JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1988, 49, 213–227 NUMBER 2 (MARCH)

CONTROL OF BEHAVIOR BY AN ESTABLISHING STIMULUS

ADAIR MCPHERSON AND J. GRAYSON OSBORNE

UTAH STATE UNIVERSITY

Seventeen pigeons were exposed to a three-key discrete-trial procedure in which a peck on the lit center key produced food if, and only if, the left keylight was lit. The center key was illuminated by a peck on the lit right key. Of interest was whether subjects pecked the right key before or after the response-independent onset of the left keylight. Pecks on the right key after left-keylight onset suggest control of behavior by the left keylight—an establishing stimulus. In three experiments, the strength of center-keylight onset as conditioned reinforcer for a response on the right key was manipulated by altering the size of the reduction in time to food delivery correlated with its onset. Control of pigeons' key pecks by onset of the left keylight occurred on more trials per session when the center keylight was a relatively weak conditioned reinforcer and on fewer trials per session when the center keylight was a relatively strong conditioned reinforcer. Differences across conditions in the degree of control by onset of the establishing stimulus were greatest when changes in conditioned reinforcer strength occurred relatively frequently and were signaled. The results provide evidence of the function of an establishing stimulus.

Key words: establishing stimulus, conditioned reinforcement, conditional conditioned reinforcement, delay-reduction hypothesis, key peck, pigeons

There are antecedent stimuli that control responses that may be neither discriminative nor eliciting stimuli. They are called establishing operations or establishing stimuli, and they presumably serve a fourth stimulus function: In their presence, there is a momentary increase in the probability of a response and in reinforcer strength (for general discussion see Chase & Hyten, 1985; Keller & Schoenfeld, 1950; Leigland, 1984; Michael, 1982; Millenson, 1967, p. 367). According to Michael (1982), *establishing operations* increase the reinforcing strength of *unconditioned reinforcers,* and *establishing stimuli* increase the strength of *conditioned reinforcers.* Because the research presented here examines putative changes in conditioned reinforcer strength, the discussion focuses on the control of behavior by establishing stimuli.

The presence of an establishing stimulus increases the conditioned reinforcing strength of some stimulus that follows a response, increasing the probability of that response (McPherson & Osborne, 1986; Michael, 1982). This conception implies that the effectiveness of a particular event as a conditioned reinforcer may depend upon the status of the relevant establishing stimulus. The control by an establishing stimulus is different than control by a conditional discriminative stimulus. A conditional discriminative stimulus controls responding as a result of being correlated with different three-term contingencies (Sidman, 1986). It clarifies which of several possible responses will be followed by reinforcement when it conditionally increases the effectiveness of a particular event as a discriminative stimulus (Sidman, 1986). In contrast, an establishing stimulus alters the probability of a response when it conditionally increases the effectiveness of a particular event as a conditioned reinforcer.

Using a three-key discrete-trial procedure with pigeons, McPherson and Osborne (1986) set up the basic features of an establishing stimulus relation to determine whether responding would be consistent with theoretical descriptions of behavior controlled by an establishing stimulus (see Michael, 1982). At the beginning of each trial, the right keylight was lit. The first peck on the lit right key produced the onset of the center keylight. Center-keylight onset was the putative conditioned reinforcer for such a response. Approximately 60 s after trial onset, the left keylight was lit. In the presence of the left keylight (an establishing stimulus), a peck on the lit center key produced food. Subjects could peck the right key

This research was conducted by the first author in partial fulfillment of the requirements for a Ph.D. degree at Utah State University under the supervision of the second author. A special thanks is extended to Lisa Abraham for help with data collection. Reprints may be obtained from Adair McPherson, 527 N. Treat, Tucson, Arizona 85716, or J. Grayson Osborne, Psychology Department, UMC 28, Utah State University, Logan, Utah 84322.

(thus lighting the center key) before or after left-keylight onset without affecting the probability or rate of food delivery. However, all three keylights had to be lit before a peck on the center key could produce food. Of interest was how strongly behavior was controlled by the establishing stimulus; that is, on how many trials per session did the first peck on the right key occur only after left-keylight onset.

Although left-keylight onset may have functioned as a discriminative stimulus for a response on the center key, its onset was not a discriminative stimulus for a response on the right key: A peck on the right key was as likely to be followed by center-keylight onset in the presence of the left keylight as in its absence. Instead, left-keylight onset was thought to function as an establishing stimulus. That is, in its presence, there was an increase in the probability of a right-key response, presumably because there was an increase in the reinforcing effectiveness of center-keylight onset. Such an increase is consistent with descriptions of the control of behavior by an establishing stimulus (McPherson & Osborne, 1986; Michael, 1982).

Responding of all 4 subjects showed development of control by the establishing stimulus (McPherson & Osborne, 1986); they eventually produced the center keylight after onset of the left keylight on the majority of the trials presented each session. Three of the 4 subjects continued to produce the center keylight primarily in the presence of the establishing stimulus throughout the experiment.

If these subjects rarely produced the center keylight in the absence of the establishing stimulus, then center-keylight onset presumably functioned as a relatively weak conditioned reinforcer until it was potentiated by the establishing stimulus. Although research on control by establishing stimuli is scant, much exists on the development of conditioned reinforcers (e.g., Dinsmoor, 1983; Fantino, 1977, 1981). An understanding of how a stimulus may come to function as a conditioned reinforcer, or, as seemed to be the case in McPherson and Osborne (1986), why a stimulus functions weakly as such, may clarify the conditions responsible for the apparent control of responding by an establishing stimulus.

According to the delay-reduction hypothesis of conditioned reinforcement, the strength of a conditioned reinforcer relates to the relative size of the reduction in time to unconditioned reinforcement correlated with its onset (e.g., Case & Fantino, 1981; Case, Fantino, & Wixted, 1985; Fantino, 1977, 1981). The greater the reduction in time to unconditioned reinforcement correlated with stimulus onset, the greater the conditioned reinforcing strength that stimulus acquires. If this is the case, then the size of the reduction in time to unconditioned reinforcement correlated with the earliest possible onset of the center keylight in the experiments of McPherson and Osborne (1986) may have determined the extent to which onset of the center keylight functioned as a conditioned reinforcer for a response on the right key. The relative size of that reduction can be calculated as $100\% [1 - (T/IRI)]$ where T is the mean time between the earliest possible onset of the center keylight and food delivery, and IRI is the mean time between food deliveries for the procedure as a whole—that is, the mean interreinforcement interval. In McPherson and Osborne (1986), T was 60 s for all 4 subjects. For 2 subjects the IRI was 60 s; for the other 2 it was 70 s. Hence, the earliest possible onset of the center keylight was correlated with either a 0% $\{100\% [1 - (60/60)] = 0\%\}$ or 14% $\{100\% [1 - (60/70)] = 14\%\}$ relative reduction in time to food delivery. According to the delay-reduction hypothesis, onset of the center keylight functioned as a relatively weak conditioned reinforcer because of the small or nonexistent reduction in time to food delivery with which it was correlated.

