 1 were that the differentially signaled and unsignaled delays of reinforcement produced generally extreme preference for the shorter delay, whereas preference with the nondifferentially signaled delays was substantially reduced. The choice schedules employed in the present study also produced orderly effects on preference.

The highest level of preference was observed when the short (FR 1) choice schedule was employed. The other three schedules (VI 30 s, Stubbs–Pliskoff, and concurrent VI 60 s VI 60 s) were similar in that they shared the same programmed mean choice phase duration of 30 s. Despite this similarity, the single VI choice schedule produced higher preference levels than the other two schedules for every subject in each of the three signal conditions. It is not surprising that both the Stubbs–Pliskoff and concurrent VI 60-s VI 60-s choice schedules produced less extreme preference, because both schedules contain contingencies that encourage changeover behavior. The Stubbs–Pliskoff schedule forces subjects to change over because only one choice alternative is operative during a given trial. The concurrent VI 60-s VI 60-s schedule also encourages changeover behavior because, unlike the VI 30-s condition, both alternatives are timing down simultaneously. Periodically responding to the long delay alternative increases the overall obtained rate of primary reinforcement. Because of these additional contingencies, both the Stubbs–Pliskoff and concurrent VI 60-s VI 60-s choice schedules might underestimate the true degree of preference for the short delay alternative. However, one benefit of these schedules, as noted previously, is that they equate or nearly equate the number of reinforcers obtained on each alternative.

Although the major focus of the present study was the effect on choice of unsignaled delayed reinforcement, it is important to consider how the other conditions that were studied relate to previous findings. The differentially signaled delay procedure used here is similar to a standard concurrent-chains procedure in that different stimuli were correlated with the different delays, which correspond to the terminal links of a concurrent chain. It is therefore of interest to compare the present results obtained using the differential delay procedure to that predicted by the major accounts of performance in standard concurrent-chains schedules. Because the condition with the concurrent VI 60-s VI 60-s choice schedule is most typical of previous research, the obtained level of performance in that condition (M = .83) can be compared with the appropriate theoretical predictions. Delay-reduction theory (Fantino, 1977) predicts only a slight preference for the 5-s delay (.58), whereas the Squires and Fantino (1971) modification of the original delay-reduction theory predicts slightly higher preference for the short delay (.62). The contextual choice model of Grace (1994) predicts a choice proportion closer to indifference (.53), with k (a scaling parameter related to terminal-link stimulus conditions), a_1 (initial-link sensitivity), and a_2 (terminal-link sensitivity) equal to 1.

Why might the obtained levels of preference with the differentially signaled delays in the present study be significantly greater than the theoretical predictions? One likely cause is that the schedules in the terminal links were fixed delays, which are known to produce more extreme preference levels than schedules with variable delays. For example, Grace (1994) compared sets of studies in which both terminal links were Fl schedules with sets of studies in which both were VI schedules. Within the framework of his contextual choice model, sensitivity to the ratio of the delays was approximately three times as great with the Fl Fl comparison.

The difference in preference between the differential signal versus the nondifferential signal conditions is consistent with previous research, which has shown greater sensitivity to relative delay values with differential stimuli (Navarick & Fantino, 1976; Williams & Fantino, 1978). Perhaps more surprising is the absolute level of preference that was obtained here with the nondifferential signal conditions. With the Stubbs–Pliskoff procedure, mean preference for the shorter delay was .63, whereas preference obtained with the independent VI 60-s VI 60-s schedules was .69. Preference was thus substantially above indifference in both conditions, indicating sensitivity to the relative delay value despite having the same stimulus immediately contingent on both choice responses. One explanation is that subjects partially discriminated the nondifferential delay signal as a function of the choice peck that produced it. The obtained preference was, however, somewhat below the predicted preference based solely on the relative delay values (.75), which corresponds to the matching of relative immediacy supported by Chung and Herrnstein (1967). But as shown by Williams and Fantino (1978), Chung and Herrnstein reported systematic departures from matching: undermatching with short absolute delay values and overmatching with longer absolute delay values. Because the delay values used here were relatively short, a small degree of undermatching is therefore expected.

The most puzzling aspect of the present results was the degree of control exerted by the unsignaled delays. Our expectation, based on the weak behavior maintained by even brief unsignaled delays in single-response situations, was that the overall response rate would be greatly reduced, which did occur (Figure 3), but also that the control by the relative delay value would be weak as well. In fact, the unsignaled delays produced levels of preference almost as extreme as those with differentially signaled delays. Such sensitivity seems to preclude any kind of theoretical analysis that depends upon the concept of conditioned reinforcement because there were no stimulus changes that indicated the transition from the choice phase to the initiation of the delay-of-reinforcement intervals. Thus, the strong control by relative delay appears to have been the result of direct contact with the response–reinforcer contingency without any apparent mediation by the conditioned reinforcement properties of the intervening stimuli.

