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THE EFFECTS OF DELAY, SIGNAL PLACEMENT AND HOUSELIGHT ILLUMINATION ON SIGNALLED REVERSAL LEARNING

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THE EFFECTS OF DELAY, SIGNAL PLACEMENT AND HOUSELIGHT ILLUMINATION ON SIGNALLED REVERSAL LEARNING

BY

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ABSTRACT

THE EFFECTS OF DELAY, SIGNAL PLACEMENT AND HOUSELIGHT ILLUMINATION ON SIGNALLED REVERSAL LEARNING

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May, 1983

The control of behavior by prior responses and stimuli was studied using pigeons in a signalled reversal learning procedure. During regular trials, an intertrial interval was followed by illumination of two keys. Initially one key was designated correct. A peck to either key turned off both keys and, if correct, produced food. After a criterion number of consecutive correct responses occurred, a reversal/nonreversal sequence was initiated. Either the reversal or nonreversal signal was presented briefly during the next intertrial interval. Following a reversal signal only, the correct and incorrect keys were reversed. A correct response on the next trial resulted in a larger food reinforcer. Responding on this trial type provided the major dependent measures of behavior. Following this, the regular sequence was reinstated.

The duration of the intertrial interval was varied from 0 to 30 sec on reversal/nonreversal trials, and the reversal/nonreversal signal could occur either at the beginning or end of the interval. Accuracy was inversely related to delay and was greater on late-signal trials. Finally, during baseline, the houslight was on for some birds and off for others during the interval. In a later phase, all birds were exposed to both conditions. Baseline illumination did not affect accuracy, but accuracy was lowered by changes in illumination.

The results were examined with respect to two cognitive accounts of memory coding. However, a behavioral account based on the effects of delays on stimulus control was adequate, and entailed fewer theoretical assumptions.

INTRODUCTION

An Overview

One of the earliest areas in experimental psychology was the study of memory. It was believed by many Associationists in the 1800's that consciousness was composed of a number of elements that could be combined to produce the perceptual and cognitive phenomena that make up consciousness (Boring, 1950). The first experimental study of memory was conducted by Ebbinghaus in the 1870's. In the Associationist tradition, he invented the nonsense syllable as a tool for studying memory processes uncontaminated by previously learned associations. His work was important not only for its empirical content, but because it was considered the first experimental study of the higher mental processes (Boring, 1950).

With the rise of Behaviorism, attempts at studying mental processes were largely abandoned. Watson (1913) declared that the goal of psychology was the prediction and control of behavior, and that all reference to consciousness should be abandoned. In the following years, the emphasis shifted to the study of relationships between observable stimuli and responses. Behavioral psychologists put less emphasis on the study of memory, the rationale and methodology for which seemed closely tied to the introspective psychology of the past. Skinner (1950) argued that reference not only to mental events but to any concept expressed at a level other than that of the observable behavior on which it is based is counterproductive. Due to this type of argument, the concept of memory itself fell into disfavor among behaviorists.

The new behavioral psychology was concerned with observable behavior and its determinants. One of the earliest statements of such a relationship was made by Thorndike (1911). His Law of Effect stated that those actions in a situation that produce satisfaction become associated with that situation and are more likely to be repeated when the situation recurs. Much subsequent work has been concerned with exploring the implications of the Law of Effect, and with providing objective means for predicting what sort of events "produce satisfaction" to an organism.

Early approaches to the control of behavior by its consequences, perhaps as a holdover from Associationism, tended to be quite molecular. For example, Guthrie believed that every association is learned from a single instance of contiguity of a stimulus and a response. The apparent gradualness of learning was explained through a molecular view of stimuli and responses. These may be broken down into specific components, with the learned behavior occurring reliably only after associations have been formed between the various components of the stimuli and responses (Schultz, 1960).

More recent approaches have questioned the utility of this molecular analysis on several grounds (Skinner, 1935, 1953; Schoenfeld and Farmer, 1970). For one, it is questionable that the stimuli and responses are really identical on different occasions; thus, the notion of stimulus and response classes seems more appropriate (Skinner, 1935). The concept of the operant emerged from this type of consideration. The operant is viewed as a unit of behavior, but it is a functional unit, consisting of a class of behavior that is controlled by its relationship to a class of stimuli. Two topographically dissimilar responses may be instances of the same operant if they are both controlled by the same classes of antecedent and consequent stimuli.

Another major advance in the study of behavior was the clear statement by Skinner (1938) of the three-term contingency between prior discriminative stimuli, behavior, and consequent stimuli. Certain consequences of behavior may be seen either to increase or decrease the frequency of that behavior. Consequences that increase the frequency of a response are called reinforcers; those that decrease it are called punishers. The nature of the behavior change depends on the nature of the consequence, and on the nature of the relationship between the response and the occurrence of the consequence. In addition, the occurrence of behavior depends on antecedent (or discriminative) stimuli. Antecedent stimuli signal that certain responses will have certain consequences. A stimulus signalling that a response will produce reinforcement may be said to set the occasion for the occurrence of that response. The rate and pattern of responding depends on the type of relationship between a response and reinforcement that is signalled by a stimulus. Thus, it may be seen that a meaningful analysis of operant behavior must incorporate the roles of both antecedent and consequent stimuli. The recognition of the three-term contingency in operant conditioning clarified the several roles of stimuli and led to better formulations of important issues in behavioral psychology. Particularly significant for this dissertation was the realization of the importance of stimuli that signal the likely consequences of behavior.

The recognition of control of operant behavior by antecedent as well as consequent events contributed to an even more molar view of behavior in a paper by Schoenfeld and Farmer (1970). Behavior was conceptualized as a continuous stream of events. While recognizing that it could be broken down into molecular units, they emphasized the importance of the behavior stream as a whole, and the context in which behavior occurs.

Some clarification of the role of stimuli in the behavior stream would be useful. If the stream is broken into units for analytical purposes, certain responses may be seen to produce consequences in the form of a change in stimulus conditions. This stimulus change may act as a discriminative stimulus, setting the occasion for subsequent behavior in the stream, or as a reinforcer, strengthening preceding behavior. Thus, the behavior stream may be viewed as a stream of responses and stimuli:

R . . . S . . . R . . . R . . . S . . .

Since some stimuli and responses may be more readily discriminable to an observer than others, the degree to which each response produces stimulus consequences presumably depends on the way in which the behavior stream is arbitrarily divided into units. This view contrasts with the approach taken by Skinner and others which views the division into units as being less arbitrary. In keeping with the concept of the three-term contingency, this approach emphasizes the alternation of responses and stimuli to a greater extent. Whichever approach is taken, it should be noted that both Skinner (1950) and Schoenfeld and Farmer (1970) caution against arbitrarily dividing behavior into units to the point where lawful relationships are obscured.

Behavior at a given point in the stream is presumably controlled jointly by earlier stimuli (both discriminative and reinforcing) and prior behavior. The control of behavior by earlier events in the stream may be referred to as memory. In this paper no further meaning will be given to this concept. The current research will focus on memory for both stimuli and responses.

Recent behavioral research on memory for stimuli has made considerable use of the delayed matching-to-sample (DMTS) paradigm. The general matching-to-sample (MTS) paradigm involves the presentation of a sample stimulus to the organism, following which the organism must choose which of two (or more) comparison stimuli matches the sample. A correct choice is generally followed by reinforcement. There are several forms of the MTS paradigm. In simultaneous MTS, the sample and comparison stimuli are presented together. In DMTS the onset of the comparison stimuli follows the offset of the standard stimulus by a specified delay. Zero-delay MTS simply means that the sample and comparison stimuli are presented successively with no delay between them.

The DMTS paradigm allows for the study of memory as it is affected by the duration of the delay. For example, in an early study with pigeons, Berryman, Cumming and Nevin (1963) studied simultaneous and zero-delay MTS and DMTS. The accuracy of MTS performance was found to decrease monotonically with increasing delays, with fairly accurate performance at delays of less than 4 sec, and above-chance performance at delays of up to 10 sec. Thus, although other variables such as sample stimulus duration may affect performance, the DMTS procedure may be seen to be useful in the study of functional relationships in the area of memory.

Because the correct test stimulus depends on the sample presented, the DMTS paradigm is particularly suited to the study of memory for stimuli; very little research has been done on memory for responses. Evidence for the control of behavior by prior responses may be traced to work by Hunter in 1913 on delayed responses in animals (Maier and Schneirla, 1964). A more recent example may be seen in a report by Hearst (1962) of delayed alternation in pigeons with delays of up to 10 sec. Following a peck at one of two keys, a variable delay was presented in which the chamber was darkened. After the delay the keys were illuminated and reinforcement was contingent upon pecking the key not pecked earlier in the trial. The relationship between delay value and performance was similar to that obtained by Berryman et al. (1963), although there was some evidence for greater accuracy at intermediate values than at shorter values. These results indicate control of behavior by responses occurring earlier in the behavior stream. Since responses as well as stimuli are part of the behavior stream, memory for responses and stimuli may be expected to be functionally similar.

This dissertation is concerned with the control of behavior by prior stimuli and responses in the behavior stream, and with the disruption of this control by the intrusion of a stimulus into the behavior stream. A reversal-learning procedure, which may be said to involve responding on the basis of a strategy (rule for responding), is used. In a reversal-learning procedure, one of two responses is designated as correct, and is reinforced. After a criterion for accuracy is reached, the correct and incorrect responses are reversed. Across a wide variety of species and experimental procedures, it has been found that with practice subjects come to reverse their responding after as few as a single error (Bitterman, 1965). This behavior has been interpreted (e.g. Warren, 1966) as an indication of the learning of a win-stay, lose-shift strategy: if a response is reinforced, keep emitting it; if not, shift to the other response.

In the usual reversal-learning procedure, a strategy based solely on the consequences of responding is sufficient to produce accurate performance. In the present research, the procedure has been modified to permit the study of joint control by external stimuli and prior behavior by presenting a signal during the intertrial interval (ITI) following the completion of the criterion for a reversal. Sometimes the signal indicates that a reversal of the correct response has been arranged. At other times it indicates a nonreversal trial, in which the correct response remains unchanged. Thus, accurate performance on the following trial reflects joint control by (memory of) the prior response and the signal.

Delayed Matching-to-Sample and Memory: A Selective Review

In the study of memory through DMTS performance, the major variables of interest have been the effects of varying the delay interval and the effects of stimulus change within the delay interval on matching accuracy. As was mentioned earlier, Berryman et al. (1963) found a monotonic decreasing function relating accuracy to the length of the delay. This was confirmed by Roberts and Grant (1978), who also used pigeons as subjects and found that accuracy decreased from over 90% correct at zero delay to under 80% correct with a 12-sec delay.

A major focus of DMTS research has been on the interference with DMTS performance by a stimulus added during part or all of the delay period. This type of experiment is frequently referred to as a retroactive interference study, because the interpolated stimulus is assumed to interfere with the memory of a prior stimulus event, the sample. While retroactive interference has been explained in many ways including the interference with a memory trace or a rehearsal process, I believe that on the basis of the short life-spans of these theories it is premature to propose any specific mechanisms. In this paper the term retroactive interference will be used only to describe the change in behavior resulting from a class of experimental manipulations.

In addition to varying the delay interval, Roberts and Grant (1978) also studied the effects of an interpolated stimulus during the delay with pigeons. During most sessions, the chamber was dark during delay intervals. During testing the houselight (HL) was turned on throughout the delay period. At zero delay, not surprisingly, there was no difference between HL on and HL off sessions. However, at a 0.5-sec delay, accuracy decreased from 90% in the HL-off condition to 75% in the HL-on condition. At delays of 4 sec or longer, accuracy in the HL-on condition was under 60%. Thus, whereas no change in the function form resulted, the overall level of accuracy was markedly reduced by the addition of the HL during the delay.

A number of studies have focussed on the relationship between the parameters of the interfering stimulus and the magnitude of the retroactive interference effect. Using either HL or center-key illumination as interfering stimuli, Grant and Roberts (1976) found that pigeons' accuracy was a monotonic decreasing function of interfering stimulus intensity; accuracy decreased from 90% to slightly above chance as the interfering stimulus intensity was increased. It seemed not to matter whether the added illumination was localized (key light) or nonlocalized (HL).

In most studies, the training and interfering stimuli have been lights, frequently differing only in color. Some research has investigated the relevance of the relationship between training and interfering stimuli, both within and across stimulus modalities. In one of the few cross-modality investigations, Worsham and D'Amato (1973) studied the interference with visual DMTS in monkeys by visual and auditory stimuli. Using delays of up to 120 sec, the HL was found to be a major disruptor of performance, whereas the effects of white noise were inconsistent. Tapes of monkey vocalizations and colony room noises were disruptive only at the longest delays. Thus, in at least one case, the stimulus modality was found to be a relevant variable.

Within the visual modality, a number of studies have examined the importance of the similarity between training and interfering stimuli. Jarvik, Goldfarb and Carley (1969) presented colored interfering stimuli to monkeys that were identical to either the correct or incorrect comparison stimuli. The stimuli were presented for 3 sec at either the beginning, middle or end of 12-sec delay periods. They found that whereas stimuli identical to the correct comparison produced a mild facilitation effect, the negative stimuli produced substantial interference. Thus, at least in the extreme case in which the comparison stimuli themselves were used as interpolated stimuli, similarity appears to have been a factor. Zentall (1973) raised the further issue that stimulus salience might be a factor as well as similarity. Using red and green training stimuli with pigeons, a yellow light on the center key was found to be a more effective disruptor than was a white vertical line. It was pointed out that this could be due to either salience or similarity.

Grant and Roberts (1976) conducted a series of experiments with pigeons to investigate these issues in more depth. In one experiment, both colors and black-and-white patterns were used as samples. It was proposed that if similarity is the important factor, the interfering stimulus from the same class would be more effective; if salience is more important, one class of disruptors (most likely colors) would be more effective with either sample type. In order to assess the role of stimulus novelty as well, one new and one old stimulus was used as a disruptor in each class. Grant and Roberts found that all stimuli produced roughly equal disruption, except the familiar pattern, which produced slightly less disruption; however, this stimulus may have been darker than the others. In a second experiment, stimulus complexity and amount of illumination were studied. Using red and green lights as samples, the disruptors were two white lines and two white crosses on black backgrounds, one of each being large and the other small. The large stimuli produced more disruption than the small ones, and if anything the crosses produced less disruption; thus degree of illumination seems to be the crucial variable in this experiment.

Within the visual modality, similarity between training and interfering stimuli appears not to be a major factor except when the interpolated stimulus is nearly identical to either the correct or incorrect comparison stimulus. Otherwise, the intensity of the stimulus is the major factor in determining the degree of interference.

One of the most interesting areas of research on retroactive interference concerns the importance of the locus of the interfering stimulus within the delay. This has often been studied together with the amount of exposure to the stimulus. Most early studies of the locus of the interfering stimulus found that at best it was a minor variable. In studies with monkeys, Jarvik et al. (1969), using incorrect comparison stimuli as disruptors, and Etkin (1972), using HL and white key illumination, found at best slight evidence for differential effects of the locus of the disrupting stimulus. Etkin found that whereas the locus was unimportant, the duration of the disrupting stimulus was significant. This finding was confirmed by Maki, Moe and Bierley (1977) for samples that were response- and reinforcer- related as well as stimulus-related (a fuller account of this experiment will appear later). Apparently the duration of an interfering stimulus acts similarly to its intensity (Grant and Roberts, 1976).

In a more recent series of experiments, Roberts and Grant (1978) found that under certain circumstances the locus of the interfering stimulus may be important. They systematically replicated Etkin's (1972) experiment with pigeons to investigate hints in the Etkin and Maki et al. experiments that interfering stimuli might be more effective at the end of the delay than near the beginning. The HL was illuminated for 1, 2, 4 or 8 sec at either the beginning or the end of 10-sec delays. Illumination at the end was found to be more disruptive, especially with shorter HL presentations. The lack of this beginning-end effect, as it was termed, with larger HL presentations was thought to be due to the presence of the HL closer to the end of the delay in these conditions, which would obscure any differences.

Although the overall amount of illumination during the delay has been one of the most important variables in the experiments that have been cited, its importance has been questioned in three studies which have asked whether retroactive interference is best explained in terms of the sheer amount of illumination or changes in illumination. D'Amato and O'Neill (1971) asked whether the important variable was a difference in the illumination level between the delay period and that of the sample and comparison periods. Using monkeys, they found that performance was worse when the HL was on during the delay period regardless of whether it was on or off during the sample and comparison periods. Thus it appeared that absolute level of illumination was the crucial variable.

The issue of relative vs. absolute illumination level was restated by Tranberg and Rilling (1980). Rather than comparing ITI and delay illumination, they asked whether the relevant variable might be a change in delay illumination from the training to testing situation. A successive DMTS procedure was used, in which following the delay, one comparison stimulus was presented. If it matched the sample, responding produced food on a fixed-interval 5-sec schedule. If it was a nonmatching stimulus, a blackout occurred after 5 sec. The dependent variable was a ratio of response rates to matching and nonmatching comparison stimuli. There were four training conditions, with the HL either on or off during the ITI and during the delay interval. Testing was done by changing the HL condition during the delay interval. Thus, in two conditions there were the usual increases in illumination during testing, but in two conditions illumination in the test sessions was decreased during the delay interval. In each case, matching performance was substantially reduced during testing. During training at least 75% of the responses were to the matching stimuli, whereas during testing performance was at best slightly above chance. Training and testing performance were unaffected by the initial HL conditions during the delay period. The only important variable was the change in delay illumination.

The importance of relative illumination was studied further by Cook (1980) using more conventional DMTS procedures with pigeons. In addition to replicating the finding that performance was disrupted by turning off the HL during the delay following training with the HL on, Cook examined the effects of duration of HL-off periods and of different levels of decrease in HL intensity. The effects were found to parallel those generally found when the HL is turned on during delays following a HL-off baseline. Longer HL off periods and greater decreases in HL intensity resulted in greater disruption of performance. Thus, further support is given to the idea that a single process related to stimulus change is responsible for disruption of performance, with the direction of stimulus change being unimportant.

Many of the findings that have been discussed are known to occur over a wide range of experimental conditions. Many features of the DMTS procedure have been varied rather unsystematically across experiments with little if any effect. These include, among others, the response requirement to the sample stimulus; whether retroactive interference testing was conducted within sessions containing regular trials or in special sessions containing only test trials; and whether the HL was on or off during the presentation of sample and comparison stimuli. The experiments have used a number of species and stimulus types. Thus, the basic findings that have been discussed have a fair degree of generality.

As was mentioned earlier, a number of theoretical accounts have been proposed. Although they have had rather short lifespans, much of the work under consideration was theoretically oriented; therefore, a brief discussion of the theory of DMTS performance is in order. A common account states that in DMTS the subject compares the comparison stimuli with a trace of the sample stored in short-term memory (STM). A response is made to the stimulus matching that memory trace most closely. The STM trace is assumed to decay fairly rapidly. At some point the STM trace is presumed to be consolidated into a long-term memory trace. This account explains the delay-accuracy function, which tends to fall rapidly at short delays and be somewhat flatter at longer delays (Peterson, 1966; Roberts and Grant, 1978). Retroactive interference may be explained in terms of the interfering stimulus degrading the STM trace and thus interfering with consolidation. This account has run into considerable trouble with the finding (Roberts and Grant, 1978) that a brief stimulus near the end of the delay period is more disruptive than at the beginning. Presumably a stimulus near the beginning would degrade the STM trace, thus preventing consolidation; later on it would have to disrupt the more permanent long-term trace. Thus, according to Roberts and Grant (1978), the theory predicts that a brief stimulus would be more disruptive if presented near the beginning of the interval than near the end; however, their data revealed the opposite pattern of disruption.

