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TEMPORAL INFLUENCES ON THE PERCEPTION OF CAUSALITY IN PIGEONS

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TEMPORAL INFLUENCES ON THE PERCEPTION OF CAUSALITY IN PIGEONS

by

RICHARD G. VALENTE

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

1981

This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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Abstract

TEMPORAL INFLUENCES ON THE PERCEPTION OF CAUSALITY IN PIGEONS

by

Richard G. Valente

Adviser: Professor Brett K. Cole

When presented with a trial by trial, non-correction task in which reinforcement may be obtained by responding on one of two choice keys, seven pigeons learned to respond on the right choice key when a discriminative stimulus change event was contingent on their behavior, and on the left when the event was non-contingent. Though changes in the visual stimuli were identical (simultaneous offset of a center key light and onset of the side key lights), each event was distinguishable on the basis of its temporal relationship to the most recent response on the key located between the two choice keys. The non-contingent events could follow the center key responses by an amount of time greater than zero. This produced a distribution of times between the subject's last response on the center key and the stimulus change (the R-SC interval), limited by coincidence at one end, and the subject's interresponse time at the other. Each contingent stimulus change was temporally contiguous with a response. When a delay was introduced between the response and the contingent stimulus

change, a distribution of times preceding contingent stimulus changes was produced, limited by coincidence at one end, and the programmed value of the imposed delay at the other.

At each of the delay values tested (.5, 1, 2, and 4 sec.) each subject seemed to have a subjective criterion below which it usually responded on the right, and above which it chose left, even where the R-SC distributions overlapped. Within this range a stimulus change terminating an R-SC interval of any value was as likely to be contingent as non-contingent. Differences between subjects in both the value of the criterion, and in the amount the criterion shifted as the programmed delay was changed, were observed. Trends in the choice response patterns of all subjects suggested that their choice behavior was subject to perceptual influences. This indicates that interpretations which explain choice behavior primarily on the basis of the subjects' ability to discriminate time are inadequate.

In addition to response rate, percent correct, and bias, a measure was derived which allowed direct comparison of objective non-contingent and contingent distributions of R-SC intervals, preceding subjective left and right choices. This measure showed that, when faced with a choice based on the length of an R-SC interval that might have preceded either a non-contingent or a contingent stimulus change, the subjects tended to respond on the left-following longer R-SC intervals, and on the right following shorter ones, regardless of the objective source of the stimulus change. The subjects whose criteria shifted the most as the distributions of intervals changed in percent of overlap were the ones whose criteria were most variable. That is, the subjects who occasionally responded on the right following the longer intervals, and on the left following shorter ones, were the subjects most "in contact" with the shifts in contingency effected when programmed delay was increased.

Despite a multitude of strategies, it remains clear that all the subjects were dividing the distributions of R-SC intervals according to some criterion, and the more sensitive that criterion was to environmental changes, the more efficient the subject, as measured by overall percent correct. This is in agreement with Killeen's concluding statement in which he said, "Viewed in this light, flexible criteria for attribution of causality...are more adaptive than fixed criteria that cannot shift to optimize expected payoff (1978, p.89)."

The present study is an example of the contention of Killeen and others, that discriminative performance does not always reflect discriminative ability.

It may also be viewed as providing clear examples of Sidman's (1980) point regarding the validity of percent correct as a measure in the analyses of conditional discrimination tasks; with suggestions for measures to be used in conjunction with, or as alternatives to, percent correct.

This work is dedicated to Pamela, Alfredo, Miriam, Amanda and Eliza Valente for their unfailing love and support.

I gratefully acknowledge the contributions of all my professors and friends who helped make this work possible. My particular gratitude goes to my mentor, Dr. Brett Cole for his constant encouragement and guidance, Dr. Daniel Sussman for his inspiration and suggestions, and Dr. David Roll for his enthusiasm and friendship. Each was an integral part of this project from its inception.

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It has been said that humans and other organisms behave as if one event reliably following another implies a causal relationship between the two (Michotte, 1963). Unless we are taught otherwise, our perceptions regarding the causal nature of an event-relationship seem to be based on the immediacy with which the second event follows the first. Learning theorists call this relationship temporal contiguity (Underwood, 1949). Given no other information, the more contiguous the events, the more confidence we have in the causal nature of their relationship.