Although the present results show that choice is strongly controlled by the relative value of two unsignaled delays, they provide little insight into how such control was accomplished. As noted in the introduction, the obtained delays between the last response and the reinforcer often will be shorter than the scheduled delay. If response rates in the shorter and longer delay intervals were similar at the start of training, it is not obvious how the subject could detect that different delay values were contingent on the two responses. Contact with the scheduled delay value could occur only if the response rates were sufficiently low that no responding occurred during at least some of the delay intervals.

This implies that a moment-to-moment analysis of responding, and its relation to reinforcer delivery, may be necessary to understand how the strong preference levels developed with the unsignaled delay conditions. Such an effort was not undertaken in Experiment 1 because we believed prior to the experiment that strong control by the relative value of the unsignaled delays was unlikely.

It is possible that the extreme levels of preference in the unsignaled conditions were obtained because relatively short delay values were used. It is not known how preference might change with longer absolute durations, but one might expect that sensitivity to the relative delay values would decrease with longer durations when the delays are unsignaled. With both differentially and nondifferentially signaled delays, however, Williams and Fantino (1978) have shown that increases in absolute duration produced increases in preference for the shorter delay. Gentry and Marr (1980) also manipulated absolute duration with nondifferentially signaled delays, but they found a nonmonotonic relation between absolute duration and preference. Experiment 2 was conducted to establish whether preference in an unsignaled delay procedure decreases, remains unchanged, or increases with a large increase in absolute duration.

EXPERIMENT 2

Experiment 2 employed the unsignaled delay procedure used in Experiment 1. Each subject from Experiment 1 participated in two conditions. One condition replicated preference with 5-s versus 15-s delays, and the other extended the delays fourfold to 20 s versus 60 s. In addition, the location of the last peck preceding reinforcement, as well as the time between the last peck and reinforcement, were recorded for each trial.

METHOD

Subjects and Apparatus

The subjects and apparatus were the same as in Experiment 1.

Procedure

The unsignaled procedure and stimulus assignments were the same as in Experiment 1. Each subject was exposed to two pairs of delay values (5 s vs. 15 s and 20 s vs. 60 s). The choice schedule employed during both conditions was a concurrent VI 60-s VI 60-s schedule. As in Experiment 1, the VI 60-s timer operated independently on each alternative. Once a delay was initiated, the remaining time from the unselected alternative was saved and reinstituted following reinforcement. The red and green choice stimuli were always present except during reinforcer delivery. In both conditions, once a choice response was effective (i.e., it initiated a delay), further responding was recorded but had no effect for the remainder of the trial. Half of the birds received training with the 5-s/15-s condition first, and the other half received training with the 20-s/60-s condition first.

Preference and stability. Preference for the short delay was measured by calculating choice proportions as the number of choice responses on the short alternative divided by the number of choice responses for both alternatives. Choice responses did not include any responses from forced-exposure trials or delay periods. Each condition was continued for a minimum of 20 sessions. After the minimum number of sessions (and for each session thereafter), the nine preceding sessions were separated into blocks of three sessions. Preference was considered stable when the means of the choice proportions within each block did not differ by more than .05 and showed neither an upward trend ($M_1 < M_2 < M_3$) nor a downward trend ($M_1 > M_2 > M_3$). If stability was not reached after 30 sessions, the next condition was instituted in the following session. The mean level of preference in each condition was determined by averaging choice proportions for the last nine sessions in each condition.

RESULTS

The data for each subject in each condition are presented in detail in Appendix B. The preference results are summarized in Figure 5, which shows the mean choice proportion for each condition for each pigeon. Half of the birds had slightly more extreme preference levels with the shorter absolute durations (differences ranged from .06 to .11), and half of the birds had slightly more extreme preferences with the longer absolute durations (differences ranged from .08 to