The research that has been considered up to this point has dealt primarily with memory for external stimuli. However, it is clear that prior behavior may serve as a discriminative stimulus as well. An early study of the discriminative function of prior behavior was conducted by Reynolds (1966). He was interested in the control of behavior by the temporal spacing of previous responses. Following two pecks at a red key, the key became blue for 30 sec. Reinforcement was available on a variable-interval schedule in the presence of blue if the pecks at the red key were separated by at least 18 sec. It was found that, although temporal control of responding during red was rather poor, there was fairly good control of response rate during blue-key illumination by the temporal spacing of red-key pecks.

A major effort at studying different types of memory under comparable circumstances was conducted by Maki, Moe and Bierley (1977). A DMTS procedure was employed to study memory for stimuli, responses and reinforcers. Stimulus memory was studied through the use of colored sample and comparison stimuli. Response memory was studied in a nonidentity MTS procedure (Cohen, Brady and Lowry, 1981) in which the samples and correct comparison stimuli are related arbitrarily rather than being identical. The samples were different fixed-ratio (FR) requirements. In the presence of a white key, the occurrence of either one response (FR 1) or twenty responses (FR 20) produced a delay period, following which the comparison stimuli (red and green key lights) were presented. Responses to the comparison stimuli were designated correct depending on the prior response requirement. Reinforcer memory was studied in a similar fashion. In the presence of a white key a response turned off the key light and resulted in a 2-sec sample of food or no food. Again, the comparison stimuli were red and green key lights, each of which was related arbitrarily to one of the sample types. For each type of procedure, Maki et al. studied the effects of HL illumination during the entire delay interval, the significance of the locus of brief HL illumination and the disruptive effects of very short ITIs. It was found in each case that HL illumination reduced DMTS accuracy from approximately 90% to slightly above chance; that 2-sec periods of HL illumination at the end of the delay were slightly more disruptive than at the beginning and less disruptive than continuous HL illumination (the magnitude of the disruption being comparable across tasks); and that short ITIs reduced accuracy by comparable amounts for each task. In the Maki et al. study there was no difference in either the baseline performance or its disruptability as a function of the type of memory involved. Maki et al. proposed that a common STM process may underlie each type of memory. They proposed two possible mechanisms: one based on the idea of rehearsal of a representation of the sample throughout the delay; the other based on identical memory traces that would result if the sample were encoded in terms of the response to be executed following the delay.

Maki et al. (1977) demonstrated that behavior may be controlled by a prior sample of behavior as well as by previous external stimulation. Cohen, Looney, Brady and Aucella (1976), Urcuioli and Honig (1980), and Cohen, Brady and Lowry (1981) have extended this in a series of experiments that studied the relative importance of response and stimulus memory under circumstances in which either could be used to perform accurately on a task.

Cohen et al. (1976) studied simultaneous MTS in pigeons using both visual stimuli and behavior as samples. The visual stimuli were orange and green key colors and horizontal and vertical lines. The behavioral samples were performances controlled by FR 16 or differential reinforcement of low rate (DRL) 3-sec schedules, in which responses must be separated by a minimum of 3 sec to be reinforced. The MTS task could be either identity or nonidentity, as explained earlier. It could be either differential or nondifferential with respect to the response required in the presence of the sample to produce the comparison stimuli. Thus, for example, in a nonidentity, differential task, a bird might be required to fulfill the FR 16 requirement in the presence of orange, or to fulfill the DRL 3-sec schedule in the presence of green, in order to produce line comparison stimuli. The correct comparison stimulus would be arbitrarily related to the sample color and response requirement.

The rate of acquisition was found to be uniform and more rapid when a differential response requirement was in effect, regardless of the type of visual sample or whether an identity or nonidentity task was used. On the other hand, with a nondifferential response requirement, the rate of acquisition was slower and ordered with respect to the type of stimuli. Acquisition was most rapid in the hue identity task, slowest in the line identity task, and intermediate for the nonidentity tasks. These findings suggest that choice in an MTS task may be controlled by sample-specific behavior related to the response requirements when differential responding is required. In the example mentioned above, the birds might learn to peck vertical after FR and horizontal after DRL.

These findings were extended by Urucioli and Honig (1980) in a series of experiments using procedures similar to those of Cohen et al. (1976). In one experiment pigeons were trained on a differential identity MTS procedure using lines as stimuli and reinforcement schedules identical to those of Cohen et al. (1976). Following training, the reinforcement schedules associated with the two stimuli were reversed for some birds. If retrained on the MTS task initial matching accuracy was below the chance level and reacquisition was slower than the original acquisition. If retrained on an oddity task, in which the nonmatching comparison stimulus is correct rather than the matching one, initial performance was above chance and reacquisition proceeded rapidly. In the oddity case, the nonmatching stimulus was the one that had originally been correct following the reinforcement schedule in effect during the sample presentation. Thus, the relationship between the behavior emitted during the sample period and the correct comparison stimulus was more crucial than the relationship between the visual stimuli. It should be noted that the visual relationship was relevant to performance. The oddity group, with the behavioral relationship intact, did not show the level of accuracy of the control group which was simply given a break from the experiment with no retraining for sample-response requirement relationships.

The relative contributions of external stimuli and behavioral cues were studied further by Cohen et al. (1981). Pigeons were given training on either identity or nonidentity MTS procedures. Comparison stimuli were produced according to the same reinforcement schedules as in Cohen et al. (1976). Some birds were given differential response requirements and others were exposed to nondifferential procedures. If the response requirement was differential, MTS performance would be learned on the basis of either external stimuli or behavioral cues; in the nondifferential procedures only visual cues were available. Following training they were given transfer tests with the type of visual cues (identity or nonidentity) reversed, and the behavioral component unchanged. Thus, if a bird was trained on a differential identity task it would be tested on a differential nonidentity task, with the same correlation between a given response requirement and the correct comparison stimulus. In general it was found that only birds given differential behavioral components performed substantially better than chance during transfer tests. These findings indicate that, if available, a behavioral cue comes to be a determinant of MTS performance even when visual cues are available simultaneously.

The more rapid rate of learning with any differential identity or nonidentity procedure than with nondifferential hue identity procedures suggested that behavioral samples might be more effective for pigeons than visual samples. When delays were gradually introduced it was found that performance on a nonidentity task was disrupted by increasing delays in the nondifferential case, but in the differential case, accuracy was maintained with delays of up to 55 sec.

The research conducted by Maki et al. (1977) suggests that there are common processes governing memory for responses and external stimuli. However, the results of the experiments by Cohen et al. (1981) and Urcuioli and Honig (1980) clearly indicate that, when both stimulus and response related cues are available simultaneously, the behavioral cues exert more control over behavior. Changing the sample stimuli while leaving the correlation between behavioral samples and correct comparison stimuli intact resulted in only partial disruption of performance. However, with all visual relationships left intact, reversing the response-comparison stimulus relationship resulted in total disruption of performance.

Reversal Learning, Response Strategies and Memory

Within the context of the MTS procedure, it has been shown that an organism's previous behavior, as well as external stimuli, may serve as discriminative stimuli (Cohen et al., 1976; Urcuioli and Honig, 1980; Cohen et al., 1981; Maki et al., 1977). However, the MTS paradigm may not be the one best suited for the study of response memory. The behavioral sample occurs under conditions that are specially arranged and different from those of other behavior in the context. In a less constrained behavior stream it is likely that behavior is controlled by events, including prior behavior, that occur in a less separated context. In the reversal learning paradigm, the behavioral sample and the choice response are similar in topography and occur at the same point in the temporal sequence of a trial. Thus, the use of this paradigm may fit in better with the concept of behavior as a continuous stream.

The reversal learning paradigm has been used widely in experimental psychology. One major use was by Bitterman and his associates in the study of the comparative psychology of learning (see Bitterman, 1965 for a discussion of this research). It was found that with successive reversals some species would learn more rapidly whereas others would show no improvement with practice. It was thought that the procedure was revealing fundamental differences in learning mechanisms across species. However, this field has grown more complicated with the finding that even within a single species the occurrence and rate of improvement depend on details of experimental procedure such as the ITI and, in related procedures employing external discriminative stimuli, the sensory modality (Nigrosh, Slotnick and Nevin, 1975, Slotnik and Katz, 1974).

Another line of research, which grew out of an older controversy in experimental psychology over whether learning is a continuous process, leads more directly toward the study of response memory as it is being considered in this paper. The continuity approach stressed the idea that learning involves the gradual strengthening of behavior through reinforcement, with some theorists also discussing the gradual weakening of other behavior through nonreinforcement. According to the noncontinuity theory, organisms learn by testing hypotheses concerning the nature of a problem rather than through gradual selection of behavior by reinforcement.

Harlow (1949), using both reversal-learning and object-quality discrimination problems, demonstrated that these two approaches could be combined to some extent. Monkeys were trained to choose one of two objects. A correct choice produced food. After some number of trials, the problem changed. In the reversal-learning procedure, the correct and incorrect responses were reversed; in the object-quality problems, two new objects were presented, with one arbitrarily designated correct. Early in training, the monkeys demonstrated behavior consistent with the continuity approach: many errors were made, with a gradual increase in accuracy over trials. As training progressed, it took fewer trials to learn each new problem. Finally, a pattern emerged which could easily be seen to fit a noncontinuity model of behavior. A single unreinforced response was sufficient to produce a switch in the choice on the next trial. Thus, Harlow had demonstrated the emergence of noncontinuity-like behavior from a gradual learning process. The development of this pattern of rapid learning of new problems was referred to as the acquisition of a learning set.

The progressive improvement involved in the reversal and object-quality learning set tasks has been characterized as the learning of a response strategy (Warren, 1966): a general rule that tells what response to make given the outcome of the previous response. The appropriate response strategy for both procedures has been called the win-stay, lose-shift strategy. Another strategy that has been studied together with this one at times is the win-shift, lose-stay strategy: in this case, the appropriate pattern is to change responses following reinforcement and to continue emitting the same response following nonreinforcement.

These strategies were studied by Shimp (1976) with pigeons. Unlike many other experiments, the strategies were in effect on a trial-by-trial basis rather than a problem-by-problem basis. Also unlike many experiments, the strategies were in effect on a probabilistic basis. During a trial the HL and two keys were illuminated. A peck to the key for which reinforcement was arranged turned off the lights and produced a two-sec reinforcer. An incorrect response turned off the key lights but not the HL. Following a 5-sec interval, the trial was recycled. This continued until a correct response was emitted. The ITI between trials following a correct response was either 2.5, 4.0 or 6.0 sec, including the time of the reinforcer. An equal amount of reinforcement was scheduled on each key overall, according to the following rules. For group A, the probability of reinforcement for staying on the same side as the last reinforcer was 0.8, and the probability of reinforcement for switching sides was 0.2. A win-stay, lose-shift strategy would be optimal. For group B, a win-shift, lose-stay strategy was optimal. For part of the experiment the probabilities for group B were simply the reverse of those for group A; at another point the probabilities of reinforcement for staying and shifting were

0.0 and 1.0 respectively.

The results of the experiment indicated that the appropriate response strategies were learned: responding was controlled by local reinforcement probabilities. The appropriate response strategies were learned. The probability of emission of the optimal response ranged from 0.96 at the 2.5-sec delay to 0.74 at the 6.0-sec delay for group A, and from 0.88 to 0.55 for the same delays for group B. Shimp concluded that an optimal strategy was approximated to the extent allowed by the pigeons' STM. The level of accuracy was lower for group B than for group A. This is consistent with Schusterman's (1962) findings that chimps do not learn the win-shift, lose-stay strategy as readily as the reverse strategy.

One interesting issue is the degree to which an organism learns a generalized response strategy as opposed to a strategy that is specific to a certain class of problems. Warren (1966) trained cats and monkeys on a series of reversal-learning problems. For some animals the correct object was reversed after a criterion of 10 consecutive correct responses was reached; for others the reversal was spatial in nature (left vs. right). Following 60 reversal problems, all animals were transferred to a set of 80 object-quality discrimination problems. Both groups of monkeys were found to learn the object-quality discriminations more rapidly than did a control group given no prior training. Among the cats, there was very little difference between groups. Thus, it appears that monkeys learned a more general strategy than cats which was generalized to problems different in nature that could be responded to according to the same rule.

In summary, it may be seen that response strategies may be taught by procedures such as reversal learning in which they are optimal solutions to the contingencies in effect. They are limited by the organism's sensitivity to (STM for) its previous behavior. Variations in the ITI seem to act similarly to variations in delay in the DMTS paradigm; thus, reversal-learning procedures are useful for studying response memory.

The Current Research: General Goals and Methodology

The current research was concerned with the study of response memory, and the joint control of behavior by both prior responses and stimuli. As was mentioned earlier, reversal-learning procedures may be less disruptive of the ongoing behavior stream than DMTS procedures because the behavioral sample and the choice responses are identical in topography and in their temporal relationships to the rest of the procedure. Thus, a modified reversal-learning procedure was used. It differs from other reversal-learning procedures in that after the criterion number of consecutive correct responses was reached, one of two signal was presented. The signal, which usually replaced the last reinforcer, was for either a reversal or a nonreversal of the correct side on the next trial. A correct response on the trial following a signal depended on memory for both the prior response and the signal: neither was adequate in itself.

The general procedure, shown in diagram form in Figure 1, is as follows. The subjects were white Carneaux pigeons. In the regular trial sequence, following an ITI of 6 sec the HL and two response keys were illuminated by white lights. At the beginning of a session one side was randomly designated correct. A peck to either key turned off the HL and key lights and initiated the next ITI. If the response was correct, the hopper light was illuminated briefly and sometimes food was presented. After a criterion number of consecutive correct responses either the reversal or nonreversal signal was presented briefly during the following ITI, which was sometimes variable in duration. This ITI will be referred to as the reversal/nonreversal (R/NR) ITI. Red lights on the response keys signalled a reversal, and green lights signalled a nonreversal. On the next trial, a correct response produced a longer food

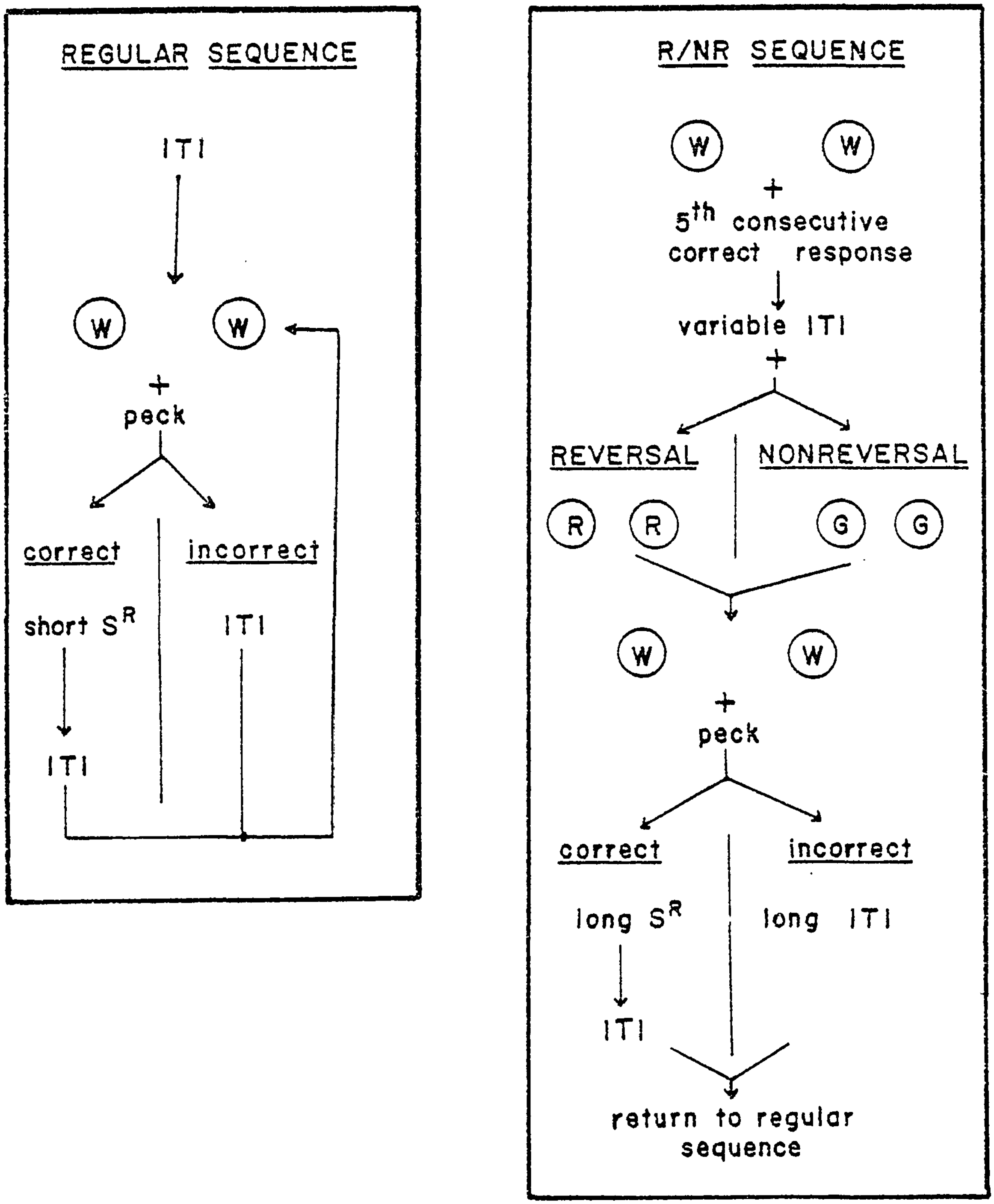

Figure 1. DIAGRAM OF GENERAL EXPERIMENTAL PROCEDURE. NOTE THAT DETAILS VARY CONSIDERABLY BETWEEN EXPERIMENTS.

reinforcer, and an incorrect response resulted in a longer ITI. At this point the regular sequence was repeated. Some of the details of procedure differed from one experiment to another. The data on which most analyses are based are from the trials immediately following the signals.

There were three major independent variables. A major interest was in the locus of the signal within the R/NR ITI: it could occur either at the beginning or the end. If the signal occurred at the beginning it was necessary for the bird to remember both its previous response and the signal across the ITI. If the signal occurred at the end of the ITI, the bird had to remember its last response across the entire ITI, but the relationship of the signal to the next response was equivalent to that of a zero-delay MTS procedure regardless of the ITI length. Thus, it was expected that performance would be more accurate with the signal occurring at the end of the delay period. Another variable was the R/NR ITI length. Several different ITI values were systematically explored, ranging from zero to 20 sec, excluding the time during which the signal was present. Varying the ITI in a reversal-learning experiment is equivalent to varying the delay in a DMTS procedure. It is of interest to see how the effects of the delay value depend on the locus of the signal in the delay. The third variable was stimulus change during the R/NR ITI. During training the HL was off during the ITI for some birds, and on for others. The birds were tested with HL illumination conditions reversed. The rate of acquisition with the HL on or off was studied as well as the relationship between baseline conditions and disruptability by stimulus change. The differential disruptability of stimulus and response memory was of interest. Although Maki et al. (1977) found no difference in disruptability between stimulus and response memory using a DMTS procedure with separate groups of subjects, the present method requires joint control within a single procedure and could result in a more sensitive comparison, as in the research by Cohen et al. (1976, 1981) and Urcuioli and Honig (1980).