It was in keeping with this prediction that subjects rarely produced the center keylight soon after trial onset (McPherson & Osborne, 1986). However, if procedures are changed so that the earliest possible onset of the center keylight is correlated with a larger reduction in time to unconditioned reinforcement, greater conditioned reinforcing strength may emerge. If onset of the center keylight functions as a more powerful conditioned reinforcer independent of the presence of the establishing stimulus, there may be more trials per session on which the center keylight is produced in the absence of the establishing stimulus.

The purpose of the three experiments presented here was to clarify the relation, if any, between the strength of the nominal conditioned reinforcer, independent of the establishing stimulus, and subsequent control of re-

sponding by the establishing stimulus. Experiment 1 determined whether manipulation of the center keylight's conditioned reinforcing strength had any effect on the development or maintenance of control by the establishing stimulus. Experiments 2 and 3 clarified the separate roles of relatively frequent and signaled changes in the center keylight's conditioned reinforcing strength in affecting the control exerted by the establishing stimulus.

EXPERIMENT 1

Subjects in this experiment were exposed alternately to one of two conditions in which the mean IRI stayed the same, but the size of the reduction in time to food delivery correlated with the earliest possible onset of the center keylight was either relatively large or small. In the 86% reduction condition, earliest possible onset of the center keylight was correlated with an 86% reduction in time to food delivery and thus should function as a relatively powerful conditioned reinforcer. In contrast, the earliest possible onset of the center keylight was correlated with a 14% reduction in time to food delivery in the 14% reduction condition and thus should function as a relatively weak conditioned reinforcer. Stronger control of right-key responding by onset of the establishing stimulus, as gauged by the number of trials per session with a response on the right key only after left-keylight onset, was anticipated in the 14% reduction condition.

METHOD

Subjects

Five experimentally naive White Carneau pigeons maintained at 80% of their free-feeding body weights served as subjects.

Apparatus

Four identical three-key chambers were used. Each chamber was 30 cm long, 22 cm wide, and 30 cm high. Subjects were always studied in the same chamber. Three standard response keys were mounted horizontally on one wall of each chamber, 16 cm above the floor and 5 cm apart. A minimum force of 0.2 N was required to operate the keys. Hues were produced by passing light from GE 1820 bulbs through Wratten filters. During autoshaping the center keylight was nominally green (Wratten Filter No. 56, principal wavelength = 555.5 nm); during the establishing stimulus procedure all three keylights were nominally red (Wratten Filter No. 23A, principal wavelength = 605.5 nm). A food hopper in each chamber was centered 9 cm below the response keys and provided access to mixed grain. When raised, the hopper was illuminated by a GE 1820 bulb. A houselight was centered 7 cm above the response keys and reflected toward the ceiling. Each chamber was housed in a sound-attenuating box with a fan that provided ventilation and masking noise. Sessions were controlled by Commodore® VIC 20 microcomputers with associated interfacing (Crossman, 1984).

Procedure

Autoshaping. Following magazine training, subjects were exposed to a response-independent autoshaping procedure. A 60-s intertrial interval (ITI) was followed by onset of the center keylight. After the center keylight was lit for 6 s, it turned off and the food magazine was raised for 3 s, during which time subjects had access to mixed grain. At the end of the 3 s, the ITI was reinstated. Subjects were exposed to the autoshaping procedure until the center key was pecked on 30 of 50 possible trials in one session.

Establishing stimulus procedure. Figure 1 depicts the procedure used here. Contrasted in Panels A and B are the two response alternatives allowed by the procedure. Trials were preceded by ITIs of randomly selected lengths (RT), during which all keys were dark. After the ITI, the right keylight was lit. The first peck on the right key resulted in onset of the center keylight, the supposed conditioned reinforcer for the right-key response. Subsequent pecks on the right key had no scheduled effect. The length of the interval between right- and left-keylight onsets was controlled by a clock. When this randomly selected interval expired, the left keylight was lit. The center keylight could be produced before (Panel B) or after (Panel A) onset of the left keylight. However, in the absence of the left keylight, pecks on the lit center key had no scheduled consequence. A peck on the lit center key was followed by food only in the presence of the left keylight, the nominal establishing stimulus. When this peck occurred, the food magazine was raised

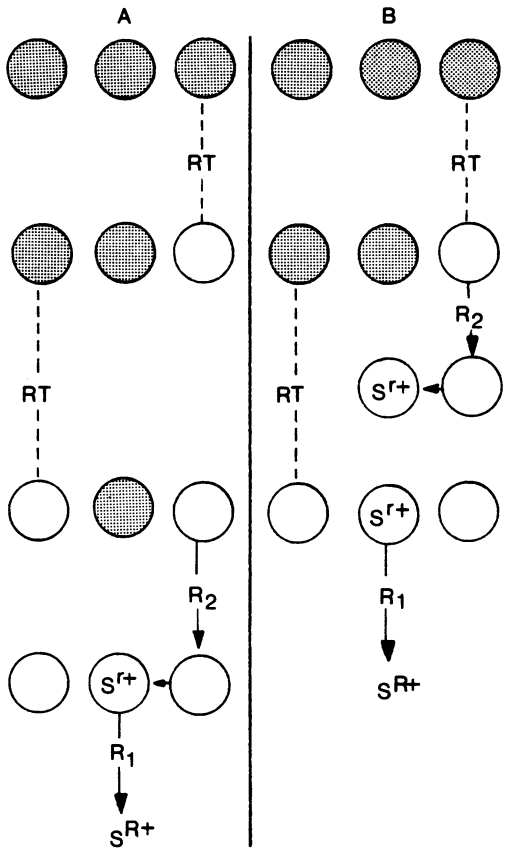

Fig. 1. Both panels illustrate the three-key procedure used here. However, Panel A depicts events that occurred when subjects pecked the right key after left-keylight onset. Panel B depicts events that occurred when subjects pecked the right key before left-keylight onset. Hatched circles represent unlit keys. After a mean ITI of either 12 or 72 s (RT), the beginning of a trial was marked by onset of the right keylight. Left-keylight onset was response independent and followed right-keylight onset by an average of 12 or 72 s (RT), depending on the condition. Pecks on the lit center key were followed by food delivery only in the presence of the left keylight. Subjects could produce center-keylight onset before (Panel B) or after (Panel A) the onset of the left keylight and still receive food approximately every 84 s.

and provided 3-s access to mixed grain. At the end of the 3 s, the ITI was reinstated. There were 50 trials per session.