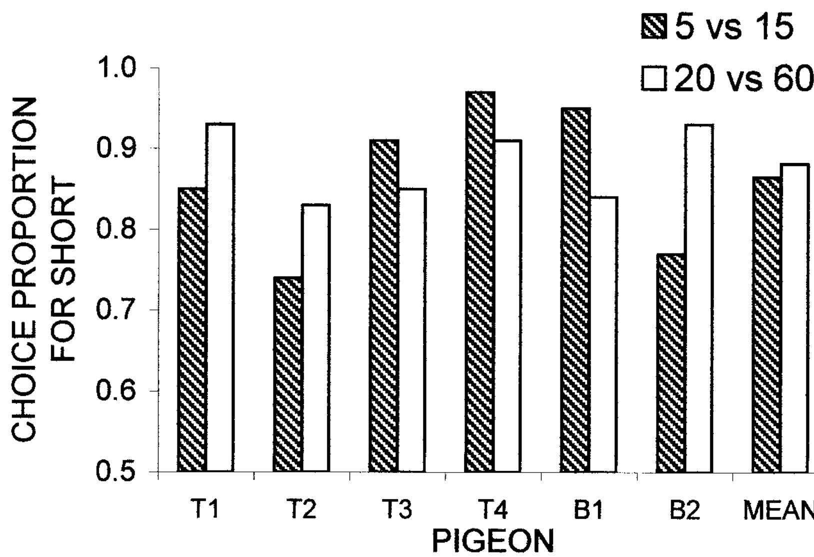

Fig. 5. Choice proportions for each pigeon with unsignaled delays in Experiment 2.

.16). Overall, preference was nearly identical in the two conditions (.87 and .88 mean choice proportions for the 5-s/15-s and 20-s/60-s conditions, respectively). A within-subject ANOVA performed on the choice proportions failed to find a significant difference between the delay conditions, $F(1, 5) = 0.14$, $p > .10$.

Figure 6 shows the mean proportion of delay intervals in which no peck occurred. In both conditions, the shorter delays were more likely to time out without a single key peck during the delay. Therefore, the obtained short-reinforcer delays were proportionally closer to their scheduled values than were the long-reinforcer delays. Figure 7

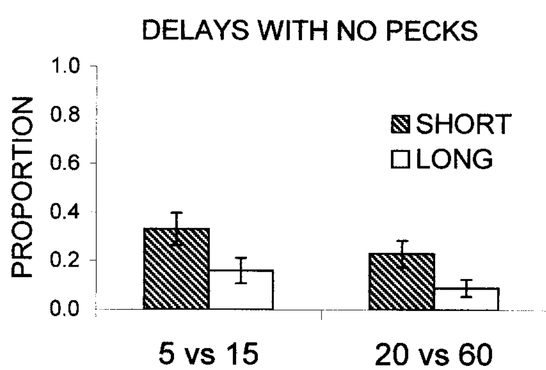

Fig. 6. The mean proportion of delay intervals in which no peck occurred following the effective choice response. Error bars represent ±1 *SE*.

compares the scheduled and obtained mean delays for the 5-s/15-s and 20-s/60-s conditions. Although the scheduled delays represented a short:long ratio of 1:3, the obtained delay ratios were closer to 1:2.

In both conditions, the last peck prior to reinforcement was usually to the short choice stimulus. In an analysis of the last nine sessions of each condition, this was true for 77% and 84% of the total reinforcers delivered in the 5-s/15-s and 20-s/60-s conditions, respectively. The majority of delay intervals contained at least one peck, and Figure 8 sorts the delay periods that contained at least one response, based on the delay (short or long) and the location of the last peck prior to food delivery (short choice stimulus or long choice stimulus). For both the 5-s/15-s and 20-s/60-s conditions, the last peck during a short delay was almost always to the short choice stimulus. However, during the long delays, the last peck was more evenly distributed between the short and long choice stimuli. During the 60-s delays, the last peck was, on average, more likely to have been to the short choice stimulus.

Because the obtained delays and the location of the last peck prior to food delivery was recorded for each subject, it was possible to calculate the obtained delays depending on where the last peck occurred (as opposed to which alternative actually produced the rein-