Analysis of the Data

It would be reasonable to expect that, in a procedure which allows a choice between continuing to emit the same response and switching responses, there might be a built-in bias towards perseveration with the response that has been reinforced over the last several trials. If so, a simple measure such as the percentage of correct responses would underestimate the accuracy of reversing and overestimate the accuracy of not reversing. A measure of performance that is capable of separating sensitivity to reinforcement contingencies from any bias towards one response or the other is needed. Such a measure may be drawn from signal detection theory. Classical signal detection theory proposes that a given stimulus, upon repeated presentation, produces somewhat different sensory effects upon the organism at different times. These sensory effects are assumed to be normally distributed around some mean value. If another stimulus that differs along some dimension such as intensity is sometimes presented, it will produce its own normal distribution of sensory effects around a different mean. The ability of an organism to discriminate between the stimuli (the organism's sensitivity) depends on the separation between the distributions. Sensitivity is considered to be independent of any bias which may be introduced (for example, by reinforcing one correct choice more frequently than the other). In such an experiment, in which one of two stimuli is presented and the subject must respond to indicate which stimulus it was exposed to, there are four possible trial outcomes which may be described by the following payoff matrix.

		STIMULUS	
		S1	S2
RESPONSE	R1	Hit	False Alarm
	R2	Miss	Correct Rejection

Generally, the occurrence of R1 in the presence of S1 or R2 in the presence of S2 is reinforced, whereas the other outcomes are extinguished or, sometimes, punished. According to classical signal detection, with its assumptions of normality of distributions, if the probabilities of R1 given S1 (R1/S1) and R1/S2 are transformed to normal deviates (z-scores), the difference between z-scores for hits and false alarms should remain constant as long as the stimuli are held constant, regardless of any bias introduced toward one response or the other. This constant measure of sensitivity is called d'.

The pigeon's task in the current research may be viewed as the detection of reversals. Although arbitrary, it permits the consistent labelling of responses following red and green stimuli as indicated in the following matrix.

		SIGNAL	
		RED	GREEN
RESPONSE	SHIFT	Hit	False Alarm
	STAY	Miss	Correct Rejection

There is no reason to assume normal distributions of sensory effects in this research. In fact, there is no reason to assume any distributions at all. Yet, the idea of separating sensitivity from bias is crucial. Accordingly, a set of statistics described by Nevin, Jenkins, Whittaker and Yarensky (1982) was employed. These statistics make no assumptions about distributions. Furthermore, these measures of sensitivity and bias, when used in logarithmic form, share the property of being unbounded with the measures used in classical signal detection theory. The measure of sensitivity is d, and the measure for bias is b. The calculation and properties of these measures are discussed in considerable detail by Nevin et al. (1982), and the sensitivity measure is discussed by Davison and Tustin (1978). It should be noted that, although no assumptions of underlying distributions are needed to estimate d, log d is linearly related to d'. The equations for d and b are as follows.

$$d = \sqrt{\frac{H}{M} \cdot \frac{CR}{FA}} \qquad b = \sqrt{\frac{H}{M} \cdot \frac{FA}{CR}}$$

The range of d is from infinity when discrimination is perfect to 0.0 when responses are always incorrect with respect to the stimuli; chance performance produces a value of 1.0. The range of b is also from 0.0 to infinity, with 1.0 indicating no bias. In the following experiments, values of b less than 1.0 indicate a bias towards perseveration on the same key, whereas values greater than 1.0 indicate a bias towards reversal. As is the case with the measure d', for both d and b the extreme values (0.0, infinity) are obtained for any sample of behavior in which one of the four possible trial outcomes does not occur. For example, a bias towards nonreversal might result in a small number of false alarms. If, due to the use of finite sample sizes, a particular sample did not include any false alarms, d would be infinite and b would be equal to 0.0, even though a larger sample might result in less extreme values. Thus, occasional extreme values of d and b are generally due to sampling error rather than to performance radically different from that represented by intermediate values.

The sensitivity and bias measures involve ratios of response frequencies. As is frequently the case with ratio data a logarithmic plot is advantageous and will be used throughout. In the case of sensitivity, a logarithmic plot causes points that represent equal sensitivity levels to be displaced equally from the chance line whether they represent above-chance or below-chance performance. A logarithmic bias plot causes equivalent degrees of bias towards either reversal or nonreversal of response location to be displayed equidistant from the no-bias line. Because the measures used in this research require fairly large samples for stability, all calculations were done on at least the last hundred trials in a condition. In many cases the calculations are based on larger sample sizes.

I. EXPERIMENT I

The first experiment was designed primarily to explore the possibility of stimulus control of a reversal strategy. It was also designed to provide preliminary data concerning some of the variables relevant to such control, and to determine the range of values over which these variables control performance. Because of the exploratory nature of this experiment, some procedural details were modified as the need became apparent.

Method

Subjects

The subjects were three white Carneaux pigeons. Birds 8 and 227 had prior experience with autoshaping procedures and bird 85 had prior experience with fixed- and variable-interval schedules.

Apparatus.

A standard two-key pigeon chamber was used. The experiment was controlled by electromechanical programming equipment.

Procedure.

Because of the pilot nature of this research, some procedural variables were changed unsystematically. The basic procedure and some major modifications will be described. A discrete-trials procedure was used. Sessions lasted for 40 min throughout most of the experiment. The HL was on throughout the session except as noted. Following a 6-sec ITI, both keys were illuminated white. Initially, one key was randomly designated correct. A single peck to either key initiated the next ITI. A correct response produced reinforcement, the duration of which was included in the ITI time. The reinforcement duration was gradually decreased from 2.25 sec to 1.25 sec. An incorrect response reset the criterion counter. This procedure continued until the criterion number of consecutive correct responses occurred. Throughout most of the experiment the criterion was 5 responses, although the criterion was 10 responses early in training. During much of the experiment a correction procedure was in effect following an incorrect response. On the next trial, only the correct key was lit. A response produced reinforcement and an ITI, but was not counted and did not advance the criterion counter. The regular procedure then resumed.

When the criterion was met, the reversal or nonreversal (R/NR) sequence began. The ITI following the criterion response (the R/NR ITI) was varied across sessions in the following sequence: 6 sec (41-48 sessions), 30 sec (25-28 sessions), 12 sec (25-26 sessions) and 6 sec (37-43 sessions). During this phase of the experiment the correction procedure was in effect. Following the ITI, the keys were illuminated red or green. If both keys were red, the correct side was reversed; green keys signalled a nonreversal. A peck to a colored key produced reinforcement and advanced the criterion counter if correct and began the regular sequence again. Following this phase of the experiment correction trials were eliminated, the reinforcer following a correct reversal or nonreversal was increased to 3 sec, and the probability of a reversal was varied as a biasing operation. Because of poor performance on R/NR trials, a number of aspects of the procedure were then modified. Reinforcement duration following regular trials was decreased to 1 sec, and the duration following R/NR trials was increased to 5 sec. Then over a series of 80 sessions the HL was turned off during ITIs preceding R/NR trials for blocks of 3 sessions, remaining on during alternate 3-session blocks. As this work preceded the publication of Tranberg and Rilling (1980), it was expected that performance would be more accurate with the HL off.

Results

Initial acquisition was fairly rapid. Accuracy on R/NR trials was above chance within 20 sessions for all birds. The value of d was greater than 7.0 for all birds by the end of the baseline condition. As soon as the R/NR ITI was lengthened to 30 sec, accuracy decreased to near the chance level for all birds. It remained low for the 12-sec ITI condition, but when the R/NR ITI was decreased to 6 sec, baseline performance was recovered. Data for the last 200 trials of each condition are displayed in Figure 2. It should be noted that the apparently divergent recovery point for bird 8 is due in part to the high sensitivity of d to small variations in performance when discrimination is at a high level of accuracy.

Figure 3 shows response bias as a function of delay for the same experimental sessions. Two trends may be seen from the data. First, there was a trend towards perseveration on the same key. Incorrect responses were more likely to

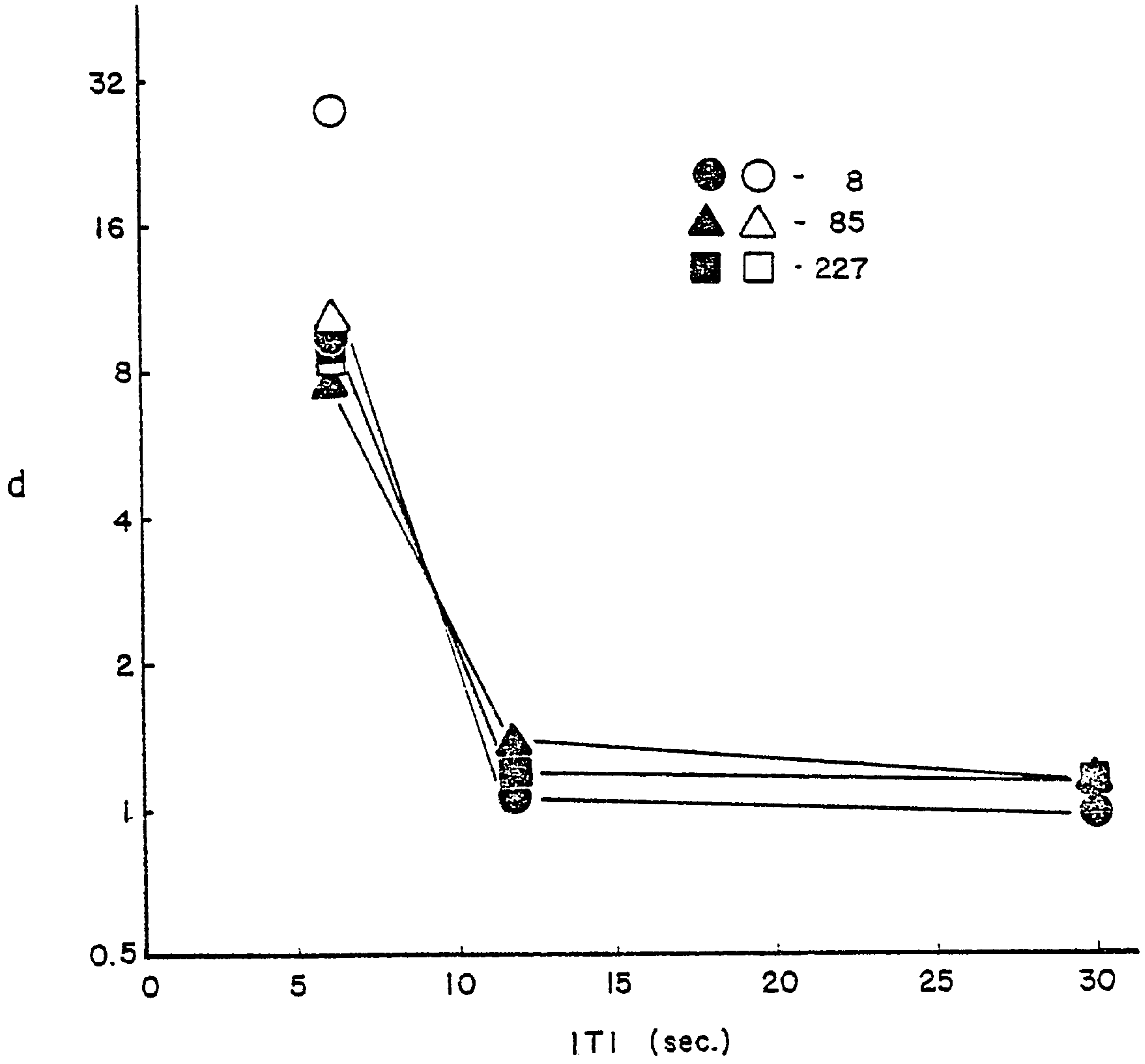

Figure 2. SENSITIVITY IN EXPERIMENT I AS A FUNCTION OF R/NR ITI DURATION. OPEN SYMBOLS INDICATE RECOVERY OF BASELINE.

involve staying incorrectly rather than incorrect response reversals. Second, with increasing delay, response bias tended to decrease. With longer delays there was at most a slight bias towards perseveration.

The elimination of correction trials resulted in at least a temporary reduction in accuracy for all birds. Birds 8 and 85 recovered completely, but bird 227 showed only partial recovery at the end of that condition, with a strong bias against reversing. At this point the probability of an R/NR trial being a reversal was increased to 0.8. Although this was expected to bias the birds towards reversing on test trials, at most minor shifts in bias were observed.

The most interesting findings of the first experiment concern the HL manipulation. For reasons that are no longer clear to the experimenter, baseline training was conducted with the HL on during all ITIs, including the R/NR ITI. Thus, when the HL manipulation was conducted, it was the birds' first exposure to darkness during an ITI, the reverse of the usual procedure in DMTS experiments. For all three birds, accuracy decreased when the HL was off, and recovered when it was on. This effect persisted throughout training for bird 85, remained strong for over 20 HL-off sessions for bird 8, and weakened considerably for 227 after 18 HL-off sessions.

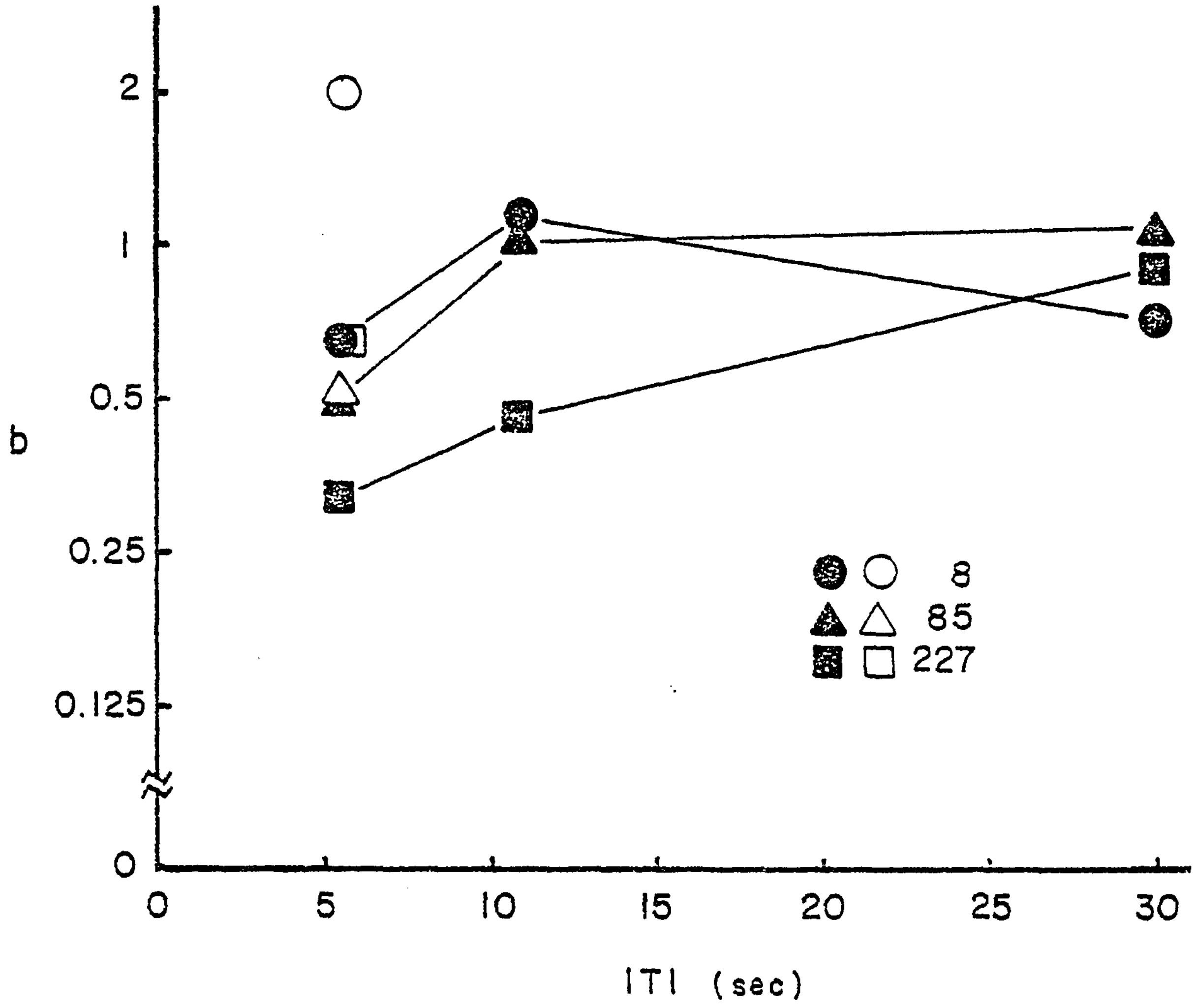

Figure 3. RESPONSE BIAS IN EXPERIMENT I AS A FUNCTION OF R/NR ITI DURATION. OPEN SYMBOLS INDICATE RECOVERY OF BASELINE.

These trends were not reflected in the response bias data in all cases. Birds 8 and 85 started with an increased bias towards perseveration in the HL-off condition, while bird 227 showed the reverse tendency. The difference between the two conditions disappeared more rapidly for bird 8 than did sensitivity differences. For bird 85, whereas sensitivity differences persisted throughout, bias differences disappeared after 9 HL-off sessions. For bird 227, the convergence of sensitivity functions was not reflected in the bias functions, which remained separated by a fairly constant amount throughout. These data are displayed in Figures 4 and 5.

Discussion

Most reported research has demonstrated that HL illumination during the delay period produces substantial disruption of DMTS performance. At the time this experiment was conducted there was no reason to believe the results of this experiment would depart from that pattern despite the unusual baseline of HL on during the R/NR ITIs. Thus, it was quite surprising to observe a decrement in performance with the introduction of HL-off ITIs. In light of research by Tranberg and Rilling (1980) and others, these findings are less surprising. However, they are still significant in

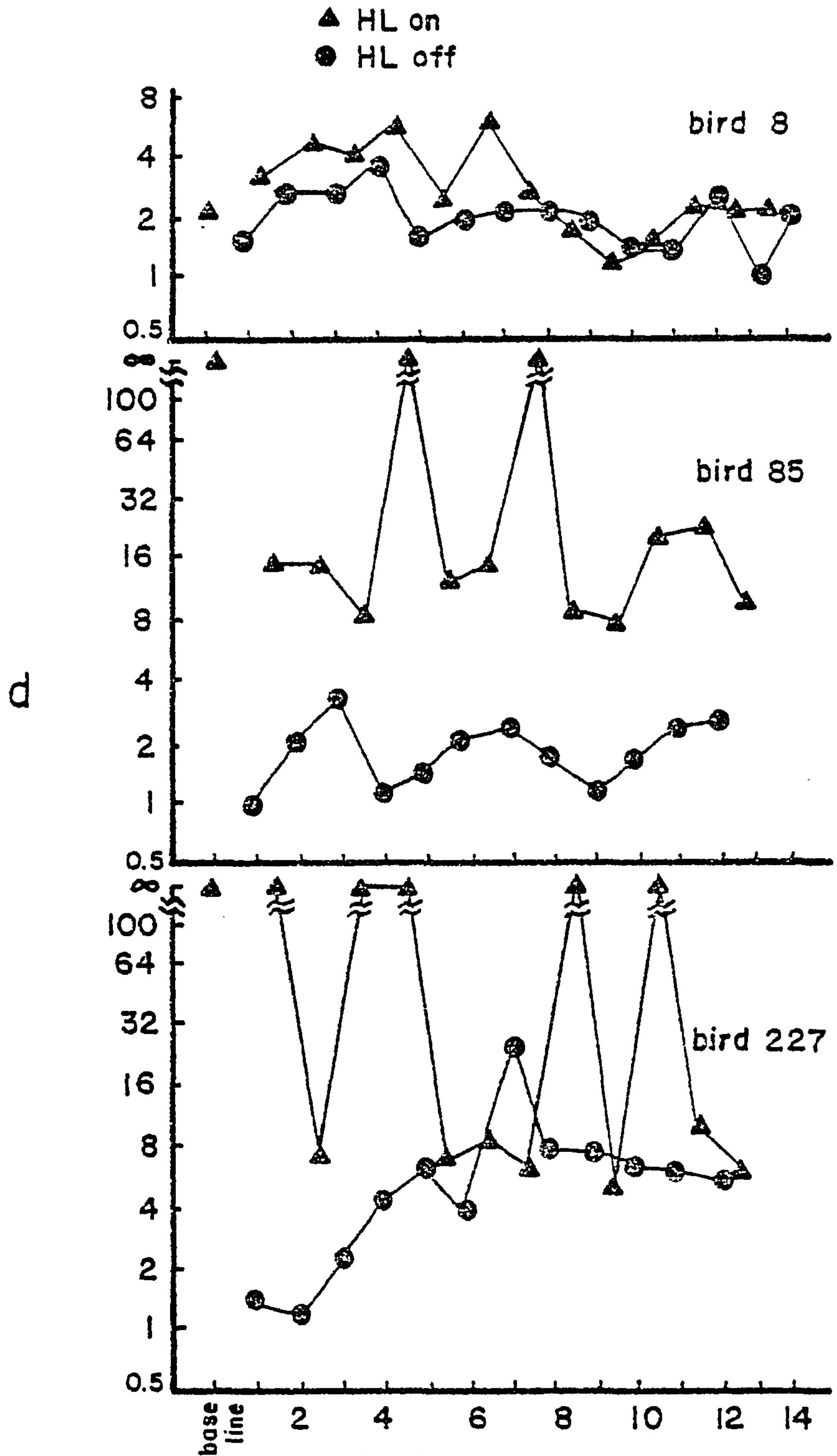

Figure 4. SENSITIVITY AS A FUNCTION OF HL ILLUMINATION ACROSS SUCCESSIVE BLOCKS OF THREE SESSIONS.