The length of time between right- and left-keylight onsets constituted the trial length. Trial lengths ranged between 6 and 18 s (M = 12 s) or between 36 and 108 s (M = 72 s) depending on the condition. When the mean trial length was 12 s, the mean ITI was 72 s, and vice versa. Hence, the mean IRI was 84 s in both conditions. When the mean trial length was 12 s, the earliest possible onset of the center keylight was correlated with an 86% reduction in time to food delivery {100% [1 − (12/84)] = 86%}. By changing the mean trial length to 72 s, the size of the reduction in time to food delivery correlated with the earliest possible onset of the center keylight decreased to 14%, that is {100% [1 − (72/84)] = 14%}. Based on our interpretation of the delay-reduction hypothesis, onset of the center keylight should function as a more powerful conditioned reinforcer when correlated with the larger reduction in time to food delivery. Hence, more trials with a response on the right key before onset of the left keylight were anticipated in the 86% reduction condition. This result was expected even though there was less time in the 86% than in the 14% reduction condition (a mean of 12 s, as opposed to a mean of 72 s) to emit a right-key response before left-keylight onset.

After an initial exposure to the first condition of at least 35 sessions, conditions changed approximately every 10 sessions. Subjects initially exposed to a mean trial length in which the earliest possible onset of the center keylight was correlated with an 86% reduction in time to food delivery were subsequently exposed to a 14% reduction, and vice versa. For each subject, conditions changed a minimum of three times.

Subsequent training procedures. Because the responding of 2 subjects did not change when conditions changed, one of two additional procedures was initiated. The purpose of the TRAIN-A procedure was to increase the number of trials with responses on the right key only after left-keylight onset when the 14% reduction condition was in effect. In this procedure, the center keylight was lit throughout the IRI. By lighting the center key continuously, it was assumed that its conditioned reinforcing strength would be disrupted so that control of responding on the right key by left-keylight onset could occur.

The TRAIN-B procedure was designed to increase the number of trials with responses on the right key before food was available when the 86% reduction condition was in effect. During this procedure, the left keylight remained lit throughout the IRI. Thus, other than the passage of time, there was no signal as to when a peck on the center key would be followed by food delivery. We assumed that

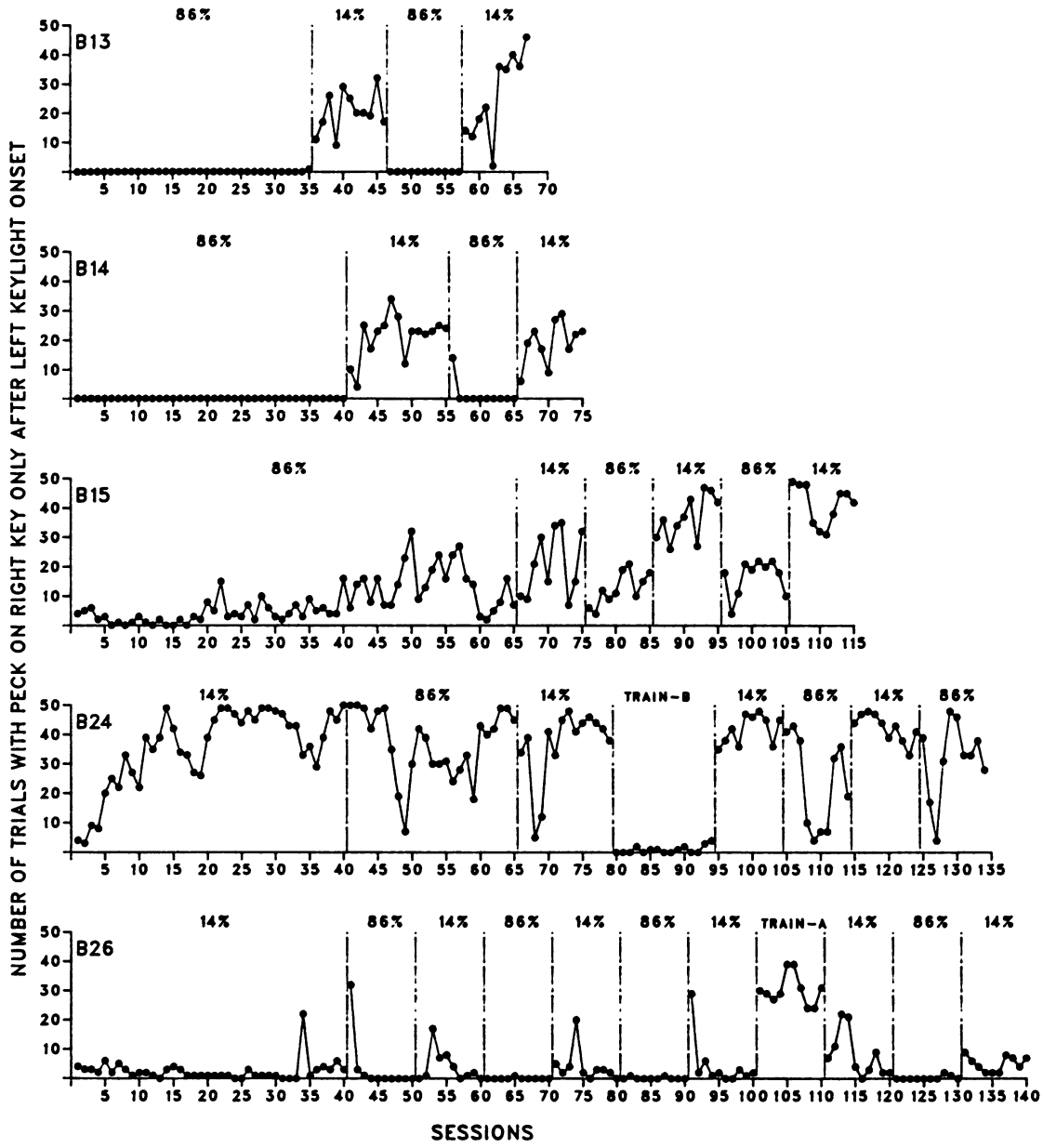

Fig. 2. Number of trials per session in which subjects in Experiment 1 produced the center keylight only after establishing-stimulus onset. The percentages across the top of each plot specify the delay-reduction condition in effect. The TRAIN-A and TRAIN-B conditions are described in the text.

this procedure would increase pecking on the right key soon after that keylight was lit.

Results

Figure 2 shows the number of trials of the 50 presented each session on which subjects pecked the right key only after left-keylight onset. For the 3 subjects initially exposed to the 86% reduction condition (B13, B14, and B15), the number of such trials was always higher when the 14% reduction condition was in effect. When the 86% reduction condition was in effect, the number of these trials per session decreased. For Subjects B24 and B26 (initially exposed to the 14% reduction condition), changes in conditions were not fol-

lowed by lasting changes in the number of trials per session on which subjects pecked the right key only after left-keylight onset. With few exceptions after Session 20, Subject B24 pecked the right key after left-keylight onset on a majority of all trials no matter which condition was in effect. Subject B26 pecked the right key in the absence of the left keylight on the majority of trials. Introduction of the 14% reduction condition resulted in an immediate but short-lived increase in the number of trials with responses on the right key only after left-keylight onset. However, that number soon returned to earlier, near-zero levels.

