THE BEHAVIOR OF PIGEONS UNDER FREE-OPERANT SCHEDULES OF SHOCK AVOIDANCE AND SHOCK FREQUENCY REDUCTION

By

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I dedicate this work to Dick Willis
who shared with me his joys, fears,
and professional expertise.

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The importance of the species generality of phenomena, especially for purposes of theoretical interpretations, has been emphasized in recent years. This report provides data which are currently unavailable concerning the acquisition of temporal response gradients during free-operant avoidance and extends the species generality of the theoretically important shock-frequency reduction procedure. Pigeons were exposed to two unsignalled, free-operant shock schedules in which the effective response was a treadle press. Experiment I consisted of long-term exposure to Sidman's free-operant avoidance schedule. The response-shock interval was 20 sec, the shock-shock interval was 5 sec and shock duration was 0.3 sec throughout the experiment. One of the pigeons in Experiment I performed under shock intensities of 6 mA and 7 mA while the shock intensity for the second pigeon was 6 mA for the entire experiment. Conditional probabilities of responses during successive tenths of the response-shock interval were collected for each of the more than 120, 100-min sessions for each pigeon. The results of Experiment I showed that the general characteristics of avoidance performance of pigeons were similar to those obtained in previous experiments with rats under comparable schedules. Response rates were typically higher, and shock rates typically lower, than those obtained from rats. The conditional-probability distributions showed that within 12 sessions, responses with IRTs longer than 12 sec predominated and that gradual emergence of high probabilities of responding at longer IRTs occurred through the 100th session. The most significant feature of the probability distributions was the rapid development of temporally-discriminated responding and the stability of the distribution functions across more than 100 sessions. The development of efficient avoidance performance prior to the appearance of temporal response gradients provided support for a least-effortful-response interpretation of the mechanism underlying these temporal discriminations; this interpretation is opposed to the Pavlovian mechanism suggested by two-factor theory.

In Experiment II, two pigeons were exposed to a shock-frequency-reduction procedure in which treadle responses reduced the overall frequency of shock from 9 per min to 3 per min for the period between a response and the next scheduled shock. Following each shock, the probability of shock remained at 9 per min until a response was emitted. One of the pigeons in the second experiment was exposed to several different shock intensities while the other pigeon received occasional probe sessions in which shock intensity was reduced from 10 mA to 7.9 mA for one 100-min session. Shock duration was 0.3 sec throughout the experiment. Both pigeons responded under the shock-frequency reduction schedule and performance was maintained for more than 170 sessions of 100-min duration. For one pigeon, exposure to increased shock intensities resulted in decreased shock rates with the exception that average shock rates at the end of two reexposures to an intensity of 7.75 mA were consistently higher than each preceding exposure. This was true whether reexposure followed a period when shock intensity was 6 mA or 10 mA. There were no consistent effects of shock intensity on response rates. For the second pigeon, exposure to probes at the reduced shock intensity produced decreased response rates and increased shock rates when probe sessions were compared to the preceding and succeeding sessions at the higher shock intensity. In other respects, the performance of the pigeons under the shock-frequency-reduction procedure was similar to that of rats. It was concluded that the process of acquisition and maintenance of responding in pigeons under free-operant schedules of shock avoidance and shock-frequency reduction is essentially similar to that of rats. The contribution of the activity-producing properties of shock to the acquisition and maintenance of responding under shock-frequency reduction procedures was discussed and the roles of the form of the avoidance response and the characteristics of the experimental space were considered.

INTRODUCTION

Thomas Kuhn (1962), a physicist and historian of science, provided an analysis of the structure of scientific discovery in the physical sciences which proves to be useful for understanding the historical development of the methodology and theory in the study of avoidance. According to Kuhn, "normal science," i.e., the particular tradition of research within a discipline, emerges from and is unified by paradigms. Paradigms are scientific achievements which produce among the practitioners of a discipline virtually universal agreement upon a model for the conduct of research, interpretations of results, and a framework for the construction of theory. Kuhn (1962) notes that the adoption of an alternative paradigm does not inevitably lead to a major upheaval within a discipline:

> These are episodes - exemplified in their most extreme and readily recognized form by the advent of Copernicanism, Darwinism or Einsteinism - in which a scientific community abandons one time-honored way of regarding the world and of pursing science in favor of some other, usually incompatible, approach to its discipline. I have argued ... that the historian constantly encounters many far smaller but structurally similar revolutionary episodes and that they are central to scientific advance ... To assimilate them the scientist must usually rearrange the intellectual and manipulative equipment he has previously relied upon, discarding some elements of his prior practice

> and belief while finding new significances in and new relationships between many others. (Kuhn, 1962, p. 42).

Seligman (1970) has recently questioned the generality of the "laws of learning," Baum (1973) has challenged the assumptions of the law of effect and several authors (Bolles, 1975; Herrnstein, 1969; Rachlin, 1976) have reviewed the findings which suggest that conventional theories of avoidance are inadequate. To varying extents, all of these authors provide documentation for Kuhn's thesis of the influence of paradigms upon a science, exemplified in this case by the historical process which characterized the study of avoidance. A brief review of this historical context of the study of avoidance behavior is necessary for an understanding of the importance of the experiments to be reported.

For the first fifty years of this century, the structure of learning theory in American psychology was built upon the foundations of the work of Pavolv and Thorndike. These men contributed the first paradigms for the study of how behavior changes as a function of experience and, to this day, conventional accounts of learning stress the respondent conditioning model of Pavlov and the instrumental conditioning model of Thorndike. These models provided the methodology used to study the acquisition and maintenance of behavior and were widely held to represent the basic processes underlying all learning. Both models were based on assumptions derived from the philosophical school of British empiricism which emphasized association of ideas by the mechanism of temporal contiguity. Complex experiences were explained through the associative linking of simple sensations which occurred at the same time: the closer in time and the more often these sensations occurred, the stronger was the associative link.

For Pavlov, the explanation of his experiments on salivary conditioning was the temporal contiguity of a neutral stimulus with a stimulus which elicited a reflex. With enough pairings of the stimuli, the previously neutral stimulus came to evoke a conditional response, similar in form to the reflex. The underlying mechanism was the associative linking of the stimuli, as represented by overlapping excitatory cortical fields triggered by the external stimuli.

Thorndike clearly showed the influence of associationist theory in his statement of the law of effect:

> Of several responses made to the same situation, those which are accompanied by or closely followed by satisfactions to the animal will, other things being equal, be more firmly connected with the situation, so that, when it recurs, they will be more likely to occur; (Thorndike, 1911, p. 244)

Like Pavlov, Thorndike sought the mechanism for the law of effect in physiological events: neurons and synapses were conduction units and conductivity was altered by experience. The major difference between the theories of Pavlov and Thorndike was in the units that were linked, stimulus-stimulus and stimulus-response, respectively. Thorndike acknowledged the importance of the ways behavior changed events by specifying "satisfying consequences" as a necessity for associative linking but tended to concentrate on the stimulus "situation" with its implied eliciting properties.

Research directed to the understanding of how behavior changes as a function of experience provided support for associative theories. The discovery that, in Pavlov's paradigm, acquisition of the conditioned response depended upon rather short delays (0.5 sec) between the conditioned stimulus (CS) and the unconditioned stimulus (US) supported the contiguity notion. Similarly, the finding that acquisition of the conditioned response (CR) was retarded or prevented by providing occasional presentations of the CS or US alone bolstered confidence in the conventional view.

As noted by Herrnstein (1969), Pavlov did not distinguish the procedures used by V. M. Bekhterev from his own; Hull's (1934) adaptation of Bekhterev's approach made no mention of the manner in which the animal's responses changed the experimental consequences.

An example of Bekhterev's procedure clearly shows that Thorndike's paradigm was in use, rather than Pavlov's:

> A dog would be exposed to a sequence consisting of some originally neutral stimulus,

> followed by a painful electric shock to a forepaw. The reflex response to the shock was leg flexion and the adaptive change was the occurrence of leg flexion as soon as the neutral stimulus was presented. Superficially, the differences between Pavlov's and Bekhterev's discoveries was minor, concerning only the physical response - muscular instead of glandular. (Herrnstein, 1969, p. 50)

Because of the similarity of the preshock signal to Pavlov's CS, the similarity of the CR to the UR (flexion), and because the preshock signal and the shock were presented in the same temporal pattern as the CS and US, the important effects of the animal's responses were overlooked, to wit, leg flexion eliminated shock delivery. In essence, Bekhterev had invented the signalled avoidance procedure: a response during a stimulus presentation prevented delivery of an aversive event scheduled to occur in the absence of responding. This arrangement differed from the Pavlovian situation in which the animal's behavior in no way controlled the sequence of stimuli presented by the experimenter.

Brogden, Lipman, and Culler (1938, in Herrnstein, 1969) were the first to challenge experimentally the conception of avoidance conditioning as a variety of Pavlovian conditioning and to support the view of avoidance as an example of instrumental conditioning, based on Thorndike's law of effect (see Appendix). The findings of Brogden *et. al*. did not challenge the principle of contiguity, of course, but clarified the place of the signalled avoidance procedure, classifying it as an instrumental conditioning procedure.

Though few workers quarrelled with the new classification, Pavlovian conditioning, as one factor in the acquisition and maintenance of avoidance responding, was not abandoned. In a series of papers, Mowrer and his co-workers developed a two-factor theory and applied it to explanations of avoidance as well as appetitive conditioning procedures (Rachlin, 1976). One appealing feature of the theory was that it dealt with the troublesome problem of why an organism would continue to perform avoidance responses when the presumed reinforcer (satisfier) for such responses was no longer present, i.e., the shock was avoided, and two -factor theory dealt with the problem without rejecting the principle of contiguity. Kuhn (1962) suggests that the typical response of scientific theory builders to discrepant data is to expand established theory rather than to re-examine assumptions on which the theory is founded. Adding a second factor to account for avoidance learning in order to maintain Pavlovian conditioning (and contiguity) as some part of the explanation is an example of the scientific conservatism Kuhn described.

The two-factor theory explains avoidance responding in the following way. Avoidance responding is typically observed to proceed in two stages: (1) escape from shock precedes (2) eventual avoidance of shock. In signalled avoidance procedures a preshock signal occurs, then shock, and finally a response which terminates both signal and shock. The temporal pairing of shock and signal is said to produce fear or anxiety or "aversiveness" as a conditioned response within the organism as a result of the first factor, Pavlovian conditioning. The second stage in the development of avoidance of the shock is due to the second factor, instrumental conditioning, because responses terminate the conditioned aversive stimulus, the preshock signal. Termination of the signal reduces the conditioned drive state called fear and this reduction is a negatively reinforcing event. The theory fitted well with the propensity of theorists of the time to postulate intervening variables which mediated the organism's behavior and was generally accepted. The two-factor theory reflected the paradigmatic influence of Pavlov and Thorndike by positing two associative mechanisms based on contiguity: the external pairing of stimulus and shock and the internal pairing of fear reduction and response.

The next major procedural variation in avoidance conditioning was Sidman's (1953) unsignalled procedure, known as free-operant avoidance. In this procedure there is no programmed preshock stimulus; shocks are simply scheduled to occur at one of two intervals. In the absence of a response, shocks occur at fixed, short intervals known as the shock-shock (S-S) interval. If a response occurs, a scheduled shock is postponed for a specified interval, called the response-shock (R-S) interval. Each response "resets" the R-S interval and shock-free time cannot be accumulated: with an R-S interval of 30 sec, shock is programmed to occur 30 sec after the last response, regardless of the overall rate of previous responses. Shocks are inescapable and of short duration. Performance under this procedure is a joint function of the length of the R-S and S-S intervals, the limiting cases being the obvious ones of a zero R-S interval, in which responses are in effect punished and a zero S-S interval, essentially the procedure of escape. Moderate rates of responding are typically acquired and maintained when the R-S interval is on the order of 30 sec and the S-S interval is somewhat shorter.

At first glance, Sidman's (1953) free-operant avoidance procedure would seem to pose a challenge to the two-factor theory, for where is the signal with aversive properties to be terminated by the response? Sidman was quick to point out that there is a regularity in the procedure, the fixed R-S and S-S intervals. A two-factor adherent simply points to the sequence of internal stimuli following a response, arguing that the passage of time (equivalently, the progression of a regular, internal stimulus sequence) provides an effective preshock stimulus. Internal stimuli early in the sequence are rarely paired with shock, while those later in the sequence are regularly paired with shock. As a result, the response which terminates these aversive stimuli is negatively reinforced. Thus, the internal stimulus sequence, or "clock," assumes the same status as the preshock signal and the two-factor theory is applied accordingly.

Sidman (1954) examined the relative frequency of various interresponse times (IRTs), the time between successive responses, in order to evaluate the hypothesis that internal stimulus sequences provided a preshock stimulus, in the manner suggested by two-factor theory. If responses late in the R-S interval terminated aversive internal stimuli, then those responses would be differentially reinforced. Early responses would tend to be less frequent because they did not terminate stimuli which were as aversive as those later in the internal sequence, i.e., those closer in time to shock.

Sidman (1954) found no evidence for more frequent responding in the later portions of the R-S interval duration, in either the relative frequency of IRTs or the cumulative frequency distribution of IRTs. He concluded that there was no evidence of the predicted temporal discriminations proposed to explain the acquisition and maintenance of responding under the free-operant avoidance schedule. Any discriminations which did develop, argued Sidman, occurred only after prolonged training and did not appear to be necessary for effective avoidance performance.

Anger (1963) challenged Sidman's (1954) conclusions on the basis of the statistical analysis. Anger criticized the use of the relative frequency statistic for description of the IRT distributions during the R-S interval since, by the definition of interresponse times, there are more opportunities for responding in the first segment of the interval than in later segments. Thus, every response is followed by the opportunity to make another response in the first segment of the interval (and the opportunities are equal to the total number of responses emitted) but the number of opportunities to respond during the second segment is decreased by however many observed responses occurred during the first segment, and the number of opportunities to respond in the third segment is decreased by the total of observed responses in the first and second segments, etc.

For example, suppose an R-S interval of 10 seconds was divided into 1 sec segments for the purpose of analyzing the IRTs. Assume that during the time IRTs were recorded, 100 responses were made, 10 in each 1 sec segment of the R-S interval. The relative frequency statistic for such an IRT distribution is 0.1 for each of the 1 sec segments. Anger (1963) argued that the relative frequency statistic does not reflect the conditional nature of the procedure: if only 100 responses occurred and if 80 of them were emitted at IRTs of 8 sec or less, then there were only 20 opportunities to respond at IRTs greater than 8 sec.

In the example above, 10 responses with IRTs of 9 sec did occur. Given that there were 20 opportunities to respond with an IRT of 9 sec, and 10 such responses were emitted, the conditional probability of a response at 9 sec is 10/20 or 0.5. Similarly, the conditional probability of a response with an IRT of 8 sec is equal to the observed number of responses (10) divided by the number of opportunities for response (100 minus the total number of responses with IRTs of less than 8 sec: 10/100-70 = 0.33). Thus, for the data of the example, the relative frequency statistic is 0.1 for all IRTs while the conditional probability distribution shows that, given an opportunity for a response with a long IRT, the probability is much higher that a response will occur: 0.5 at 9 sec, 0.33 at 8 sec, 0.25 at 7 sec, etc. Anger (1963) proposed that, based on the argument above, the appropriate statistic for the evaluation of the temporal discrimination during free-operant avoidance is the IRT/Op (opportunity) statistic.

Anger (1963) reanalyzed the data presented by Sidman (1954), substituting the IRT/Op statistic for the relative frequency measure, and showed that the conditional probability of responses in the later segments of the R-S interval was consistently and considerably greater than the probabilities of a response in early segments, even during the early stages of acquisition. Clearly, there was evidence for temporal discrimination as an underlying process in the acquisition and maintenance of responding under free-operant avoidance schedules. Anger (1963) interpreted the results as support for either of two views, the two-factor theory or the less-effortful reduction in shock frequency, as explained below.

The first view postulates the reduction of conditioned aversive stimuli, internal and unobservable, as the reinforcing event and responses late in the interval are said to produce a greater decrement in aversiveness than do early responses. The second view (Sidman, 1962) attributes avoidance to the reduction in shock rate. A few spaced responses produce the equivalent amount of shock frequency reduction as numerous short-latency responses. Thus, spaced responding is less effortful.

Herrnstein and Hineline (1966) designed a procedure intended to provide the lacking evidence, a procedure which incorporated no fixed shock-free periods following responses such as the R-S interval in free-operant schedules. Their random-shock procedure eliminated fixed relationships between the occurrence of shock and _any other_ aspects of the situation, providing, instead, a statistical correlation between responses and shock. Shock rate is reduced following a response and reverts to the original rate after the next shock, which is programmed to occur at varying intervals following a response. The shock-free period following a response is, on the average, longer than the shock-free periods following any other point in time.

The parameters of the random-shock procedure which determine response rate are the probabilities of shock programmed by two independent shock distributions, the postshock,and postresponse distributions. The postshock distribution has a higher probability of shock than the postresponse distribution. Following a shock, the high probability distribution is in effect. A response serves only to instate the lower probability shock distribution and responses that follow a previous response have no effect. The low probability distribution remains in effect until a shock is delivered, at which time shocks are again programmed to occur according to the high probability distribution.

Herrnstein and Hineline (1966) showed that acquisition and maintenance of responding occurred when the probabilities of shock were 0.1 and 0.3 per 2 sec (3 and 9 per min) for the postresponse and postshock distributions, respectively. Unlike Sidman's (1954) results, the conditional probabilities of a response across the maximum intershock intervals showed no evidence of temporal discrimination. Herrnstein and Hineline (1966) concluded that " a response-dependent change in the amount of subsequent aversive stimulation appears to be the *sine qua non* of avoidance conditioning" (Herrnstein and Hineline, 1966, p. 429). Only by postulating "covert stimuli whose properties vary in concert with the changes in shock rate" (Herrnstein and Hineline, 1966, p. 429) could a two-factor explanation of the results be maintained. Herrnstein and Hineline proposed that such an extension of the two-factor theory precluded the possibility of disproof of the theory, a condition eschewed by theorists and deplored by historians of the scientific enterprise.

However, the major import of Herrnstein and Hineline's work is not the critique of two-factor theory but, rather, the attention it focused on other variables, inherent in avoidance procedures, which may affect avoidance performance. The emphasis upon contiguity explanations of avoidance was shifted to analysis of the contingent relationships between behavior and consequences _over periods of time_. In their words,

> We are familiar with theories that say a response is influenced by its having terminated an electric shock or by its having terminated a conditioned stimulus associated with shock. But we are unaccustomed to the notion that a response can be influenced by changing the rate of a stimulus, a change that itself can be manifested only over some period of time. (Herrnstein and Hineline, 1966, p. 429)

According to Kuhn's (1962) view, a scientific revolution had occurred in the theory of avoidance conditioning; abandoning the narrow concept of contiguity led to the investigation of other underlying principles to account for the phenomena.

Hineline (1970) soon provided data on another variable affecting acquisition and maintenance of avoidance responding. Noting that the Herrnstein and Hineline's (1966) procedure confounded the average delay to shock onset with the frequency of shock, Hineline designed a trial-by-trial procedure whereby a response delayed the onset of a single shock without changing the overall frequency of shock. A trial consisted of a 20 sec period which began with presentation of a retractable lever to the rat. If no response was emitted in the first 8 sec a shock was delivered, 2 sec later the lever was withdrawn, and 10 sec after withdrawal, the lever was again presented for another trial. If a response was emitted in the first 8 sec of a trial, the lever was withdrawn immediately and the shock was not delivered until the 18th sec of the 20 sec cycle. Thus, responses delayed shock without changing the shock frequency. All rats acquired the lever-pressing response and typically responded on 85% of the trials.

Hineline (1970) performed a second experiment in which responding resulted in a statistical increase in the shock rate. The situation was similar to the first: shocks occurred in the 8th sec of the cycle in the absence of a response and 2 sec before the end of the cycle if a response occurred. However, a response affected the duration of the cycle because the lever was retracted for 10 sec regardless of when the response occurred. Thus, a response at 2 sec from the onset of the cycle still produced a delay before shock delivery but shortened the cycle by 8 sec. Cycles were 20 sec long in the absence of a response. Since every cycle produced a shock, delayed or otherwise, shortening the cycyle produced more trials per session and thereby increased shock frequency. No rat, even if previously trained to lever press in an avoidance situation, acquired and maintained responding under this regimen. As Herrnstein (1969) points out in his review of avoidance, "The difference between the two procedures proved to be crucial - one fully adequate, the other totally inadequate" (Herrnstein, 1969, p. 65). And as Herrnstein did not note, the "*sine qua non*" status of shock frequency reduction in avoidance performance was challenged. Shock delay alone would maintain avoidance behavior.

At this point in time it was clear that the two conditions sufficient for acquisition and maintenance of avoidance behavior were (1) shock frequency reduction combined with (2) increased average delay to shock onset and the delay of shock onset. Lambert, Bersh, Hineline, and Smith (1973) attempted to isolate the effects upon avoidance behavior of shock frequency reduction without shock delay. Their procedure was essentially one of punished avoidance: a response caused an immediate shock and eliminated five shocks scheduled to occur in the absence of a response. Lambert *et al*. (1973) also varied the presence or absence of an escape contingency and the topography of the avoidance response. It has long been recognized that the opportunity for escape responses facilitates acquisition of an avoidance response and Bolles (1970) has summarized the evidence that the compatibility of the avoidance response with the species-specific defense reactions (SSDR) of the organism determines the ease of conditioning.

The results of Lambert, Bersh, Hineline,and Smith (1973) revealed the interaction of all of these variables. When the avoidance behavior was a shuttling response, compatible with the SSDRs of the rats, the procedure resulted in acquisition and maintenance of responding without an escape contingency. When a lever-press, incompatible with SSDRs, was the avoidance response an escape contingency was necessary for the maintenance of responding. For rats trained with the escape contingency in effect, removal of the contingency reduced avoidance rates and reintroduction of escape increased the rates. A conservative interpretation of Lambert _et al_.'s (1973) results is that it is possible to produce avoidance responding under conditions of shock frequency reduction without shock delay if the avoidance response is high in the hierarchy of SSDRs (Bolles, 1970) of the organism. The variability of responding across sessions suggests that punished avoidance behavior was not strongly under control of shock frequency reduction, at least with the parameters employed.

Further exposition of the role of shock delay in avoidance performance resulted from the experiments of Gardner and Lewis (1976) using a free-operant procedure in which a response produced 10, 88,or 165 sec delays of shock onset. In the absence of responses, shocks were delivered according to a variable time schedule at an average rate of two per min (VT 30 sec). A response produced a stimulus change for 3 min and, depending upon the delay condition, six shocks were delivered in the six sec beginning 10, 88, or 165 sec after the response. The shock rate during the 3 min this response-dependent stimulus change was in effect was thus equal to the rate under the VT 30 schedule of shock delivery. At the end of 3 min in the response-produced condition, the VT 30 sec shock schedule was again imposed. Responses during the delay condition had no programmed consequences.