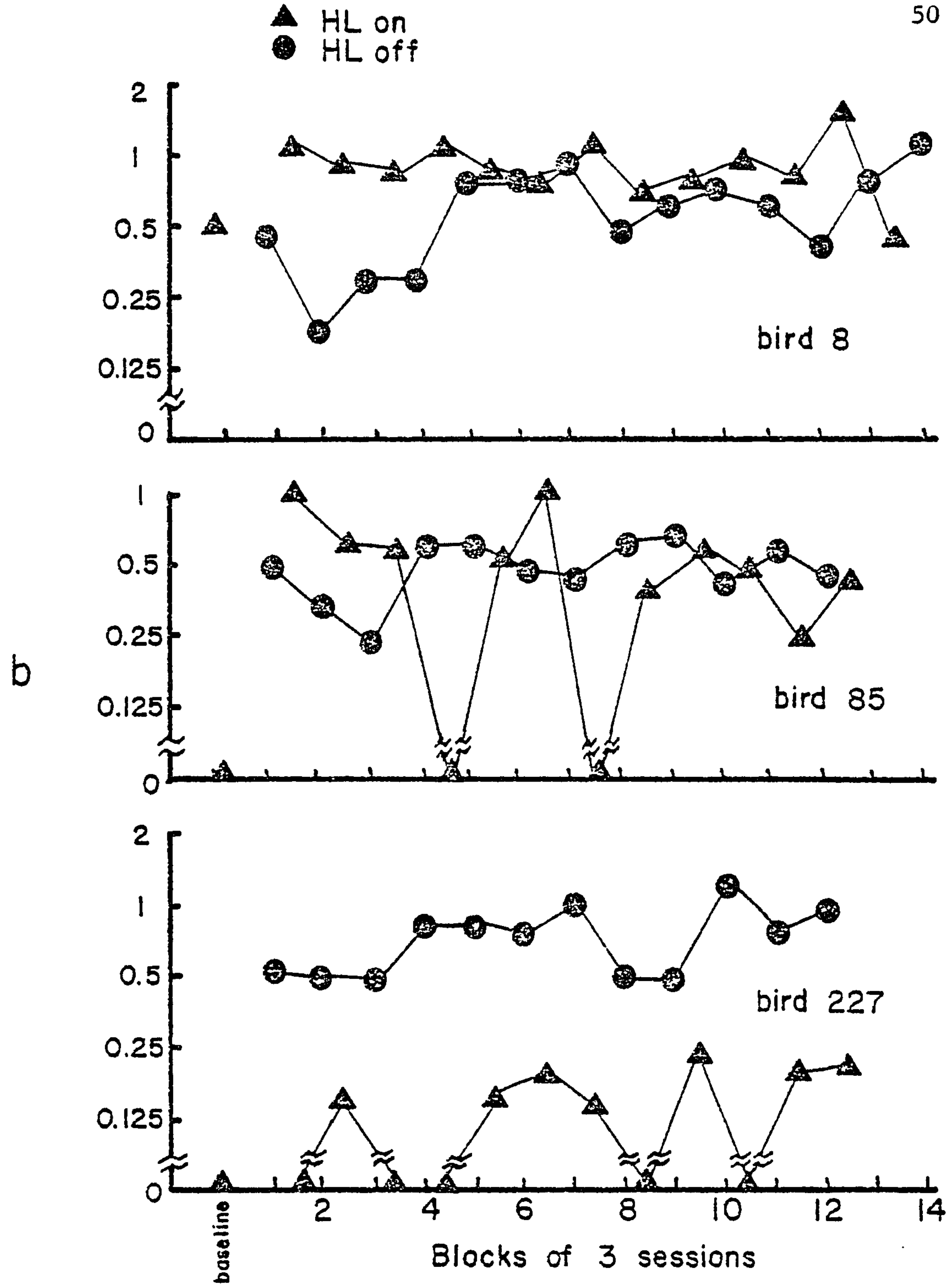

Figure 5. BIAS AS A FUNCTION OF HL ILLUMINATION ACROSS SUCCESSIVE BLOCKS OF THREE SESSIONS.

that they support the notion that the critical variable is change in stimulation rather than the absolute level of stimulation during the delay period. They also extend this finding to a procedure that differs substantially from the usual DMTS procedure.

The data on response bias are interesting as well as the sensitivity data. The advantage of a signal detection analysis is that it allows for the independent measurement of sensitivity and bias. The data from the HL manipulation phase of this experiment clearly indicate the value of such a separation, as it was seen that a manipulation may affect one aspect of behavior differently from the other. However, as may be seen by comparison of Figures 2 and 3, sensitivity and bias may not always be independent. In this experiment there was a clear covariation between the two measures: as sensitivity decreased, the degree of response bias also decreased. This is due to an unusual property of a reversal procedure: unlike many signal detection procedures the correct response depends on prior behavior as well as on the stimuli presented. Thus, for example, in a brightness discrimination experiment the right key might be pecked if a bright light is presented and the left key given a dim light. If the lights become less distinguishable sensitivity should decrease, but the relationship of each response to relative brightness remains constant. In a reversal procedure such as the one in this experiment, a left-key response may be a reversal or a nonreversal, depending on the previous response. With increasing delay, sensitivity (memory) decreases. As the bird becomes less able to discriminate its own prior behavior, the relationship of the two available responses to the R/NR signal becomes less defined to the bird. In the absence of memory for the previous response, a consistent response bias would be impossible. Thus, in a procedure of this sort, the observed covariation of sensitivity and bias is an expected result.

The first experiment demonstrated that stimulus control over a win-stay, lose-shift strategy could be established. It also delineated the range of delay values that would control a wide range of sensitivity, thus setting the stage for an analysis of memory in the remaining experiments.

II. EXPERIMENT II

Rather than continue with the first experiment, it was felt that the research should be repeated in a more systematic fashion with new subjects. The procedure of the second experiment was similar to that used in Experiment I with two major exceptions. First, R/NR signals were presented during the R/NR ITI, with trial stimuli always being white key lights. Second, delays were variable within sessions. Another significant difference was in the introduction of delay values. In the first experiment, delays were introduced suddenly, changing from 6 sec to 30 sec in one step. All trials in a session had the same delay. The sudden increase in difficulty may have been unnecessarily disruptive to R/NR trial accuracy. Thus, in the second experiment, the values of R/NR ITIs were gradually increased from zero to insure that no sudden increase in difficulty would result in chance performance. At all times, at least 25% of the R/NR trials had zero delays, so there would be some easy problems in all sessions.

The second experiment involved the systematic exploration of performance with R/NR ITIs ranging from 0 to 20 sec, excluding the 1.5-sec signal times. During the first half of the experiment the signal occurred immediately following the criterion response; during the second half, it occurred immediately preceding the R/NR trial. In each half of the experiment, the effects of HI illumination during the R/NR ITI were studied. The baseline was the HL-off condition.

Method

Subjects

Birds 481, 482 and 483 served. Bird 481 was eliminated from the second half of the experiment due to blindness. All birds had extensive histories of exposure to signal detection and other procedures.

Apparatus

The experimental chamber was as in Experiment I. The first half of the experiment was conducted with standard electromechanical equipment. The sequence of events within a session was controlled by an 8-channel tape reader. The second half was run by a MINC computer.

Procedure

1. General procedure. Following a 6-sec ITI, both keys and the HL were lit with white lights. A single peck to either key turned off the keys and the HL and initiated the next ITI. If correct, a short reinforcer was presented during the ITI (see below for actual durations of reinforcers). Following five consecutive correct responses, the R/NR sequence was initiated. During the ITI following the criterion response, the HL was off during the baseline condition. During this ITI reinforcement was not presented; instead the red or green signal was presented at either the beginning or the end of the ITI. The rest of the ITI was spent in darkness for a variable amount of time ranging from 0 to 20 sec. Following the ITI the HL and keys were white again. A correct response produced a long reinforcer as part of a 6-sec ITI and an incorrect response produces a 15-sec ITI. Then the regular trial sequence was continued.

2. Phase I. In this phase the R/NR signals occurred at the beginning of the ITIs. The sequence of conditions is outlined in Table 1. Initially all R/NR ITIs were of 0-sec duration, excluding the time of the R/NR signals. The short reinforcers were 2 sec and the long ones were 6 sec.

Following initial variation in length, sessions consisted of 32 R/NR trials. After approximately 80 sessions, the R/NR ITIs were gradually lengthened over a period of approximately 110 sessions to their final values. Each tape had four ITI values including zero occurring in an irregular order, balanced between reversal and nonreversal trials. Thus, each bird was exposed to seven delay values. The delay values were 0, 0.5, 1, 2, 4, 7 and 12 sec for bird 481, and 0, 1, 2, 4, 7, 12 and 16 sec for birds 482 and 483. After approximately 80 sessions, the procedure was changed to allow sessions of 64 R/NR trials. After approximately 10 more sessions reinforcement during regular trials was made intermittent to keep the birds from gaining weight. Short reinforcers were delivered after only 20% of the correct responses. On other trials a correct response produced a 2-sec hopper light but no food. Long reinforcers were decreased to 4.0 and then to 3.5 sec. After approximately 40 sessions, the HL was turned on during R/NR ITIs for half the sessions in an irregular sequence. This procedure continued for 96 sessions for all birds.

3. <u>Phase II</u>. In the second phase of the experiment, the R/NR signals occurred at the end of the ITIs. With the introduction of computer technology, it was possible to program all ITI values in each session. On 25% of the R/NR ITIs, the zero-delay condition was in effect. Due to

TABLE 1

Sequence of conditions in Experiment II. See text for additional details.

Experimental Condition	Number of Sessions		
	481	482	483
PHASE I: Early Signal.			
A. Initial training: Zero delay	79	83	72
B. Gradual introduction of delays	116	108	112
C. Final delay values: Irregular tape alternation	96	88	90
D. Modified procedure: Intermittent reinforcement on regular trials	41	41	43
E. Houselight variation: Irregular alternation of HL on and HL off during R/NR ITI	96	96	96
PHASE II: Late Signal.			
A. Baseline: HL off during R/NR ITI		108	111
B. Houselight variation: Irregular alternation of HL on and HL off during R/NR ITI.		49	46

improvement in accuracy, the longest ITI was increased to 20 sec. This phase of the experiment consisted of a baseline in which the HL was not on during R/NR ITIs, followed by a test phase in which half the R/NR ITIs in each session had the HL illuminated and half were dark.

Results

As all birds had extensive prior experience, acquisition was rapid. All birds were responding at above the chance level within the first ten sessions. The introduction of delays between signals and R/NR trials proceeded with little disruption of performance in the zero-delay condition. Thus, it appears that gradually introducing longer R/NR ITI values while keeping some short ITIs in each session was effective for maintaining performance.

During the first phase of the experiment the signals occurred at the beginning of the R/NR ITI. The major variables of interest in this phase of the experiment were the effects of varying delay and the effects of lighting the HL during the delay on accuracy. As the HL was turned on and off during the delays over a period of 96 sessions, it is of interest to examine the changes in the effects of HL illumination with extended adaptation.

The effects of delay value and HL illumination on sensitivity may be seen in Figures 6 and 7, which display data for each bird for the first third of the period of HL variation. Since this manipulation has typically been done in fairly brief test phases in previous research, the data from this portion of the HL variation phase are most comparable to data from other research.

In a signal-detection experiment it is common to plot the two independent response probabilities p(R1/S1) and p(R1/S2) against each other. Such a plot is shown in Figure 6. Although difficult to interpret in this form, it may be seen that in general the points for HL-off tend to be further into the upper-left corner than those for the HL-on condition, indicating greater sensitivity in the HL-off condition. The majority of points are to the left of the minor diagonal, indicating a tendency towards response perseveration.

These trends may be seen more clearly in Figure 7 in which sensitivity is plotted as a function of delay for the HL-on and off conditions. Accuracy was very high for all birds in the zero-delay condition with the HL off. With minor exceptions, accuracy decreased with longer R/NR ITIs, although the extent to which performance deteriorated varied widely across birds.

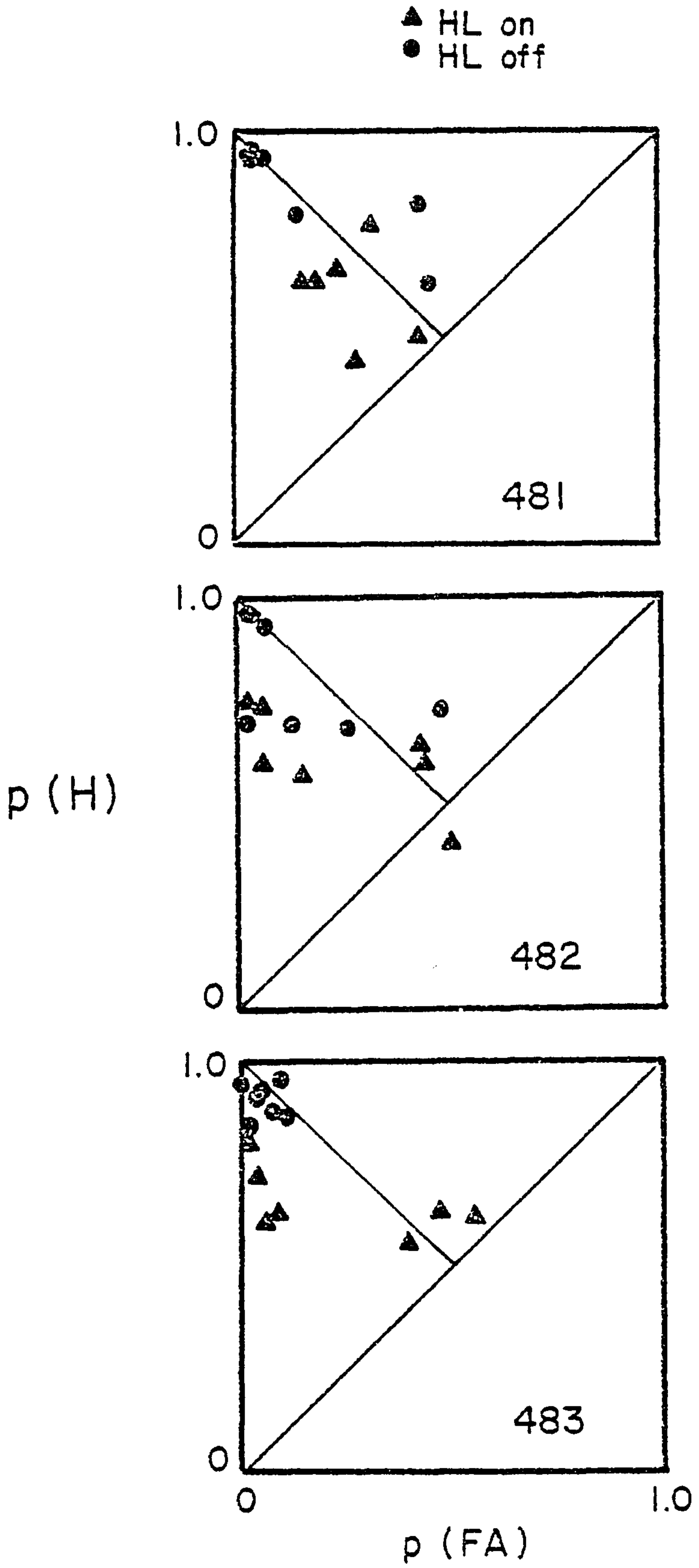

Figure 6. RESPONSE PROBABILITIES IN THE FIRST THIRD OF THE HL VARIATION PORTION OF EXPERIMENT II, PHASE I.