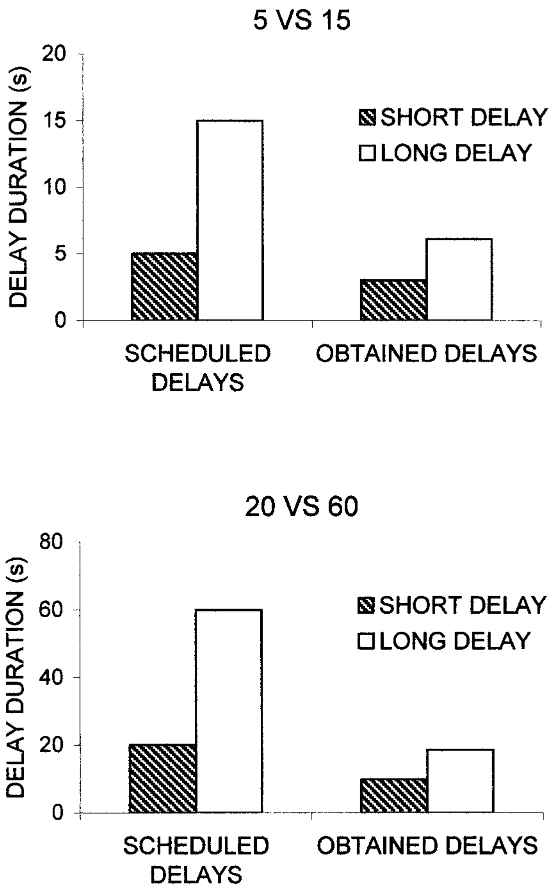

Fig. 7. The scheduled and obtained mean delays for the two alternatives in the 5-s/15-s (top graph) and 20-s/60-s unsignaled delay conditions of Experiment 2.

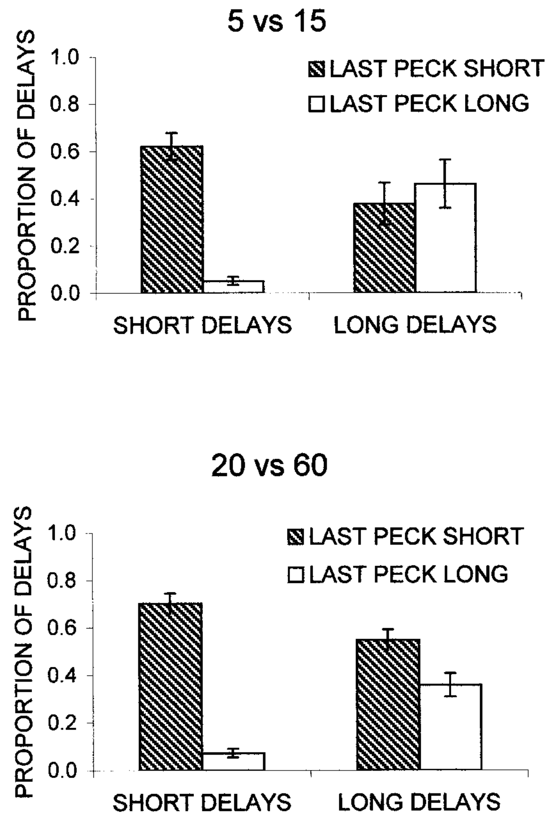

Fig. 8. The mean proportion of delay intervals in which the last peck occurred to the short stimulus and the long stimulus, for both short and long reinforcers. The top graph shows the data for the 5-s/15-s condition, and the bottom graph shows the data for the 20-s/60-s condition.

forcer). Specifically, if a given reinforcer strengthens only the last response that occurs (which in most cases is not the choice response), then the obtained choice proportions may be predicted by re-sorting the obtained delays by the location of the last peck. This analysis was done for the final nine sessions (the sessions used to meet the stability requirement) for each subject. All choice trials were analyzed, including delays in which the last peck was the choice response itself. For the 5-s/15-s condition, the overall mean obtained delay was 3.1 when the last peck was to the short stimulus and 7.5 when the last peck was to the long stimulus. The ratio was similar in the 20-s/60-s condition: 10.4 when the last peck was to the short stimulus and 20.0 when the last peck was to the long stimulus. Table 2 summarizes the obtained delay data for both choice and forced-exposure trials, calculated in terms of arithmetic and harmonic means.

The overall rate of responding was lower in the 20-s/60-s condition. Mean number of responses per minute during the choice period were 13 and 1 to the short and long choice stimuli, respectively, in the 5-s/15-s condition and 8 and 1 in the 20-s/60-s condition. Response rates during the delay were similar for the two conditions, although rates were generally higher during the unsignaled short delays. Individual-subject response rates are presented in Appendix B.

DISCUSSION

Experiment 2 measured preference between two unsignaled delay alternatives. As in Experiment 1, the unsignaled delay proce-

Table 2

Obtained delays from Experiment 2, averaged across subjects. Choice trials and forced-exposure trials show the obtained delays sorted by the location of the choice peck. Choice trials (last peck) shows the obtained delays sorted by the location of the last peck prior to reinforcer delivery, irrespective of the location of the effective choice peck.