Although separated by blocks of sessions during which the 86% reduction condition was in effect, during the 14% reduction conditions there was an increase across sessions in the number of trials with responses on the right key only after left-keylight onset for Subjects B13 and B15. Data for Subject B24 showed a similar increase across the first 30 sessions. With the exception of Subject B15, no equivalent evidence of change in control of right-key responding by left-keylight onset was noted in the 86% reduction conditions.

The training procedure used with Subject B24 was designed to decrease the number of trials with a peck on the right key only after left-keylight onset when the 86% reduction condition was in effect (TRAIN-B). The number of these trials decreased during exposure to the procedure, and was more variable during subsequent 86% reduction conditions. However, the differences across the last four conditions in the number of trials with pecks on the right key after left-keylight onset were small.

Subject B26 was exposed to a training procedure designed to increase responding exclusively in the presence of the establishing stimulus when the 14% reduction condition was in effect (TRAIN-A). While exposed to the procedure, the number of trials with pecks on the right key after left-keylight onset increased, but decreased to previously obtained levels during subsequent 14% reduction conditions. This procedure produced a small, short-lived increase in the number of trials per session on which subjects pecked the right key only after left-keylight onset.

The data presented here replicate and extend those of McPherson and Osborne (1986). As measured by the number of trials with responding on the right key only after left-keylight onset, the acquisition of a relatively large degree of control by the establishing stimulus was observed in the data of 4 of the 5 subjects in Experiment 1 when the 14% reduction condition was in effect. Subjects were more likely to wait until left-keylight onset before pecking the right key in the 14% than in the 86% reduction condition, even though the mean time between right- and left-keylight onsets was 72 s rather than 12 s. It is the 14% reduction condition that more closely resembles the procedure used by McPherson and Osborne (1986). During the last 14% reduction condition, Subjects B13, B14, B15, and B24 pecked the right key after onset of the left keylight on 53%, 38%, 83%, and 85% of the trials to which they were exposed, respectively. Subject B26 also pecked the right key only after the onset of the left keylight on more trials in the 14% than in the 86% reduction condition. However, these trials constituted only 10% of all the trials to which the subject was exposed in the last 14% reduction condition.

Discussion

These data suggest that there may be an inverse relation between the strength of the conditioned reinforcer and the number of trials per session in which responses are controlled by the establishing stimulus. Conditions that should have made center-keylight onset function as a relatively potent conditioned reinforcer independent of the left keylight generated the fewest trials in which the right key was pecked only after left-keylight onset. In contrast, when conditions favored the center keylight functioning as a relatively weak conditioned reinforcer, a peck on the right key was more likely to occur only after onset of the left keylight. Such control is expected if the left keylight functions as an establishing stimulus.

The responding of Subjects B24 and B26 raises questions about the generality of the possible relation between conditioned reinforcer strength and control of responding by an establishing stimulus. Training that was designed to affect the number of trials with responses on the right key only after left-keylight onset was minimally effective. A second experiment was conducted to determine if earlier and more frequent condition changes would result in more consistent differences across conditions in the number of trials per session

on which subjects responded in the presence of the left keylight.

EXPERIMENT 2

Six subjects were exposed to a procedure in which the size of the reduction in time to unconditioned reinforcement correlated with center-keylight onset changed every 5 or 10 sessions. Because the responding of subjects initially exposed to a 14% reduction condition in Experiment 1 failed to change when conditions changed, all subjects in Experiment 2 were exposed initially to the 14% reduction condition. The purpose of the experiment was to determine whether earlier and more frequent condition changes would result in larger differences across conditions in the number of trials on which subjects pecked the right key only after left-keylight onset.

Method

Subjects and Apparatus

Six locally bred homing pigeons served. All were experimentally naive and maintained at 80% of free-feeding weights. The same equipment used in Experiment 1 was used in Experiment 2.

Procedure

The procedure was identical to that used in Experiment 1, with the following exceptions. Three subjects (B31, B32, and B33) alternated conditions every 5 days for a total of 40 sessions. Conditions for the remaining 3 subjects (B34, B35, and B36) alternated every 10 sessions for a total of 60 sessions. For Subjects B31 and B34 all keylight colors were nominally blue (Wratten Filter No. 38; principle wavelength = 494.3 nm); for Subjects B32, B33, B35, and B36 all keylight colors were nominally red (Wratten Filter No. 23A; principle wavelength = 605.5 nm).

Results

The results are presented in Figure 3. For all subjects, there were few trials during the first 14% reduction condition with a peck on the right key after left-keylight onset. The exception was Subject B33, who pecked the right key after left-keylight onset on the majority of all trials presented during Sessions 4 and 5 of the first 14% reduction condition. After additional sessions, Subjects B31, B32, and B34 also came to peck the right key in the presence of the establishing stimulus on more trials per session in the 14% than in the 86% reduction conditions. For all subjects, the number of such trials per session was near zero during every 86% reduction condition. For Subjects B35 and B36, the number of trials with responses on the right key only after left-keylight onset was near zero regardless of condition.

Five-day alternations of the center keylight's conditioned reinforcing strength produced larger and more consistent cross-condition differences in the number of trials with responses on the right key only after left-keylight onset than did the 10-day alternations. The responding of all 3 subjects exposed to 5-day alternations eventually showed clear differences across conditions in the number of trials with responses on the right key after left-keylight onset. However, for the 3 subjects exposed to 10-day alternations, only the data for Subject B34 showed a difference in the numbers of such trials across conditions. The responding of Subjects B35 and B36 paralleled that of Subject B26 in Experiment 1. Each pecked the right key before left-keylight onset on most trials regardless of the condition in effect.

Data obtained with 4 of the 6 subjects (B31, B32, B33, and B34) in Experiment 2 reflect differential control of responding across 14% and 86% reduction conditions by the establishing stimulus. This finding replicates the general results from Experiment 1 and from McPherson and Osborne (1986). When center-keylight onset should have functioned as a relatively strong conditioned reinforcer (86% reduction condition), there were fewer trials with responses on the right key only after left-keylight onset. When center-keylight onset should have functioned as a relatively weak conditioned reinforcer (14% reduction condition), there were more trials with responses on the right key only after left-keylight onset. On these trials, subjects responded as if center-keylight onset functioned as a conditioned reinforcer only after onset of the establishing stimulus.