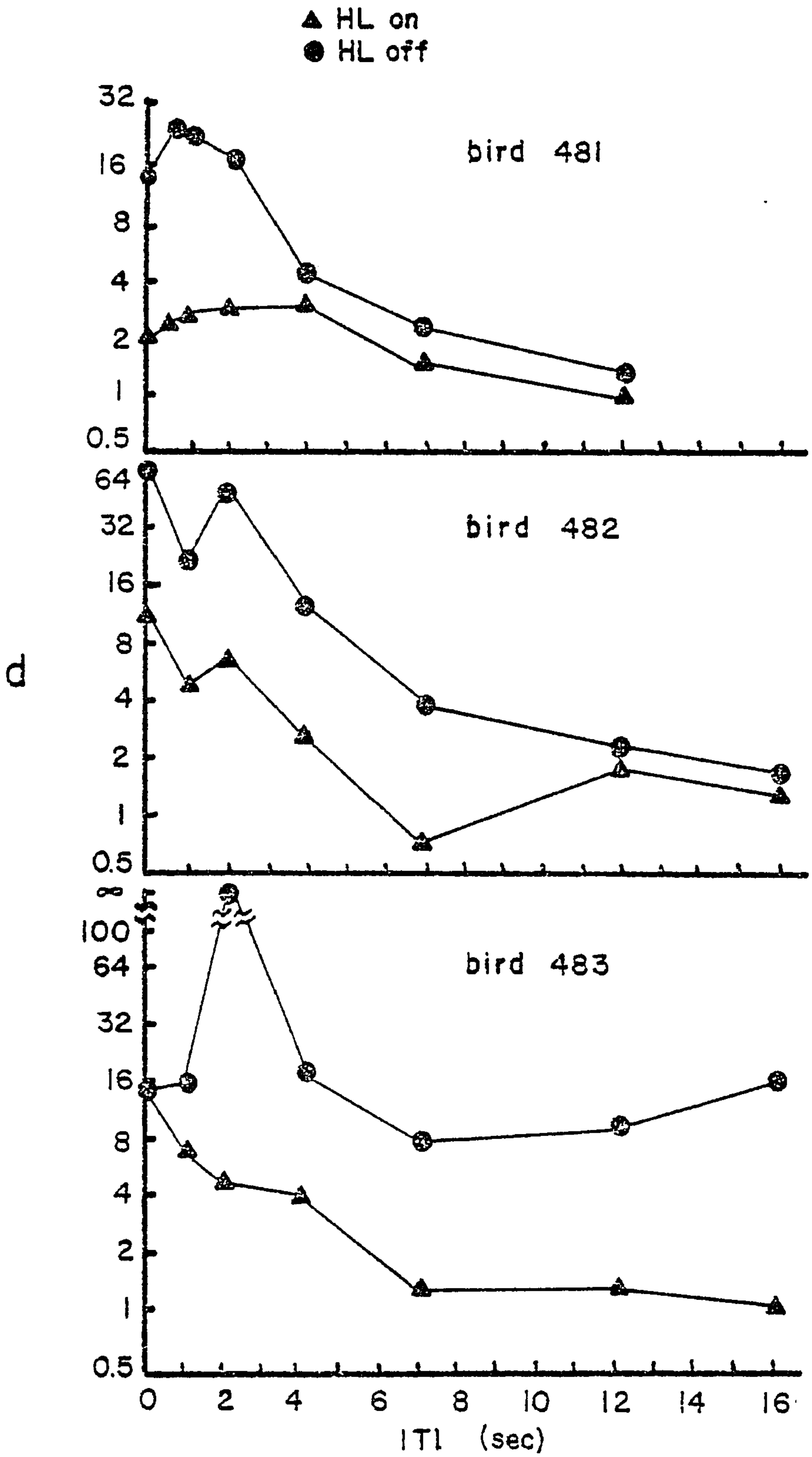

Figure 7. SENSITIVITY AS A FUNCTION OF R/NR ITI DURING THE FIRST THIRD OF THE HL VARIATION PORTION OF EXPERIMENT II, PHASE I.

Without exception, the introduction of HL illumination during the R/NR ITI caused substantial decreases in accuracy at all delay values. Bird 481 exhibited an unusual change in the relationship between delay and accuracy with the HL on: performance was actually more accurate at 2 to 4 sec than at shorter delays.

Figure 8 displays response bias as a function of delay and HL condition. Particularly for birds 482 and 483, the trend toward decreased bias with decreased sensitivity was continued. There was no clear relationship between the HL condition and response bias.

Figures 9 and 10 display sensitivity data from the second and last thirds of the HL alternation phase. With further exposure to the HL during the ITI, its disruptiveness diminished considerably. In fact, with extended exposure, birds 481 (Figures 9 and 10) and 483 (Figure 10) show reversals at longer delays, with the greater accuracy occurring with the HL on.

Sensitivity data from the HL variation portion of the second phase of the experiment are displayed in Figure 11. The data from this phase are similar to those obtained in the last portion of Phase I in that there is very little disruption by the HL illumination.

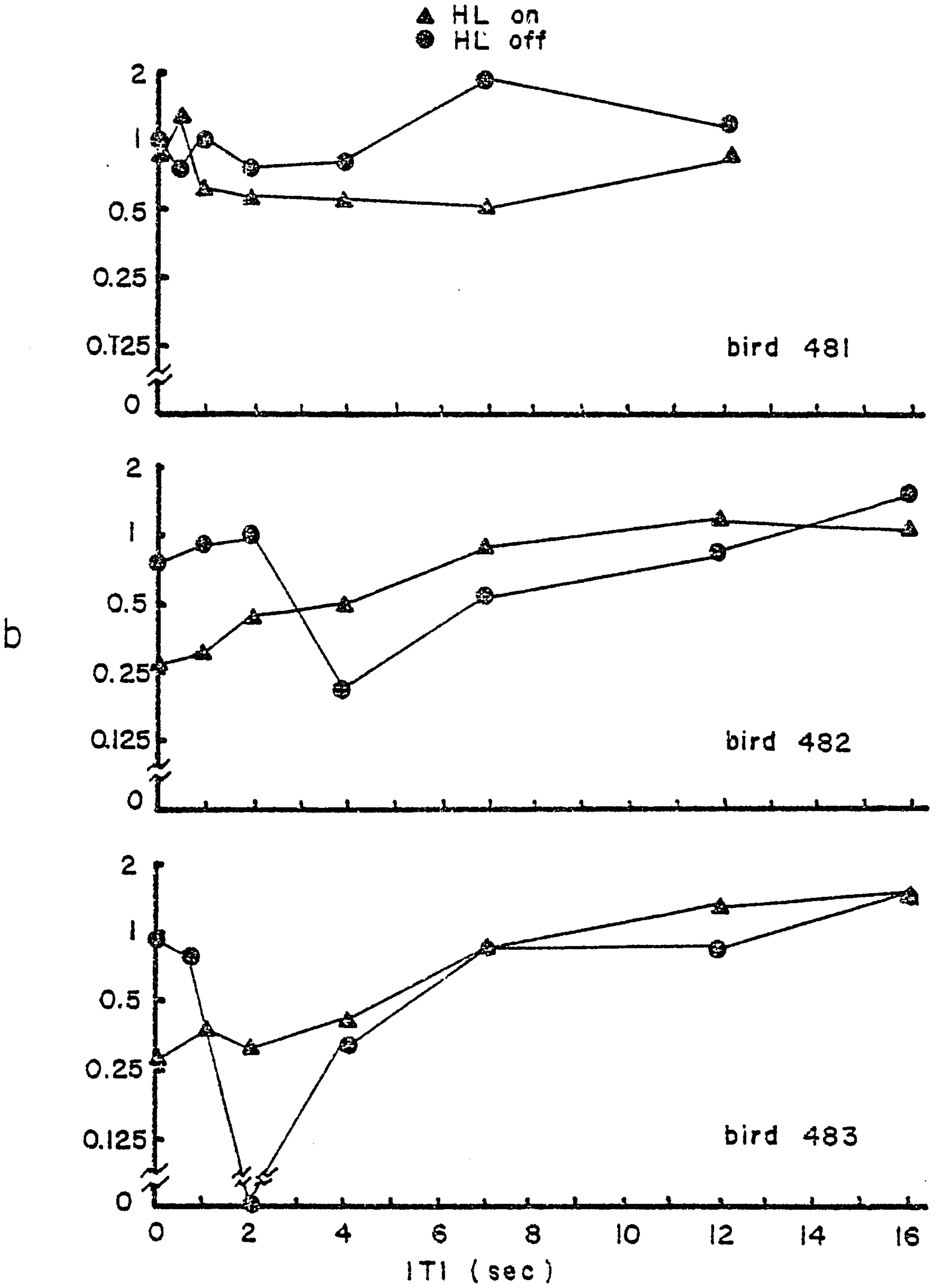

Figure 8 . BIAS AS A FUNCTION OF R/NR ITI DURING THE FIRST THIRD OF THE HL VARIATION PORTION OF EXPERIMENT II , PHASE I .

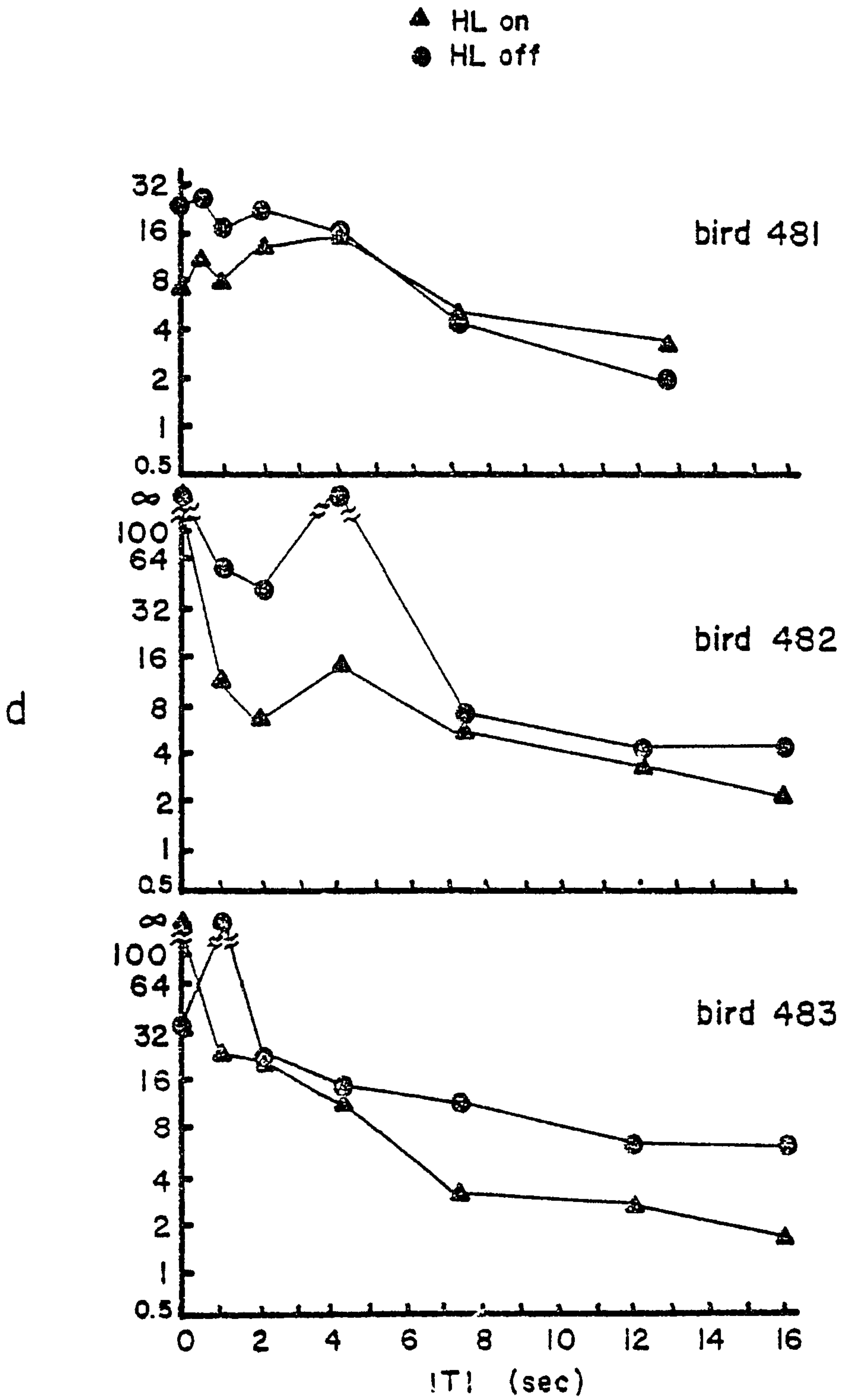

Figure 9. SENSITIVITY AS A FUNCTION OF R/NR ITI : SECOND THIRD.

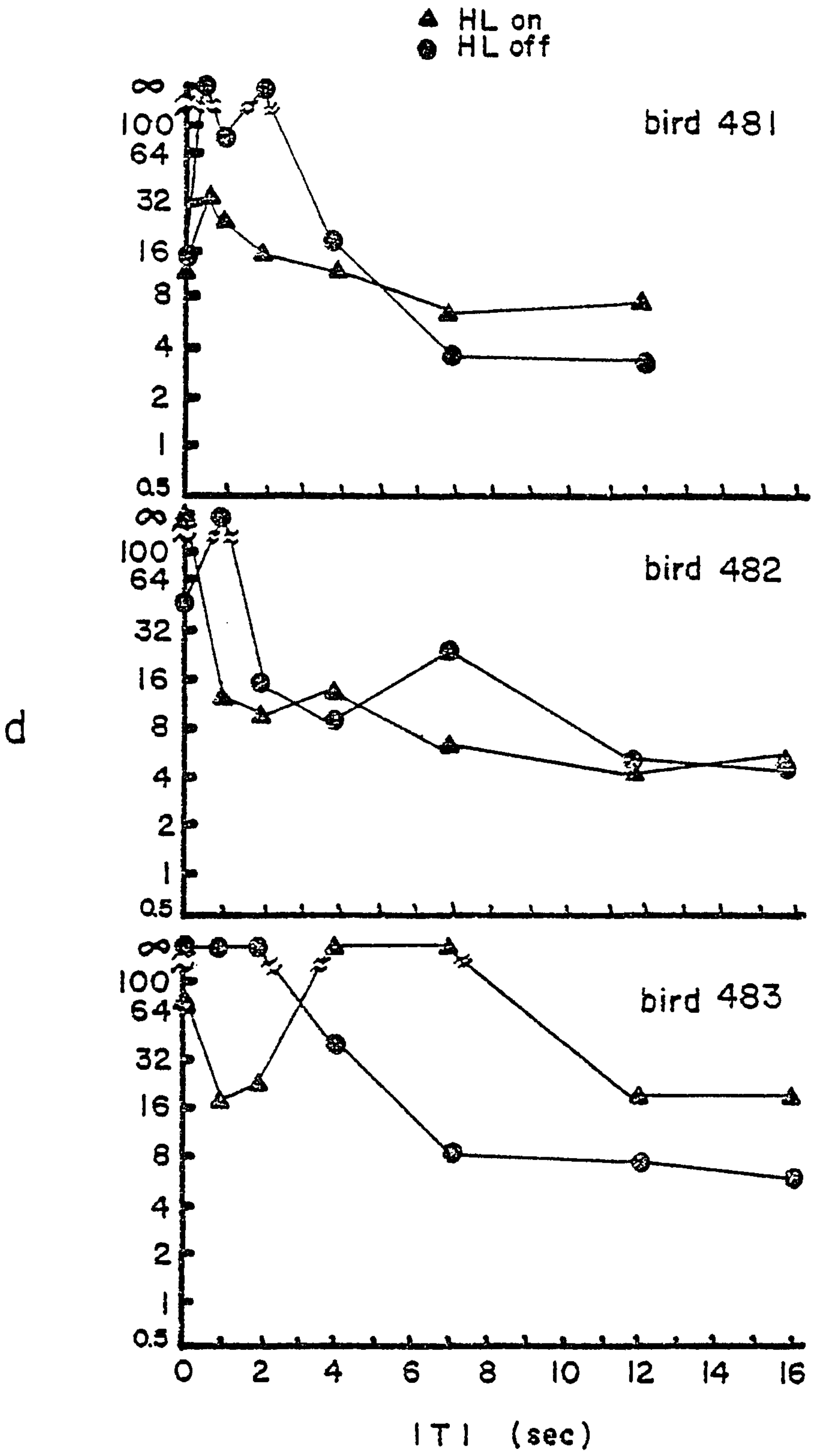

Figure 10. SENSITIVITY AS A FUNCTION OF R/NR ITI : LAST THIRD.

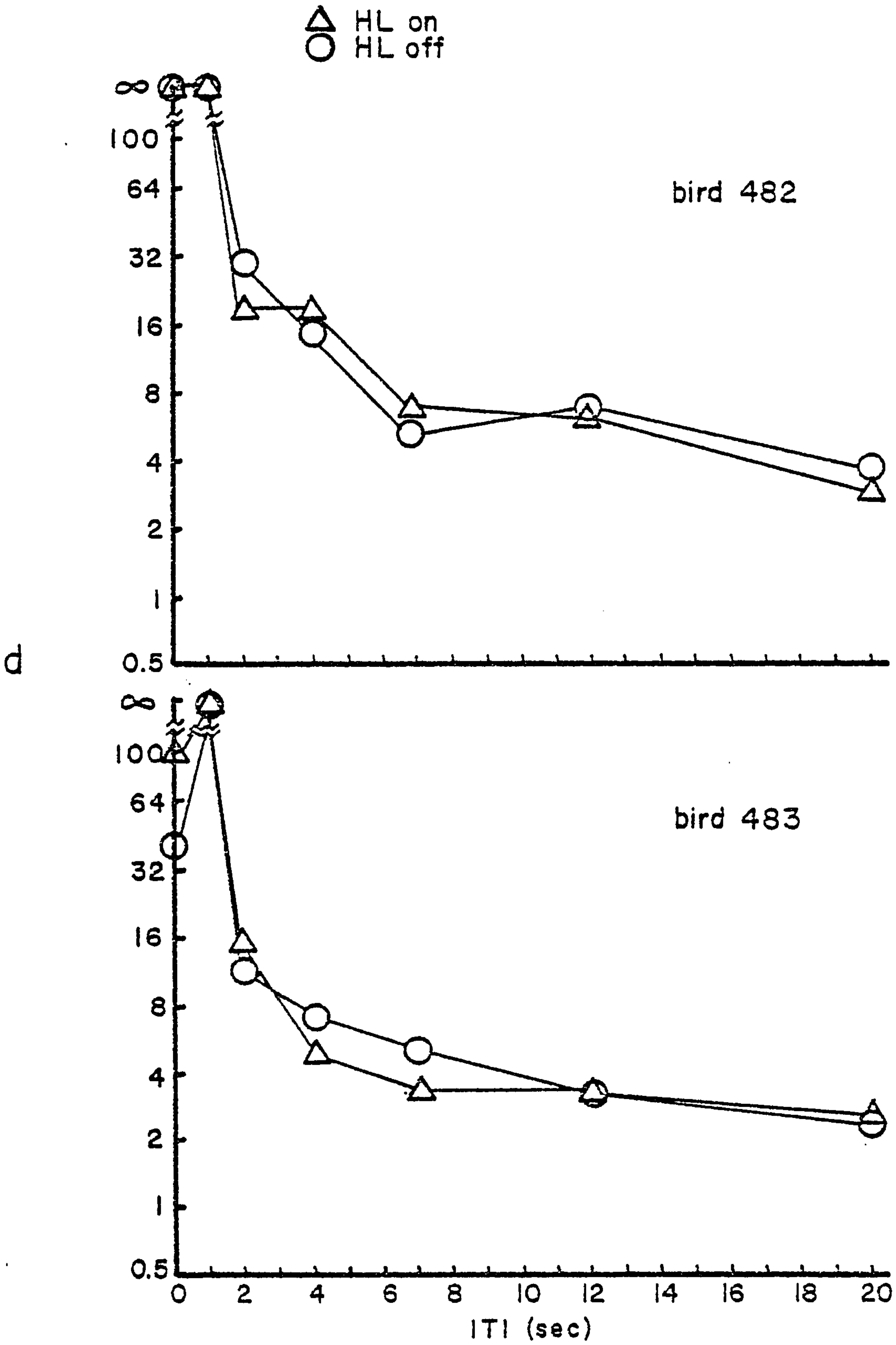

Figure 11. SENSITIVITY AS A FUNCTION OF R/NR ITI: PHASE TWO.

Discussion

The decline in accuracy with the onset of HL illumination during R/NR ITIs was expected on the basis of previous research. The nonmonotonic form of the HL-on function for bird 481 was unexpected. Although Hearst (1962) noted a similar nonmonotonic delay function in a delayed alternation task, it is not clear why this pattern occurred. However, it should be noted that until partial reinforcement was introduced on regular trials, 481 had exhibited a similar nonmonotonic pattern of responding with the HL off.

Most research has involved only short periods of testing with the HL on during delay intervals. Thus, the adaptation to the HL-on condition is of interest. The decline in disruption by HL illumination is consistent with Tranberg and Rilling's (1980) suggestion that it is the change in HL illumination that disrupts performance rather than absolute illumination level. It is not clear why, with extended practice, two birds had greater accuracy with the HL on than off at longer delays. One possibility is that some sequence of behavior developed during the delay which helped to maintain accuracy over longer ITI values. If so, the tendency of pigeons to be more active in a lighted chamber than in darkness might have facilitated the occurrence of this behavior when the HL was on.