After 30 hours of exposure, rats under the 88 sec delay condition were spending about 80% of the time in the response-produced (delayed shock) periods; rats in the 165 sec delay condition were spending 95%, while those in the 10 sec delay condition spent less than 20% of the time in the delayed condition. Furthermore, the length of the delay appeared to influence the patterning of responses: rats in the longest delay condition responded most frequently after the transition from the delayed to the VT 30 sec condition, rats in the 88 sec delay condition responded primarily after shock delivery,and rats in the shortest delay condition showed neither pattern.

In a second experiment, Gardner and Lewis (1976) demonstrated that when responses produced a condition of 156 sec delay and an increase in shock frequency, responding was still acquired and maintained. Experimental conditions were the same as in Experiment I. in most respects: shocks were delivered on a VT 30 sec schedule in the absence of responding, a response produced a delayed shock-onset condition for 3 min and additional responses during this condition had no programmed effects. The important change in Experiment II. was the shock rate during the delay period. Three groups of rats received 9, 12, or 18 shocks, delivered at 1 sec intervals beginning 156 sec from the onset of the delayed condition. Thus, for the three rats in each group, the delayed condition produced an increase in shock frequency of 1.5, 2, and 3 times the rate compared to the VT 30 sec condition.

All three rats in each of the first two groups spent 80-90% of the time in the delay condition in spite of the increased shock density. One of the three rats in the delay condition with a tripled shock frequency spent 90% of its time in the delay condition but two other rats rarely produced the delay condition. Those rats that produced the delayed, increased shock-frequency condition responded primarily after the transitions from the delay to the VT 30 sec condition. Responding was maintained for 60 hr under all conditions.

Three control groups, of 3 rats each, were exposed to comparable conditions without the delay feature. Shocks were delivered under a VT 30 sec schedule in the absence of responding and under VT 20, 15, or 10 sec schedules for the 3 min following a response. Under these conditions, no rat showed response rates comparable to the delayed-condition groups during the 60 hr of exposure to the control condition. When the control conditions were changed to those of the experimental group (delayed shock), one rat in the 1.5 shock-rate increase, all three rats in the 2.0 shock-rate increase, and one rat in the 3.0 shock-rate increase condition produced the delay (and shock-increase) condition more frequently and were spending 80% or more of the time in the delayed condition by the end of 60 hr of additional training.

Obviously, Hineline's (1970) findings that increased shock frequency prevents the development of responding under shock-delay conditions depended upon the duration of the delay. Gardner and Lewis' (1976) rats in the 10 sec delay condition showed little responding even when shock frequency did not increase. Differences in the two procedures are undoubtedly significant but the one specifically mentioned by Gardner and Lewis (1976) is the prevention of postshock responding through the retraction of the lever in Hineline's (1970) study. Nevertheless, it is clear that rats will produce a condition of increased shock frequency if the onset of the shocks is sufficiently delayed. Under conditions of delay without shock frequency increases, longer delays engender more responding and affect the patterns, posttransition or postshock, of responding.

Thus, the history of methods and theories of avoidance conditioning shows an evolution from the original procedure of Bekhterev, considered as an example of Pavlovian motor conditioning for the first 40 years of this century, through a period of analysis from the two-factor viewpoint which combined Pavlovian and instrumental factors to explain the phenomena, to the point where Herrnstein (1969) reviewed the evidence for a shock frequency reduction explanation and challenged researchers to concentrate on the observable variables which could be demonstrated to affect the acquisition and maintenance of avoidance responding. Experiments by Herrnstein and Hineline (1966), Hineline (1970), Lambert, Bersh, Hineline,and Smith (1973), and Gardner and Lewis (1976) showed that response-contingent reductions in shock frequency and response-produced delays of shock are two variables sufficient to support acquisition and maintenance of avoidance responding and that shock delay of sufficient duration may be more powerful a variable than the shock frequency. The studies reviewed fall generally within the methodological framework of the experimental analysis of behavior. The analytic emphasis is upon contingent and correlative relationships rather than simple contiguous ones and covert associative processes are disregarded in favor of observable behavior and procedural events for explaining phenomena.

As Lambert, Bersh, Hineline,and Smith (1973) acknowledged, other variables, such as species-specific behaviors, interact with the procedures employed to study avoidance behavior. The generality of results and theories based on such results may be limited by considering "the avoidance response" as an abstraction, to be arbitrarily chosen to fit the experimenter's requirements. Seligman (1970) has challenged the generality of the laws of learning in a recent review. Like Herrnstein (1969), he questioned the contiguity explanation of learning, marshaling evidence that all events are not equally associable. Seligman proposed that the evolutionary history of a particular species predisposes individuals of the species to associate certain events, leaves them unprepared to associate other events and contraprepared to associate still others.

Bolles (1970) has been the main investigator to provide empirical evidence that the form of the avoidance response has important consequences for the outcome of avoidance procedures. Bolles' (Bolles, 1969; Bolles & Riley, 1973) results clearly demonstrate that certain responses selected as the avoidance response are rarely conditioned while other responses are readily conditionable. Bolles (1970, 1972) has made a strong argument for the compatibility of the avoidance response with the innate species-typical hierarchy of behaviors which comprise the organism's defensive repertoire. These species-specific defense reactions (SSDRs) are prepotent responses in the presence of aversive stimuli and tend to compete with avoidance responses lower in the SSDR hierarchy. Thus, lever pressing which decreases shock frequency is less readily acquired than a wheel-turning response because wheel-turning more closely resembles the rat's SSDR of running. The difficulty of teaching pigeons to avoid shock by pecking a key depends upon the reactions of pigeons to sudden, intense shock - running and flying - which are incompatible with pecking (Rachlin, 1976, p. 357). Under conditions of gradually increasing intensities of pulsed shock, pigeons tend to attack (peck) and can be trained to avoid by key pecking. (Rachlin, 1969; Moraes and Todorov, 1977)

The similarity of the thinking of Bolles (1970) and Seligman (1970) to that of Herrnstein (1969) is their concentration upon the observable variables which affect an organism's performance under various conditions. Bolles and Seligman have extended the consideration to variables in the evolutionary history of the species. Staddon and Simmelhag (1971) emphasized similar considerations, pointing out that all behavior, and the mechanisms by which it is changed, are part of biological inheritance and that evolutionary mechanisms probably underlie both the production and selection of behaviors in any laboratory situation. Herrnstein (1969) concentrated on the observable and manipulable variables when evaluating theoretical interpretations of avoidance.

This then is the background against which the following experiments were conceived and conducted. Pigeons were used as subjects in all experiments for several reasons. First, relatively few systematic data on the avoidance behavior of pigeons are available. Smith and Keller (1970) were the first to demonstrate the acquisition and maintenance of responding in pigeons under free-operant schedules of shock avoidance. They used a small chamber with a floor area of 68 in^2 and treadle pressing as the avoidance response. The R-S interval was 32 sec, the S-S interval was 10 sec, shock duration was 0.25 sec and the shock source was 6.2 vac. No details of the resistance of the pigeons or series resistance of the shock delivery circuit were provided. Consequently, no accurate knowledge of shock intensity is possible. Sessions were 90 min long.

Smith and Keller (1970) reported rapid acquisition of the response and efficient shock avoidance performance for all five of their birds within 20 sessions. Response rates tended to be high for all subjects and shock rates were approximately 0.05 to 0.10 per min, as estimated from Figure 3, page 213. An analysis of the conditional probability of a response as a function of the time since the previous response was provided for the data from one session for two birds. In general, the IRT/Op distributions were quite similar to those presented by Anger (1963) for Sidman's (1954) rats: the probability of a response increased as a function of the time since the last response and response bursts accounted for the high probability of very short IRTs.

Foree and LoLordo (1970) trained pigeons under signalled and unsignalled free-operant avoidance schedules in which a treadle press was the avoidance response. The R-S interval was 20 sec and in the signalled condition, the last 10 sec of the R-S interval were accompanied by a change in illumination from white to red. The chamber used by Foree and LoLordo (1970) was larger in floor area than Smith and Keller's (1970) and so was the surface of the treadle. Shock duration was 0.25 sec, shocks consisted of 50 vac delivered to the base of the pigeons' wings via a beaded chain. No resistance parameters were published so no estimate of shock intensity is possible. Foree and LoLordo (1970) demonstrated acquisition of responding in most subjects although response rates were highly variable both within and between birds in both conditions. The restricted number of sessions (less than 20 for most subjects) and the extreme range of shock rates between and within birds relegates this study to the status of a demonstration that avoidance responding under these conditions is acquired by the majority of pigeons.

Klein and Rilling (1972) conducted a parametric study of the effects of various R-S interval durations and various shock intensities on the free-operant avoidance performance of pigeons. Treadle pressing was the avoidance response.

Klein and Rilling (1972) varied the R-S interval from 2.5 to 150 sec while shock duration (0.25 sec), shock intensity (8mA) and the S-S interval (10 sec) were held constant. Response rates decreased in all four pigeons as the R-S interval increased beyond 7 sec, a finding that replicated the functions described by Sidman (1953 b), using rats, in a similar parametric study. Conditional probability distributions of responding, averaged over the last three sessions at each R-S interval duration, showed evidence of temporal discriminations at 15 and 20 sec for all birds and at 10 sec for three of the four birds.

In a second experiment, the R-S interval (20 sec), S-S interval (5 sec) and shock duration (0.25 sec) were held constant while each of four birds was exposed to shock intensities of 2, 4, 8, and 16 mA in randomized orders. As shock intensity increased from 2 to 8 mA response rates for all four pigeons increased: beyond 8 mA, one bird showed continued rate increases, two showed slight decreases, and one bird died. These relationships between response rate and shock intensity replicated the functions obtained by Boren, Sidman and Herrnstein (1959) with rats.

Although Klein and Rilling's (1972) results represent the single source of parametric data on free-operant avoidance in pigeons, the shock rate stability criterion they used bears examination. Their criterion was "five percentage points or less difference in the mean percentage of S-S shocks avoided over the same two consecutive blocks of three sessions" (Klein and Rilling, 1972, p. 296). Most investigators, influenced by Sidman (1953 a, b), have used the total number of shocks delivered, whether from expiration of the R-S or S-S interval, to calculate shock rates. Leander and Jowaisas (1971) observed very few S-S shocks delivered to pigeons in the early stages of exposure to free-operant avoidance schedules, a time when shock and response rates were still changing. Previous work with pigeons in my laboratory agrees with this observation. Rats typically show similar avoidance of S-S shocks well before overall shock rates become stable and, in both pigeons and rats, response rates often stabilize before overall shock rates do. Because of these observations and the different shock rate criterion, Klein and Rilling's (1972) results cannot be readily compared to those using the more common shock rate measures.

For example, Figure 1 of Klein and Rilling's (1972) study purports to show shock rate as a function of the R-S interval duration: shock rate is said to decrease as the R-S interval duration increases. A more accurate interpretation is that the four pigeons rarely failed to depress the treadle following a shock. No information on the overall frequency of shock is contained in Klein and Rilling's report even though shock rate is the primary measure of avoidance performance under free-operant schedules!

Experiment I was also designed to provide data on the stability of the behavior of pigeons as maintained by a free-operant avoidance schedule and on the conditional probability distribution of responses during acquisition; that is, the development of temporal gradients in response patterns. Knowledge of the concurrent or sequential development of efficient shock avoidance and temporal discrimination bears directly on the question raised by Anger (1963) and the interpretation of Sidman (1962) concerning conditional probability distributions, as discussed on page 12 herein. If temporal gradients of responding develop after efficient avoidance responding is apparent, then this feature of avoidance performance is most parsimoniously interpreted as the result of response effort or efficiency rather than due to the Pavlovian component of a two-factor mechanism. No such information for pigeons or rats currently exists in the literature.

The second experiment is a replication of the random shock procedure of Herrnstein and Hineline (1966). For a procedure which marked such a dramatic departure from conventional method and theory in the study of avoidance, there is a surprising lack of information on the characteristics of behavior engendered and maintained by this procedure. In addition to the original report, Leander (1973 a) provided the only other data on the procedure. The rats used as subjects in both studies showed highly variable response rates: shock rates were near the minimum allowed by the parameters of the procedure (3 shocks per min). Neither Herrnstein and Hineline (1966) nor Leander (1973 a) intended to study the characteristics of behavior under these procedures: Herrnstein and Hineline (1966) merely intended to demonstrate the possibility of acquisition of a response under conditions where shocks could not be eliminated and Leander (1973 a) used the procedure to assess the generality of the effects of food deprivation upon avoidance performance.

Herrnstein and Hineline (1966) did manipulate the parameters of the two shock probability programs and found that, in general, response rates were higher when responses produced greater reductions in shock frequencies. They also observed the course of extinction for one rat. Extinction was defined as equality of shock probability from the two shock distributions and the probabilities for the distributions were 0.1/2 sec. The remarkable feature of extinction was the persistence of responding; over 17,000 min of exposure were required before responding was eliminated. Powell and Peck (1969) reported similar effects upon the responding of rats with a history of avoidance conditioning.

In addition to a replication with another species, Experiment II represents an extension of the Herrnstein and Hineline (1966) procedure in several ways. First, the behavior of the two birds was studied for an extended period of time in order to assess the stability of response and shock rates; second, the effects of several shock intensities upon the performance of one bird were studied. If the Herrnstein and Hineline (1966) procedure bears a similarity to previous work on shock-avoidance behavior, then response and shock rates should vary as a function of shock intensity (Leander, 1973 b). For a second bird in Experiment II, shock intensity was occasionally reduced for one session in order to observe the effects of a short-term change in shock intensity. Finally, much of the importance of the second experiment reported herein lies in the additional information provided about a procedure with major theoretical implications, information which is presently unavailable.

CHAPTER II

EXPERIMENT I.

METHOD

Subjects: One male feral pigeon (Pigeon D), captured as a fledgling in the halls of the Psychology Department at Oklahoma City University, and one two-year old male White Carneaux pigeon (Pigeon N) obtained from Palmetto Pigeon Plant, served. Between experimental sessions, the pigeons were individually housed in large cages (Hirota, 1971) and had free access to mixed grain and water. The colony room had a regulated 14 hr light/ 10 hr dark cycle.

Pigeon D had an extensive history of exposure to simple FR, FI, mult FI FI, and mult FI FT appetitive schedules and to schedules of signalled, discrete-trial, and unsignalled, free-operant avoidance of electric shock. The parameters of the unsignalled free-operant avoidance schedule were identical to the parameters in Experiment I.

Pigeon N had been exposed to one hr of the shock-frequency reduction schedule described by Herrnstein and Hineline (1966). The session was ended when Pigeon N was seen struggling in the experimental chamber: Pigeon N had spastic paralysis of the lower legs and little ability to control his left foot. The following day only spasticity of the lower left leg was evident and after two weeks of gradual recovery, no symptoms remained. His electrodes were re-implanted and two days later Pigeon N was exposed to the conditions of Experiment I. No further symptoms recurred during the course of the experiment.

Apparatus: A Plexiglas and metal chamber, 25.4 x 25.4 x 38.1 cm high, formed the experimental space. The floor was a plastic grid of 1.2-cm squares and the ceiling was #2 hardware cloth with a 3 cm diameter hole for the shock delivery cable to enter. The chamber door and the wall opposite the door were of Plexiglas. Illumination of the chamber was accomplished by lighting separate pairs of 24 vdc bulbs (GE 1812) covered with white, red, or green translucent plastic and mounted outside the chamber on the wall, 25.4 cm above the floor.

The manipulandum was a treadle similar to that used by Smith and Keller (1970). The treadle, 12.7 cm long on the side parallel to the wall and 10.2 cm wide, extended 8.5 cm into the chamber from one metal wall, forming an angle of approximately 36 degrees with the floor, through which it extended. A piece of soft leather attached to the floor and the face of the treadle prevented the pigeons from catching their feet in the gap. A force of approximately 0.75 N applied to the center of the treadle closed the attached microswitch and the switch closures defined the response recorded on counters and a cumulative recorder. A feedback relay was mounted behind the wall with the treadle.

The entire chamber was housed in a sound-attenuating, ventilated enclosure located in the colony room. The electromechanical equipment which controlled experimental events and recorded responses was in a nearby room.

The shock source was a Layfayette 601-B shocker equipped with selectable series resistors in 10K ohm values from 10 to 990 K ohms and a continuously adjustable voltage range of 775 VAC. Shocks were delivered to the pigeons through the series resistors via an LVE mercury commutator and a two-conductor jack terminating the cable which entered the chamber through the ceiling.

Procedure: Both pigeons were implanted with stainless steel electrodes around the pubis bones in the manner described by Azrin (1959) and the connecting wires attached to a Switchcraft two-conductor plug fastened by a wing harness to the pigeon's back. Prior to each session the pigeons were captured in a pitcher, weighed and the resistance of their electrodes measured with a vacuum tube volt meter. The polarity of the dc measuring-current was alternated three times a sec by a hand-operated switch to eliminate the effects of body capacitance on the measurement. The reading was recorded and if it differed by 1 K or more from the preceeding day's value or if it exceeded 5.5 K, the embedded portion of the electrode was rotated out of the pigeon's flesh and scraped clean of any accumulated deposits. In the absence of resistance changes, the inspection and cleaning was done weekly.

With exceptions as noted, each pigeon was run daily for 100 min. Each session began and ended with 5 min of darkness and white illumination was correlated with the operation of the shock avoidance schedule. Each closure of the treadle microswitch during white illumination produced the audible click of the feedback relay.

The R-S interval duration was 20 sec, the S-S interval duration was 5 sec and shock duration was 0.3 sec throughout the experiment. The treadle microswitch was disabled for the 0.3 sec of shock delivery. As noted in Table 1, the shock intensity was increased at Session 54 for Pigeon N.

RESULTS

For the first 15 min of each session responses and shocks were counted separately so that the highly variable period of responding (warm-up) that characterizes performance at the beginning of daily sessions (Powell, 1970) could be evaluated. The response rates and shock rates shown in Figures 1, 2, 5, and 6 are the mean rates during the last 85 min of each session.

As can be seen in Figure 1, Pigeon D, with prior experience under free-operant avoidance schedules, received very few shocks after his first session. Although shock rates were extremely stable during the first 20 sessions, Pigeon D's response rates showed a consistent

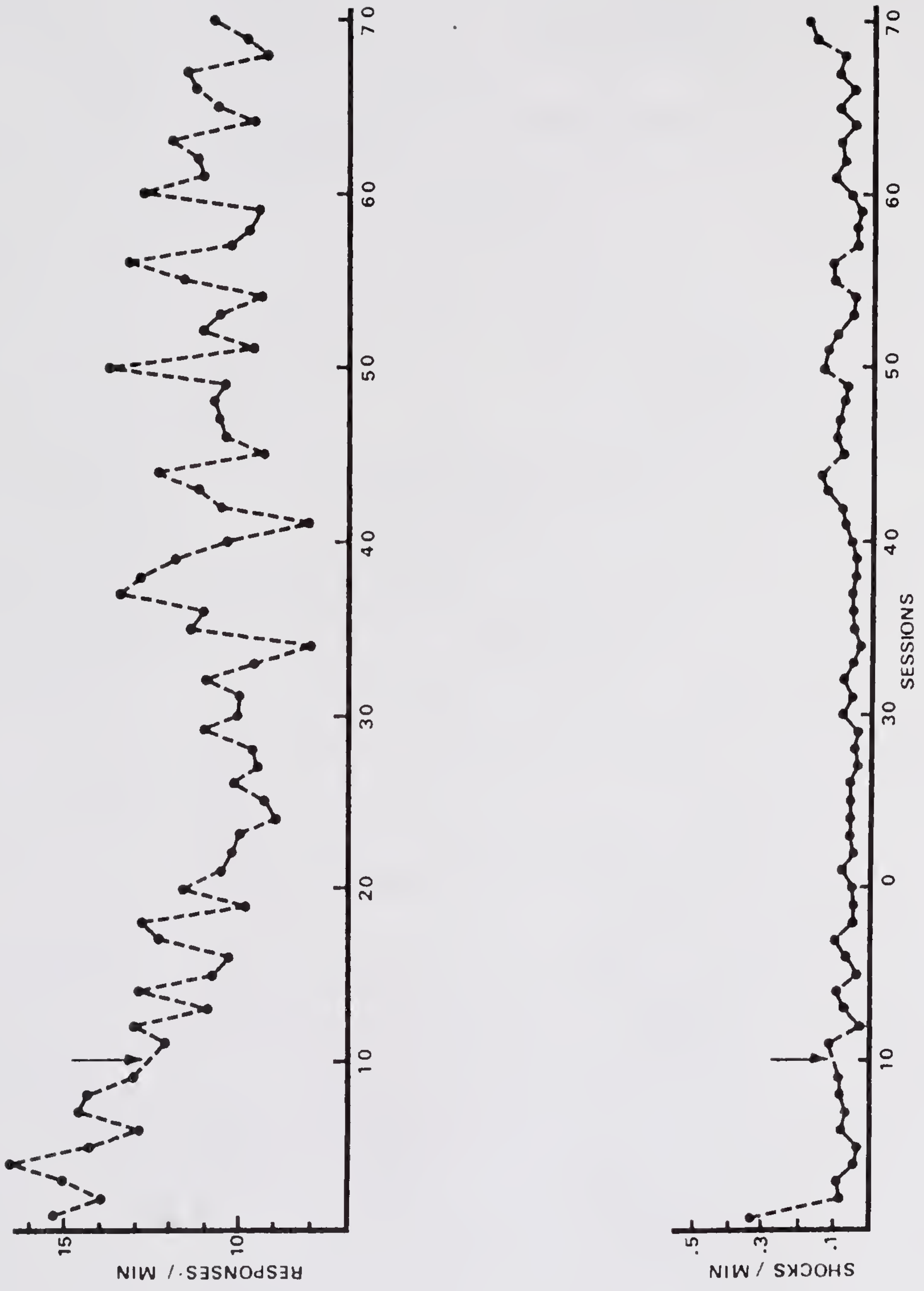
Table 1

Sequence of Conditions in Experiment I.

SESSIONS	SHOCK INTENSITY (mA) **	SESSION LENGTH (min)
Pigeon N		
1-8	6	50
9-13	6	75
14-53	6	100
54-126	7	100
Pigeon D		
1-125	6	100

** R-S = 20, S-S = 5 and shock duration = 0.3 sec throughout the experiment.

Fig. 1. Mean response and shock rates for the last 85 min of each 100 min session, Pigeon D. Data collected from consecutive sessions are connected by a line. Arrows indicate a daily session for which data were lost due to counter malfunctions.