	Obtained delays (s)					
	Choice trials		Forced-exposure trials		Choice trials (last peck)	
	Short	Long	Short	Long	Short	Long
5 vs. 15						
M	3.0	6.1	2.7	7.3	3.1	7.5
Harmonic mean	1.5	1.8	1.3	2.2	1.5	2.6
20 vs. 60						
M	9.9	18.6	10.4	21.1	10.4	20.0
Harmonic mean	2.6	3.1	2.6	3.7	2.6	4.8

dure resulted in extreme levels of preference. One condition reassessed preference using the delay durations used in Experiment 1, and the overall level of preference increased in Experiment 2 from .77 to .87. However, a closer examination reveals that the increase in preference was largely due to 2 subjects (T1 and T2) that had much lower estimates of preference in Experiment 1 compared to the other 4 subjects. If T1 and T2 are excluded from the estimates of preference, preference levels for the two experiments are not systematically different (mean choice proportions of .88 and .90 for Experiments 1 and 2, respectively).

The main goal of Experiment 2 was to determine how increases in absolute duration affect preference in the unsignaled delay procedure. Preference for the shorter delay was, on average, nearly identical when 5-s versus 15-s delays were compared to 20-s versus 60-s delays. Thus, sensitivity to the relative delay values did not decrease with longer absolute durations as was expected, nor did the degree of preference increase as it does with differentially signaled delays (Williams & Fantino, 1978).

The extreme degree of behavioral control observed with unsignaled delays of 20 and 60 s is particularly surprising in light of the studies showing marked deterioration of behavior with even short unsignaled delays in single-response situations (e.g., Catania & Keller, 1981; Royalty et al., 1987; Sizemore & Lattal, 1977; Williams, 1976). Thus, it cannot be assumed that subjects will be insensitive to the difference between unsignaled delays simply because the overall rate of responding is greatly reduced in single-response situations.

Figure 9 shows the choice proportion predictions based on the assumption that the proportion of responding matches the frequency of reinforcement (Herrnstein, 1970). Predictions are based on data from the last nine sessions of each condition. The horizontal line in each graph represents the obtained choice proportion for that condition. In both conditions, choice proportions are significantly underestimated if the scheduled reinforcer delays or obtained reinforcer delays are used. When the obtained delays are averaged based on the location of the last peck prior to reinforcement (instead of the location of the choice peck), choice proportions are also greatly underestimated. For the last column in Figure 9, we combined the differences in reinforcer frequency and delay value. We assumed that each individual reinforcer contributed to response strength inversely to its delay value by converting each delay into a reciprocal, and then summing the separate contributions to response strength for each reinforcer (sorting delay values based on the location of the last peck prior to reinforcer delivery). The last column in Figure 9 shows this measure, cumulated immediacies (by last peck), in terms of relative value for the short delay choice. The cumulated immediacies measure provides a much better predictor of the obtained choice proportions: It slightly underpredicted the choice proportions for the 5-s/15-s compari-

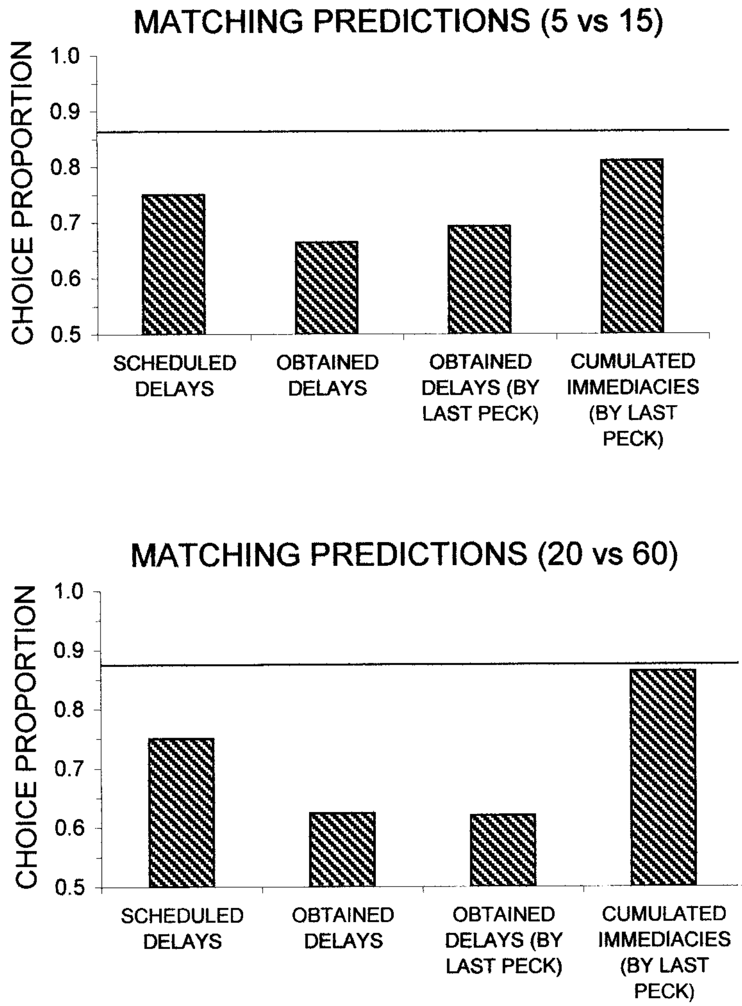

Fig. 9. Choice proportion predictions using the scheduled delay values, average obtained delay values (sorted by the location of the choice response), average obtained delay values (sorted by the location of the last peck prior to food delivery), and cumulated immediacies (sorted by the location of the last peck prior to food delivery). The horizontal line in each graph represents the obtained choice proportion for that condition.

son but accurately predicted choice for the 20-s/60-s comparison.