The results of the second phase of the experiment are less informative than those of the first phase. The adaptation effects observed in the first phase continued into the second phase. As a result, very little change in performance was observed as a function of HL illumination. The crossovers of the HL-on and HL-off functions observed with longer delays in Phase I were not repeated.

Because of order effects due to the adaptation to HL illumination with extended exposure, and the need for a large number of sessions in each condition in order to obtain stable measures of performance, it was felt that the experiment should be repeated with early and late signals occurring in the same session. Thus, a third experiment was conducted to eliminate these order effects.

III. EXPERIMENT III

In the earlier experiments, some variables were manipulated across sessions, leading to the occurrence of order effects that complicated the interpretation of the data. In the third experiment most of the experimental manipulations were conducted on a within-session basis, thus circumventing these problems.

Tranberg and Rilling (1980) and Cook (1980), using DMTS procedures, found that visual stimulus change during the delay period disrupted memory regardless of whether absolute stimulus intensity was increased or decreased. This has been extended to the reversal learning paradigm in the current series of experiments. Both turning off the HL during the R/NR ITI following a baseline with the HL on (Experiment I) and illuminating it during the R/NR ITI following a HL-off baseline (Experiment II) produced qualitatively similar disruption of performance. The third experiment attempted to study this issue quantitatively. Following a baseline in which the HL was on during the R/NR ITI for half the birds and off for the others, all birds experienced an equal proportion of HL-on and HL-off trials during testing. The symmetry of experimental conditions should allow for comparisons of both acquisition and disruption of reversal performance across baseline conditions. Unfortunately, as will be discussed shortly, a computer programming error interfered with this comparison.

Conceptually, this experiment was also somewhat different. It was designed to be more like Shimp's (1976) experiment than a conventional reversal learning experiment. Rather than requiring five consecutive correct responses for an R/NR trial to occur, a single correct response sufficed. The advantage to using this procedure is that the proportion of trials on which useful data may be collected was increased.

Method

Subjects

Four white Carneaux pigeons served. Birds 476, 495 and 496 had limited prior experience with autoshaping procedures. Bird 72 had experience with multiple schedules of reinforcement.

Apparatus

As in Experiment II phase II.

Procedure

The procedure was similar to that used in Experiment II, phase II, except that the criterion for reversal was one correct response, and all trial types were presented in each session during part of the experiment.

The pigeons were introduced to the experimental procedure in much the same way as in Experiment II. A summary of experimental conditions is displayed in Table 2. Initial training used a criterion of five consecutive correct responses for a reversal. In this experiment responses on R/NR trials did not advance the criterion counter. Reinforcement occurred on all trials in which a correct response occurred, except for the one which completed the criterion. R/NR signals occurred at the beginning of the R/NR ITI half the time, and at the end the rest of the time. Two birds (476, 495) were run with the HL off during R/NR ITIs, and the others (496, 72) were run on a HL-on baseline. There were 16 R/NR trials per session.

TABLE 2

Sequence of conditions in Experiment III. See text for additional details.

Experimental Condition	Number of Sessions			
	476	495	496	72
PHASE I: Baseline.				
A. Initial training	30	31	28	15
B. Gradual introduction of delays	36	35	33	27
C. Gradual reduction of criterion	49	44	44	46
D. Baseline with programming error	62	61	62	62
E. Corrected baseline	92	93	93	92
PHASE II: Experimental Condition.				
A. Experimental Phase	58	61	60	61

After approximately 20 sessions (8 for 72) reinforcement was delivered for only 20% of the correct responses on regular trials as in Experiment II. Sessions were increased to 24 R/NR trials. This condition was in effect for 7 to 10 sessions.

Following this, over a period of 27-36 sessions, delay values were introduced in seven steps in the same gradual fashion as in Experiment II. The same final series of delays was used as in the second phase of Experiment II. When the final delay values were in effect, the criterion for a reversal was decreased gradually to 1 over a period of 44-49 sessions. At the same time, sessions were increased to 64 R/NR trials.

After the final baseline condition had been in effect for 61-62 sessions, it was discovered that an accidental modification of the computer program had been made early in the period of reducing the criterion, remaining in effect for 120 sessions. During this period, all birds received the HL-off condition with early signals and nonreversals on all even-numbered trials. Odd-numbered trials were normal. This error obviously confuses the interpretation of data for pigeons given the HL-on baseline, although it may not have affected the birds given the HL-off baseline very seriously.

This error was corrected, and the birds were run correctly for 92-93 sessions on the corrected baseline procedure. At this point the final condition was introduced, in which for all birds the HL was on for 50% of the R/NR ITIs, and off on the remaining trials. This condition was in effect for 58-61 sessions.

Results

The procedure in this experiment was more complex than in the second experiment with more variables being manipulated simultaneously. This is reflected to some degree in the data. Sensitivity levels for the birds in this experiment tended to be lower than in the second experiment for equivalent delay values.

The sensitivity data for the baseline condition are shown in Figure 12. As was usually the case in previous experiments, sensitivity was a monotonic decreasing function of the R/NR ITI value. Excluding the zero-delay condition for which both conditions are identical and the longer-delay conditions for which performance was near the chance level, there was considerable separation of the delay functions between the early and late signal conditions. All birds responded more accurately during the late-signal condition than during the early-signal condition. The bias data are

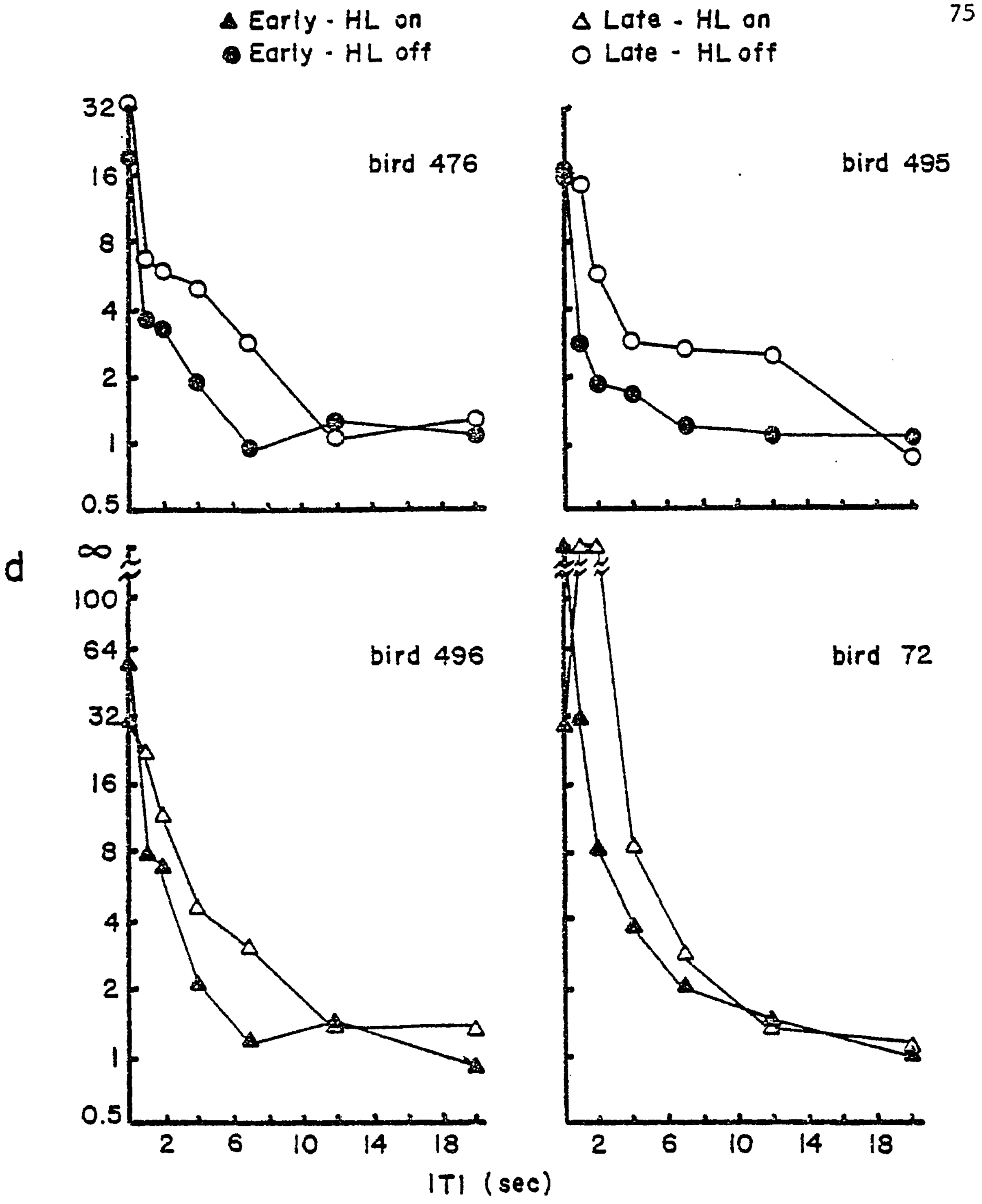

Figure 12. SENSITIVITY AS A FUNCTION OF R/NR ITI DURING THE FIRST PHASE OF EXPERIMENT III.

displayed in Figure 13. The differences in sensitivity are paralleled by substantial differences in bias. In the late-signal conditions, all birds exhibit considerable bias towards nonreversals. In the early-signal conditions, the biases are less pronounced, with three birds displaying moderate biases towards reversals at some or most delay values.

Another way of viewing the data is to plot sensitivity against bias for each experimental condition. This type of plot is shown in Figure 14 for each bird. Several trends are evident. In each case there is a convergence on no bias as sensitivity approaches the chance level. In the early-signal condition, the condition associated with the highest sensitivity is also associated with the greatest bias toward nonreversals in each case. For three birds the intermediate sensitivity levels are associated with a shift in bias towards reversals before converging on no bias at low sensitivity levels. The baseline HL condition seems not to have been a factor. In the late signal condition, the greatest degree of sensitivity was associated with an intermediate level of bias towards nonreversals. At intermediate sensitivity levels, all birds showed increased bias towards nonreversals, finally converging on no bias as sensitivity approached chance. Thus, the relationship between sensitivity and bias was quite regular, although the

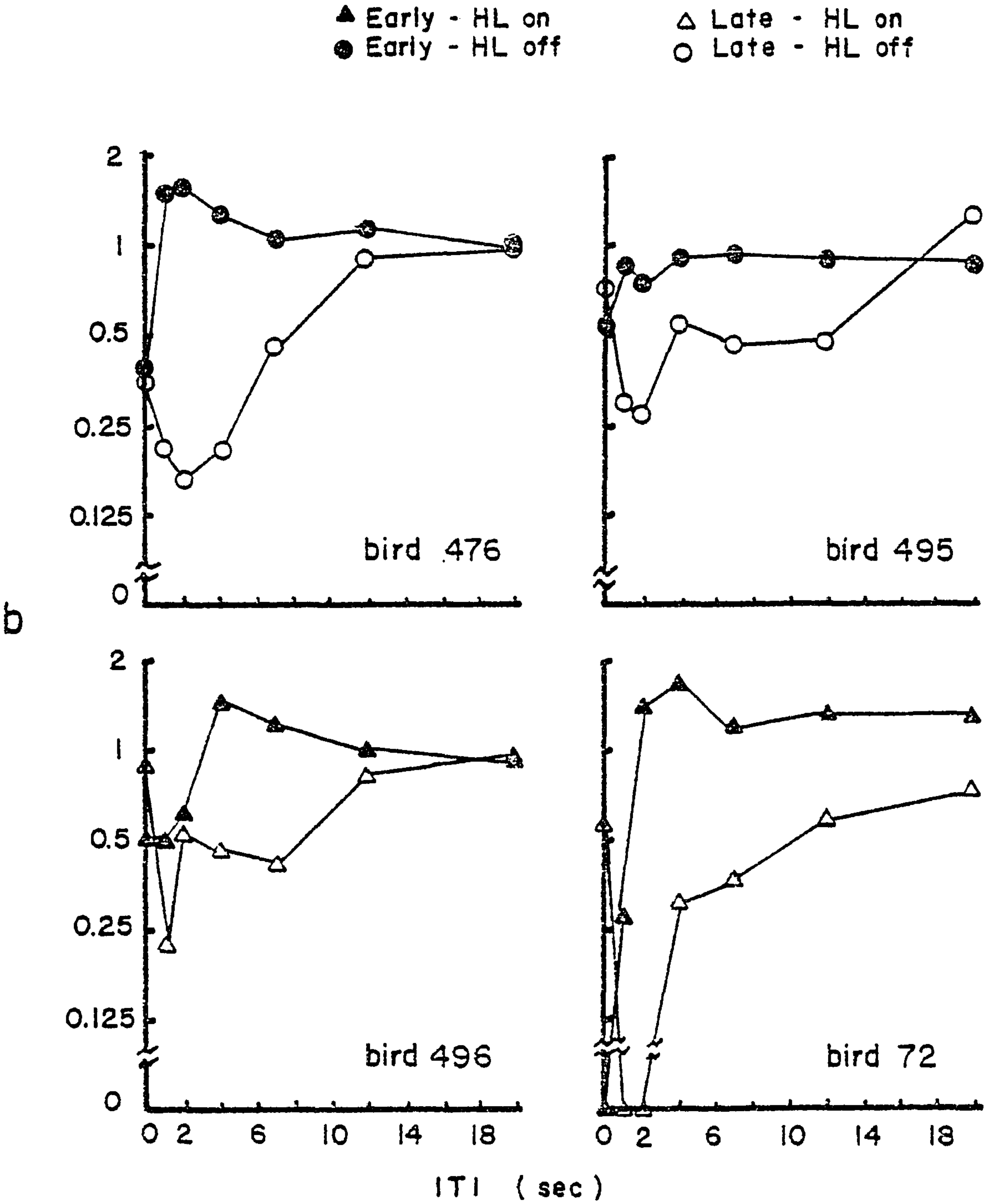

Figure 13. BIAS AS A FUNCTION OF R/NR ITI DURING THE FIRST PHASE OF EXPERIMENT III.

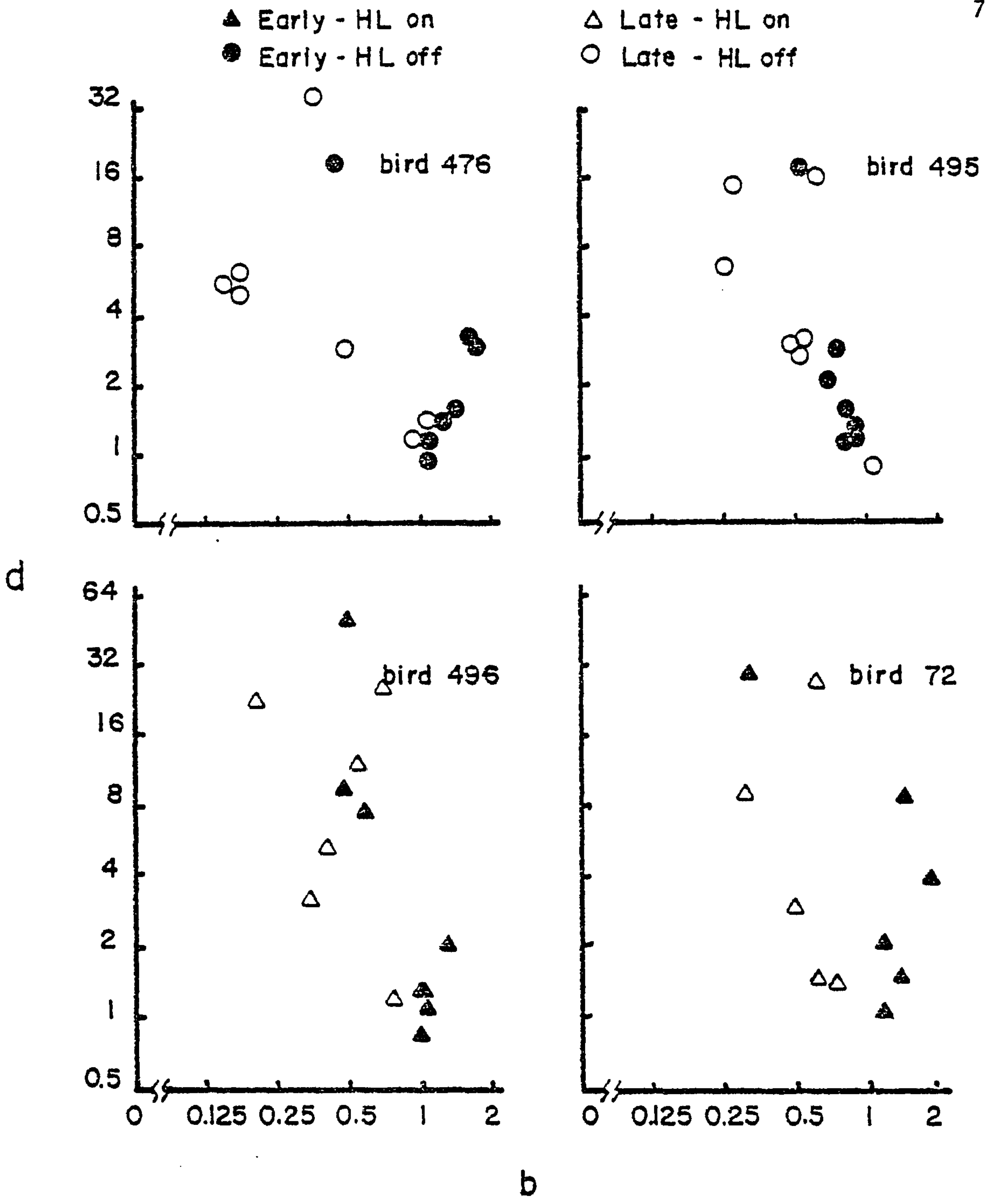

Figure 14. COVARIATION OF SENSITIVITY AND BIAS IN THE FIRST PHASE OF EXPERIMENT III.

plots for the early- and late-signal conditions are curved in opposite directions. This is most clearly seen in the data for birds 476 and 72.

The data from the second phase are more complex, especially considering the fact that the birds nominally given a HL-on baseline received considerable exposure to the HL-off condition (although not when a reversal was to occur). Sensitivity data for the second phase are displayed in Figure 15. A summary of these data and of the bias data is presented in Table 3. The added complexity of the procedure resulted in a slight further decrease in sensitivity levels. The differences in sensitivity between early and late signal conditions remained pronounced for three of the four birds. This may be seen most clearly by comparing the early- and late-signal conditions separately for the HL-on and HL-off conditions. As in the first phase, the data for intermediate delay values are most informative. For three birds, there were consistent, and frequently rather large separations between the early- and late-signal conditions for both HL conditions, with greater accuracy occurring in the late-signal conditions. Bird 72 showed a similar pattern in the HL-off condition, but not in the HL-on condition.