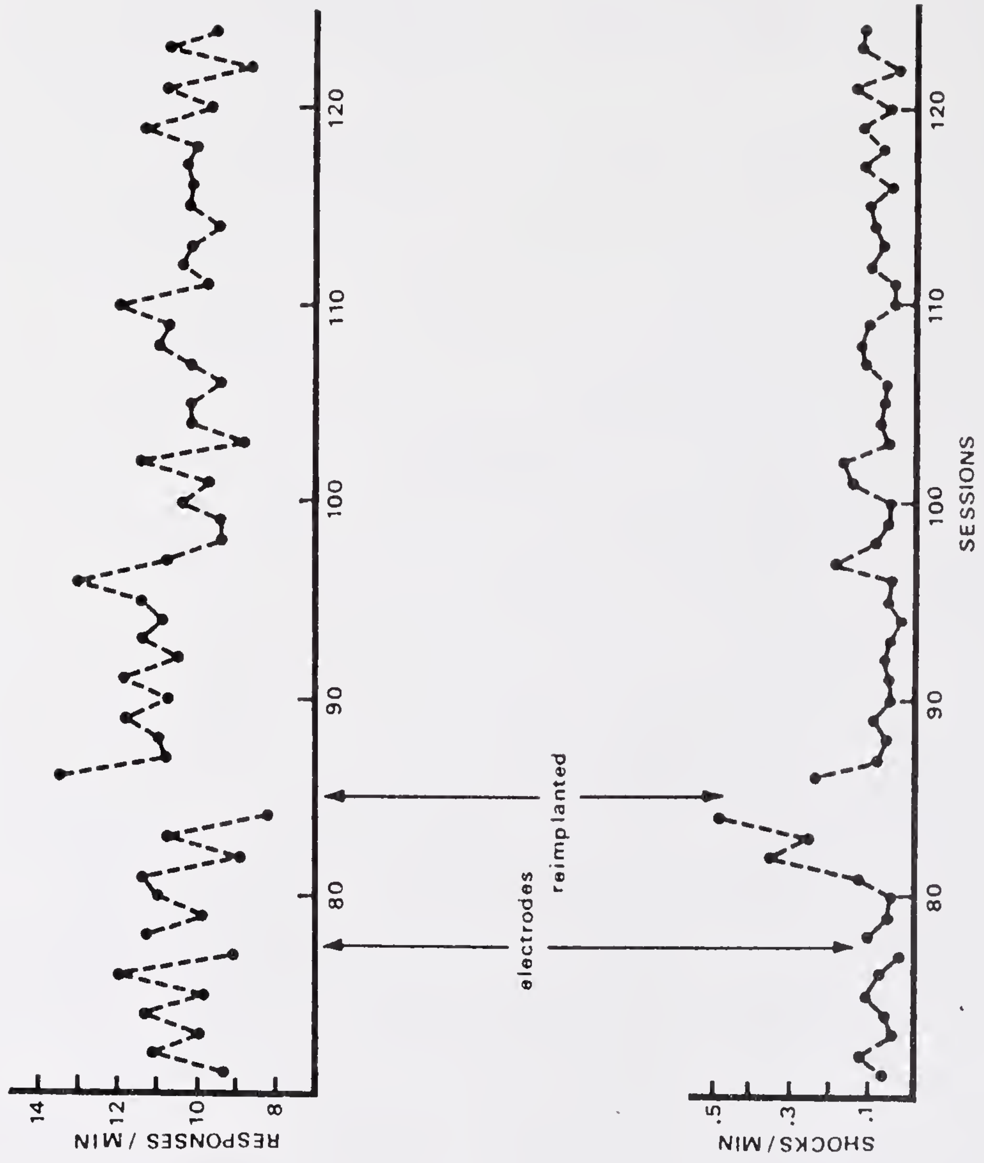

RESPONSES / MIN
15
10
SHOCKS / MIN
.5
.3
.1
SESSIONS
10
20
30
40
50
60
70

decreasing trend from 16 to 10 per min. Shock rates remained stable from Sessions 21-33 when response rates showed no trends and varied between 9 and 11 per min. Sessions 34-41 were characterized by stable shock rates and widely varying response rates (8-13 per min) and from Sessions 42-68 responding varied from 9-14 responses per min around a mean of 10.9 (standard deviation: 1.2) while shock rates were still low but slightly more variable.

Response and shock rates remained in the same general range from Sessions 69-76 (Figure 2) at which time Pigeon D's right electrode was discovered imbedded in the skin only, rather than looped around the pubis bone. The electrode was reimplanted around the bone. The decreasing response and increasing shock rates during Sessions 77-84 are attributed to dislocation of the left electrode from the bone and a broken connection to the right electrode. The electrodes were removed, reimplanted after five days and Pigeon D was run again after a 12 day vacation.

The effects of the vacation are clearly seen in the data from Session 86: response and shock rates are higher, in the range of those from Session 1. From Sessions 87 to 96, response rates varied between 10.5 and 11.8 per min and shock rates were stable at less than 0.1 per min. Response rates then decreased by one per min and were more variable while shock rates increased slightly and also showed more variability: these changes persisted from Session 97 through 124 when equipment malfunctions

Fig. 2. Mean response and shock rates for the last 85 min of each 100 min session, Pigeon D. Consecutive daily sessions are connected by a line.


RESPONSES / MIN
14
12
10
8
SHOCKS / MIN
.5
.3
.1
80
90
100
110
120
SESSIONS
electrodes
reimplanted

precipitated the end of the experiment. The mean response rate for the last five sessions was 10.46/min and the mean shock rate was 0.084/min. The mean response and shock rates for the preceeding five sessions were 9.88 and 0.096/min, respectively.

Conditional probabilities of a response (IRT/Op) in successive 2-sec segments of the R-S interval for Pigeon D are shown in Figure 3. The probability for the segment ending at the 20th sec is not shown since the IRT/Op statistic fixes that probability at 1.0. The functions are an average over four sessions and presented for all sessions from 1 to 44, in order to detect changes in temporal discriminations. Since it is clear from the data shown in Figure 3 that no major changes in the conditional probability functions occurred after Session 40, beginning with the 49th Session, the functions are shown for the first four sessions of every 10 until the end of the experiment (Figure 4).

The distribution for Sessions 1-4 indicates that responding was equiprobable in all 2-sec segments of the R-S interval; by Sessions 13-16 a temporal discrimination had developed, as indicated by the sharp decrease in response probability at 4 sec and monotonicly increasing probabilities at 6, 8, and 10 sec. The function continued to change through Sessions 37-40 at which point the conditional probability was consistently highest at the 12 sec. Further sharpening of the temporal discrimination was evident until the conditional probability of a

Fig. 3. Conditional probabilities of a response during 2 sec segments of the R-S interval, Pigeon D. All functions represent the mean of the four sessions indicated by the numbers in the upper center of each set of coordinates.

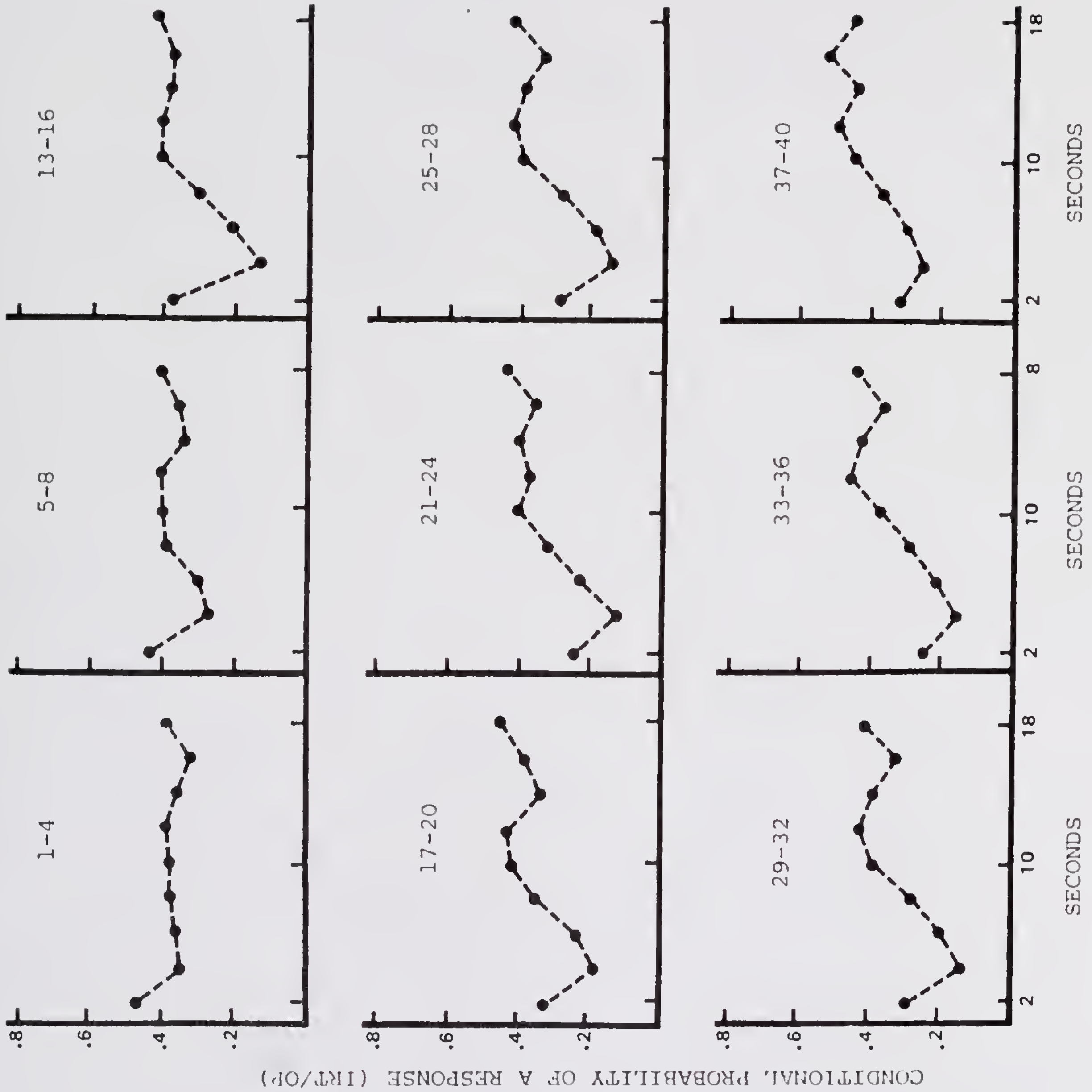
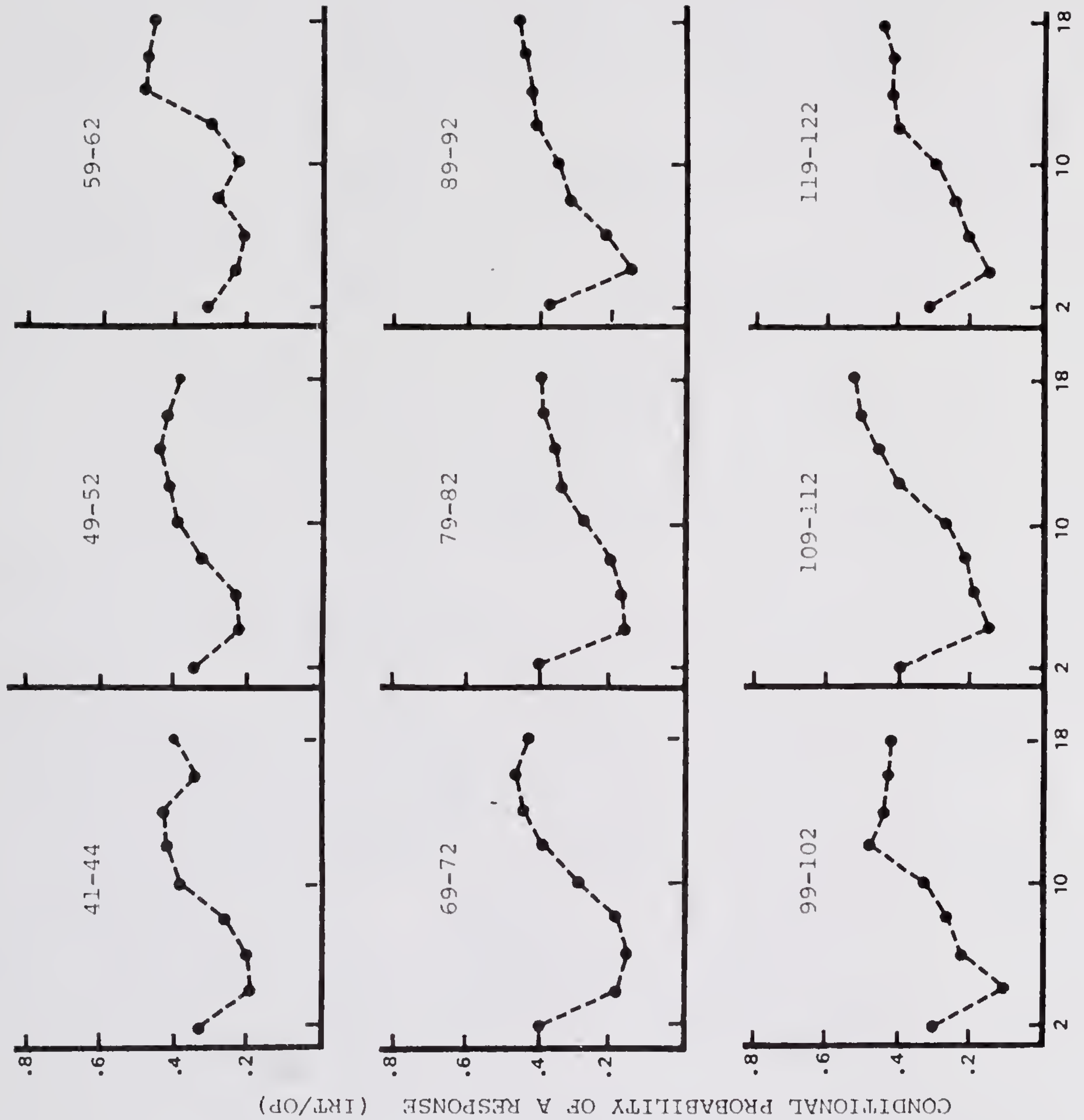

1-4
5-8
13-16
17-20
21-24
25-28
29-32
33-36
37-40
.8
.6
.4
.2
2
10
18
8
SECONDS
CONDITIONAL PROBABILITY OF A RESPONSE (IRT/OP)

Fig. 4. Conditional probabilities of a response during 2 sec segments of the R-S interval, Pigeon D.


CONDITIONAL PROBABILITY OF A RESPONSE (IRT/OP)
41-44
49-52
59-62
69-72
79-82
89-92
99-102
109-112
119-122
.8
.6
.4
.2
2
10
18
SECONDS

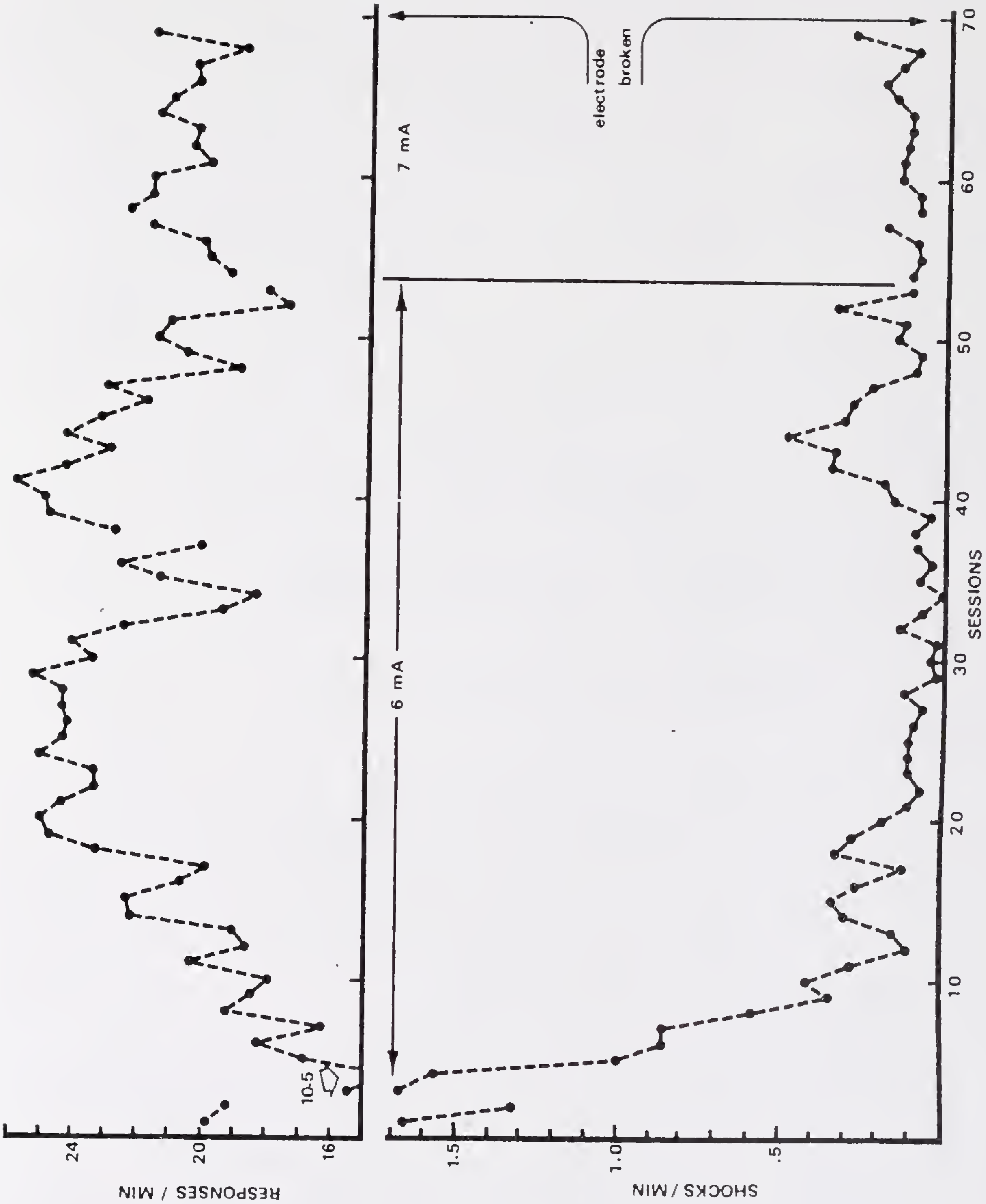
response was consistently highest at 14 and 16 sec by the end of the experiment. However, the most striking feature of these data is the similarity in the function from Sessions 20-124. The acquisition of temporally-spaced responding is quite rapid and stable for a pigeon with previous avoidance experience.

Response and shock rates for all sessions of the experiment for Pigeon N are shown in Figures 5 and 6. Compared to Pigeon D, Pigeon N showed slower acquisition of the response and higher response rates,and higher and more variable shock rates throughout the experiment. Pigeon N lacked the avoidance conditioning history of Pigeon D. Response rates increased during the first 20 sessions, remained at 22-25 responses per min for 10 sessions and then decreased sharply to 18 per min at Sessions 32-34.

During this same period, shock rates had declined dramatically by Session 20 and remained at about 0.15 per min through the 39th Session. From Sessions 38-53, both response and shock rates increased and then decreased. The conditional probability functions (Figure 7, Sessions 41-44, and 44-48) reflect this disruption of avoidance behavior. No extraexperimental events were identified to account for the sudden change in performance during this time.

Shock intensity was increased to 7 mA at Session 54

Fig. 5. Mean response and shock rates for the last 85 min of each 100 min session, Pigeon N. Consecutive daily sessions are connected by a line.