Discussion

The results of Experiment 2 are more consistent with our earlier predictions about the relation between conditioned reinforcer strength and control of responding by an es-

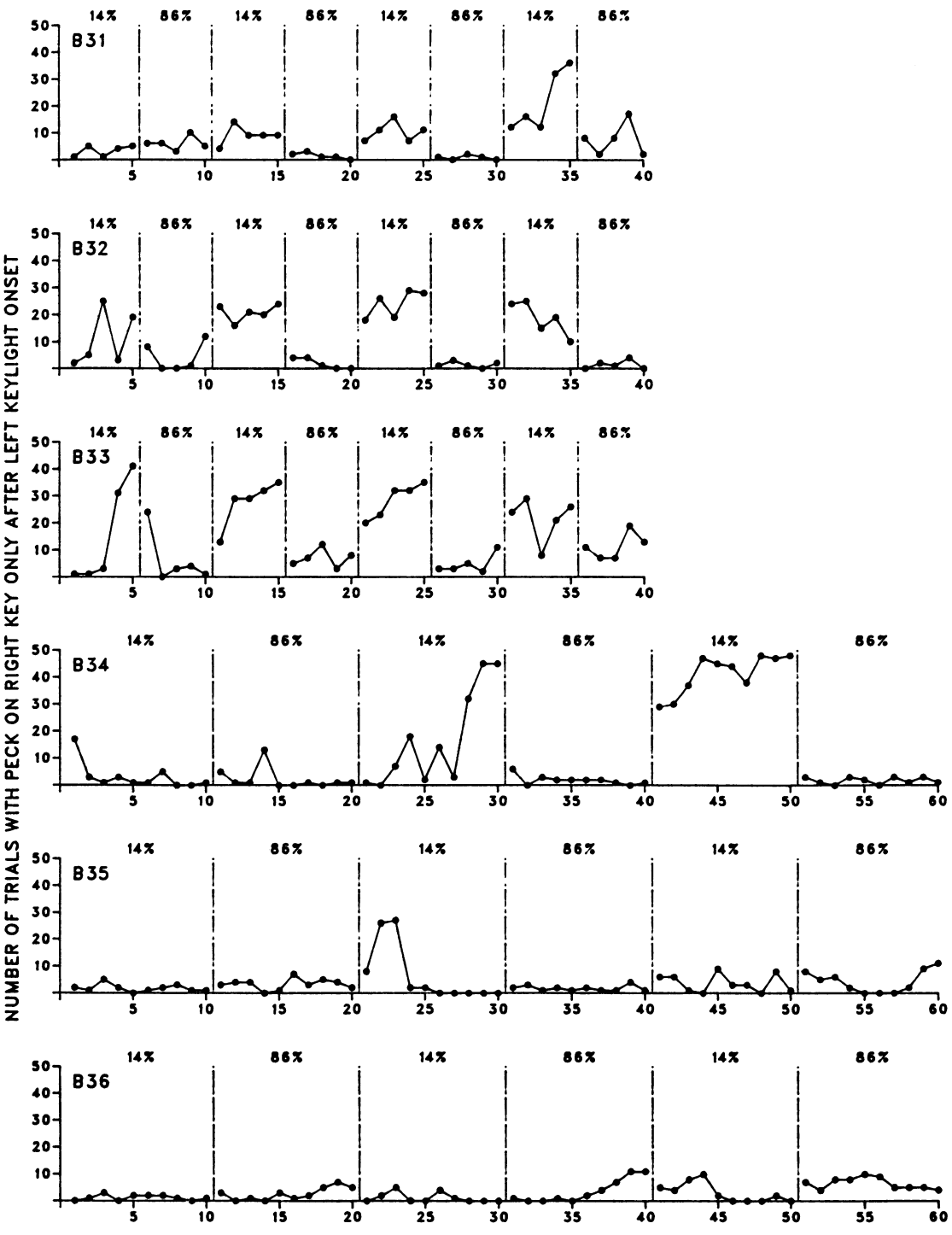

Fig. 3. Number of trials per session in which subjects in Experiment 2 produced the center keylight only after establishing-stimulus onset. The percentages across the top of each plot specify the delay-reduction condition in effect.

tablishing stimulus than were those obtained from the 2 subjects in Experiment 1 that were initially exposed to the 14% reduction condition (B24 and B26). In Experiment 2, 4 of 6 subjects pecked the right key after left-keylight onset on more trials in the 14% than in the 86% reduction conditions even though they were all initially exposed to the 14% reduction condition. All 3 subjects exposed to five-session alternations of conditions responded as if control by the establishing stimulus was stronger in the 14% reduction condition. Attention in Experiment 3 turned to further modification of the procedure to determine whether more consistent results could be obtained across conditions and subjects in the control of behavior by an establishing stimulus.

EXPERIMENT 3

Results from previous research show that greater response differences emerge across experimental conditions when conditions are correlated with different stimuli, for example, different keylight colors (e.g., Navarick & Fantino, 1976; Williams & Fantino, 1978). In Experiments 1 and 2, keylight colors were the same regardless of the condition in effect. In Experiment 3, the two delay-reduction conditions were correlated with separate sets of keylight colors to assess whether signaled changes in delay-reduction values would result in more consistent differences across conditions in the number of trials on which responding on the right key occurred only after onset of the left keylight.

METHOD

Subjects and Apparatus

Six locally bred homing pigeons served as subjects. All were experimentally naive and were maintained at 80% of their free-feeding body weights. The equipment was the same as that used in Experiments 1 and 2.

Procedure

The procedure was the same as that used in Experiment 2, except that for Subjects B41 and B45, keylights were red in the 14% reduction condition and blue in the 86% reduction condition. For Subjects B42, B43, B44, and B46, keylights were blue in the 14% reduction condition and red in the 86% reduction condition. Conditions changed every five sessions for Subjects B42 and B43 for a total of 40 sessions. Subject B41 was exposed to a total of 50 sessions so that responding in an additional 14% reduction condition could be observed. For Subjects B44, B45, and B46, conditions changed every 10 sessions for a total of 60 sessions.

RESULTS AND DISCUSSION

Figure 4 presents the number of trials, of the 50 presented each session, on which subjects pecked the right key only after left-keylight onset. All subjects pecked the right key only after onset of the left keylight on more trials during the 14% than during the 86% reduction condition. There was minimal overlap in the number of such trials recorded across conditions. With one exception (Subject B41, first condition change) the number of trials with responses on the right key after left-keylight onset decreased when the 86% reduction condition was introduced and, without exception, increased when a 14% reduction condition began. The data for all subjects show an initial systematic increase across the 14% reduction condition in the number of trials per session with a response on the right key after left-keylight onset. There was a subsequent decrease in such trials for Subjects B42 and B43; however, there continued to be more trials per session with responses on the right key after left-keylight onset in the 14% reduction condition. These results systematically replicate the results of Experiments 1 and 2 and those of McPherson and Osborne (1986).

Different response patterns emerged under the 14% and 86% reduction conditions. To illustrate those differences, Figure 5 shows, for Subject B44, the cumulative number of responses made during each of the four possible keylight combinations in Sessions 1 to 60. Data from this subject were used because its performance, with regard to cumulative number of responses made during different keylight combinations, was reflective of and intermediate to other subjects' performances. Bars within individual plots are stacked to depict the total number of responses that occurred during a particular keylight combination. The possible keylight combinations were right keylight (R); center and right keylights (CR); left and right keylights (LR); and left, center, and right keylights (LCR).