GENERAL DISCUSSION

In Experiment 1, preference for the shorter of two delays was assessed in a number of conditions differing in the presence and informativeness of the delay signals and the choice schedule contingencies. Reliable effects were found for both variables. Choice schedules that encouraged switching behavior (Stubbs–Pliskoff and concurrent VI VI) resulted in lower estimates of preference, as expected. Surprisingly, preference for the shorter delay was nearly as high in conditions with no stimulus changes (unsignaled delay condition) as in conditions in which the two delays were differentially signaled. Preference was reliably lower when the same stimulus signaled both delay intervals (nondifferential signal condition). Experiment 2 further examined choice in an unsignaled delay procedure, and again found high levels of preference for the shorter delay.

One factor that may have facilitated the strong control by the delays in all signal conditions was the inclusion of forced-exposure trials. On these trials, the subjects were exposed separately to the individual delay values, which presumably made it easier to discriminate the different contingencies. For example, if no reinforcement had occurred on the free-choice trials, so that any differential behavior was due to training on the forced-exposure trials, it is possible that preference would still have been as extreme as that obtained here. This possibility is supported by previous studies that trained two response alternatives separately and then combined them in a choice procedure. For example, Edmon, Lucki, and Grisham (1980) first presented pigeons with a multiple schedule with two or three components, and then presented pairs of the components together (with extinction in effect) in a choice procedure. Preference in the choice procedure was considerably more extreme than that predicted by the relative reinforcement rates used during prior training with the multiple schedule.

A similar procedure of separately trained response alternatives was studied by Young (1981), using differential amounts of reinforcement rather than differential frequencies. One response alternative was always associated with a probability of .5 of receiving either 10 food pellets or 0 pellets. The second alternative was associated with a probability of 1.0 of receiving a constant amount of food, ranging from 1 to 10 pellets across different experimental conditions. The critical feature of the procedure was that each alternative was presented individually in a long series of forced-exposure trials before being paired together. A fit of the generalized matching law,

$$B_1/B_2 = b(R_1/R_2)^s, \qquad (1)$$

in which B refers to the behavior and R to the corresponding reinforcement rates, showed both a significant bias (b) for the probabilistic alternative and an exponent in Equation 1 of approximately 2.0, indicating that preference was again considerably more extreme than that predicted by the relative reinforcement rates.

The fact that preference levels substantially exceed matching when separately trained choice alternatives are presented in a choice situation for the first time, for differences in both reinforcement rate and reinforcement amount, suggests that it presumably would occur for reinforcer immediacy as well. One major difference between these studies and the present study is that in the latter, both types of trials were interspersed throughout training.

Burrill and Spear (1969) presented rats with a choice between two magnitudes of reinforcement. For half of the subjects, all trials were free choice, whereas the remaining subjects experienced both forced and free trials. Preference for the larger magnitude of reinforcement developed faster and was more extreme for the group that received forced-exposure trials. Thus, some of the tendency for extreme preferences seen in the present study could have been due to the inclusion of the forced-exposure training that occupied half of the experimental sessions.

It should be pointed out, however, that the forced-exposure trials were essentially single-response delayed reinforcement trials. Many previous studies of unsignaled delay of reinforcement have been conducted in the context of the single-response situation, and they have found that even short delays can have markedly detrimental effects on responding. Thus, although it is possible that the forced-exposure trials elevated preference, it still does not explain how such behavioral control is achieved in the absence of any discernible conditioned reinforcement.

One possibility is that the choice rule is not matching to relative value, but rather some approximation of maximizing, such that the alternative with the greater value is chosen exclusively (sometimes referred to as the "all-or-none" rule). It is important to recognize that virtually all previous theoretical attempts to provide quantitative accounts of choice have assumed that matching is the choice rule, and then have proceeded to develop estimates of the values of the different choice alternatives that are consistent with matching (e.g., Catania, 1973; Fantino, 1969; Grace, 1994; Mazur, 1997). That is, the difference between these theoretical alternatives has been in terms of the equations defining value, not in the choice rule. If instead the all-or-none choice rule were correct, very different rules for estimating the value of choice alternatives would be needed.