RESPONSES / MIN
24
20
16
10.5
SHOCKS / MIN
1.5
1.0
.5
SESSIONS
10
20
30
40
50
60
70
6 mA
7 mA
electrode
broken

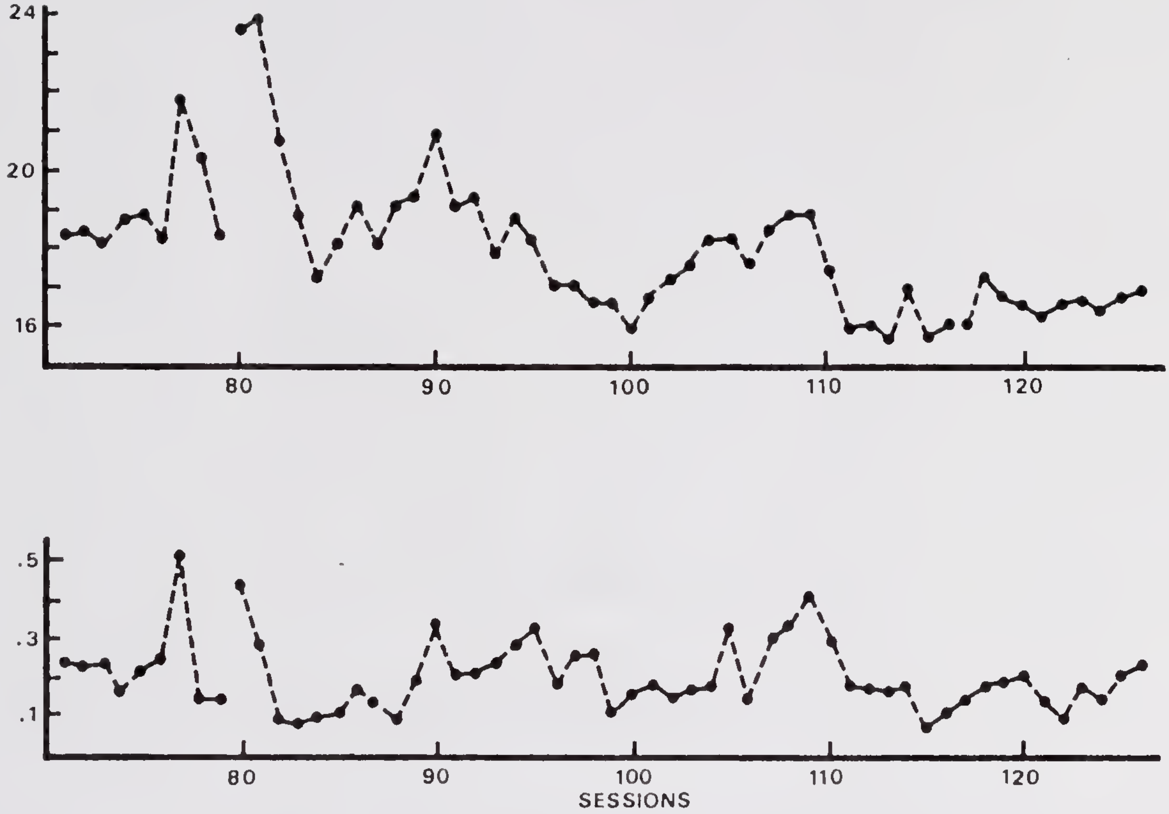
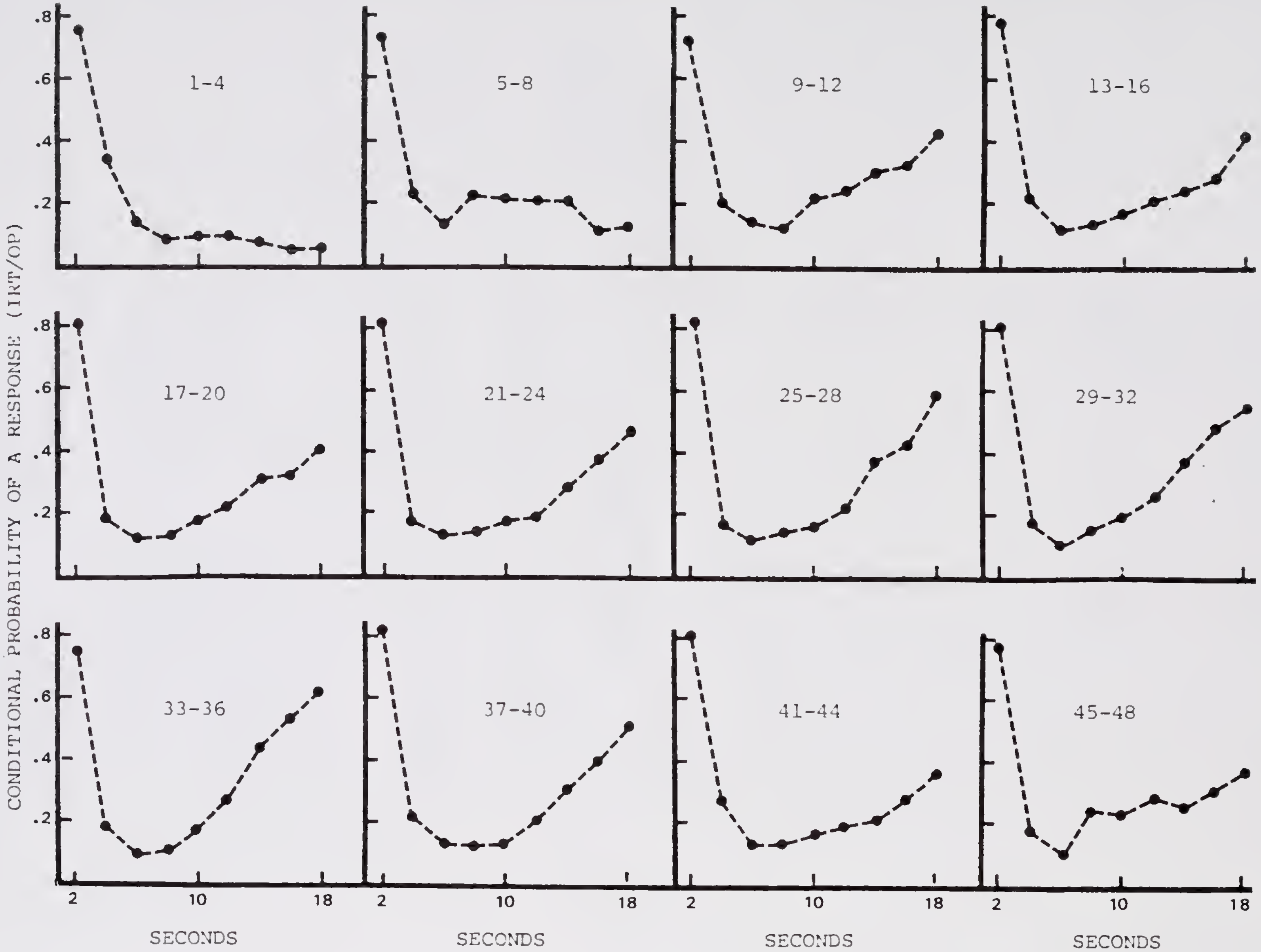


Fig. 6. Mean response and shock rates for the last 85 min of each 100 min session. Consecutive daily sessions are connected by a line.

Fig. 7. Conditional probabilities of a response during 2 sec segments of the R-S interval, Pigeon N. All functions are based on the mean of the four sessions indicated by the numbers in the upper center of each set of coordinates.

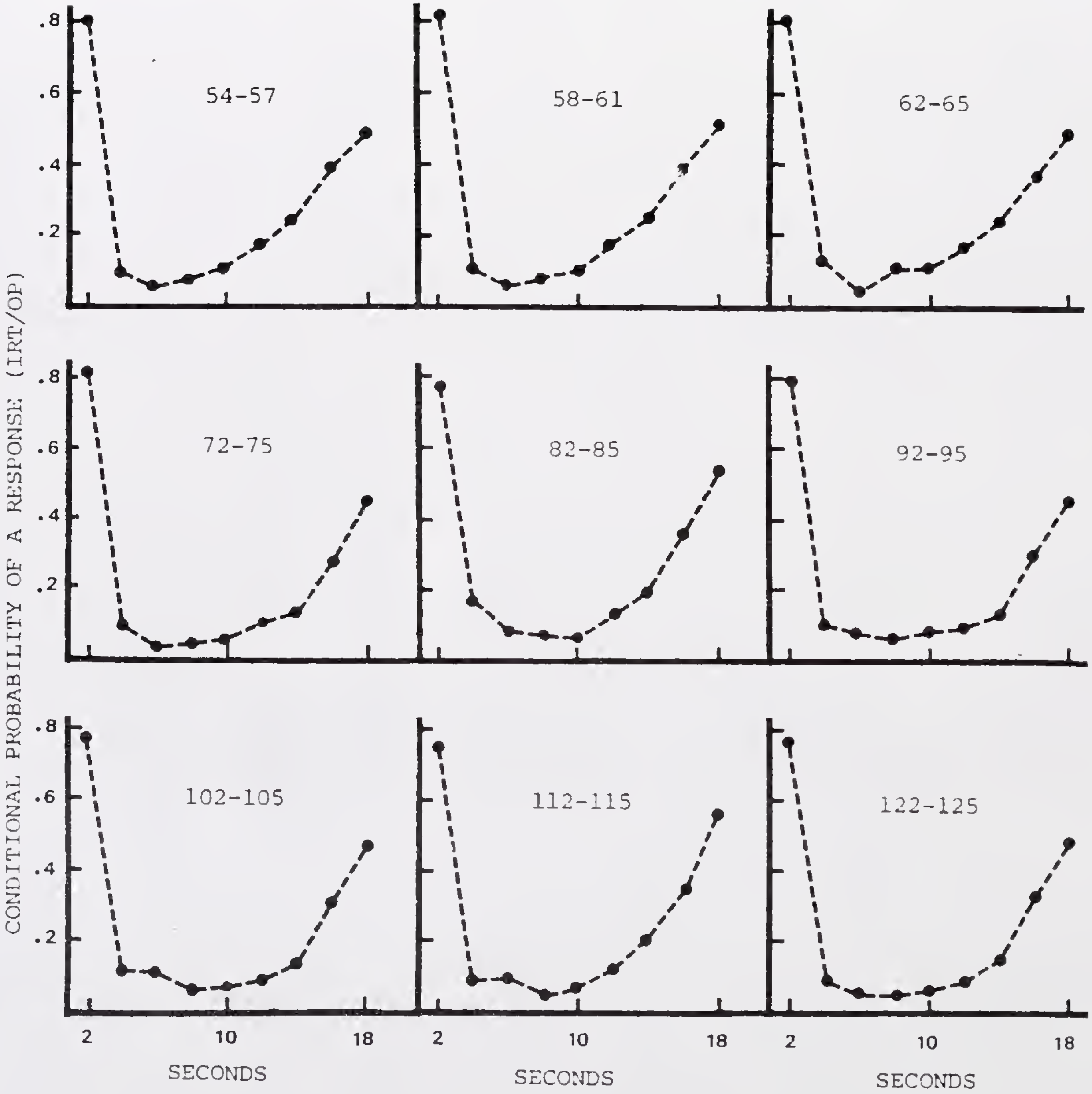

CONDITIONAL PROBABILITY OF A RESPONSE (IRT/OP)
.8
.6
.4
.2
1-4
5-8
9-12
13-16
17-20
21-24
25-28
29-32
33-36
37-40
41-44
45-48
2
10
18
SECONDS

and from Sessions 60-68 both shock and response rates were relatively stable. The increases seen in Session 69 were due to a broken electrode connection discovered in the early part of the 70th Session. The dramatic increase in rates during Session 77 was correlated with increased shock rates in the other three pigeons run that day, suggesting that some unidentified equipment malfunction may have been the cause. Voltage measurements of the shocker and resistance measurements on the cable revealed no malfunction in the delivery system.

Prior to Session 80, Pigeon N was not run for five days and the effects of the vacation (comparable to those for Pigeon D in Figure 2, Session 86) can be seen in the increased response and shock rates (Figure 6). Both rates were variable until Session 111 at which time Pigeon N displayed response rates from 16-18 per min and shock rates from 0.1 to 0.2 per min until the end of the experiment. The mean response rate for the last five sessions was 16.62 and mean shock rate was 0.165. The response and shock rates for the preceeding five sessions were 16.56 and 0.162.

The conditional probability distributions of responding during the R-S interval for Pigeon N are shown in Figures 7 and 8. Similar to the distributions for Pigeon D, four session means were plotted until little change was evident in the functions for 12 sessions. At

Fig. 8. Conditional probabilities of a response during 2 sec segments of the R-S interval, Pigeon N.


54-57
58-61
62-65
72-75
82-85
92-95
102-105
112-115
122-125
.8
.6
.4
.2
CONDITIONAL PROBABILITY OF A RESPONSE (IRT/OP)
2
10
18
SECONDS

that point (Session 65), the conditional probability functions are shown for the first four of every 10 sessions until the end of the experiment.

Pigeon N showed a pattern of bursts of responding, as seen in the cumulative records of Figures 9 through 14, and these bursts, a consistent feature of this bird's pattern throughout the experiment, account for the high probability of a response in the first 2 sec. The development of temporally-patterned responding was slower to develop in Pigeon N: with the exception of the first 2 sec, responses were randomly distributed during the first eight sessions. Some evidence of a discrimination can be seen by Sessions 9-12 and the probability of a response in the 14th, 16th, and 18th sec increased reliably from Sessions 13-40. Increasing shock intensity had no discernible effect upon IRTs. During the rest of the experiment, changes in the distribution of responding consisted of decreases in the probability of a response during the second segment of the R-S interval. The cumulative records as well as the overall decrease in response rates, in the later stages of training suggest that this feature of the probability distributions was the result of a decline in the duration of bursts which characterized Pigeon N's responding. This decline can be seen by comparing Figures 10 and 14. The lack of bursts of responding in the cumulative records of Pigeon D (Figures 15 through 19) and the lower probability of a

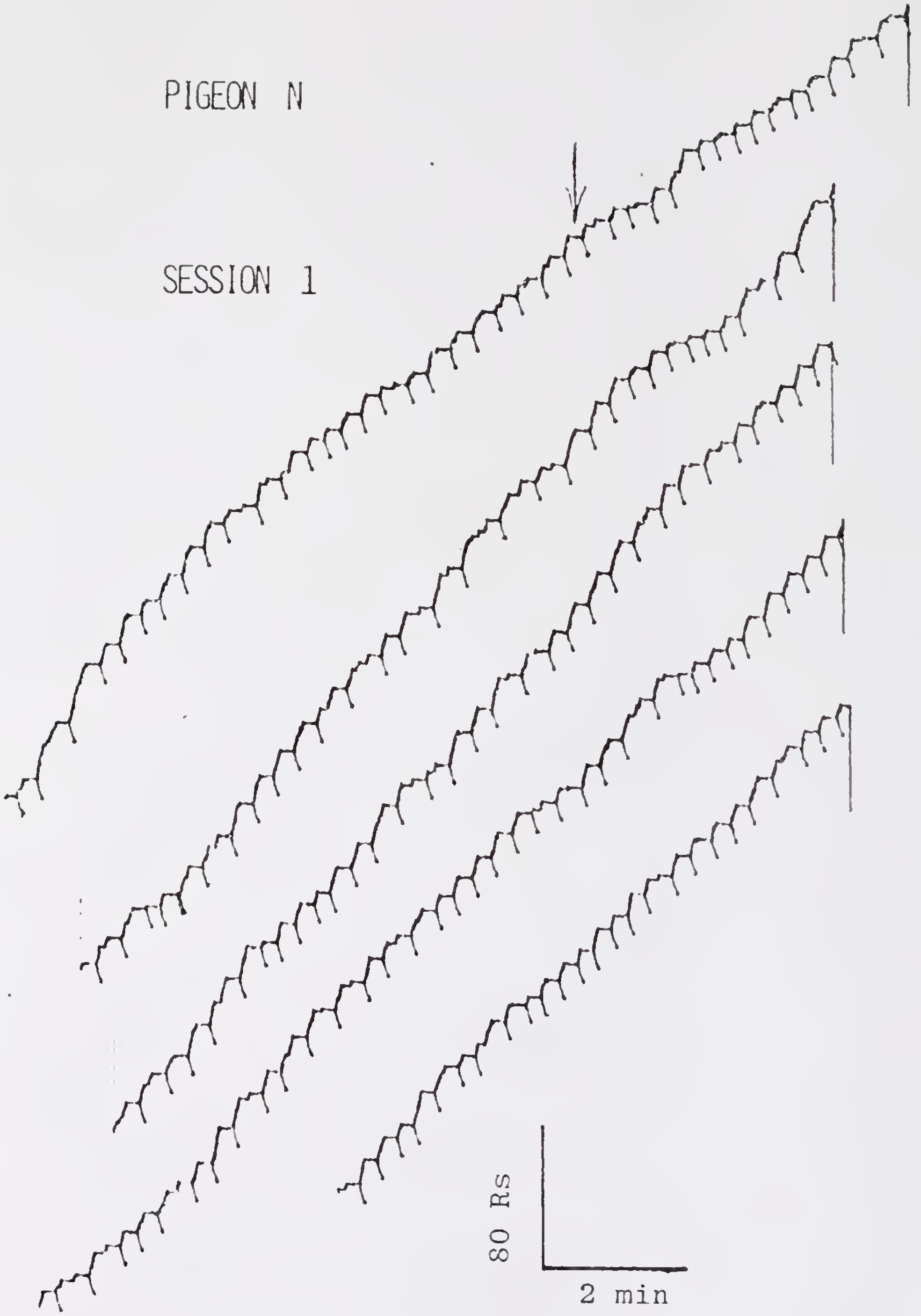


Fig. 9. Cumulative record of the entire 100 min session indicated for Pigeon N. Each treadle press moved the pen upward and slashes denote shocks. Successive segments have been collapsed with the earliest segments at the top. The arrow indicates the end of the 15 min period defined as warm-up.

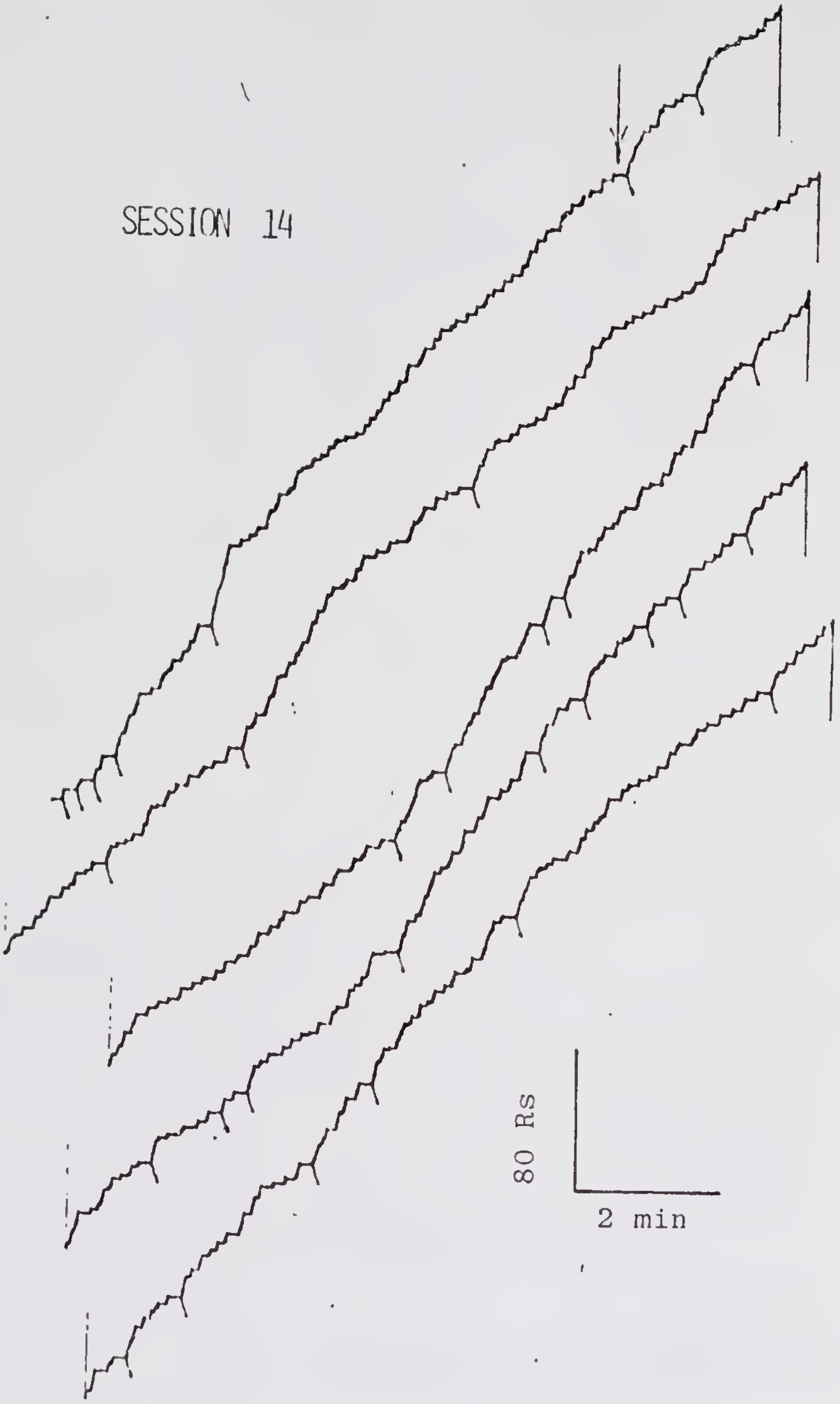


Fig. 10. Cumulative record of the entire 100 min session indicated for Pigeon N. Recording conventions are as in Fig. 9.

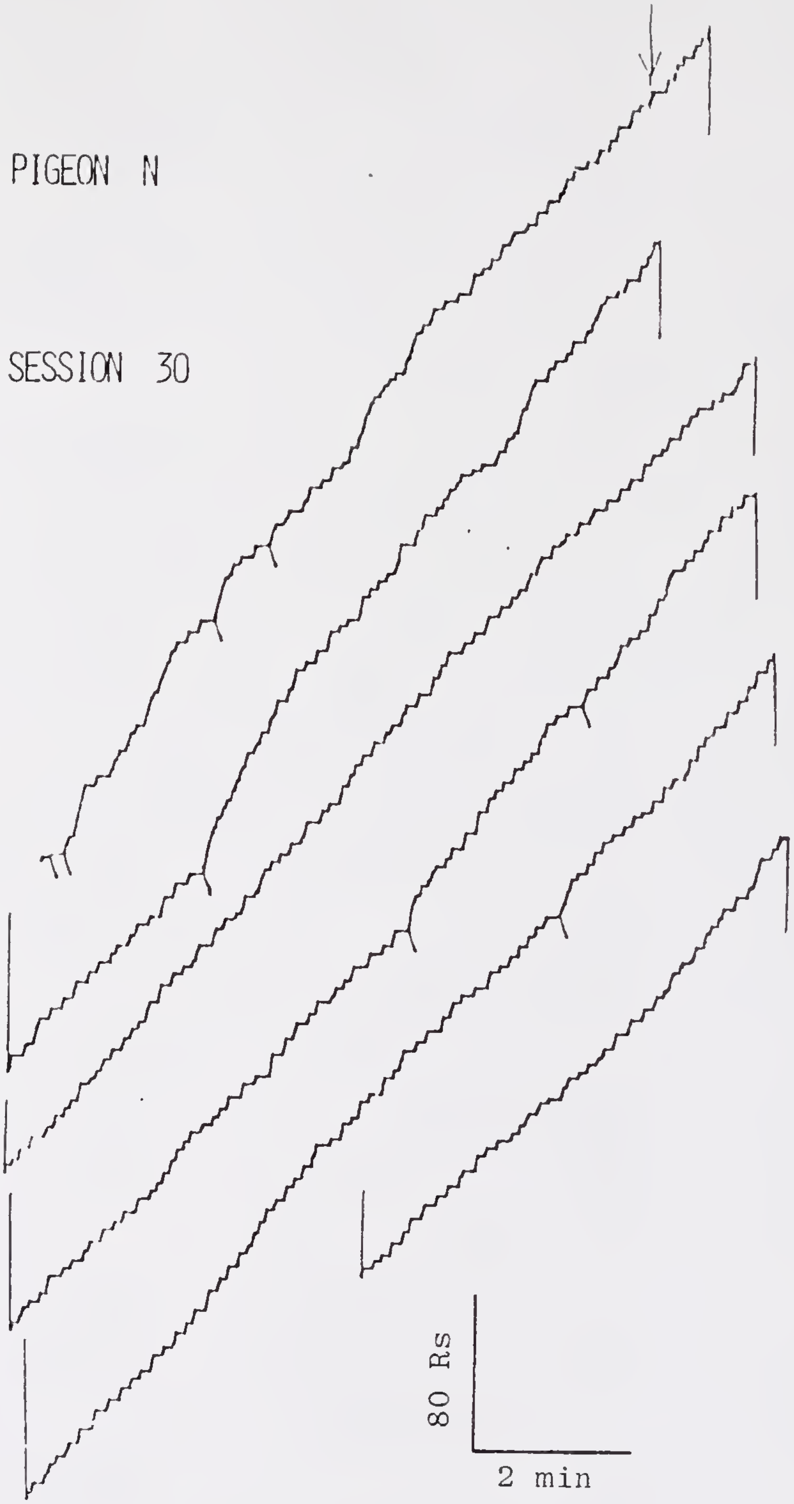


Fig. 11. Cumulative record of the entire 100 min session indicated for Pigeon N. Recording conventions are as in Fig. 9.