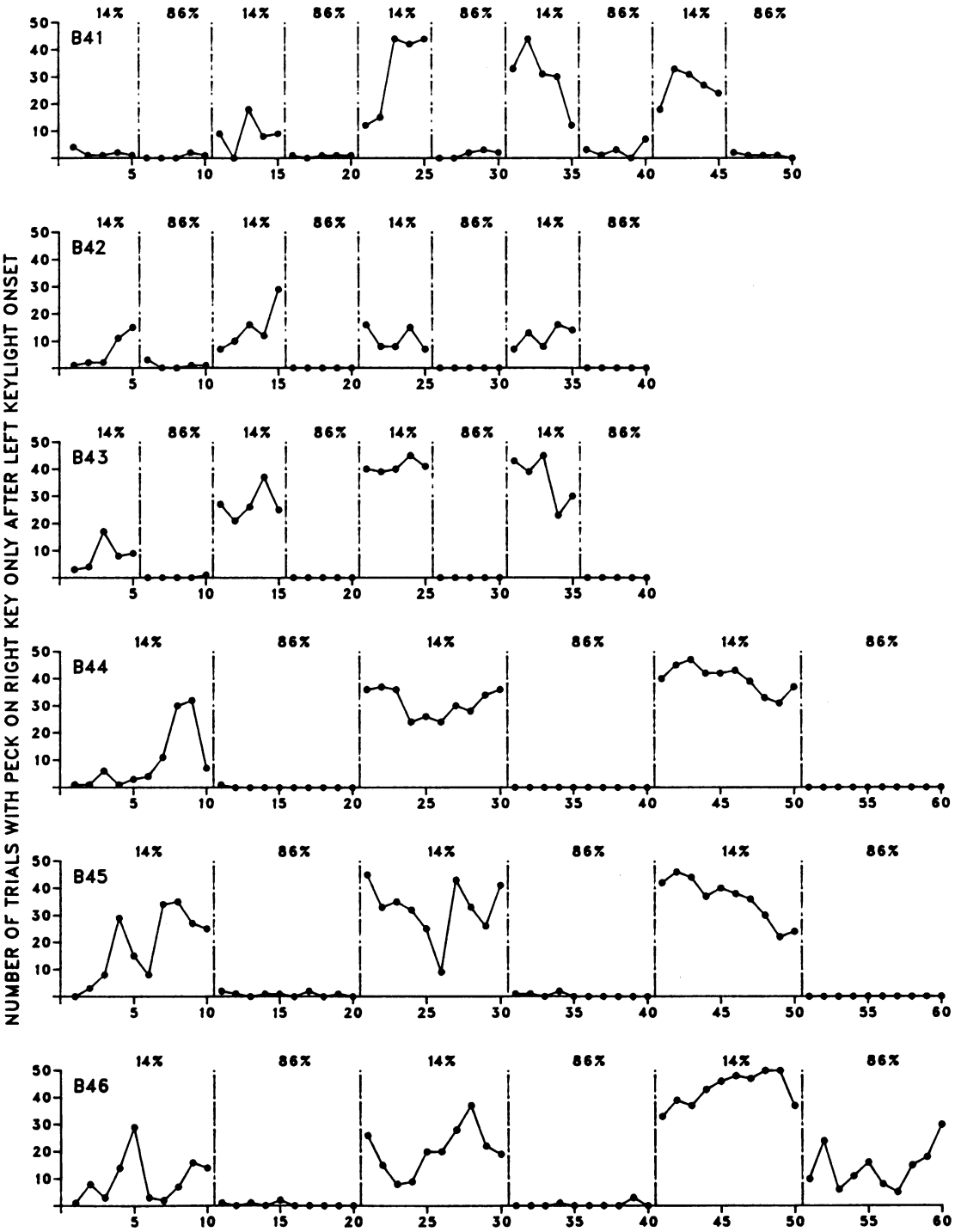

Fig. 4. Number of trials per session in which subjects in Experiment 3 produced the center keylight only after establishing-stimulus onset. The percentages across the top of each plot specify the delay-reduction condition in effect.