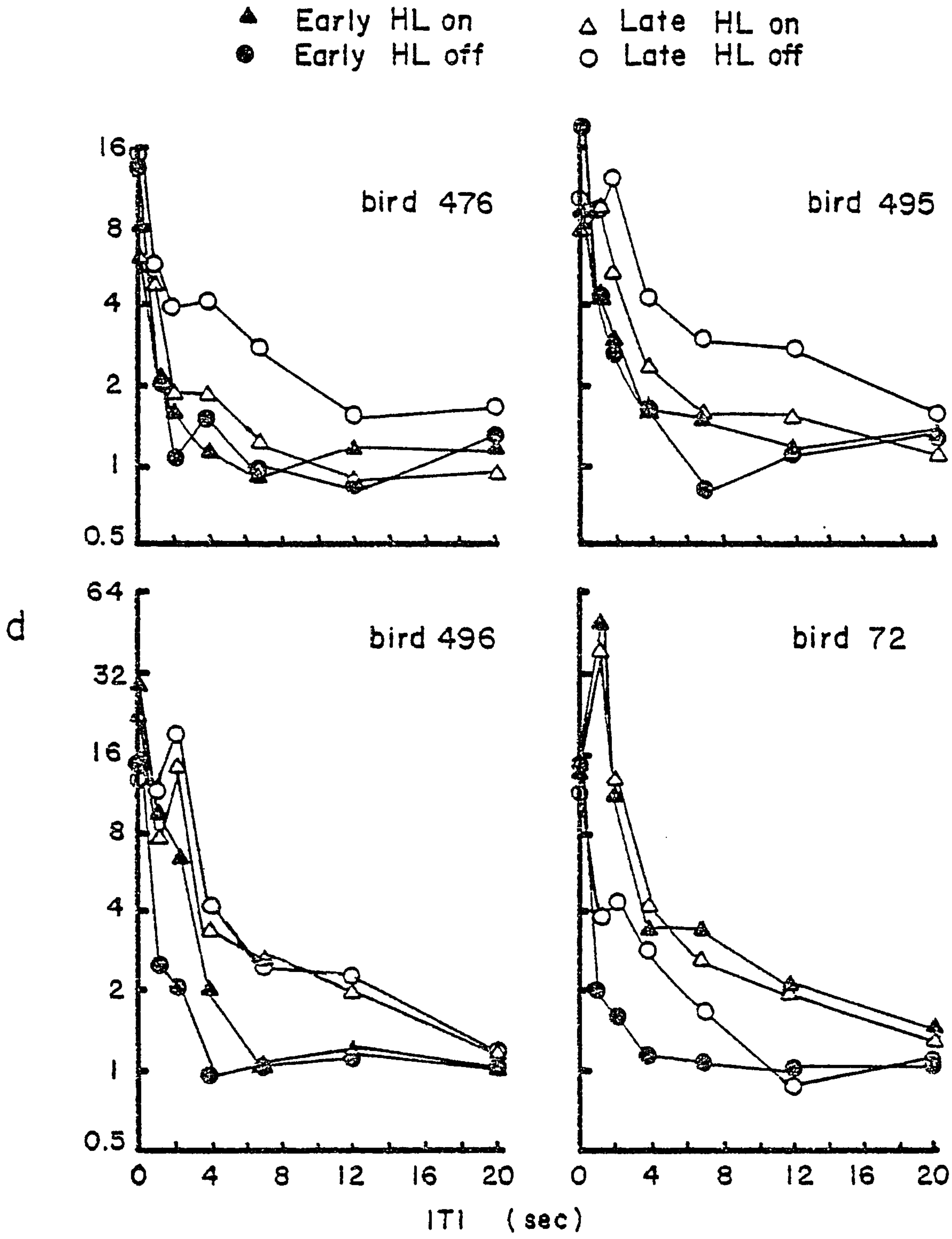

Figure 15. SENSITIVITY AS A FUNCTION OF R/NR ITI DURING PHASE TWO.

TABLE 3

A summary of the sensitivity and bias data for the second phase of Experiment 3. See Figures 15 and 17 for a more complete presentation of these data. The left half of the table compares data for the early (E) and late (L) conditions for both the HL-on and HL-off conditions. The right half compares HL-on with HL-off for both the early and late conditions.

BIRD	BASELINE	EARLY VS. LATE	HL-ON VS. HL-OFF
		SENSITIVITY	
476	HL-OFF	OFF-E < OFF-L	E-ON = E-OFF
		ON-E < ON-L	L-ON < L-OFF
495	HL-OFF	OFF-E < OFF-L	E-ON = E-OFF
		ON-E < ON-L	L-ON < L-OFF
496	HL-ON	OFF-E < OFF-L	E-ON > E-OFF
		ON-E < ON-L	L-ON = L-OFF
72	HL-ON	OFF-E < OFF-L	E-ON > E-OFF
		ON-E = ON-L	L-ON > L-OFF
		BIAS	
476	HL-OFF	OFF-E > OFF-L	E-ON < E-OFF
		ON-E > ON-L	L-ON = L-OFF
495	HL-OFF	OFF-E > OFF-L	E-ON < E-OFF
		ON-E > ON-L	L-ON = L-OFF
496	HL-ON	OFF-E > OFF-L	E-ON = E-OFF
		ON-E > ON-L	L-ON > L-OFF
72	HL-ON	OFF-E > OFF-L	E-ON > E-OFF
		ON-E > ON-L	L-ON > L-OFF

The effects of HL illumination on sensitivity were not so simple. Both birds given the HL-off baseline showed substantial decrements in performance with the HL on in the late-signal condition, but very little effect of HL illumination in the early-signal condition. In the group given the HL-on baseline, both birds showed substantial decrements in performance with the HL off in the early-signal condition.In the late-signal condition, bird 72 also showed a substantial effect of HL illumination, but bird 496 showed very little consistent difference in performance due to HL illumination.

In Figure 15 it was seen that sensitivity was generally greater when the signal occurred at the end of the R/NR ITI. It was also shown that, in general, changes in HL illumination from that of the baseline condition tended to disrupt performance. A related issue is the relative resistance of performance to disruption by changes in HL illumination. An analysis of this issue is presented in Figure 16. The dependent measure is the ratio of sensitivity in the changed HL condition to sensitivity in the condition identical to that presented during the baseline phase. This ratio is plotted separately for the early- and late-signal conditions for each delay value. A ratio of 1.0 indicates no effect of HL illumination on performance. A ratio of less than one indicates disruption by the changed HL conditions, and a ratio of greater than 1.0 indicates facilitation. As in most of the figures, the data from the intermediate delay values are the most informative. Two of the four birds showed greater disruption by changes in HL illumination in the late-signal condition, and two showed greater disruption in the early condition. Thus, there is no consistent relationship between signal location and disruptability by changes in HL illumination. A somewhat different picture would emerge if all sensitivity ratios were of HL on to HL off, regardless of baseline condition. This would have the effect of inverting the function for birds 496 and 72. For all birds, accuracy in the early-signal condition was the same or greater with the HL on than with it off. For three of the four birds, accuracy in the late-signal condition was lower with the HL on. For all four birds the ratio of sensitivities for HL on to HL off was greater in the early-signal condition than in the late-signal condition. Thus, in general, it seems that the HL-on condition favors the early-signal condition, and the HL-off condition favors the late-signal condition.

The bias data for this condition are displayed in Figure 17. As was the case during baseline, there was greater bias towards nonreversals in the late-signal condition than in the early-signal condition for all four

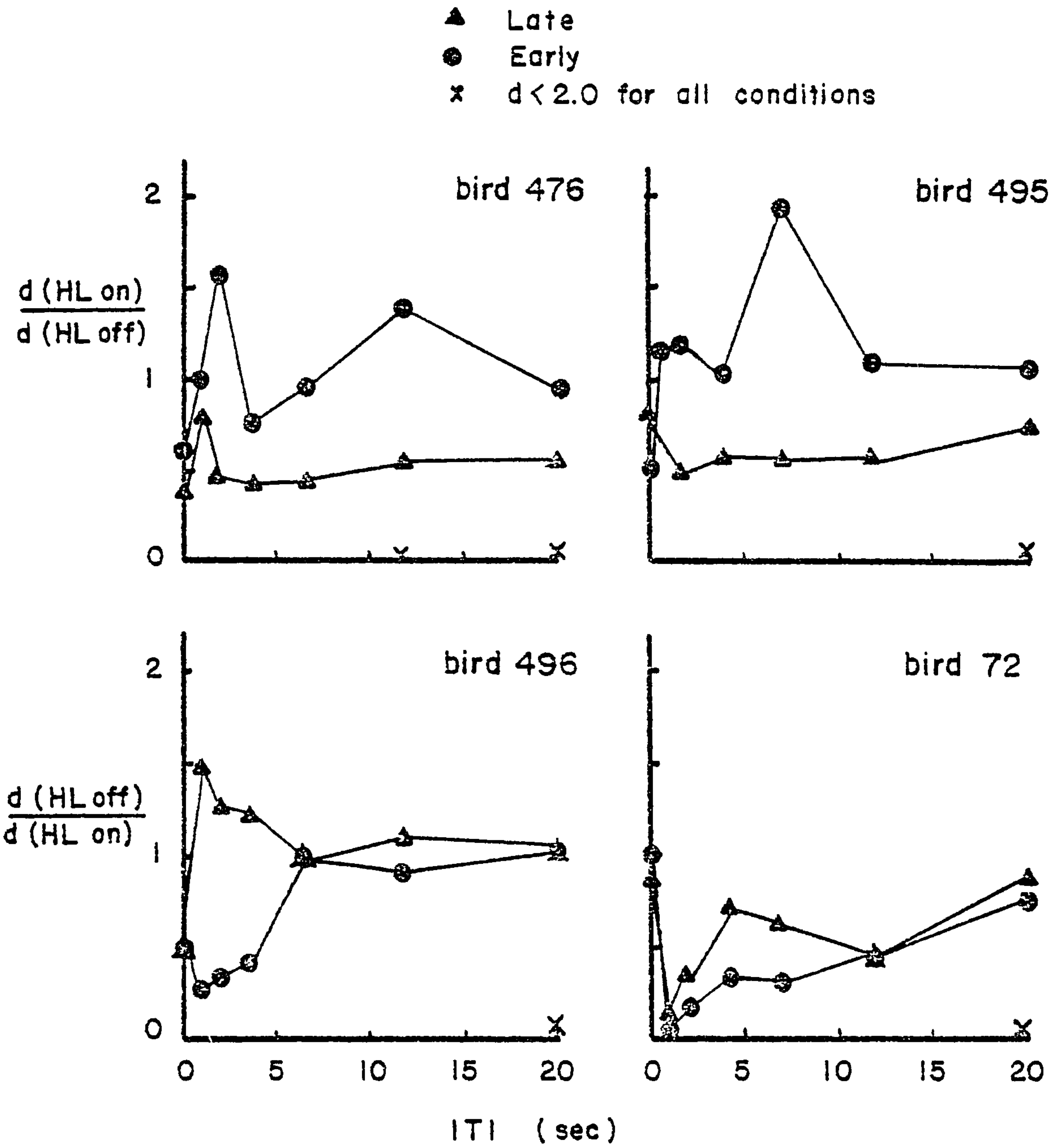

Figure 16 . SENSITIVITY RATIO AS A FUNCTION OF R/NR ITI DURING PHASE TWO . SEE TEXT FOR FURTHER EXPLANATION .

birds. This finding held up for both HL conditions. Although there was less bias towards nonreversals in the early-signal condition, the switch to a reversal bias observed in the baseline condition was not present in this phase; rather, the performance simply showed little bias in most cases except at the shortest delay values.

The effects of HL on bias were more complex. For birds given the HL-off baseline, there was no effect of HL on bias in the late-signal condition, and in the early-signal condition there was more bias towards nonreversals in the HL-on condition. For birds given the HL-on baseline, in the late-signal condition there was more bias towards nonreversals with the HL off; in the early-signal condition this held for one bird with the other bird showing no difference. Thus, if any effect was present, changing the HL condition resulted in increased perseveration on the previously-pecked key.

Discussion

The third experiment produced a substantial amount of data that goes beyond that obtained in the first two experiments. Three major variables were studied: delay, HL illumination, and the locus of the R/NR signal within the R/NR ITI. As in the earlier research, sensitivity was a

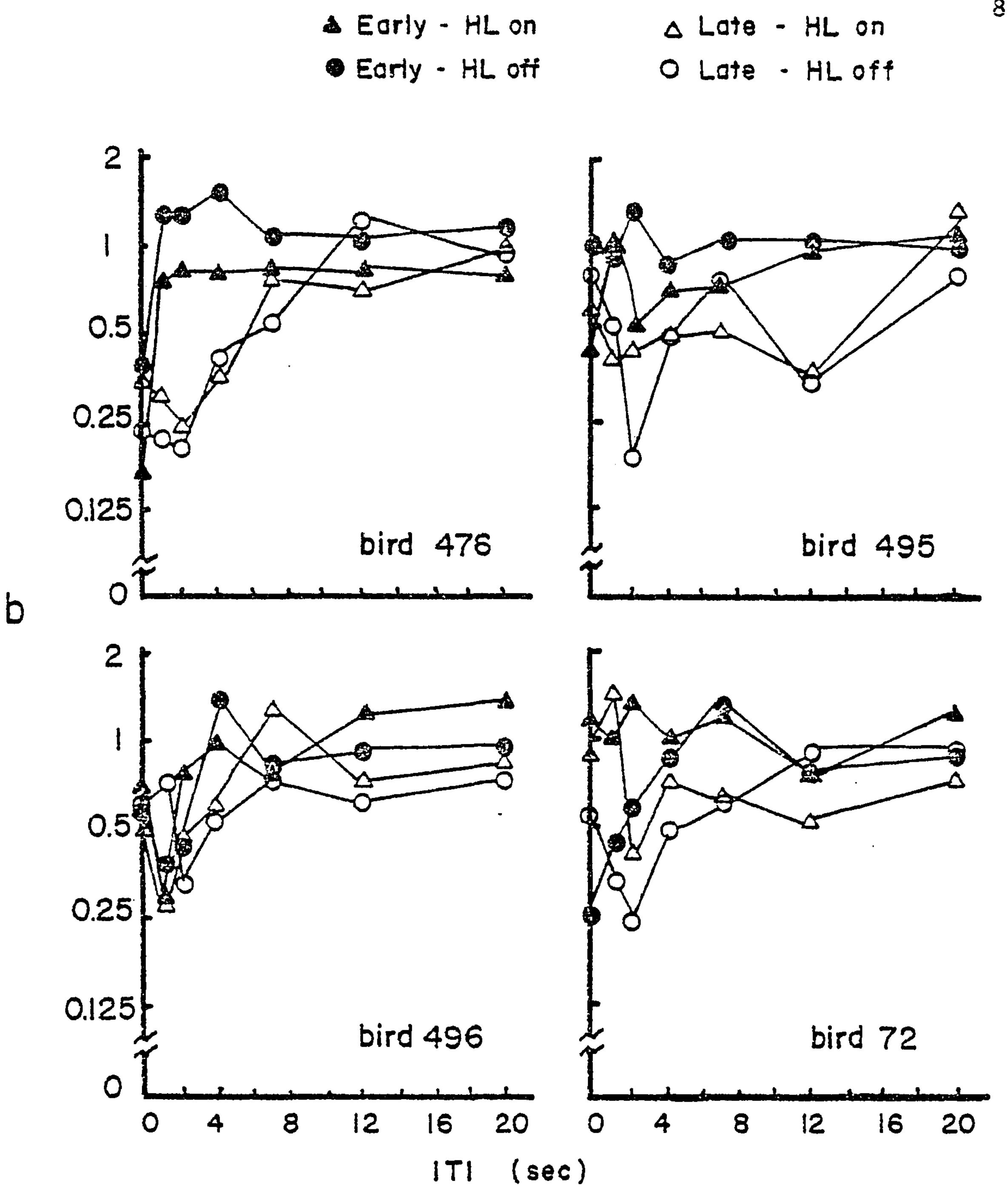

Figure 17. BIAS AS A FUNCTION OF R/NR ITI DURING PHASE TWO.

monotonically decreasing function of the R/NR ITI. Also replicating earlier findings, bias was generally greater at ITI values for which sensitivity was well above the chance level, with very little bias at longer ITI values.

One of the major issues being addressed by this experiment was that of the effects of HL illumination. Tranberg and Rilling (1980) and Cook (1980) have demonstrated that, in a DMTS procedure, it is the change in delay illumination from training to testing that disrupts performance, and not the absolute illumination level. Although the data in Experiments I and II of this series were suggestive, they were not conclusive in themselves. The data from Experiment III are considerably stronger. Although changes in HL illumination did not affect sensitivity in all conditions, those behavior changes that did occur were all consistent with the idea of relative illumination being the determining factor. Birds given the HL-off baseline showed decrements in performance when the HL was illuminated during R/NR ITIs, and birds given the HL-on baseline showed decrements in performance when the HL was turned off during these periods. Thus, despite the fact that HL effects may have been weakened by the programming error during baseline, any effects that occurred supported the relative illumination approach.

Changes in HL illumination also affected response bias in a way that suggests that relative illumination was the crucial factor in the disruption of reversal performance. Birds given the HL-off baseline showed greater bias towards nonreversals when the HL was illuminated, and birds given the HL-on baseline showed increased bias towards nonreversals when the HL was turned off. Thus, in each case in which bias shifts occurred, a change in HL illumination, whether an increase or a decrease, produced a shift towards perseveration on the same key; absolute illumination was not a factor.

Although changes in HL illumination did not affect either sensitivity or bias in all conditions, one or the other measure of performance was affected in each condition with each bird. Both birds given the HL-off baseline showed sensitivity changes only in the late-signal conditions and bias shifts only in the early-signal conditions. Of the birds given the HL-on baseline one showed sensitivity and bias shifts in both the early- and late-signal conditions, and one showed sensitivity changes in the early-signal condition and bias shifts in the late-signal condition. It is not clear why this pattern should emerge; however, it points out the need for analyzing sensitivity and bias separately in this type of study.

The delay and HL variables that have been considered up to this point have direct analogs in the DMTS paradigm. The third major variable, the locus of the R/NR signal within the R/NR ITI, does not have a direct analog. The most similar variable in the DMTS paradigm is the locus of the stimulus change (e.g. HL illumination or darkening) within the delay. Roberts and Grant (1978) found that HL illumination was more disruptive at the end of the delay interval than at the beginning. The R/NR signal, although inserted into the trial sequence in the same fashion, differs from HL illumination in a DMTS procedure in that it functions as a discriminative stimulus. However, it may, at least initially, have some disruptive properties as well, which would presumably follow the same pattern that was found by Roberts and Grant (1978).

One of the clearest findings in this experiment was that the locus of the R/NR signal had major effects on both sensitivity and bias. All birds showed clear differences in sensitivity except bird 72 in the HL-on condition, with sensitivity being higher in the late-signal condition. This result is opposite from the pattern observed when locus of a disrupting stimulus is studied in a DMTS procedure. However, the present findings would be expected based on the idea that in the early-signal conditions the birds had to remember both their own previous behavior and the signal, but in the late-signal condition the birds need only have remembered their previous behavior across the delay because the signal occurred just prior to their making the required response.

The effects of signal locus on bias were equally clear: in all cases there was greater bias towards the nonreversal response following the late signal. In part, this may reflect the necessary decrease in bias as sensitivity declines in this type of procedure. However, as was seen in Figure 14, the function forms relating sensitivity to bias differed between the early- and late-signal conditions during baseline. Since there were no obvious differences in reinforcement contingencies to produce these effects, it is not clear why such consistent behavioral differences were found.