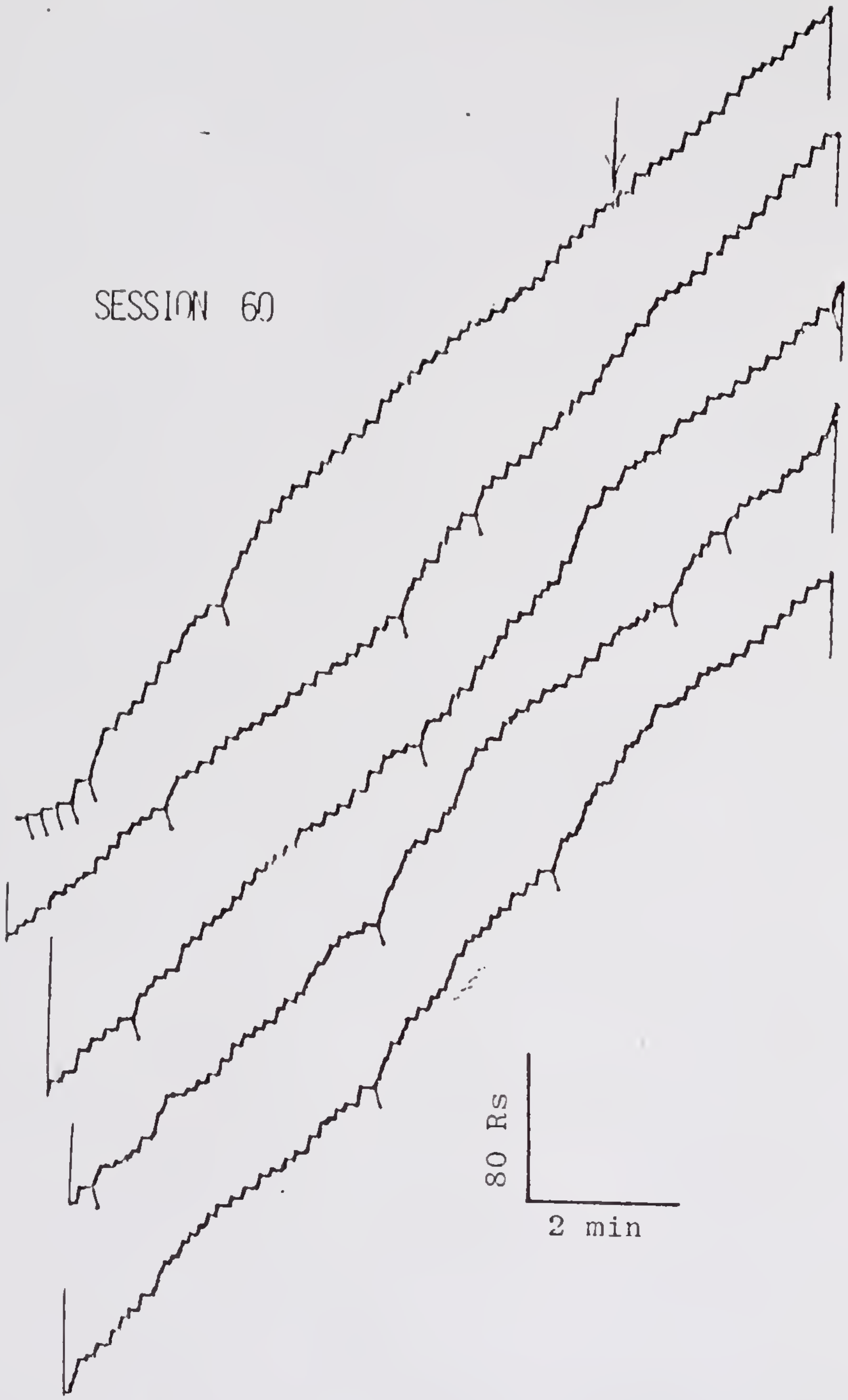


Fig. 12. Cumulative record of the entire 100 min session indicated for Pigeon N. Recording conventions are as in Fig. 9.

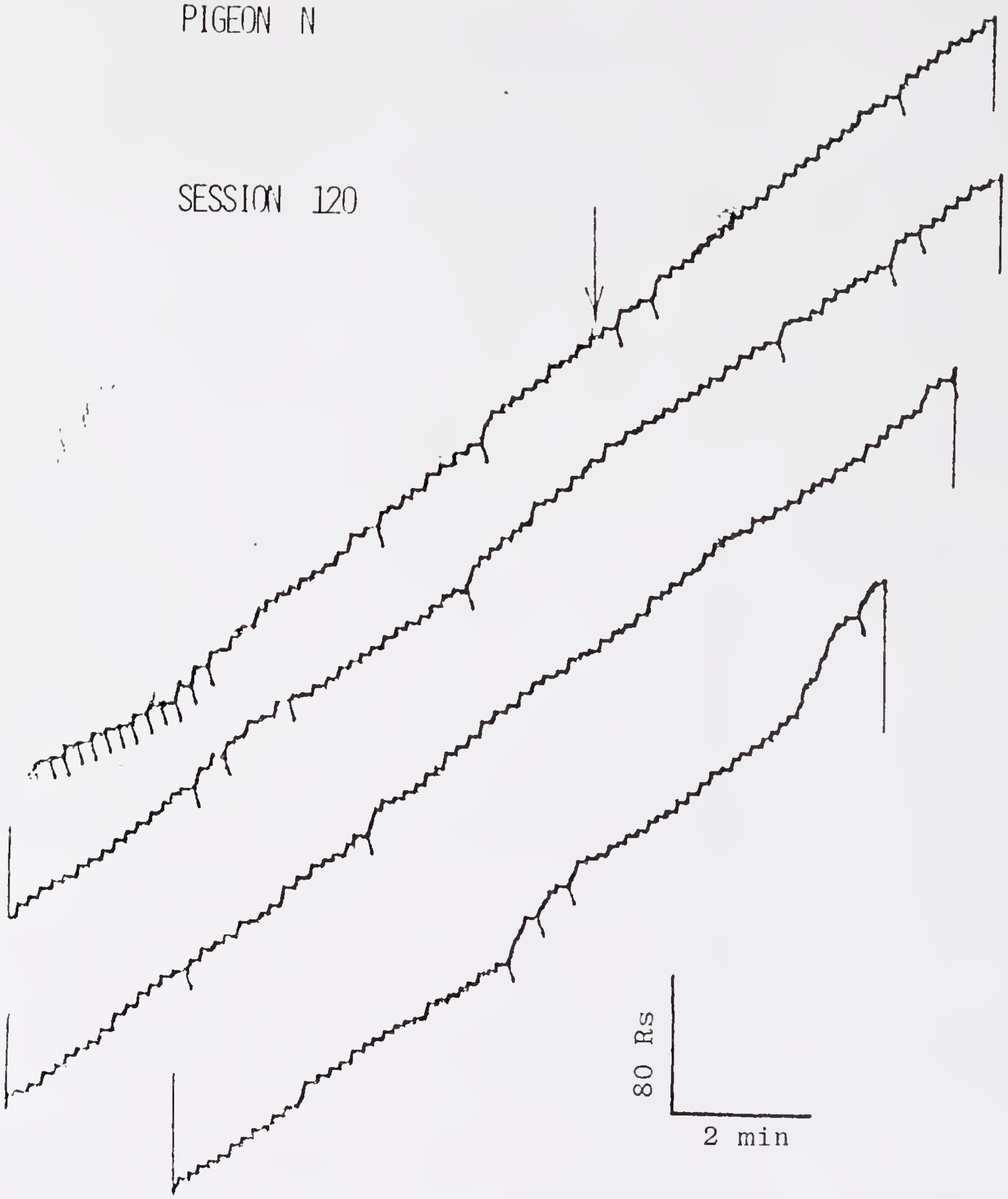


Fig. 13. Cumulative record of the entire 100 min session indicated for Pigeon N. Recording conventions are as in Fig. 9.

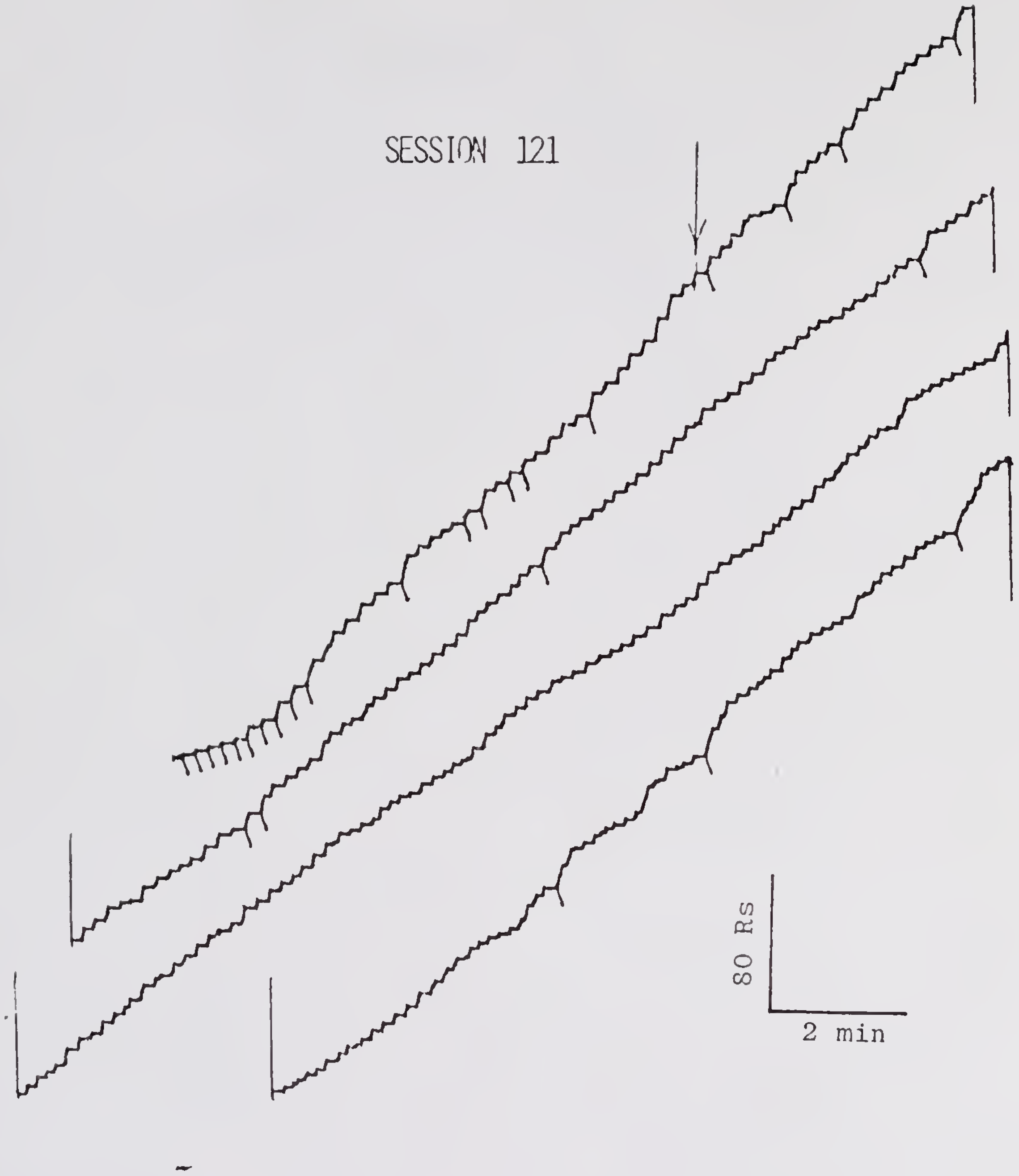


Fig. 14. Cumulative record of the entire 100 min session indicated for Pigeon N. Recording conventions are as in Fig. 9.

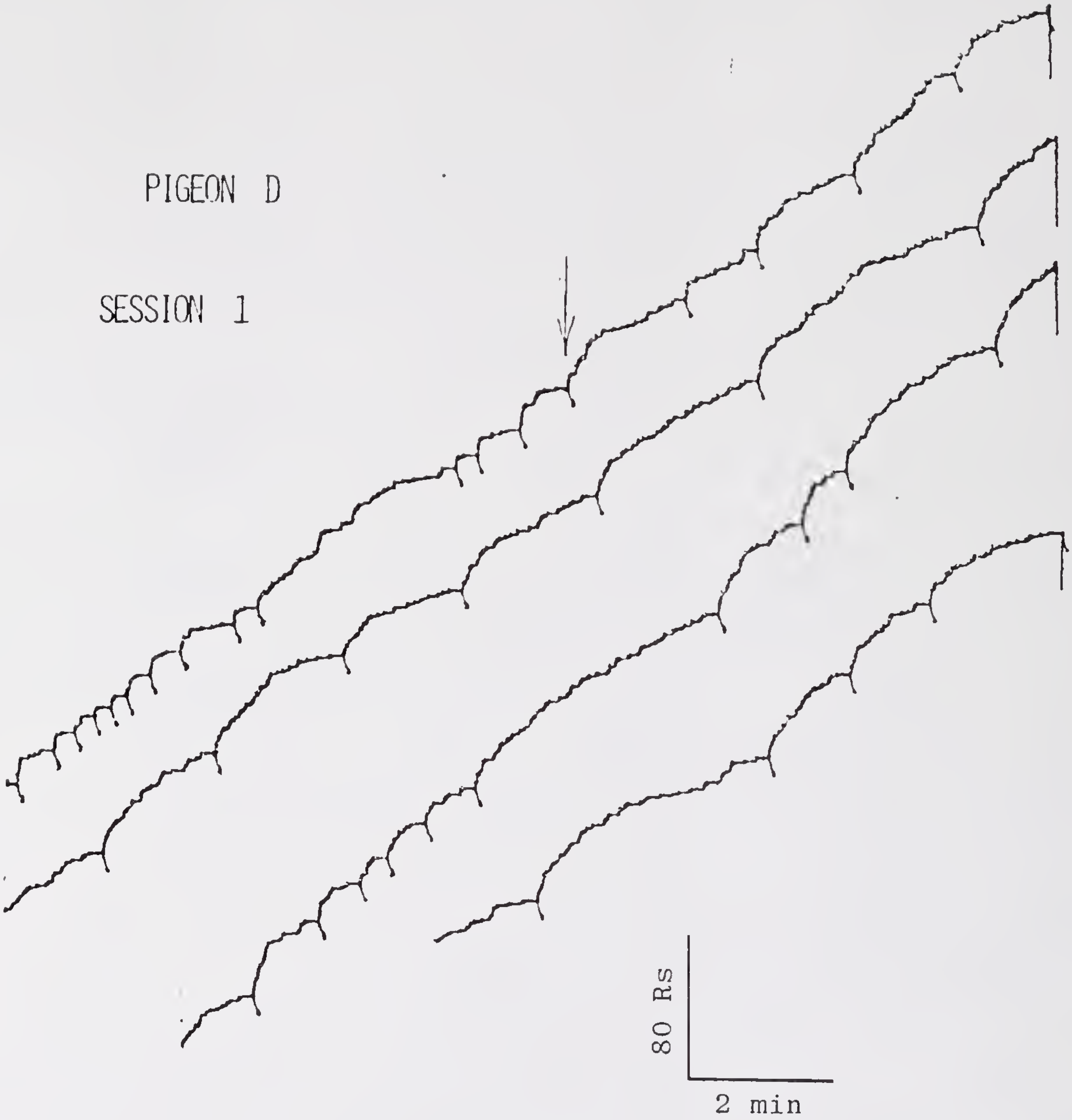


Fig. 15. Cumulative record for the entire 100 min session indicated for Pigeon D. Each treadle press moved the pen upward and slashes indicate shocks. Successive segments have been collapsed with the earliest segments at the top. The arrow indicates the end of the 15 min period defined as warm-up.

Fig. 16. Cumulative record for the entire 100 min session indicated for Pigeon D. Recording conventions are as in Fig. 15.

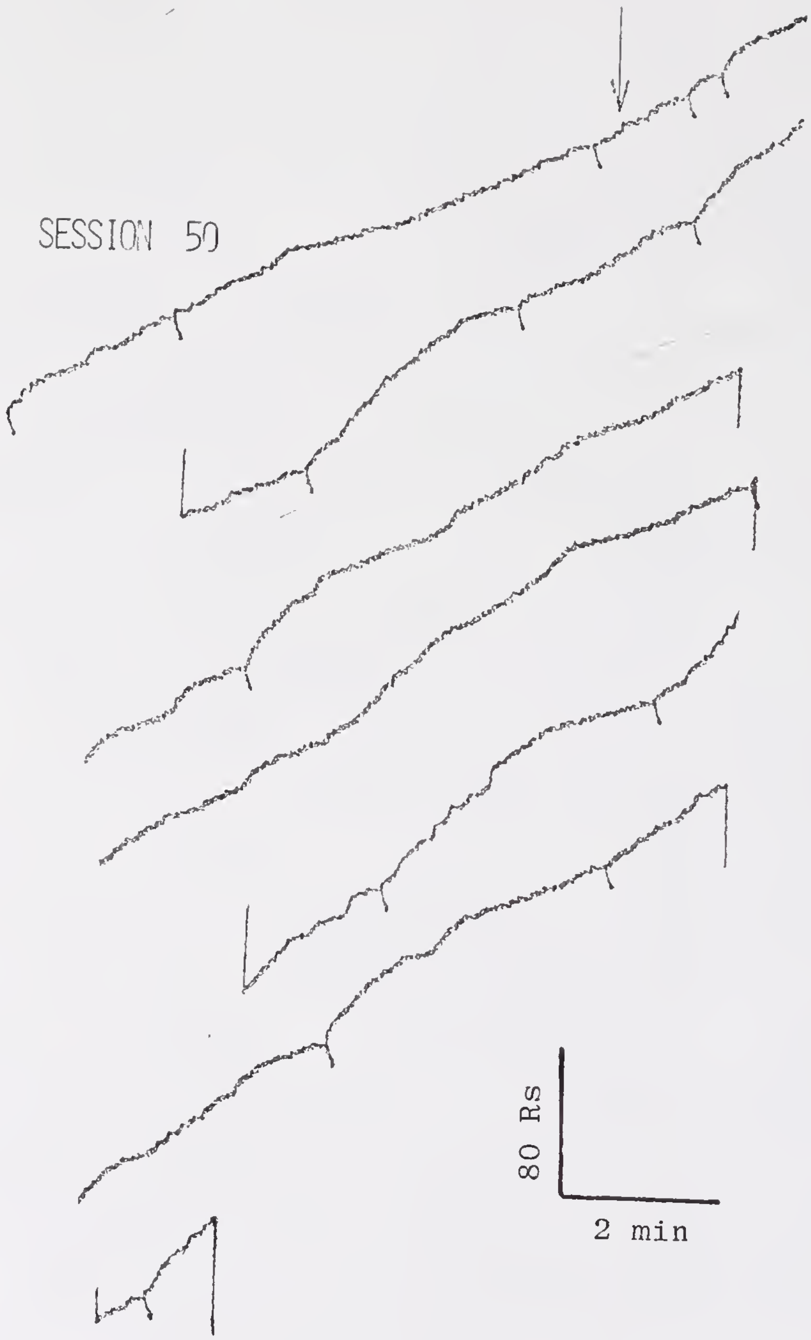


Fig. 17. Cumulative record for the entire 100 min session indicated for Pigeon D. Recording conventions are as in Fig. 15.

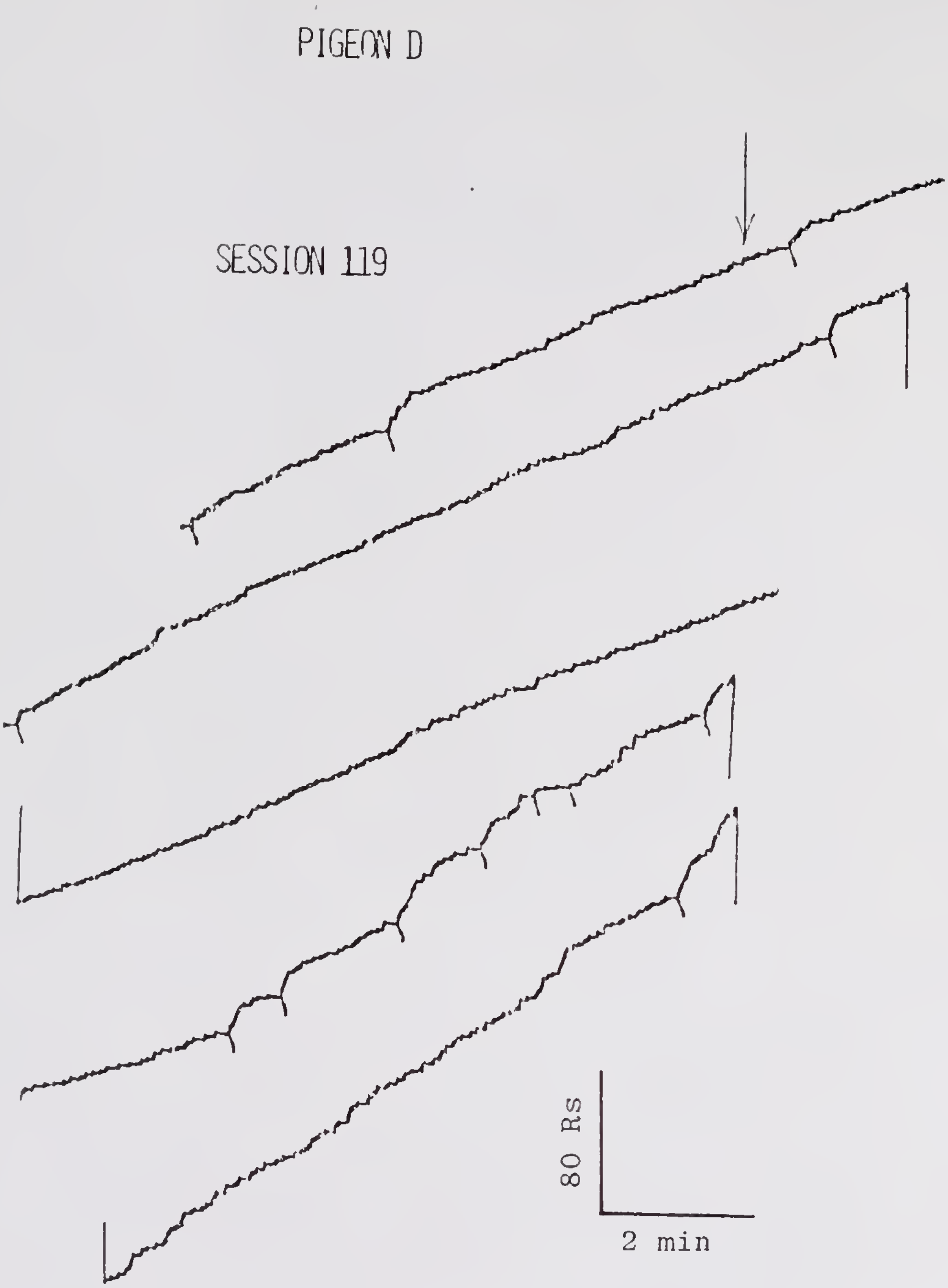


Fig. 18. Cumulative record for the entire 100 min session indicated for Pigeon D. Recording conventions are as in Fig. 15.