Although the choice proportions greatly exceeded the preference predicted by the scheduled delay values, one analysis in Experiment 2 of the obtained delays was much more consistent with the matching law. The cumulated immediacies measure shown in Figure 9, which combines both the effects of number of reinforcers following a response with the immediacy of each of those reinforcers, was a surprisingly accurate predictor of preference. However, it remains unclear whether cumulative immediacy caused the observed level of preference or simply reflects that preference. Further work, which follows the development of preference and its relation to reinforcer immediacy and allocation (preferably with naive subjects), is needed to verify that these variables are in fact useful in explaining the high preference levels achieved with unsignaled delays.

Overall, the major result of similar sensitivity to delays under unsignaled and differentially signaled conditions has broad implications for theories of choice that focus exclusively on the influence of conditioned reinforcement. Although unsignaled delayed reinforcement reduced the total amount of behavior, it did not appear to diminish the degree of discriminative control. Thus, whether or not the effects of delayed primary reinforcement can ultimately be explained by the preceding analysis, these results challenge the prevailing assumption that conditioned reinforcement is the primary mechanism responsible for choice.

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APPENDIX A

Data for individual subjects in each condition of Experiment 1. The order of conditions differed for individual subjects and is presented in Table 1. Rev. indicates that the choice stimulus assignments were reversed. All other conditions used the original stimulus assignments. Dashes indicate that data are not available because of extreme choice proportions. Data are means of the last nine sessions of each condition.

					Response rates (responses/minute)						
				Obtained rfmt	Choice		Unsignaled delay		Nondifferential	Differential delay	
Bird	Choice schedule	Signal contingency	Choice prop.	prop.	Short	Long	Short	Long	delay	Short	Long
T1	FR 1	Unsignaled	1.0	1.0	17	0	25	0			
	VI 30	Unsignaled	.94	.86	12	1	13	1			
	Stubbs–Pliskoff	Unsignaled	.91	.50	18	2	18	4			
	FR 1	Nondifferential	.99	.99	24	0			1		
	Stubbs–Pliskoff	Nondifferential	.55	.50	16	13			7		
	VI 30	Nondifferential	.71	.70	27	11			11		
	FR 1	Differential	1.0	1.0	21	0				1	—
	VI 30	Differential	.97	.99	38	1				1	—
	Stubbs–Pliskoff	Differential	.93	.51	38	3				0	0
	Stubbs–Pliskoff (rev.)	Unsignaled	.73	.51	14	5	13	12			
	VI 60	Unsignaled	.54	.54	13	11	11	23			
	VI 60	Nondifferential	.73	.52	29	11			5		
	VI 60	Differential	.94	.63	39	3				1	0
T2	FR 1	Unsignaled	.99	.99	35	0	154	0			
	VI 30	Unsignaled	.87	.86	16	2	24	3			
	Stubbs–Pliskoff	Unsignaled	.80	.50	12	3	10	10			
	FR 1	Nondifferential	.97	.97	27	1			18		
	Stubbs–Pliskoff	Nondifferential	.69	.50	63	29			193		
	VI 30	Nondifferential	.77	.74	76	22			180		
	FR 1	Differential	1.0	1.0	29	0				300	—
	VI 30	Differential	.99	.98	85	1				279	—
	Stubbs–Pliskoff	Differential	.87	.49	57	8				215	9
	Stubbs–Pliskoff (rev.)	Unsignaled	.84	.51	10	2	12	5			
	VI 60	Unsignaled	.52	.51	6	6	7	10			
	VI 60	Nondifferential	.58	.53	32	24			105		
	VI 60	Differential	.80	.53	54	13				230	40
T3	FR 1	Unsignaled	.83	.83	4	1	19	1			
	VI 30	Unsignaled	.96	.96	10	0	15	0			
	Stubbs–Pliskoff	Unsignaled	.89	.51	5	1	5	2			
	FR 1	Nondifferential	.94	.94	13	1			16		
	Stubbs–Pliskoff	Nondifferential	.72	.50	26	10			33		
	VI 30	Nondifferential	.97	.97	33	1			35		
	FR 1	Differential	1.0	1.0	26	0				42	—
	VI 30	Differential	.99	1.0	46	0				37	—
	Stubbs–Pliskoff	Differential	.90	.50	37	4				24	0
	Stubbs–Pliskoff (rev.)	Unsignaled	.86	.50	7	1	10	3			
	VI 60	Unsignaled	.95	.77	10	4	10	1			
	VI 60	Nondifferential	.84	.53	32	6			22		
	VI 60	Differential	.94	.59	41	3				42	1
T4	FR 1	Unsignaled	1.0	1.0	26	0	129	0			
	VI 30	Unsignaled	.92	.87	15	1	18	1			
	Stubbs–Pliskoff	Unsignaled	.73	.50	6	2	5	4			
	FR 1	Nondifferential	.68	.68	16	7			21		
	Stubbs–Pliskoff	Nondifferential	.55	.49	36	29			27		
	VI 30	Nondifferential	.77	.76	53	15			32		
	FR 1	Differential	1.0	1.0	39	0				55	—
	VI 30	Differential	.99	.97	60	1				66	—
	Stubbs–Pliskoff	Differential	.87	.51	52	8				72	7
	Stubbs–Pliskoff (rev.)	Unsignaled	.78	.51	4	1	4	2			
	VI 60	Unsignaled	.91	.66	15	1	17	3			
	VI 60	Nondifferential	.60	.52	27	18			10		
	VI 60	Differential	.75	.51	36	12				82	1