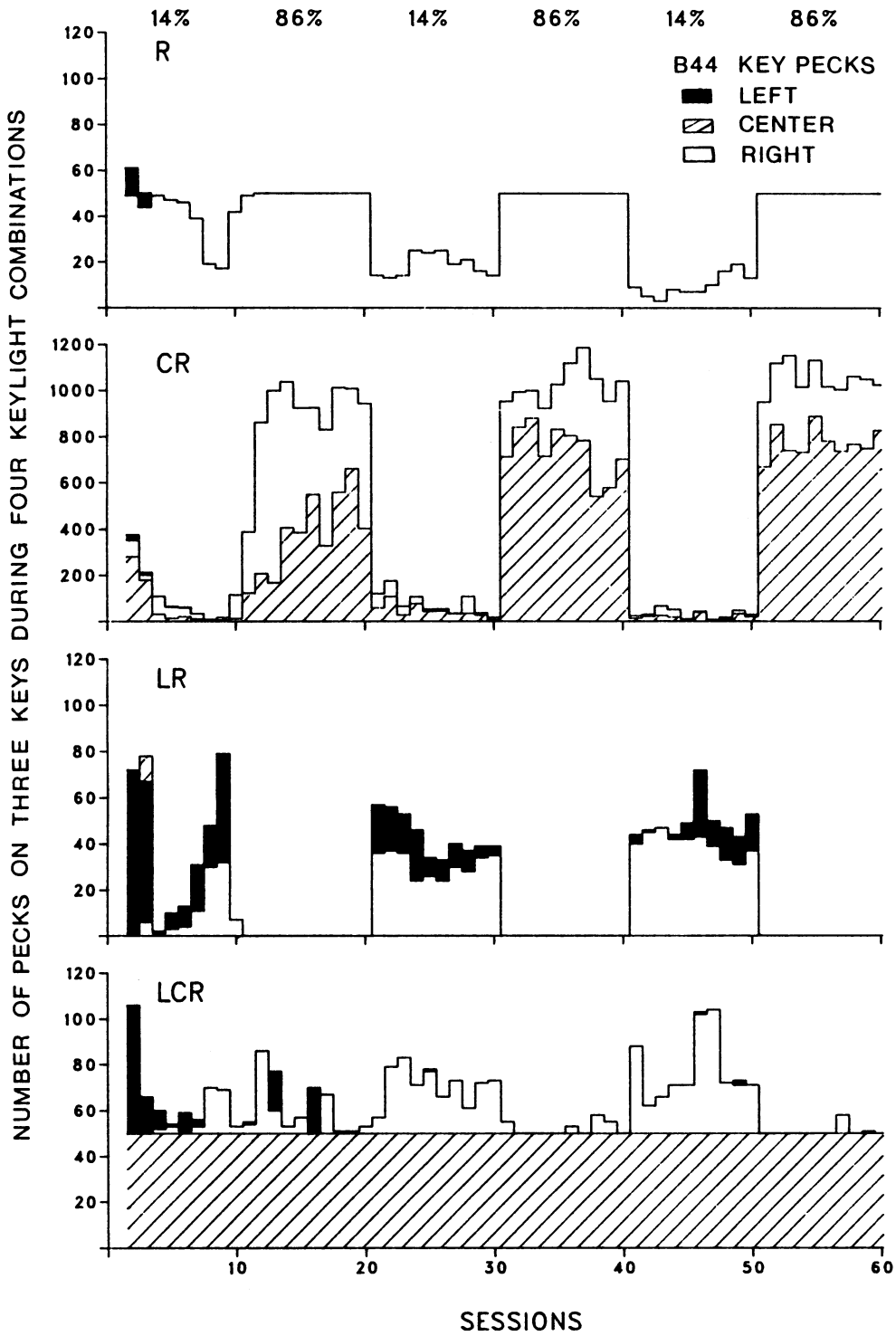

Fig. 5. Cumulative number of responses made by Subject B44 across sessions on each key during the four possible keylight combinations. Those combinations are right only (R); center and right (CR); left and right (LR); and left, center, and right (LCR). The bars are stacked, so that the total height of a bar indicates total key pecks in the given session.

All keylights were dark and no pecks occurred during the ITI. Regardless of the condition in effect, each trial began with onset of the right keylight. Hence, Subject B44 was exposed to the right keylight alone (R) 50 times each session. The right keylight remained the only keylight lit until either the response-independent onset of the left keylight (changing the keylight combination to LR) or the response-dependent onset of the center keylight (changing the keylight combination to CR). When the 86% reduction condition was in effect, Subject B44 always produced the center keylight shortly after right-keylight onset. Because there were 50 trials per session, there are usually 50 right-key responses recorded on the R plot when the 86% reduction condition was in effect. When the 14% reduction condition was in effect, there were fewer responses on the right key when it was the only key lit. Except during the first two sessions, there were no responses on the left and center dark keys.

Because there were trials every session in which Subject B44 pecked the right key before left-keylight onset, there were also trials every session in which the CR keylight combination occurred. Responding during this keylight condition occurred primarily on the center key and secondarily on the right key. (Note the difference between the scaling of the ordinate on the CR plot and all other ordinates.) There was an order of magnitude difference in the number of responses emitted when this keylight combination was in effect. No responding on the dark left key was recorded during the CR keylight combination.

If Subject B44 did not peck the right key before the response-independent onset of the left keylight, it was eventually exposed to the LR keylight combination. When the 86% reduction condition was in effect, Subject B44 usually pecked the right key before onset of the left keylight, precluding the possibility that the LR keylight combination could occur. Thus, there was little or no responding recorded on the LR plot when the 86% reduction condition was in effect. During the 14% reduction condition, the LR keylight combination occurred in most trials. The data in the LR plot show that Subject B44 sometimes pecked the lit left key before pecking the lit right key. Left-key responses were necessarily emitted before right-key responses because the first peck on the right key changed the keylight combination to LCR. The maximum number of right-key responses that could occur during the LR stimulus combination was 50—one per trial.

Because the first response on the center key in the LCR keylight combination resulted in food delivery, there were always exactly 50 such responses each session, regardless of the condition in effect. However, Subject B44 sometimes pecked the left and right keys before pecking the center key. More such responding occurred during the 14% than during the 86% reduction condition.

The most interesting data are those in the CR plot, particularly because they are orthogonal to data on the number of trials per session with responding only after establishing stimulus onset: Response differences were not required, simply because the subject either did or did not peck the right key until after onset of the establishing stimulus. As previously stated, the differences in the number of responses that occurred across the 14% and 86% reduction conditions when the CR keylight combination was present were larger than can be accounted for by the differences in the number of trials in which the CR keylight combination occurred. During the last 14% reduction condition, Subject B44 emitted a mean of two center-key responses per trial when the CR keylight combination was present. During the last 86% reduction condition, Subject B44 emitted a mean of 16 center-key responses per trial when the CR keylight combination occurred. This higher number of responses per trial occurred even though there was less time to respond in the 86% reduction condition. With a mean of 12 s and 72 s between right- and left-keylight onsets in the 86% and 14% reduction conditions, respectively, there was more time during the 14% reduction condition for subjects to peck the center key. Nevertheless, the number of center-key pecks per trial was consistently higher in the 86% reduction condition. Although the majority of the pecks that occurred during the CR keylight combination occurred on the center key, Figure 5 shows that there was also substantial responding on the right key.

Although these data are independent of data showing the numbers of trials on which responding was controlled by the establishing stimulus, they also suggest that stimulus functions changed across conditions. These data are

consistent with the center-keylight onset having functioned relatively weakly as a conditioned reinforcer in the 14% reduction condition. Even though there were trials in the 14% reduction condition on which the right key was pecked before establishing stimulus onset, very little responding occurred on either the right or center keys while the CR keylight combination was present. Not only were there more trials with responses on the right key before establishing-stimulus onset during the 86% reduction condition, there was also more responding on the center and right keys.

GENERAL DISCUSSION

An establishing stimulus evokes responding because it empowers or establishes an event as a conditioned reinforcer when that event does not already function as such (Chase & Hyten, 1985; Keller & Schoenfeld, 1950; Leigland, 1984; McPherson & Osborne, 1986; Michael, 1982; Millenson, 1967). In its presence there is an increase in the conditioned reinforcing strength of a particular event such that the response upon which conditioned reinforcement is contingent occurs. In the three experiments presented here, responding was observed across two conditions in which, independent of the nominal establishing stimulus, onset of the center keylight appeared to function to a greater or lesser extent as a conditioned reinforcer. When the earliest possible onset of the center keylight was correlated with the larger reduction in time to food delivery, the center keylight was produced shortly after trial onset in a majority of trials per session despite the absence of the putative establishing stimulus. However, when correlated with the smaller reduction in time to food delivery, onset of the center keylight did not occur in most trials per session until after onset of the putative establishing stimulus. In the smaller delay-reduction condition, subjects were more likely to respond as if the conditioned reinforcing strength of the center keylight depended upon the presence of the establishing stimulus. This outcome was observed in the responding of 13 of the 17 subjects in the experiments presented here.

Differences across conditions in the control of responding by establishing-stimulus onset were greatest in Experiment 3. The use of signaled, earlier, and more frequent condition changes produced the largest and most consistent response differences across conditions. Unsignaled changes of experimental conditions were moderately effective in controlling the development and maintenance of an establishing-stimulus function, especially when conditions changed every five sessions. Of the 11 subjects exposed to unsignaled changes in delay-reduction values in Experiments 1 and 2, the responding of 7 reflected control by those manipulations. Such results, however, are not as compelling as those of Experiment 3, in which signaled changes in delay-reduction values produced immediate differential responding across conditions by all 6 subjects.