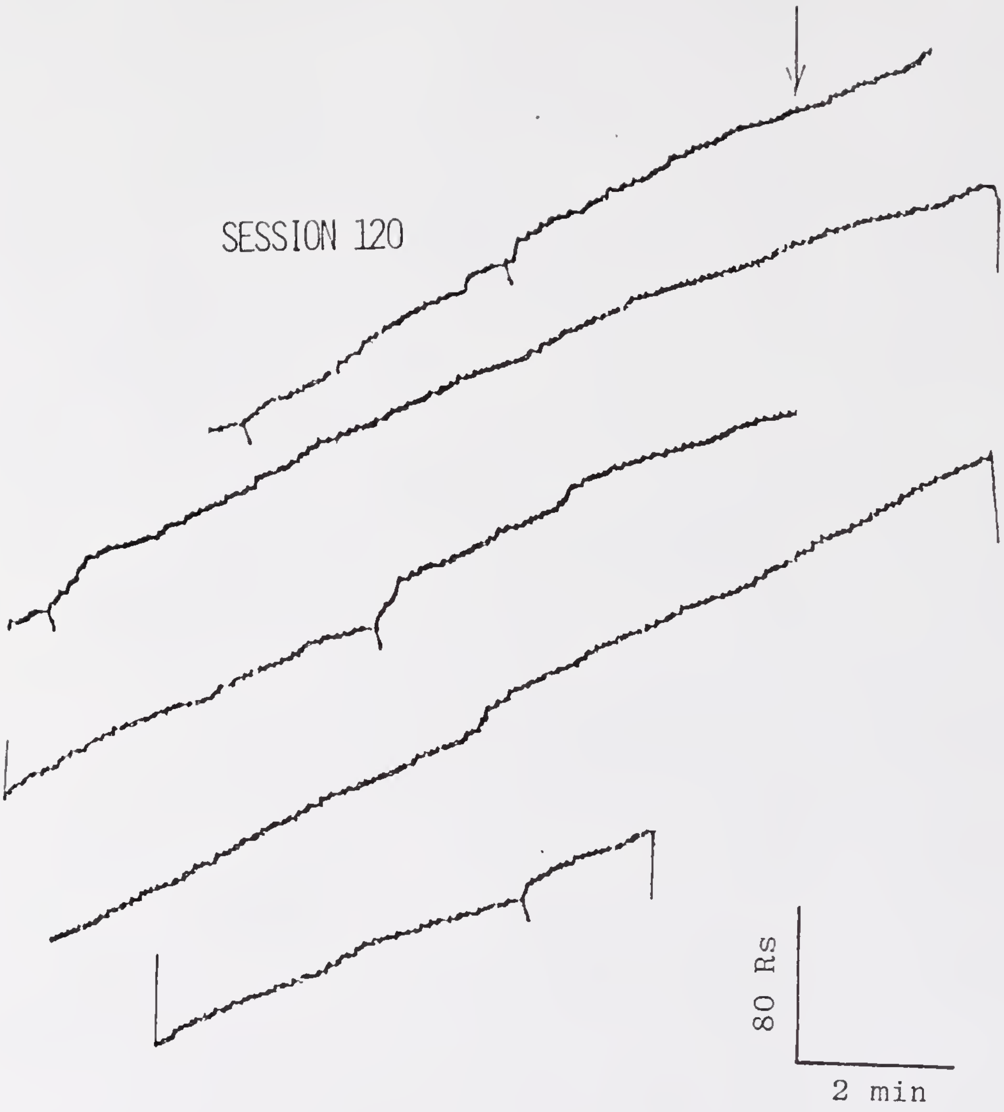


Fig. 19. Cumulative record for the entire 100 min session indicated for Pigeon D. Recording conventions are as in Fig. 15.

response in the first segment of the conditional probability distribution (Figures 3 and 4) support this explanation. It should be noted that Pigeon N's response bursts occurred in the absence of shock and thus represent emitted rather than shock-elicited behavior.

EXPERIMENT II.

METHOD

Subjects: Two male White Carneaux pigeons, each about 2 years old, served. All care and housing conditions were the same as in Experiment I.

Apparatus: The identical apparatus of Experiment I was used throughout Experiment II.

Procedure: Implantation, weighing and resistance checking followed the procedures of the first experiment. Each pigeon was run daily for 100 min and each session began and ended with 5 min of darkness. Illumination of the pairs of bulbs behind the red and green translucent plastic covers was correlated with the operation of the random shock schedule devised and described by Herrnstein and Hineline (1966). On this schedule, shock is delivered independently of the behavior of the subject but the frequency of the shock differs following responses.

Two independent shock distributions were programmed on stepping switches, stepped every two sec by the same clock. The high probability shock program was in effect following a shock and remained in effect until a response occurred. Shocks were delivered in a randomized sequence with an average frequency of 9 per min while the high probability program operated and at 3 per min while the low probability program operated. When a shock was delivered from the low probability program the high probability shock program was reinstated. Thus, responses following shocks had the effect of instating the low probability shock program and responses following responses had no programmed effects. The minimum number of shocks, regardless of response rates, was fixed by the program at approximately 3 per min.

Every treadle press produced an audible click of the feedback relay except for the duration of a delivered shock when the treadle microswitch was disabled. No programmed stimuli accompanied either shock program. Shock duration was 0.3 sec and the probabilities of shock for any two sec period were 0.1 and 0.3 for the low and high shock programs, respectively: these parameters remained fixed for the course of the experiment. The point in the shock distributions at which each daily session started was varied unsystematically from day to day to destroy any regularity in the shock sequences.

The sequence of experimental manipulations of shock intensity for both pigeons is shown in Table 2. Initial shock intensities were determined during the first session by slowly increasing the intensity until the pigeon showed

Table 2

Sequence of Conditions in Experiment II.

PIGEON	SESSIONS		SHOCK INTENSITY
	Sequence	Total No.	
S	1-13	(13)	6.5
	14-35	(22)	7.0
	36	(1)	8.0
	37-56	(20)	7.0
	57-76	(20)	7.75
	77-100	(24)	6.0
	101-145	(46)	7.75
	146-164	(19)	10.0
	165-171	(7)	7.75
C	1-8	(8)	7.5
	9-17	(9)	8.25
	18-66	(49)	9.0
	67-182	(116)	10.0
PROBES	119, 122, 131, 141, 155	(5)	7.9

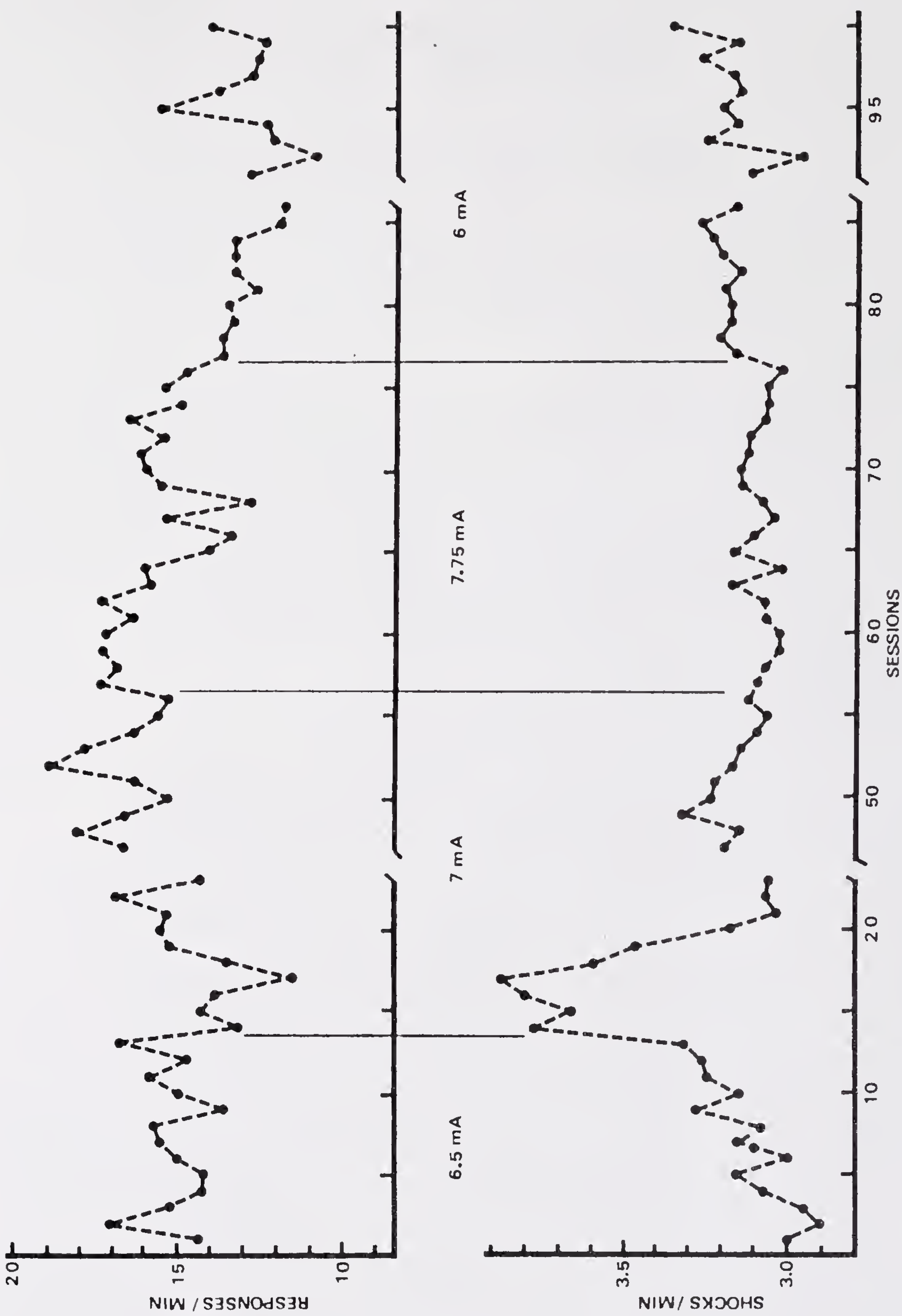
bobbing and wing flapping of moderate intensity when shocked. Repeated observations were made during the course of a session to evaluate the pigeons' reactions to shock and to check for adaptation. Increases in shock intensity were made cautiously because of the paralysis inflicted on Pigeon N in the first experiment and a similar accident suffered by a mixed-breed pigeon intended as a sujbect in this experiment. No symptoms of paralysis were ever observed in Pigeons C and S during Experiment II.

RESULTS

The overall response and shock rates for both pigeons are shown in Figures 20-24. The rates represent the total number of responses in the session without regard for the effectiveness of a response. Effective responses, i.e., those following a shock, varied over a narrow range of 275 to 300 responses in 100 min and the variation in rates seen in the figures resulted from ineffective responses, emitted while the low probability shock program was already in effect. Overall shock rates were calculated without regard for the program source, high or low, from which they were delivered.

Pigeon S displayed a stable range of response rates and increasing shock rates during the 13 sessions at a shock intensity of 6.5 mA (Figure 20). Pigeon S's observed reactions to shock during the 12th and 13th

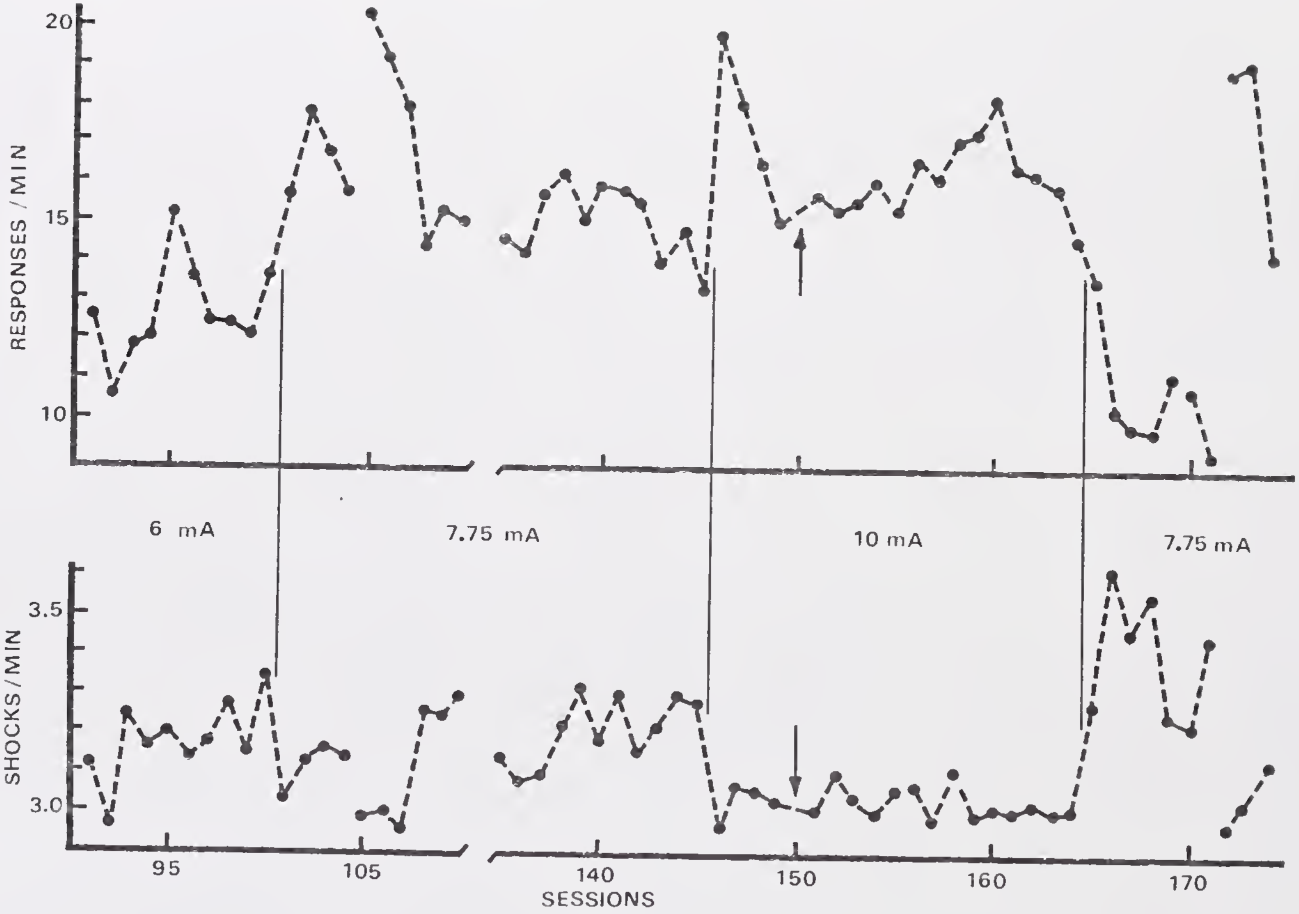
Fig. 20. Mean response and shock rates for each 100 min session, Pigeon S. For shock intensities in effect for more than 20 sessions, only the first and last 10 sessions data are shown. The numbers in parentheses give the total number of sessions at any intensity. Consecutive daily sessions are connected by a line.


RESPONSES / MIN
20
15
10
SHOCKS / MIN
3.5
3.0
6.5 mA
7 mA
7.75 mA
6 mA
10
20
50
60
70
80
95
SESSIONS

Sessions were of very low intensity and shock delivery could not be reliably detected from his reaction. During the first ten sessions at 7 mA Pigeon S's response rates were variable and his shock rates decreased sharply after the sixth Session at 7 mA. After 22 sessions at 7 mA response rates varied around 16.5 responses per min, shock rates were variable with a downward trend and Pigeon S was again showing little reaction to shock.

During the 20 sessions in which shock intensity was 7.75 mA, shock rates were stable in the range of 3.05 to 3.2 per min and response rates showed a downward trend. Decreasing the shock intensity to 6 mA produced an immediate increase in shock rates while response rates were somewhat lower and more variable.

In Figure 21 the rates for the last ten sessions at 6 mA presented in Figure 20 are repeated for ease of comparison. Increasing shock intensity from 6.0 mA to 7.75 mA resulted in an immediate increase in responding and little decrease in shock rates over four sessions. Equipment problems necessitated a vacation and the effects are clearly seen in the high response rates and low shock rates during the next three sessions. Similar effects of vacation from daily avoidance sessions were seen in Experiment I. (Figure 2). By the end of 46 sessions at 7.75 mA, response rates were more stable and slightly higher than those of the last sessions at 6 mA. Shock


20
15
10
RESPONSES / MIN
6 mA
7.75 mA
10 mA
7.75 mA
3.5
3.0
SHOCKS / MIN
95
105
140
150
160
170
SESSIONS

rates were stable and equal to those under the 6 mA condition and slightly higher than shock rates at the end of the first exposure to 7.75 mA.

A change to 10 mA shock intensity produced elevated response rates and sharply decreased shock rates in the first session. Shock rates remained low during the 19 sessions at 10 mA: shock rates were often at the minimum rate dictated by the procedure. Response rates were generally higher than those at lower shock intensities but were decreasing at the end of 19 sessions. Since response rates can be expected to be variable due to the lack of explicit contingencies except the correlative shock reduction effected by a response following shock and since no further reduction in shock rates was possible, an attempt was made to replicate the effects of shock intensity at 7.75 mA upon shock rates (or alternatively, on effective response rates). Following the exposure to 6 mA, Pigeon S's rate of effective responses had not increased (shock rate did not decrease) upon reintroduction to 7.75 mA. Effective response rate at the second exposure to 7.75 mA was thus lower (shock rates increased) than those of the first 7.75 mA condition.

The third exposure to a shock intensity of 7.75 mA resulted in increased shock rates, higher than those at any time except the beginning of the experiment. Response rates decreased to the lowest values observed during the experiment. After seven sessions equipment problems prevented daily sessions and Pigeon S died within two hr after the third session following the vacation. Cumulative records of the last session showed no obvious disruptions of responding but Pigeon S was bleeding from the anus when removed from the chamber. A crude autopsy indicated that he had suffered a hemorrhage of the intestinal wall.

The overall response rates and shock rates for all sessions for Pigeon C are shown in Figures 22 through 24. Pigeon C showed a very high tolerance for shock as indicated by his reaction to shock. In general, response rates and shock rates varied considerably (Figure 22) at intensities from 7 to 9 mA (Sessions 1-66).

The effects of increasing shock intensity to 10 mA can be seen in Figure 23. Response rates stabilized during Sessions 72-83 and shock rates declined. At Session 87 Pigeon C showed increased response rates and his shock rates decreased to near the minimum possible rate of 3 per min. Following a period of decreasing response and increasing shock rates (Sessions 99-106, Figure 23) Pigeon C's electrodes were removed in order to treat an infection which had developed in the area of the right electrode.

Upon return from the 10 day vacation and following the vacation effect of increased response and decreased shock rates observed throughout these experiments, a

Fig. 22. Mean response and shock rates for each 100 min session for Pigeon C. Data from consecutive daily sessions are connected by a line.