Although the effects of signal location and changes in HL illumination on sensitivity were quite clear, the resistance of sensitivity in the early- and late-signal conditions to disruption by changes in HL illumination was more complex. Changes in HL illumination had no simple effect on sensitivity as a function of the locus of the signal within the R/NR ITI. However, it was clear that the HL-on condition favored the early-signal condition and the HL-off condition favored late-signal performance, regardless of the baseline HL illumination. This is the only instance of an effect of absolute HL illumination rather than change in illumination relative to baseline. Although this finding was quite clear in every bird, it is not clear why it should have occurred. There is nothing in the concept of relative illumination as the important variable that would suggest this pattern. Most theoretical accounts specifying absolute illumination as a factor suggest that increased illumination results in increased visual stimulation during a retention interval, and thus further disruption of visual memory. This type of account would suggest greater disruption of performance by HL illumination in the early-signal condition than in the late-signal condition, as the pigeon need only remember its previous response in the late-signal condition, but it must remember the signal color as well in the early-signal condition. Thus, the data clearly contradict conventional accounts relying on absolute illumination.

In summary, although relative resistance to disruption by changes in HL illumination was not orderly wth respect to signal locus, several patterns emerged quite clearly from this experiment. Both sensitivity and bias were found to be dependent on relative, rather than absolute, HL illumination. Changes in illumination resulted in decreased sensitivity and greater tendencies towards perseveration on the most recently pecked key. The locus of the signal was also found to have clear effects. Sensitivity was greater when the signal occurred at the end of the delay, and more bias was found towards response perseveration in this condition.

IV. GENERAL DISCUSSION

The major findings of this series of experiments may be organized around the effects of the three major independent variables on performance: duration of the R/NR ITI, changes in HL illumination, and locus of the R/NR signal. The first section is concerned with the effects of varying the duration of the R/NR ITI.

Duration of R/NR ITI

In each experiment, with minor irregularities, a monotonic decreasing relationship was obtained between R/NR ITI duration and sensitivity. This finding is in agreement with earlier findings using DMTS procedures (e.g. Berryman et al., 1963). Although procedural differences prevent any direct comparison, the data suggest that the manner of introduction of longer intervals and the complexity of the experimental procedure may affect the degree to which sensitivity falls off with increasing delay. This may be examined through comparison of performance at a 12-sec delay in different conditions, as this delay value was used in each experiment. In Experiment I, with sudden introduction of longer delays, at 12 sec the sensitivity measure d ranged from 1.02 to 1.33. In Experiment II, with more gradual introduction of delay, d ranged from 1.41 to 8.61 for the same delay in the HL-off condition during the first third of the test for HL effects. Thus, it is possible that gradual introduction of delay results in a shallower delay-sensitivity gradient than does sudden introduction. In Experiment III Phase 1, d ranged from 1.13 to 2.53 for the 12-sec delay. As the manner of introduction of delays was nearly identical for the two experiments, the greater complexity of the procedure may be responsible for steeper sensitivity gradients in the latter.

The effects of delay value on bias were also quite regular across experiments. In general there was a bias towards nonreversal of responding (perseveration). This bias tended to be strongest at short delay values, decreasing to near zero as delay increased. As sensitivity decreased with increasing delay, it seemed likely that the decrease in bias was related to the decrease in sensitivity. This finding at first was rather disturbing, as a major reason for using a signal-detection analysis was to obtain independent measures of sensitivity and bias. However, in the type of procedure used in these experiments, whereas sensitivity and bias may be measured independently, they are not behaviorally independent. In this series of experiments, bias implies switching responses or perseverating independent of the R/NR signal. As the ITI value increased, sensitivity, or the likelihood of the bird discriminating (remembering) its own previous behavior, decreased. As the bird became less able to emit a response based on its own prior behavior, it necessarily became less able to maintain a consistent response bias. Thus, covariation of sensitivity and bias is simply a built-in feature of the experiment, and does not reflect inadequacies in the signal-detection analysis.

Changes in HL Illumination

For reasons that have been lost to history, the first experiment was run with a HL-on baseline. As this experiment was run before the appearance of Tranberg and Rilling's (1980) paper, it was expected that turning off the HL would result in increased sensitivity. Therefore it was a surprise when accuracy in this condition was lower than in the baseline condition for all birds. The second experiment was run with a more conventional HL-off baseline in the hopes of getting the expected disruption of performance by turning on the HL. The data from this experiment were quite clear: for all birds, and at all delays, performance was disrupted considerably by the introduction of HL illumination during the R/NR ITI, with only gradual recovery over time. During the period in which the second experiment was being run, the papers by Tranberg and Rilling (1980) and Cook (1980) were published, and it became clear that the results of the present research were consistent with their findings. The third experiment was designed to extend their findings to the reversal learning paradigm more directly. Two birds were given a HL-on baseline, and two a HL-off baseline. In the second phase, each HL condition was presented equally often to each bird. Due to the computer programming error mentioned earlier, the expected effects may have been weakened; however, all birds showed clear effects of HI illumination in at least one of two conditions (early and late signal), and in each case any observed effect was in accordance with a prediction based on change in intensity as the relevant variable. Birds given a HL-on baseline showed decrements in the HL-off condition, and birds given a HL-off baseline showed decrements in the HL-on condition. Thus, the results of this experiment, taken together with the results of the first two experiments, provide clear support for changes in illumination during the R/NR ITI being the controlling variable rather than absolute stimulus intensity. Furthermore, these results represent an extension of this pattern to a paradigm that differs significantly from the DMTS paradigm, particularly in that the correct response on a given trial depends on the previous response as well as a discriminative stimulus.

In Experiment II the irregular alternation of HL-on and HL-off sessions was continued for 96 sessions to explore the effects of prolonged exposure to the new HL condition. The effects of HL illumination diminished considerably over time, as would be expected if stimulus change were the relevant factor. With prolonged exposure, neither HL condition would represent a change from conditions prevalent in earlier sessions, so neither should be disruptive. Interestingly, there was a tendency in 2 of 3 birds to be more accurate in the HL-on condition, particularly at longer delays, following extended training. It is possible that some sequence of behavior developed during the delay which maintained accurate responding over long delays. Such behavior has frequently been observed in procedures which require the emission of temporal intervals (e.g. Laties, Weiss and Weiss, 1969), and might serve a similar function in this procedure. As pigeons tend to be more active in a lighted chamber, this behavior might be facilitated by the illumination of the HL.

The effects of HL illumination on response bias were considerably less consistent. In Experiments I and II, there was little evidence for consistent effects of changing

HL illumination on response bias. In the third experiment, although differences were not observed in all conditions for each bird, those differences that did occur were in the direction of nonreversal of responding in the conditions with changed HL illumination. Although not a strong effect, it may represent a tendency towards response perseveration under novel stimulus conditions. Perhaps more importantly, response bias varied as a function of relative rather than absolute illumination, a finding that strengthens the pattern observed with sensitivity measures.

Locus of the R/NR Signal

The only meaningful data concerning the effects of the locus of the R/NR signal on performance were obtained in the third experiment. The pattern was quite clear: sensitivity was greater in the late-signal condition than in the early-signal condition, and there was also a stronger bias towards perseveration in the late-signal condition.

The sensitivity differences were consistent with earlier expectations. In both cases the birds had to remember their previous responses across the delay interval. In the early-signal case they had to remember the signal as well, whereas in the late-signal condition the signal occurred immediately before the availability of the next response. Thus, the early-signal condition was expected to be the more difficult of the two.

Although sensitivity was greater in the late-signal condition, behavior in both conditions appeared to be equally disruptable by changes in HL illumination. Initially this appears to be contrary to what might have been expected. However, whereas differences in the difficulty of the discriminations affected absolute sensitivity levels, the disruptability of established discrimination performances may be more closely related to the contingencies of reinforcement. In both conditions a single correct response on the R/NR trial was sufficient to produce reinforcement; thus it might be expected that behavior in the two conditions would be equally resistant to disruption.

Theoretical Implications: What is Remembered

Although every attempt has been made to discuss the research presented in this paper at a behavioral level, certain assumptions have been made that have much in common with related cognitive theories of memory. Although this research was not conducted to test any of these theories, it is worth examining the assumptions that have been made, and any implications of the current research for these theories.

The major point of intersection between the current research and the more cognitive side of the animal memory field comes in the issue of what is remembered. In behavioral terminology, it appears reasonable to discuss this research in terms of stimulus control of switching and staying; the delay variable may be viewed as simply a means of degrading control by antecedent stimuli. However, when the effects of the locus of the R/NR signal are examined, the role of the delay period becomes more significant. There is still no problem with maintaining a behavioral perspective; however, proper use of behavioral terminology starts to become cumbersome, and it is simpler to use the more cognitive memory vocabulary. Use of this vocabulary is acceptable from a behavioral perspective as long as the words are used with consistent, behavioral meanings; however, that may not always be the case.

On several occasions in this paper, the following analysis was given of the effects of locus of the R/NR signal on performance. In the early-signal case, it was stated that the bird must remember both its own previous response and the signal across the ITI in order to respond correctly on the next trial. In the late-signal case, the bird need only remember its last response across the entire interval, the relationship of the signal to the next response being equivalent to a zero-delay MTS situation regardless of delay length. On the basis of such an analysis, the correct prediction was made that sensitivity would be greater at an equivalent delay value in the late-signal condition, as less needed to be remembered across the delay period.

As will be shown later, this discussion of memory could be stated in the more explicitly behavioral terminology of stimulus control of behavior by antecedent events; I do not believe that the behavioral approach was compromised in this case by the use of memory terminology. However, the use of memory terminology does point to a more cognitively oriented issue that is worth addressing: what is actually remembered? Although this issue has previously been considered primarily from a cognitive perspective, it is likely that a behavioral approach will provide a fresh view of the question.

The analysis of what was remembered presented above carries the assumption that pigeons remember what has happened: what was the signal, and what was the bird's previous response. This has been labelled the trace, or retrospective theory of memory (Grant, 1981, 1982, Roitblat, 1980, 1982) because it implies that pigeons remember a trace of the antecedent stimuli, or that they remember "what has happened". An alternative viewpoint is that pigeons remember "what to do", without necessarily remembering much about antecedent conditions. This has been termed the prospective theory of memory. Grant (1981, 1982), Roitblat (1980, 1982) and others have proposed that the prospective view may be more valid than the retrospective view of memory.

It is worth presenting a couple of examples of the type of work that may permit this distinction to be made, as the basic research is clearly behavioral in nature. One clear example was presented by Roitblat (1980) in an experiment using a symbolic DMTS procedure. Color samples were correlated with line-orientation test stimuli for two birds, the reverse correlation holding for the other two. There were three stimuli from each dimension, two being very similar and the third quite different. All three test stimuli were presented on each trial. One incorrect test stimulus closely resembled the correct one; the other was associated with the sample closely resembling the one actually presented. The idea was that, if pigeons remember retrospectively (what has happened), errors should involve incorrectly pecking the test stimulus correlated with the similar sample. If pigeons remember prospectively (what to do), errors should involve pecking at the test stimulus closely resembling the correct one. The results indicated that the second pattern of errors occurred, and thus are consistent with the idea that pigeons in this experiment remembered prospectively.

Further evidence was presented by Grant (1982) in a DMTS procedure with multiple sample presentations. One, two or three samples were presented on each trial. Multiple-sample trials were of either same- or different-sample type. On same-sample trials, the same sample was simply repeated successively. On different-sample trials, the samples were physically different but associatively identical: they each signalled that the same response would be reinforced. Both the prospective and retrospective theories should predict that a single memorial representation would be activated on same-sample trials. There would presumably be summation of memory trace strength with repetition of the samples. On different-sample trials, the prospective account would again predict a single representation, as each stimulus carried the same implications of what to do. However, the retrospective account would predict multiple memory traces of weaker strength, as the animal would remember a trace of each sample stimulus. Thus, the prospective theory predicts equal accuracy in each trial type. The retrospective theory would predict greater accuracy on same-sample trials, as they would have a single, stronger memory trace than the multiple memory traces in the different-sample trials. The results of the experiment were quite clear: although performance improved with multiple sample presentations, there was no difference between performance on same- and different-sample trials. Thus, again it was found that animals performed in a manner consistent with the prospective account of memory.

In light of this recent evidence for the prospective view of memory, it is worth examining the data in the current research in the context of these opposing views of what is remembered. According to the retrospective view, the pigeon remembers a trace of the stimulus (or, presumably, response when relevant) presented in the previous trial. This trace decays as a function of time. On the basis of available information, the pigeon applies some rule just prior to emitting its next response to determine which choice will be made. The prospective view says that the pigeon immediately applies a rule and remembers which response is to be made on the next trial. There are three types of trials in the current research: regular trials, early-signal trials, and late-signal trials. On regular trials, the retrospective theory would say that the pigeon remembers its previous response, and then when the next trial begins it applies a win-stay, lose-shift rule. The prospective theory would differ only in that the rule would be applied earlier and the pigeon would remember its next response. In the case of regular trials there is no major advantage of one type of memory over the other.

In the case of early- and late-signal trials, there are clear differences in the predictions made by the two theories. On early-signal trials, the retrospective theory would say that two memory representations are needed: the pigeon's last response, and the color of the signal. Both traces would decay over time, but both are necessary in order to apply a rule and emit the correct response on the next trial. On late-signal trials, according to the retrospective theory, the bird would only have to remember its previous response across the delay; the signal would occur in a zero-delay relationship to the next trial. The short response latencies that typically occur to trial onset in this type of procedure suggest that the response rule would be applied either during the signal or immediately following its offset. Thus, the retrospective theory makes a clear prediction of more accurate performance in the late-signal condition.

According to the prospective theory, on early-signal trials there would be only one thing to remember: the response to make on the next trial. This would be determined immediately following the trial by the birds's previous response and the signal color. On late-signal trials, the bird's task would be more complex. There wouldn't be enough information following a trial to make a final determination of the correct response on the next trial. Memory would be coded prospectively in the form of two conditional relationships. For example, if the previous correct response were left, the pigeon might remember "if green, peck left; if red, peck right". This is clearly more complex than in the early-signal case, and a reasonable prediction would be that the birds would perform more accurately on early-signal trials.

The third experiment provides very clear data: with only one exception, in both phases of the experiment all birds did substantially better in the late-signal condition. Thus, although this research was not designed to address this issue it provides clear evidence that, in the language of these two theories of memory, the birds were behaving in a manner consistent with a retrospective coding hypothesis.

It is reasonable to ask why, given the recent evidence for prospective coding in DMTS procedures, the present research on reversal learning provides equally clear evidence for retrospective coding. To approach this issue fruitfully, a comparison of cognitive and behavioral views may be helpful. The cognitive approach appears to be concerned primarily with identifying and studying (by inference) internal mechanisms that may explain observable behavior. The behavioral approach is more concerned with explaining observable behavior in terms of observable antecedent and consequent events. If it deals with hypothetical internal processes at all, it tries to connect them quite explicitly to environmental determinants. Thus, in terms of the issue of retrospective versus prospective coding, the goal of a cognitive psychologist would be to identify possible memory mechanisms, and to ask which one actually explains observable behavior. A behaviorist would view the issue of what is remembered as being equivalent to the issue of what discriminative events (stimuli or responses) control behavior, and what reinforcement parameters determine this control. The behaviorist would be unlikely to propose these internal mechanisms. However, given that they have been proposed, a behaviorist interested in this issue would be more likely to inquire into the environmental determinants of memory coding: under what circumstances does one or the other coding process occur. In fact, Grant (1981, 1982) mentioned the issue of stimulus control of retrospective and prospective coding briefly as being worthy of future study.

If prospective and retrospective coding may be accepted provisionally for the purposes of this argument, it is not hard to understand the apparently contradictory findings that have been obtained from the behavioral point of view. In a DMTS procedure, prospective coding would work well, as all information is available to allow for memory of what to do. Prospective coding would probably be more efficient, as decision-making would occur before any memory trace for the sample stimulus had time to decay, and no decision-making need occur at the time of making the response. In the Grant (1982) experiment, prospective coding would be particularly efficient, as it would allow for the use of a single memory representation where retrospective coding would require several. The situation is different in the present research. In the early-signal condition, prospective coding would again be more efficient, since only one thing need be remembered as opposed to two with retrospective coding. However, in the late-signal case, the reverse is true: retrospective coding would be more efficient than prospective coding. From a behavioral perspective, two possibilities might be expected. The birds might adopt a retrospective coding process in the late-signal condition and a prospective coding process in the early-signal condition. This would result in little difference in performance as a function of signal locus. However, it would result in the need to apply an additional rule to determine which coding process to use on a given trial; this might make the overall level of complexity greater than if one rule were adopted throughout. The results of Experiment III indicate that the birds responded in a manner consistent with the retrospective coding hypothesis throughout. From a behavioral perspective this is quite reasonable. In the unfavorable condition with both retrospective and prospective coding there are two things to remember. However, in the prospective case both of these are conditional representations; thus there might be differential reinforcement for adopting retrospective coding.

From the line of reasoning suggested here, it may be seen that, rather than looking for how memory works in an absolute sense, a behavioral approach to this subject should be to study how memory is controlled by reinforcement contingencies. Apparently it is possible to arrange contingencies that favor either retrospective or prospective coding; neither should be viewed as properties inherent in the workings of the experimental organism. A logical extension of this line of reasoning is that it should be possible to obtain stimulus control of memory mechanisms. In order to obtain retrospective coding in one condition of an experiment and prospective coding in another, conditions would have to be arranged in which the advantages of using both mechanisms would outweigh the advantage of simply adopting one strategy throughout.

Although the above argument demonstrates that a behavioral approach may be used to examine cognitively oriented issues in the memory literature, the results of the third experiment may be explained quite easily without going beyond established principles of stimulus control. Behavior in an R/NR trial may be seen as being controlled by two prior discriminative events: the pigeon's response on the previous trial, and the R/NR signal. Control of behavior by a prior discriminative stimulus has been shown to decrease monotonically as a function of the delay between signal presentation and the opportunity to emit the response (Berryman et al., 1963). Control of behavior by a prior response has been shown to decrease similarly at longer delays (Hearst, 1962), although some evidence existed for greater accuracy at intermediate delays than at the shortest delays. Since behavior in Experiment III was controlled by both stimuli and responses, the delay gradients should reflect some combinatorial rule for the stimulus and response gradients. Control by the prior response would always be the same for a given delay value. Control by the R/NR signal would depend on the signal locus. In the early-signal condition, the delay would be equal to the ITI duration. In the late-signal condition, the delay would be zero. Any plausible combinatorial rule would thus predict greater accuracy in the late-signal condition, as was observed in the third experiment.

Concluding Statement

There has been a disturbing trend recently in the study of complex discrimination phenomena to resort to both the vocabulary and the theoretical orientation of cognitive psychology. In a certain sense this is not hard to understand, as the vocabulary of cognitive psychology is often easier to apply to these situations than the behavioral terminology which was often designed for use in much simpler situations. Having adopted the cognitive vocabulary, it is a rather small step to incorporate the theoretical assumptions that go with it. However, the problems with speculating about internal states of organisms, particularly when nonverbal in nature, remain the same as they were around the turn of the century when they caused people like Thorndike and Watson to adopt a behavioral approach in the first place.

In this paper I have presented some research on fairly complex discrimination performance in the pigeon while maintaining a behavioral approach. Although it was convenient to adopt the vocabulary of memory, the terminology was not given added, nonbehavioral meaning. The paper ended with a discussion of a cognitive issue which is related to this research. Although the issue is clearly cognitive in nature, I have shown that a behavioral approach was able to deal with it in a productive manner.

I do not wish to suggest that behaviorists ignore the cognitive field. The differences in theoretical orientations lead to the likelihood that each approach will raise issues relevant to the others' interests that would not have been considered otherwise. However, it does not seem necessary or desirable at this point to abandon a behavioral point of view simply because some interesting issues are more conveniently discussed in cognitive terms. as I have shown, the behavioral perspective has contributions to make even to issues that have traditionally been viewed as quite cognitive in nature.

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