In the 14% reduction conditions of these experiments, the center keylight's role as a conditioned reinforcer seemed to be conditional in most trials on the presence of the left keylight, the establishing stimulus. Although center-keylight onset alone was not a powerful enough conditioned reinforcer to support a response on the right key, with onset of the left keylight there seemed to be a momentary increase in its conditioned reinforcing strength so that a peck on the right key occurred. When the 86% reduction condition was in effect, center-keylight onset seemed to function as a conditioned reinforcer independent of the presence or absence of the left keylight. Presumably, if an event already functions as a strong conditioned reinforcer, there may be little control observed by a presumed establishing stimulus.

There are several ways to discuss the results obtained in the 14% reduction condition that do not require incorporation of the establishing stimulus function. One way is to suggest that the discriminative stimulus was inaccurately identified: Perhaps the discriminative stimulus for a response on the right key was actually onset of the right- and left-keylight combination. However, the probability of center-keylight onset was the same whether the right key was pecked in the presence of the right key alone or in the presence of the right- and left-keylight combination. Hence, that keylight combination does not satisfy the definition of discriminative stimulus for a right-key response.

Alternatively, perhaps onset of the left keylight served as a discriminative stimulus for a two-response chain: first peck right, then peck center (Michael, 1982). Another account might be that the conditioned reinforcer in the 14%

reduction condition was inaccurately identified (Michael, 1982). The functional conditioned reinforcer for a response on the right key may have been onset of the center keylight in the presence of the left- and right-keylight combination. Each of these accounts avoids the introduction of an establishing stimulus function, but implies a more complicated view of some aspect of the three-term contingency (Michael, 1982). If any one part of the three-term contingency can be reconceptualized to account for the behavior observed here, which part should be reconceptualized? It seems conceptually simpler, and therefore preferable, to say that in the 14% reduction condition, onset of the left keylight functioned as an establishing stimulus. The probability of a response increased, and there was a momentary increase in the strength of the nominal conditioned reinforcer.

As measured here, there were differences in the development of responding across the 14% and 86% reduction conditions. With most subjects, there was an increase across sessions in the number of trials in which subjects pecked the right key only after left-keylight onset when the 14% reduction condition was in effect. No concomitant change was observed across sessions in which the 86% reduction condition was in effect. Whether after initial or extended exposure to the 86% reduction condition, there were consistently few trials with responses on the right key only after left-keylight onset. This outcome made it appear that the variables that controlled responding did so almost instantaneously. It is possible that the course of development of control in the 86% reduction condition was masked by a "floor effect." Observation of the development of the center keylight's greater conditioned reinforcing strength in the 86% reduction condition might be more likely if the schedule requirement that controlled center-keylight onset were more stringent. For example, if a moderately sized fixed-ratio schedule of conditioned reinforcement controlled onset of the center keylight, there might be a decrease across the first few sessions of the 86% reduction conditions in the number of trials with responding only after establishing-stimulus onset. Such a decrease might be more likely to be observed if a smaller delay-reduction value was used (e.g., 50%).

It is also possible that in the 86% reduction condition the large number of pecks on the right key before left-keylight onset, and the consistently fewer than 100% of such trials in the 14% reduction condition, reflect an interaction between the minimal schedule requirement for production of the center keylight (FR1) and the pigeons' propensity to peck. There are similarities between the scheduling of the temporal events in this procedure and in autoshaping procedures, with the similarities being greatest in the 86% reduction condition (Gibbon & Balsam, 1981). In that condition, illumination of the right key subsumed a relatively small portion of the IRI and, although food delivery was response dependent, right-keylight onset was followed by food delivery approximately 12 s later. Thus, the responding that produced center-keylight onset may have, in whole or in part, been due to a stimulus–stimulus relation. The importance of the dependency between a right-key peck and onset of the center keylight was not investigated. Speculations regarding elicited responding could be explored by manipulating the nature of the response requirement (e.g., treadle press vs. key peck, FR30 vs. FR1, or requirement of responses with particular latencies) or of the stimulus correlated with unconditioned reinforcement (houselight or tone vs. keylight), and comparing the findings with these results.

The research presented here was conducted to determine whether an event could be shown to serve an establishing-stimulus function. The type of stimulus control that left-keylight onset served with regard to a response on the right key did not appear to be discriminative or eliciting in the 14% reduction conditions. Instead, it evoked responding and appeared to be correlated with a momentary increase in the reinforcing strength of the center keylight. This account of stimulus functions provides a simple and complete characterization of the obtained results. It seems appropriate to utilize the establishing stimulus to account for these data.

REFERENCES

Case, D. A., & Fantino, E. (1981). The delay-reduction hypothesis of conditioned reinforcement and punishment: Observing behavior. *Journal of the Experimental Analysis of Behavior,* **35,** 93–108.

Case, D. A., Fantino, E., & Wixted, J. (1985). Human observing: Maintained by negative informative stimuli only if correlated with improvement in response efficiency. *Journal of the Experimental Analysis of Behavior,* **43,** 289–300.

Chase, P. N., & Hyten, C. (1985). A historical and pedagogic note on establishing operations. *Behavior Analyst,* **8,** 121–122.

Crossman, E. K. (1984). An inexpensive operant chamber interface for the VIC 20 microcomputer. *Behavior Research Methods, Instruments, & Computers,* **16,** 338–340.

Dinsmoor, J. A. (1983). Observing and conditioned reinforcement. *Behavioral and Brain Sciences,* **6,** 693–728. (Includes commentary)

Fantino, E. (1977). Conditioned reinforcement: Choice and information. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 313–339). Englewood Cliffs, NJ: Prentice-Hall.

Fantino, E. (1981). Contiguity, response strength, and the delay-reduction hypothesis. In P. Harzem & M. D. Zeiler (Eds.), *Advances in analysis of behaviour: Vol. 2. Predictability, correlation, and contiguity* (pp. 169–201). Chichester, England: Wiley.

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

Keller, F. S., & Schoenfeld, W. N. (1950). *Principles of psychology.* New York: Appleton-Century-Crofts.

Leigland, S. (1984). On "setting events" and related concepts. *Behavior Analyst,* **7,** 41–45.

McPherson, A., & Osborne, J. G. (1986). The emergence of establishing stimulus control. *Psychological Record,* **36,** 375–386.

Michael, J. (1982). Distinguishing between discriminative and motivational functions of stimuli. *Journal of the Experimental Analysis of Behavior,* **37,** 149–155.

Millenson, J. R. (1967). *Principles of behavioral analysis.* New York: MacMillan.

Navarick, D. J., & Fantino, E. (1976). Self-control and general models of choice. *Journal of Experimental Psychology: Animal Behavior Processes,* **2,** 75–87.

Sidman, M. (1986). Functional analysis of emergent verbal classes. In T. Thompson & M. D. Zeiler (Eds.), *Analysis and integration of behavioral units* (pp. 213–245). Hillsdale, NJ: Erlbaum.

Williams, B. A., & Fantino, E. (1978). Effects on choice of reinforcement delay and conditioned reinforcement. *Journal of the Experimental Analysis of Behavior,* **29,** 77–86.

Received November 3, 1986
Final acceptance November 25, 1987