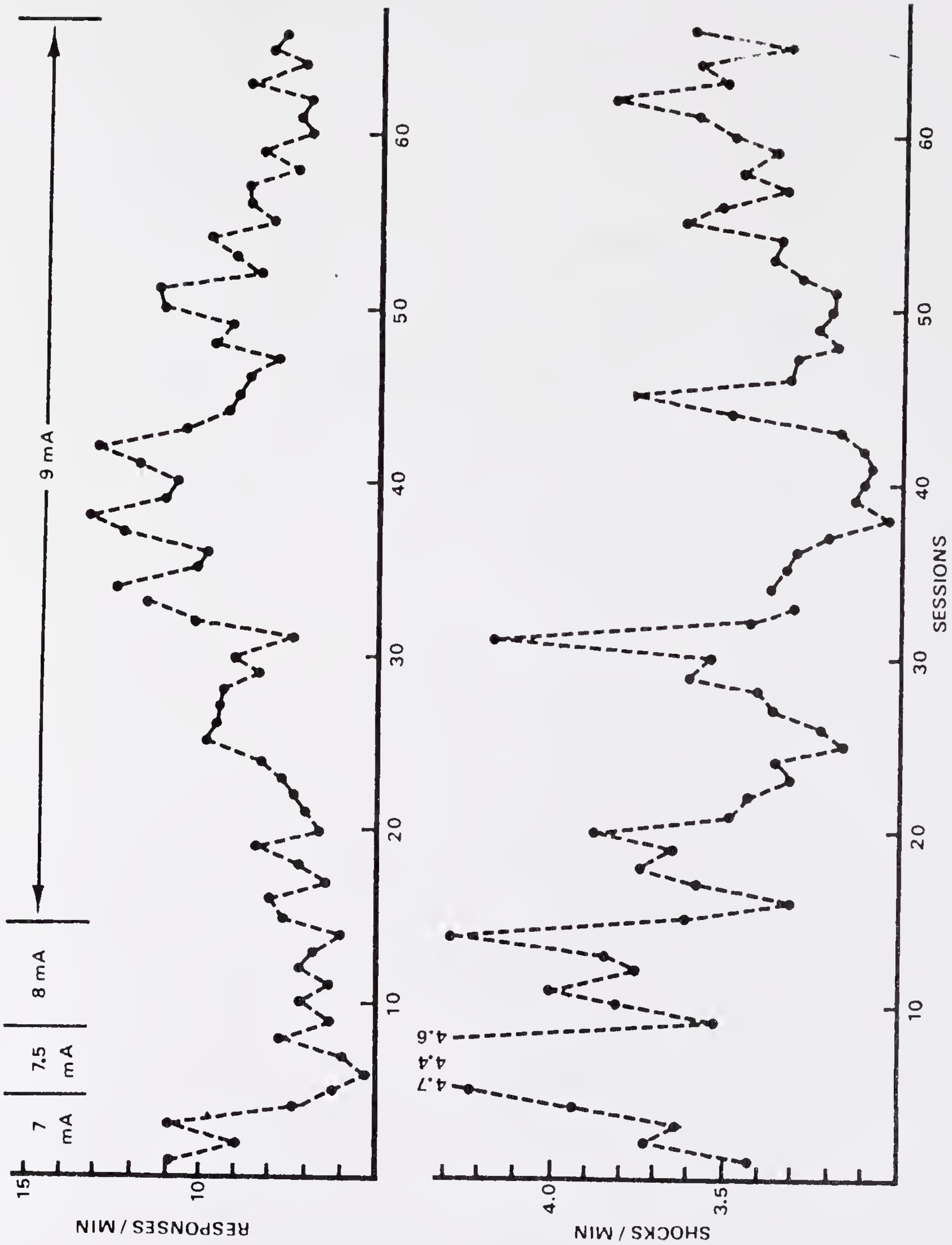
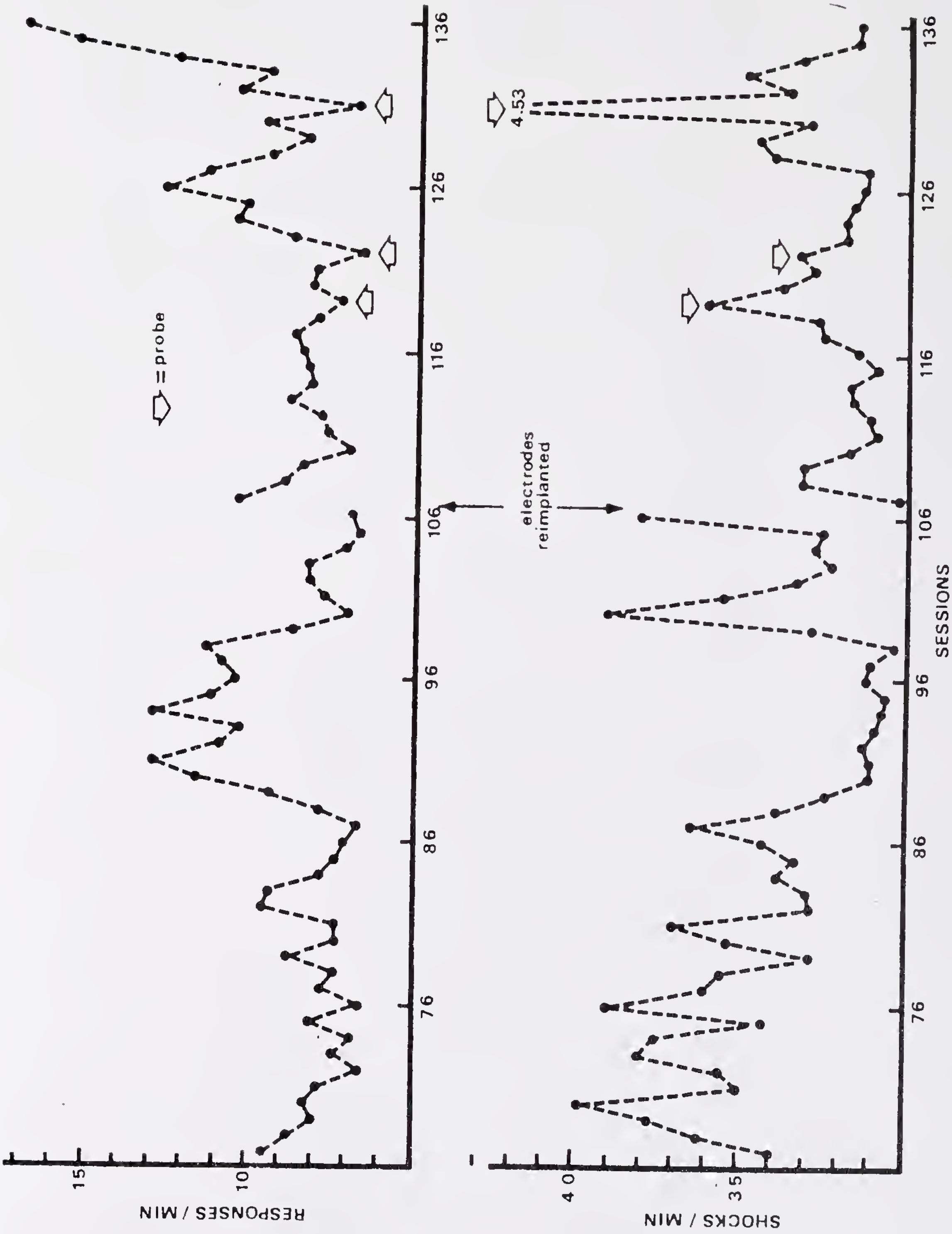

7 mA
7.5 mA
8 mA
9 mA
RESPONSES / MIN
15
10
SHOCKS / MIN
4.0
3.5
4.7
4.4
4.6
SESSIONS
10
20
30
40
50
60

Fig. 23. Mean response and shock rates for each 100 min daily session for Pigeon C. Data from consecutive daily sessions are connected by a line. Data from sessions indicated by the open arrows were collected at an intensity of 7.9 mA (probe sessions).

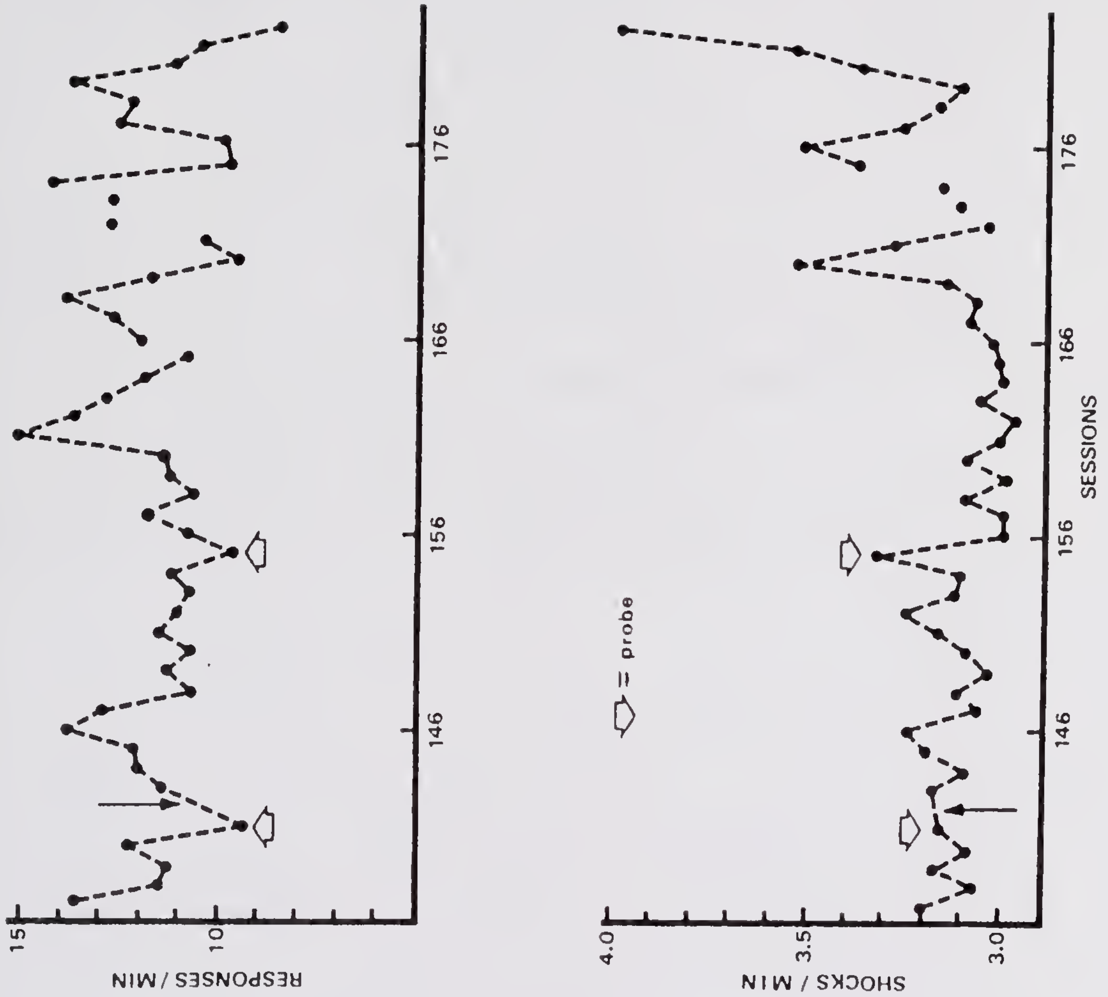

RESPONSES / MIN
15
10
= probe
SHOCKS / MIN
40
35
4.53
electrodes reimplanted
76
86
96
106
116
126
136
SESSIONS

period of relatively stable rates ensued and was disrupted by two procedural errors which resulted in exposure to a shock intensity of 7.9 mA (Sessions 119 and 122). At this lower shock intensity response rates were lower and shock rates were higher than in the preceeding and succeeding sessions. Since Pigeon C seemed rather unreactive to shock and because of our experience with the damaging effects of shock intensities higher than 10 mA, and because the data from Pigeon S suggested that adaptation to higher shock intensity may result from extended exposure to varied shock intensities, a series of intended probes (as opposed to the unintended probes in Sessions 119 and 122) at 7.9 mA was carried out.

The first intended probe (third exposure to 7.9 mA) occurred in Session 131 (Figure 23) and resulted in a reduced response rate and sharply increased shock rate. Following that probe, response rates were high for the next five sessions and shock rates were low. The probe at Session 141 produced a decreased response rate and little effect upon shock rate (Figure 24). It should be noted that a counter malfunction resulted in the loss of data from the following session, Session 142. A comparison of the cumulative records for Sessions 142 and 140 revealed no dramatic differences.

The last probe at Session 155 was programmed to follow a stable period of response and shock rates. The

Fig. 24. Mean response and shock rates for 100 min sessions for Pigeon C. Consecutive daily sessions are connected by a line, the small dark arrow indicates a session for which data were lost due to a counter malfunction and the open arrows indicate probe sessions when shock intensity was 7.9 mA.


RESPONSES / MIN
15
10
146
156
166
176
= probe
SHOCKS / MIN
4.0
3.5
3.0
146
156
166
176
SESSIONS

mean rate of responding for the three sessions (152, 153, 154) prior to the probe was 11.11 per min and differed by 0.5% from the mean response rate of 11.17 for the three preceeding sessions (149, 150, 151). The mean shock rates for these three-session blocks were 3.16 and 3.09 per min (a difference of 2.2%), respectively. The response rate during the probe session was 9.6 per min and the shock rate was 3.32 per min. Following the last probe, shock rates remained stable and at the lower possible limits for 10 sessions and response rates showed wide variations. There followed a series of equipment problems and the variability in rates associated with vacations from daily sessions. The experiment was terminated when infection around the electrode implantation area developed and the electrodes consistently showed encrustation and discharge of fluids from the entry site.

A summary of the results of shock intensity manipulations for Pigeon S is presented in Figure 25. The mean response and shock rates for the last five sessions at each intensity are shown and the line through each data point represents the limits of plus and minus one standard deviation from the mean. As can be seen in Figure 25, increasing the shock intensity from 6.5 mA to 7 mA, and from 7 mA to 7.75 mA, resulted in decreased shock rates. The first exposure to a lower shock intensity, 6 mA, produced an increase in shocks. The first reexposure to

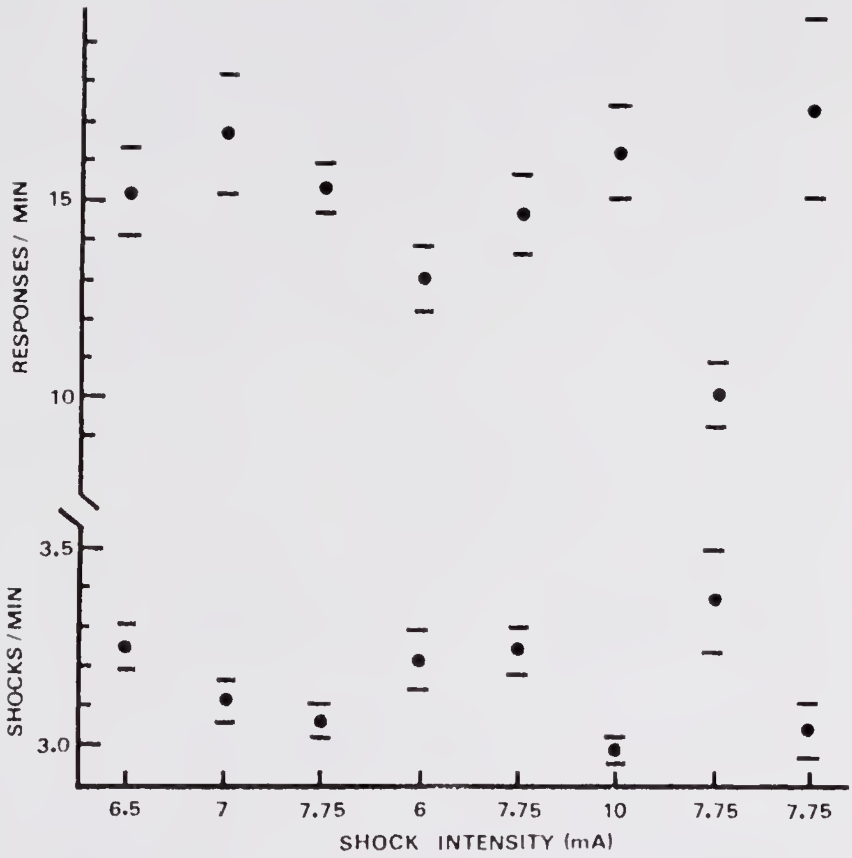


Fig. 25. Mean response and shock rates for the last 5 sessions under each shock intensity for Pigeon S. The heavy lines above and below each mean indicate plus and minus one standard deviation. The mean for the last 7.75 mA condition is based on the 3 sessions immediately preceding the death of Pigeon S.

7.75 mA produced no change in the shock rate whereas increasing shock intensity to 10 mA did decrease the shock rate. When Pigeon S was subjected to 7.75 mA, shock rates increased compared to the rate under 10 mA and the shock rate was higher than at either previous exposure to 7.75 mA. The last mean is the average of the last three sessions following a vacation from daily sessions and prior to Pigeon S's death. Shock rate fell to levels similar to those at the first exposure to 7.75 mA and the 10 mA condition. Whether this low average rate was the result of the vacation effect (Clay-Findley, 1971; Experiment I. of the present study) or of increased aversive properties of shock due to a pathology resulting in death at the end of the third session cannot be determined. What is clear is that the effects of changes in shock intensity upon shock rates under the Herrnstein and Hineline (1966) procedure may be partially irreversible. Initial exposures to increased intensities of 7.0, 7.75, and 10 mA produced decreased shock rates. Increasing the intensity from 6.0 to 7.75 mA (second exposure) did not and shock rates during the second exposure were higher than under the first. The third return to the 7.75 mA intensity followed exposure to 10 mA and produced the highest terminal shock rates of any of the shock intensity conditions. Thus, the three exposures to 7.75 mA produced successively greater mean shock rates each time, even though two of these changes followed conditions of lower shock intensity.

To further assess the effects of the probes conducted with Pigeon C at reduced shock intensity, the response and shock rates of the probe sessions were compared with the rates from the sessions immediately preceding and succeeding the probe. Again, the probe data from Session 131 were omitted from the comparison because of their unusual value. A t-test for correlated means was employed to test the hypothesis that the mean difference (2.02 responses per min) in the response rates of the immediately preceding sessions and the probe sessions was a chance occurrence. The hypothesis was rejected: $t(3) = 5.01$, $p > .05$. For the corresponding comparison of probe rates and those of immediately succeeding sessions the null hypothesis was again rejected: $t(3) = 5.69$, $p > .05$. The mean difference for the latter comparison was 1.56 responses per min. The comparisons of mean shock rate differences were not significant in either case.

Under the random shock procedure used in this experiment, the conditional probability distributions of a response following a response (IRT/Op) should be an essentially flat function because the only responses which effect a change in shock frequency are those immediately following a shock. Thus, except for the interval immediately after a shock, differential reinforcement of IRTs does not occur and responses should be distributed randomly. Herrnstein and Hineline (1966) found the predicted flat function with rats.

In Table 3 are shown the conditional probabilities of a response for two sec intervals for the average shock-free duration (20 sec) of the low probability shock program. Intervals with less than 20 responses were not computed because of the error associated with such small samples (Anger, 1956). An inspection of Table 3 shows that the conditional response probability was highest during the four sec after shock and equiprobable for the intervals beyond four sec for Pigeon S. Pigeon C showed a decreasing probability of responding from the second through the ninth 2 sec interval after a response. The high response probability at short IRTs was a result of the burst of responses which typically followed shock.

No effect of shock intensity upon the conditional probability of ineffective responses is evident for Pigeon S in Table 3. Some suggestion of such an effect for Pigeon C can be seen in the lack of responses at long IRTs for all sessions at shock intensities less than 10 mA and in the early sessions (77-80) following the change to 10 mA. This effect disappears with further training when shock rates are lower and

Table 3

Conditional Probability of Ineffective Responses

SESSIONS	LATENCY (sec)								
PIGEON C	2	4	6	8	10	12	14	16	18
21-24	.68	.53	.38	.36	.38	.43	-	-	-
34-37	.49	.44	.43	.45	.37	.45	.38	-	-
63-66	.60	.53	.45	.39	.34	.41	-	-	-
77-80	.64	.53	.49	.44	-	-	-	-	-
112-115	.54	.41	.37	.33	.27	.25	.27	.32	-
147-150	.56	.41	.39	.34	.25	.19	.21	.15	.28
177-180	.44	.38	.37	.36	.31	.27	.26	.16	.19
(probes) 119, 121, 141, 155	.59	.51	.48	.36	.26	.21	-	-	-
PIGEON S									
21-24	.41	.31	.27	.23	.22	.23	.24	.22	.17
53-56	.41	.32	.28	.22	.13	.15	.16	.19	.20
73-76	.42	.31	.25	.19	.16	.15	.17	.16	.17
96-100	.49	.32	.27	.22	.19	.22	.24	.25	.26
142-145	.46	.31	.23	.23	.18	.19	.23	.18	.21
161-164	.51	.30	.19	.15	.11	.15	.15	.14	.18

reappears in the probability distribution average of four probe sessions. Again, the data from the probe at Session 131 were not included because of the unusually large change in shock rate.

CHAPTER III

DISCUSSION

EXPERIMENT I.

The results of Experiment I extend the results of Smith and Keller (1970), Foree and LoLordo (1970), and Klein and Rilling (1972) by providing data on response and shock rates during both acquisition and maintenance of responding in pigeons under free-operant avoidance schedules. The present data are more comparable to those collected with rats because of two factors: session durations were more comparable and the important parameters of free-operant avoidance were held constant. Klein and Rilling (1972) presented data based on 28-min sessions and varied R-S intervals and shock intensities. Their response rate data were comparable to the functions obtained from rats when shock intensity and R-S interval durations are varied but their measure of shock rate was based on shocks delivered from the S-S interval only: this estimate of shock rate bears little relationship to the data presented in studies with rats (Leander, 1973 a; Powell, 1970; Sidman, 1962).

In the present experiment, shock rates were generally lower than those obtained at comparable parameters with rats, a finding which supports the original, preliminary data obtained by Smith and Keller (1970). Response rates were generally higher. Perhaps the response selected may influence these rates more than any species differences. According to the SSDR theory espoused by Bolles (1970), SSDR-compatible responses would be higher in the hierarchy of behaviors in the avoidance situation and hence more frequently emitted. The rapid reduction of shock frequency to asymptotic levels by both pigeons is consistent with the idea that treadle pressing is an SSDR (Bolles, 1970; Seligman, 1970). In general, however, the results of the present study should be taken as indicative of the performance of pigeons under certain conditions: the fruitlessness of precise comparisons of operant rates across species has been generally recognized.

The present study extends our knowledge of the course of acquisition of temporally-patterned responding in free-operant avoidance. No similar data for pigeons exist in the literature. The significant feature of the conditional probability data was the stability of the distributions across time and conditions. The shape of the conditional probability functions replicates the functions derived by Anger (1963) based on Sidman's (1953 a, b) data and are similar to those of Klein and Rilling's (1970) pigeons at later stages in training.

The rapid development (within 12 sessions) of the high conditional probabilities for responses with IRTs of more than 10 sec is a finding of the present experiment for which no comparable data have been published. It may well be that such rapid acquisition is peculiar to pigeons. Pigeons do show a reduced warm-up period (Klein and Rilling, 1972; Smith and Keller, 1970) compared to rats (Powell, 1970). Squirrel monkeys and macaques typically show little or no warm-up effects and the behavior of pigeons under shock avoidance schedules may be more comparable to primates than to rodents. On the other hand, the effects of vacation upon the response and shock rates of the pigeons in Experiment I were similar to those found for rats (Clay-Finley, 1971).

EXPERIMENT II.

The results of the random shock procedure with pigeons replicated the essential findings of Herrnstein and Hineline (1966). Responding was maintained when the only effect of a response was to reduce the average shock density rather than eliminate shock. For both pigeons, shock rates tended to be reduced to the lowest value permitted by the procedure, consistently for Pigeon S and eventually, after 80 sessions at 10 mA, for Pigeon C. The shock rates maintained by Pigeon S during his first exposure to 7.75 mA and during the 10 mA condition, and for Pigeon C at 10 mA during Sessions 140 through 166, compare favorably with shock rates of rats in the random shock procedure (Leander, 1973 a).Herrnstein and Hineline (1966) did not provide data on shock rate.

Response rates for both pigeons were consistently higher than those obtained from rats (Herrnstein and Hineline, 1966; Leander, 1973 a) and similar to the response rates observed in the first experiment. Increases in shock intensity produced increased response rates and decreased shock rates in both pigeons and some evidence was found that the initial exposure to a higher intensity had more of an effect than subsequent exposures. Partial irreversibility of effects is not an uncommon finding in studies using shock.

The variability in response rates observed in the present experiment was well within the percentage of variation shown by the two rats in Leander's (1973 a) study and approximately equal to the variations reported in Herrnstein and Hineline (1966). The range of variability in response rate which is attributable to the procedure itself is difficult to assess. Under random shock procedures, some effective responses are immediately followed by shock; in effect, some responses are punished. The relation of shock to response is random so the punishment probabilities vary in complex ways depending upon the latency of the response relative to shock, the points at which the two shock delivery programs are started by the experimenter and entered by the pigeon and the relative detectability of any shock rate reductions which occur. Since the procedure was devised to test the "mere possibility of obtaining avoidance" (Herrnstein and Hineline, 1966, p. 426) little parametric data on rate variability is not surprising. The data of Herrnstein and Hineline (1966), Leander (1973 a), and the present study suggest response rate variability is relatively large compared to other avoidance paradigms. The data on shock rates from Leander's (1973 a) rats and the pigeons in the present study indicate that minimum shock rates, determined by the program, are typically maintained under the random shock procedure and the consistent finding that conditional probabilities of responding are equiprobable for all but the time immediately after shock suggest that shock delivery is an effective discriminative stimulus for responding.