APPENDIX A

(*Continued*)

Bird	Choice schedule	Signal contingency	Choice prop.	Obtained rfmt prop.	Response rates (responses/minute): Choice Short	Choice Long	Unsignaled delay Short	Unsignaled delay Long	Nondifferential delay	Differential delay Short	Differential delay Long
B1	FR 1	Unsignaled	.97	.97	5	0	9	0			
	VI 30	Unsignaled	.86	.80	8	1	12	3			
	Stubbs–Pliskoff	Unsignaled	.76	.51	7	2	8	5			
	FR 1	Nondifferential	.87	.87	8	1			6		
	Stubbs–Pliskoff	Nondifferential	.66	.50	49	26			3		
	VI 30	Nondifferential	.98	.98	13	0			0		
	FR 1	Differential	.98	.98	12	0				10	—
	VI 30	Differential	.94	.92	32	2				42	4
	Stubbs–Pliskoff	Differential	.87	.51	49	7				53	2
	Stubbs–Pliskoff (rev.)	Unsignaled	.63	.50	5	3	7	7			
	VI 60	Unsignaled	.85	.64	6	1	13	3			
	VI 60	Nondifferential	.79	.52	66	17			0		
	VI 60	Differential	.77	.53	57	17				16	1
B2	FR 1	Unsignaled	1.0	1.0	39	0	77	0			
	VI 30	Unsignaled	.98	.96	84	2	3	0			
	Stubbs–Pliskoff	Unsignaled	.78	.51	22	6	22	10			
	FR 1	Nondifferential	.93	.93	20	1			0		
	Stubbs–Pliskoff	Nondifferential	.62	.50	42	25			1		
	VI 30	Nondifferential	.95	.92	81	4			0		
	FR 1	Differential	1.0	1.0	52	0				108	—
	VI 30	Differential	.98	.99	64	1				83	—
	Stubbs–Pliskoff	Differential	.68	.50	45	21				94	36
	Stubbs–Pliskoff (rev.)	Unsignaled	.60	.50	8	5	11	9			
	VI 60	Unsignaled	.82	.64	11	2	10	5			
	VI 60	Nondifferential	.60	.51	43	29			0		
	VI 60	Differential	.79	.50	60	16				36	4

APPENDIX B

Data for individual subjects in each condition of Experiment 2. The data are means from the last nine sessions of each condition. FE choice refers to the period of time during a forced-exposure trial prior to initiation of an unsignaled delay.

Bird	Delay condition	Order/ sessions	Choice prop.	Obtained rfmt prop.	Response rates (responses/minute): Choice Short	Choice Long	Unsignaled delay Short	Unsignaled delay Long	FE choice Short	FE choice Long
T1	5/15	1/21	.85	.68	9	1	9	5	14	11
	20/60	2/22	.93	.86	3	0	5	1	5	2
T2	5/15	2/21	.74	.59	10	3	13	8	16	11
	20/60	1/26	.83	.62	14	3	15	7	21	13
T3	5/15	1/20	.91	.78	4	0	7	1	6	2
	20/60	2/20	.85	.74	4	1	5	1	4	2
T4	5/15	2/31	.97	.71	34	1	42	3	34	6
	20/60	1/30	.91	.72	12	1	16	1	11	4
B1	5/15	1/26	.95	.77	10	1	14	2	10	4
	20/60	2/25	.84	.71	5	1	8	3	5	6
B2	5/15	1/20	.77	.66	8	2	5	9	10	8
	20/60	2/28	.93	.84	9	1	7	2	8	3