Empirically, the terms "caused" and "uncaused" may be related to the objective circumstances upon which that distinction depends (Michotte, 1963). The contingency of an event-relationship is determined by whether or not one event produces another event. In a contingent relationship the occurrence of the second event is dependent upon the occurrence of the first. In a non-contingent relationship the second event may occur regardless of whether or not the first occurred. This is to say that the occurrence of the first event, be it a stimulus event or a response event, is a necessary condition for the occurrence of the second event in a contingent event-relationship. In a non-contingent relationship between events the occurrence of one has no direct effect on, nor does it receive any effect from, the occurrence of the other. Defined in this way, response contingent and non-contingent events are examples of an objective distinction between caused and uncaused event-relationships. Contingent events can be made to immediately follow a response, while non-contingent events follow responses by an unspecified period of time.

If perception of causality, as reflected in the discrimination of contingent from non-contingent events, is controlled by the degree of temporal separation between the response and the succeeding event, then time may be the objective context for specifying both caused and uncaused events as contingent and non-contingent events. If causation in an event-relationship is perceived on the basis of contiguity in time, then parameters that alter the temporal separation of the responses from the contingent events (causes from effects) should alter the discrimination of contingent from non-contingent events. Therefore, one prominent parameter affecting the discrimination of contingent from non-contingent events is delay of contingent events, and an appropriate experiment would measure the discriminative performance of an animal in distinguishing delayed contingent from non-contingent events.

Causality and contiguity. That animals, including man, perceive causality primarily on the basis of contiguity is an assumption almost universal among experimental analysts of behavior (cf. Wallace's discussion of determinism, 1972). There have been few instances with evidence to the contrary (e.g., Garcia, Kimeldorf and Koelling, 1968; Smith and Roll, 1967); however, the fact that the relationship between behavior and its consequences occasionally seems to transcend the usual temporal boundaries suggests that some logical connection between the two events was made in the absence of direct temporal contiguity, and/or, that some additional, unspecified property of the stimulus or the organism is in control.

Despite the apparent exceptions, temporal contiguity seems to be a primary determinant in the perception of causal relationships in conventional operant situations. The evidence regarding the control of responding by a reinforcer following the response has shown that effective control declines rapidly as the temporal distance from the response to its subsequent reinforcer increases (cf. Dews, 1970; Catania, 1979).

One may infer that animals perceive causality because of the way they behave: If they behave differentially in the presence of stimuli which precede different types of events we may infer that relationships between their behavior and its causes and/or its effects are determining behavior. Killeen (1978) put it, "...the nature of learning has evolved to keep animals en rapport with the causal structure of their environments (p. 88)". The Law of Effect literature clearly shows that organisms behave as though there is a relationship between such contiguous events as a response that is followed by a reinforcer, by repeatedly demonstrating that control over specific responses may be manipulated as temporal distance between the response and the controlling stimulus varies (cf. Lachter, 1971). It is also clear from studies using partial reinforcement, that the stimulus need not follow every response in order for behavior to be affected.

Skinner (1948), in a persuasive, logical account backed by experimental evidence, argued that contiguity alone was both necessary and sufficient in maintaining behavior, even though the exact form of the behavior may elude prediction. That is, contiguity exerts greater control in determining whether or not sequential events are perceived to be causally related than does actual contingency. This may be due to the fact that information about the contiguity of events is often the most obvious, if not the only, basis upon which to judge the causal nature of a relationship. Herrnstein (1966) said that an occasional occurrence of at least approximate temporal contiguity between a response and a reinforcer was both sufficient and necessary for superstitious responding to be conditioned.

Contingency and temporal discrimination. In an ingenious application of Skinner's (1948) superstition findings, Killeen had four pigeons discriminating events that occurred as a result of their own behavior from stimulus events that were independent of their behavior. His subjects pecked the illuminated center key in a standard three-key situation. Virtually simultaneously, a computer was generating pulses at the same rate as the pigeon was responding. Each subject-generated peck and each computer-generated peck had an a priori .05 probability of causing the center key to darken, and the side keys to light up. The pigeon was then required to peck one of the side keys. If the stimulus change event (SC) was the result of the subject's last response on the center key, then a peck on the right was reinforced. If the SC was computer-generated, a peck on the left was reinforced. Pecks on the wrong side key produced a brief blackout. The end of the blackout or reinforcement period was immediately followed by the illumination of the center key again. Killeen concluded that his "...data indicate that pigeons are accurate in their perception of contingencies between behavior and environment, and that the discrimination...was probably based on the delay between the response and its effects (1978, p. 89)".