A second factor which may contribute to the variability of response rates under random shock procedures is the discriminability between average rates of shock delivery. Under conditions where the local shock frequency varies considerably, what magnitude of change in frequency can be detected by a pigeon? No direct answer appears to be available in the literature but the study of Schuster and Rachlin (1968) on indifference between free shock and punishment bears on the question.

Schuster and Rachlin (1968) exposed pigeons to a concurrent-chain schedule on which pecks on either of two lighted keys during the initial link produced, on a VI 2 min schedule, one of two conditions in the second link. Correlated with each key in the second link was a different schedule of shock delivery. On one key, each peck produced a brief shock (punishment) and on the other key, shocks were delivered at various intervals without regard for responses. Only one key at a time remained lit in the second link and responding was maintained by a VI 1 min schedule of grain delivery during the time either second link was in effect. The duration was 5 min for either the punished or free-shock link. In effect, the pigeon could choose which of the two second links he would enter by pecking one of the two keys during the first link. Once the second link was entered, the pigeon was forced to remain in the link for 5 min.

Schuster and Rachlin (1968) found that when shock frequencies were equal in the second links, pecks in the first link were evenly distributed between the two keys: they showed indifference to the contingent relationship of response and shock. Choice of the second link was dependent upon the frequency of shocks in the second link: pigeons consistently entered the second link which had the lower frequency of shock. The data from the four pigeons indicated that the relative rate of shock on the two second links of the chain must differ by 10-15% before one link was entered more often. This suggests that pigeons do not reliably discriminate between shock distributions unless the relative frequencies differ by more than 10%.

If the extrapolation from Schuster and Rachlin's (1968) data is sound, then for the pigeons in Experiment II, shock rates would have to vary by 10% or more before response rates would be affected. For a shock rate of 3.10 per min, a rate regularly attained by both pigeons in Experiment II, a change to a shock rate of 3.30 per min would be needed before a trend in response rates might be expected to occur. In the absence of such a change, little precise control over response rates under random shock procedures can be expected. Additional data on the discriminability of shock frequencies would be required before the amount of control over response rates by shock frequencies under the random shock procedure could be evaluated.

General Discussion

The question of the effects of electric shock upon generalized activity of the organism needs to be considered. Recent research findings have focussed attention upon the activating properties of the events which maintain behavior. For example, Staddon and

Simmelhag (1971) demonstrated that many species-typical behaviors occur with a high frequency in pigeons during the early parts of fixed and variable intervals of time which separated response-independent grain presentations. Behaviors which were related to the consummatory sequence were the behaviors most probable during the period just prior to grain delivery. Response-independent grain deliveries had the effect of further increasing those behaviors which preceeded grain presentation but those behaviors whose frequency increased were the behaviors initially produced by the grain delivery. Staddon and Simmelhag (1971) account for their results by suggesting that reinforcement, rather than strengthening responses, simply prevents responses which terminate the fixed interval from being shifted to an interim point in the response sequence. The importance of Staddon and Simmelhag's (1971) experiment and analysis is that they emphasize the interaction of elicited responses and responses which come under the control of response-contingent events. As they point out, the effects of response-dependent grain presentations using interval schedules of reinforcement may be primarily the determination of the location of pecking rather than its form or frequency of occurrence.

Schwartz (1977 a, 1977 b) has shown that the duration of key pecks by pigeons varies as a function of the stage of training under continuous reinforcement, as a function of the point at which they occur in a fixed interval or fixed ratio, and that long duration but not short duration pecks are suppressed by duration-dependent shock delivery. Long duration pecks appear to be operant, and short duration pecks appear to be respondent behaviors. Jenkins and Moore (1973) found that the topography of the pigeons' key pecks depended upon the kind of reinforcer used, food or water, and that pecks resembled the consummatory response associated with each reinforcer. These studies indicate that the nature of the operant selected as the response interacts with the kind of reinforcer as well as the schedule of reinforcement and that the response maintained by reinforcement is highly influenced by the character and form of responses elicited by reinforcer presentation.

Anyone who has ever arranged to deliver shock to a rat, pigeon or monkey and observed the results can testify to the eliciting properties of electric shock. The general effect is a dramatic increase in gross motor activity, often followed by species-typical attack behaviors (Hutchinson, Azrin, and Renfrew, 1968; Hutchinson, Renfrew, and Young, 1971). To the extent that such elicited behaviors produced reduced shock frequency, such behaviors, or behavior topographically similar or temporally contiguous, are "selected" (Staddon and Simmelhag, 1971) by reinforcement and increase in frequency.

Hutchinson, Renfrew, and Young (1971) demonstrated the functional relationship of shock intensity and intershock interval to the temporal patterning of biting in squirrel monkeys under response-independent, fixed-frequency shocks. Manual lever pressing and chain pulling were also shown to be produced by shock deliveries and occurred concurrently with bite responses. When biting responses avoided shocks under a signalled avoidance schedule, bite responses were easily conditioned in monkeys: when rats were presented with a situation in which attack responses or a different escape response could occur, they attacked and did not escape shock (Hutchinson, Azrin and Renfrew, 1968). Smith and Keller (1970) and Foree and LoLordo (1970) specifically mentioned the usefulness of a small chamber, a relatively large treadle and the shock-elicited activity in pigeons as important factors in the rapid acquisition of responding under free-operant avoidance schedules.

Such features of the apparatus undoubtedly contribute to the acquisition of avoidance, just as size of chamber affects behavior under DRL schedules (Skuban and Richardson, 1975) and the distance of the pigeon from the key during a trial affects responding under auto-shaping procedures (Barrera, 1974). Under the free-operant avoidance procedure in Experiment I, it is safe to assume that the contribution of shock-elicited behavior to the maintenance of avoidance behavior was minimal since after several sessions very few shocks were delivered. The course of acquisition is surely accelerated by the amount of locomotion induced by the delivery of shocks and the response burst patterns seen during the efficient avoidance behavior late in the conditioning sequence may well be determined by the original response patterns elicited by shock. Sidman (1958) discussed such possibilities and response bursts characterize much of the responding under shock avoidance schedules.

But what of the responding under schedules in which shock frequency is reduced but shock is not eliminated? In Experiment II, shock was fixed to occur at a minimum rate of 3 per min and the procedure dictated that responses following shock reduced the shock deliveries from 9 per min to 3 per min for some average period of time. How can operant and elicited behavior be distinguished under conditions of frequent shock and a response requirement which is highly compatible with the activity elicited by shock?

One possibility exists in the conditional probability distribution of ineffective responses shown in Table 3 of the previous section. If responses were merely shock-elicited, high response rates and low shock rates similar to those found in Experiment II would be expected but the distribution of IRTs might peak at very short intervals. Clearly, other than the 2-sec interval, such is not the pattern for Pigeon S, even under shock intensities which might be expected to maximize elicited activity. Casual observations of Pigeon S's treadle-pressing topography consistently revealed a marked similarity to the topography of the two pigeons in Experiment I., where shock-elicited behavior cannot be an explanation for responding after the initial sessions. For Pigeon C in Experiment II., the data are not as clear. Pigeon C was observed to engage in frequent bouts of bowing in the corner opposite the treadle and strutting back and forth along that opposite wall. These behaviors were noted most often during the first portion of the experiment and seemed to be less frequent during later stages. Figures 23 and 24 contain features which suggest that these casual observations may be correlated with the more effective shock-reduction performance displayed by Pigeon C beginning with Session 135. It is at approximately that time that the conditional probability distributions for Pigeon C indicate that responding was more frequent during longer periods following an effective response, as indicated by the greater number of IRT bins which contain 20 or more responses (Table 3).

However, such arguments can only be suggestive. Since the Herrnstein and Hineline (1966) procedure defines effective responses as those following a shock, shock-elicited behavior could be quite effective in reducing the number of shocks and efficient operant treadle pressing would also occur immediately after a shock. The conditional probability distributions may only show that shock-elicited behavior in pigeons following an effective response endures for the recording period used in Experiment II. Alternatively, it might be argued that the random shock procedure interacts with the nature of the avoidance response and the configuration of the chamber so as to negatively reinforce periods of activity rather than behavior selectively directed towards the treadle.

No resolution of these alternative explanations is possible from the data of Experiment II. The Herrnstein and Hineline (1966) procedure itself makes it difficult to untangle the relative contribution of shock-elicited behavior to either the acquisition or the maintenance of responding because the effective responses, if operant in origin, would occur immediately after shock, the only event reliably associated with a change from one shock program to the other. Shock-elicited responses would also occur at that time. The theoretical importance of Herrnstein and Hineline's (1966) procedure suggests that experiments directed at assessing the role of shock-elicited behavior should be carried out.

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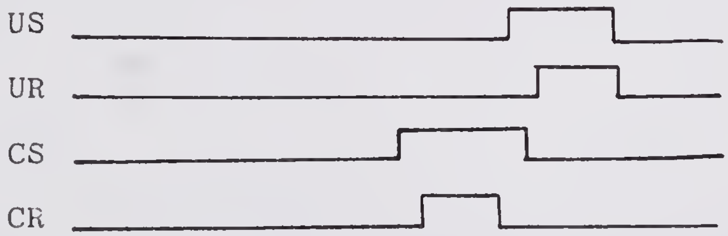
APPENDIX
BASIC PARADIGMS RELEVANT TO THE STUDY OF AVOIDANCE CONDITIONING

Pavlovian or Respondent Conditioning

The essential feature of respondent conditioning is the temporal relationship of the conditioned stimulus (CS) and the unconditioned stimulus (US). The CS is a stimulus which elicits no response, reflexive or otherwise, that is similar to the reflexive response produced by the US. The unconditioned response (UR) elicited by the US is glandular in nature and depends upon the characteristics of the nervous system of the organism being studied. The essential experimental manipulations of a respondent conditioning experiment are described by the time lines below. It is the temporal relationships between the CS and US which result in the gradual emergence of the adaptive response, the conditioned response (CR).



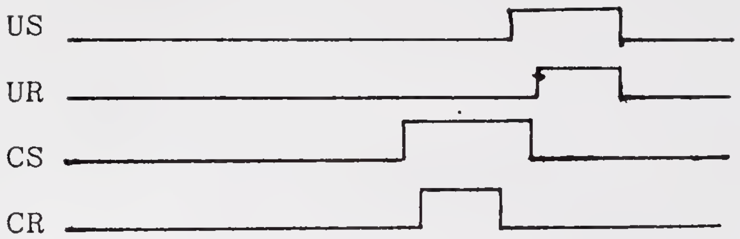
In the time lines above, and in all which follow, the indicated events are absent when the line is at its lowest extent and present for the periods when the line moves upward. Time proceeds from left to right; that is, events farther to the right occur later in time. In respondent conditioning, the US is presented and elicits the reflexive response. In Pavlov's experiments, the US was usually food powder or a dilute HCl acid solution and this stimulus elicited the UR of salivation. When the CS was presented shortly before the onset of the US, the appearance of the CR was evident within 5 to 10 pairings. The CR was similar in form to the UR, though not identical. Of course, in the case of salivation, only the response which occurred between the time the CS came on, and prior to the onset of the US, could be described as the CR. The important experimental manipulation is that, regardless of the presence or absence of the CR, the CS occurred on every trial: the animal's behavior did not determine the sequence of experimental stimuli.

Thorndikian or Instrumental Conditioning

In contrast to Pavlovian procedures, in Thorndike's paradigm, the behavior of the animal determined whether or not certain events would occur. The original demonstration of the law of effect entailed placing food-deprived cats in a small cage from which escape was possible if the door mechanism were activated: pulling a string, pushing a pole or depressing a pedal were some of the effective responses Thorndike used. Upon emitting the effective response, the deprived cat was released from the cage and allowed to eat a helping of fish outside the door of the cage. Time line comparisons to respondent procedures have little utility in comparing Thorndike's and Pavlov's procedures. The important relationship which distinguishes instrumental and respondent procedures is that, in instrumental conditioning, the animal's behavior is required in order to change the experimental conditions: a response must be emitted before release from confinement or feeding can occur.

Bekhterev's "Motor Conditioning" Procedure

Pavlov's contemporary attempted to extend the respondent conditioning procedure to motor responses and in so doing inadvertently invented the signalled avoidance procedure, an instrumental conditioning paradigm. As explained in the introduction, the procedural differences went unrecognized for some time and produced confusion regarding theoretical interpretations of avoidance learning. Bekhterev's procedure, as shown in the time lines below, bore strong similarities to the experimenter-controlled relationships of the true respondent conditioning paradigm.



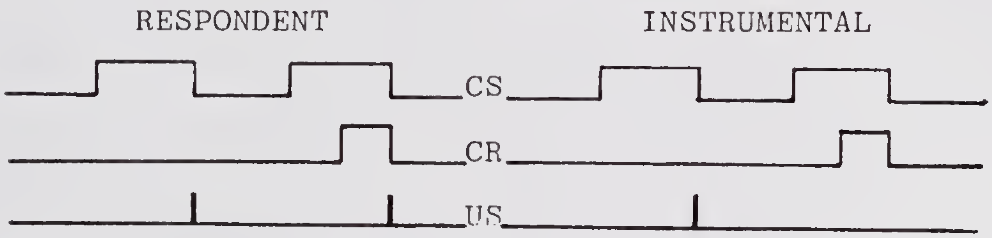
The US was electric shock to the paw of the dog and the UR consisted of leg flexion. Each shock was preceeded by some exteroceptive stimulus (CS) such as a bell or light and leg flexion soon occurred during the CS period and was considered the CR.

The paradigmatic confusion arose due to the fact that Bekhterev sometimes arranged to have the shock delivered via electrodes attached to the dog's paw and sometimes via a plate on which the dog rested its paw. In the second case, leg flexion was effective in preventing the shock from being received! In other words, the animal's behavior changed the sequence of experimental events, essentially the instrumental conditioning procedure. Since leg flexion occurred to the CS in either of Bekhterev's arrangements, the subtle nature of the differences was long unrecognized.

Bekhterev's second procedure was the signalled avoidance procedure: a pre-shock signal, often termed the CS, preceeded each shock and if a flexion response occurred during the pre-shock signal period the shock was not delivered to the dog's paw. That is, the shock could be avoided.

Brogden, Lipman, and Culler's Experiment Comparing the Respondent and Instrumental Paradigms

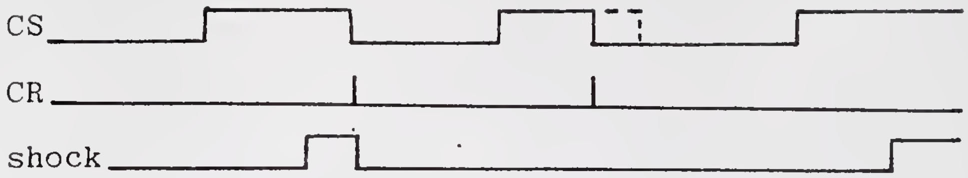
Brogden *et al*. compared the two paradigms using guinea pigs and a wheel turning response. The conditions are indicated by the time lines below:



In either case, the CS was a buzzer and the US was electric shock delivered to the guinea pigs' feet. The CR was a partial turn of the wheel. The only difference in the conditions was the effect of the response: in the respondent condition, the US occurred without regard to the presence or absence of the CR while in the instrumental condition, a CR during the CS period eliminated shock delivery. Under these conditions, wheel turning was acquired and maintained only by the instrumental group.

Two-factor Theory

Two-factor explanations of avoidance conditioning arose from the findings of Mowrer and his co-workers. The essential experimental conditions are shown in the time lines below.



Note that there are two contingencies under this procedure, an avoidance contingency and an escape contingency. If, as shown for the first CS presentation, the animal responds after shock comes on, the response terminates the CS and the shock. If the response occurs during the CS and prior to shock onset, the CS is escaped and the shock avoided. The last CS presentation in the time line indicates that, in the absence of responding, the CS and shock continue indefinitely.

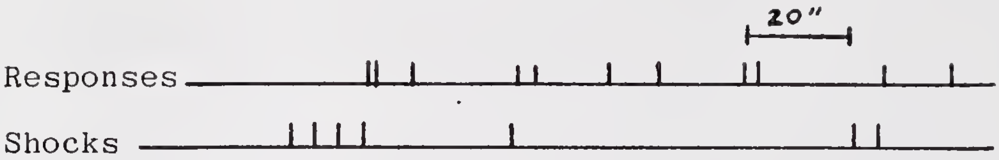
Two control conditions are essential to an understanding of the role of the response's consequences. To evaluate the contribution of the escape contingency to the learning of the avoidance response, two different responses were required, one which terminated the CS and prevented shock (avoidance) and a second, different response which terminated shock (escape). If the avoidance response was learned under these conditions, the escape contingency could be seen to be unnecessary for avoidance conditioning.

The second control condition consisted of allowing a response to terminate the CS but have no effect upon shock delivery. Under the experimental and dual response control conditions, animals learned to perform the avoidance response. The experimental condition was superior in facilitating the learning of the response. The second control condition, in which shock could not be avoided or escaped was relatively ineffective in producing acquisition of the response. Thus, the dual contingency condition was most effective for learning but the dual response condition could also support acquisition of new behaviors.

Based on these findings, two-factor theorists conceptualized avoidance conditioning as the result of respondent and instrumental factors. The assumption was that fear or anxiety is conditionable. Pairing the CS and shock results in fear being elicited by the CS and so responses which terminate the CS are instrumentally reinforced. The Pavlovian component is the pairing of CS and shock with the resulting "conditioned fear" response to the CS. The instrumental component is the avoidance or escape from the CS and/or the shock.

Sidman's Free-operant Avoidance Schedule

Sidman attempted to eliminate the CS in avoidance conditioning by providing no exteroceptive cues. Shock is programmed to occur at short intervals (S-S interval) in the absence of responding, as shown in the first part of the time line below.



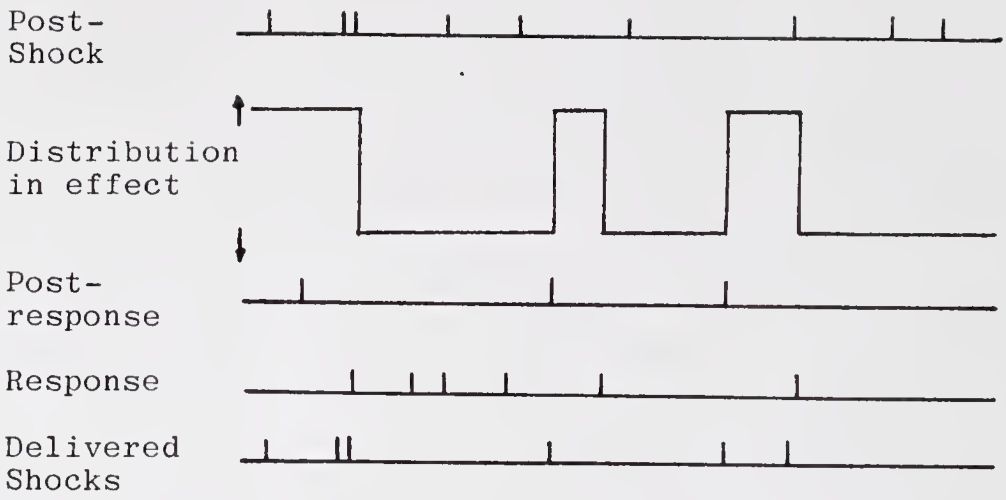
A response provides a shock-free period following the response and this interval is called the response-shock (R-S) interval. Shock-free time cannot be accumulated by multiple responses: shock is simply a fixed-time (the R-S interval) away from the last response.

Herrnstein and Hineline's Random Shock Procedure

Since Sidman's free-operant procedure did contain temporal regularities and since respondent conditioning is possible when the US is presented at fixed intervals without an exteroceptive CS, Herrnstein and Hineline designed their procedure to eliminate fixed relationships between the occurrence of shock and any other feature of the experimental situation. It is not a shock-avoidance procedure since a minimum shock frequency is dictated by the program. The most accurate description is to call the paradigm a shock-frequency reduction procedure.

Shock rate is reduced following a response and shock rate increases during periods of no responding following a delivered shock. The intervals at which shocks are programmed to occur are variable, rather than fixed, and the two shock distribution programs from which shocks are delivered are independent of all aspects of the animal's behavior. The only effect of a response is to determine which of the shock distributions, high-frequency or low-frequency, is in control of delivered shocks.

As can be seen in the time lines below, a response instates the low-probability shock distribution which remains in effect until a shock is delivered. At that time the high probability shock distribution is in effect and remains in effect until such time as a response occurs. Thus, responding can reduce the overall frequency of shocks to the minimum specified by the low-probability distribution and increase the average shock-free time. But responding does not avoid all shocks and shocks may occur immediately after any particular response, depending upon the point in the low-probability distribution at which the response occurred. Under this procedure, the difference in the probabilities of shock between the high and low shock distributions control response acquisition and rate. The characteristic of the organism required to behave with maximum shock-frequency reduction under this procedure is of a correlative, integrative nature.


Post-Shock
Distribution in effect
Post-response
Response
Delivered Shocks

BIOGRAPHICAL SKETCH

Dennis Brian Jowaisas was born April 12, 1939, in Brooklyn, New York. In October, 1952, his family moved to West Palm Beach, Florida, and in May, 1957, he was graduated from Saint Ann High School. From September, 1957, to December, 1959, he was a student at Georgetown University, Washington, D. C. After 22 months as a service technician for Burroughs Corporation he enlisted in the United States Army and served as an electronics technician until 1964. In January, 1965, he entered the University of Florida and graduated with honors in psychology in 1966. He was elected to Phi Beta Kappa in December, 1966.

He completed his Master's degree in psychology in 1969, and began work toward a doctoral degree in 1970. In September, 1972, he began teaching at Oklahoma City University, Oklahoma City, Oklahoma, and continues to do so at the present time. He is married to a University of Florida alumna, the former Marion Catherine Lewis. They have two sons, Brian and Christopher.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

E. F. Malagodi

E. F. Malagodi, Chairman
Associate Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Donald A Dewsbury

Donald A. Dewsbury
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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Marc Branch
Assistant Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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William Wolking
Professor of Education

This dissertation was submitted to the Graduate Faculty of the Department of Psychology in the College of Arts and Sciences and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

June, 1977

Dean, Graduate School