Presumably, Killeen was using Skinner's 1948 definition of contingency which was synonomous with contiguity. Schoenfeld, Cole, Lang, and Mankoff (1973) have argued that a contingent relationship exists whenever changes in the distribution of stimuli are determined by changes in the distribution of responses. This is strictly true for both the "contingent" and "non-contingent" SCs in Killeen's experiment but the strength of his findings are not jeopardized by that distinction. The probabilistic source of the non-contingent SCs, although ultimately affected by the subject's behavior, served the practical purpose of allowing the experimenter to control the relative production of contingent and non-contingent SCs. His investigation concerned the effect that motivational variables may have on choices made subsequent to judgment of the causal source of the stimulus change event. The parameter manipulated was the relative amount of reinforcement made available for being correct on one side or the other.

The discriminanda were temporal intervals prior to the subject's choice responses. His animals were obliged to detect contingency by discriminating the immediacy with which the SC followed their last response on the center key. If any delay was detected they were to report on the left key, signifying that they perceived the change to be non-contingent. Killeen reasoned that "...the putative existence of superstitions suggest a gross breakdown in an organism's ability to detect causality (p. 88)"; and, further, that this ability is modifiable, depending on the circumstances under which it is brought about. By manipulating the relative amount of reward for reporting on one side key *versus* the other, Killeen was able to affect his subjects' tendency to respond toward one choice key or the other. This was especially true when the SC immediately, or almost immediately, followed a response on the center key. These changes in the distribution of the subjects' responses were interpreted as changes in their criteria for attributing a causal nature to the relationship between their responses and the succeeding SCs.

In the present study the goal was similar. Whereas Killeen chose a dimension purportedly reflecting changes in his subjects' level of motivation, the present procedure was an attempt to affect directly our subjects' judgments regarding the source of the SCs by manipulating the amount of time from the contingent responses to the SCs they produced.

An experimental situation similar to Killeen's was arranged so as to present cues about the contingent or non-contingent nature of a stimulus event via the length of time which preceded it. These temporal cues served as discriminative stimuli signalling the source of each succeeding SC. Immediate SCs reliably signalled that the event was caused by the subject's last response, and a delay of any length between his last response and the SC signified that the change was not caused by him.

The distribution of possible times from the subject's last center key peck to a non-contingent SC ranged from virtually zero to a value approaching 20 sec. The time from the subject's last center key peck to a contingent SC constituted the limiting case of that range. The SC was immediate. The subject who was placing his choice responses according to the length of the interval between his last response and the SC (the R-SC interval), was limited only by his ability to discriminate immediate SCs from all others. In subsequent phases of the experiment shorter time intervals were no longer reliable in identifying contingent stimulus events. A short delay between the response and the SC became just as likely to precede a contingent event as a non-contingent event.

Abolishment. Skinner (1938) described a procedure for eliminating discriminative behavior that is the logical opposite of extinction. Rather than terminating reinforcement for responding in the presence of a stimulus that had previously been associated with reinforcement as in extinction, reinforcement is made equally available in the presence of both the previously reinforced and the previously extinguished stimuli. The distinguishing features of the consequences for responding differentially are thereby removed, resulting in the restoration of responding to the stimulus previously present only during extinction, and the _abolishment_ of the discrimination (see also Keller and Schoenfeld, 1950).

Extinction is commonly conceptualized as being the limiting case along a continuum of relative reinforcement operations associated with two stimuli. This fact is evident in theoretical discussions of concurrent scheduling parameters, intermittent reinforcement, and other widely researched areas of conditioning. Abolishment may be logically conceptualized as the limiting case at the other end of the same continuum.

Abolishment as an operation differs from extinction in that extinction may be applied in the presence of one or more selected stimuli, while abolishment implies an equalization of reinforcement contingencies among stimuli. Honig's pseudodiscrimination procedure (1965;1969) is virtually identical to the abolishment procedure. Rather than abolish a discrimination, however, Honig's procedure provided equal reinforcement to naive pigeons for responding in the presence of either of two stimuli. The resulting behavior was then compared to that of subjects who were differentially reinforced in the presence of the same two stimuli.

In the Pavlovian paradigm called experimental neurosis (Pavlov, 1927) two easily discriminable stimuli are made gradually more similar. The discriminative properties of the stimuli themselves are systematically removed, resulting in the functional decrease of discriminative behavior. The term "experimental neurosis" happens to emphasize the behavioral result of a situation that can be brought about through many different operations. It does not seem inappropriate to extend the referents of Skinner's term by producing the outcome of abolishment with operations other than just those that change the consequences of responding in the presence of the previously extinguished stimulus. In the present study the term <u>abolishment</u> shall refer to the systematic elimination of the discriminative properties of some of the stimuli and their associated consequences which distinguish contingent from non-contingent SCs.

The operation of abolishment was accomplished through the manipulation of the programmed delay from the contingent response to the contingent SC. This extended the range of possible values of R-SC intervals preceding contingent SCs. The programmed delay values were 0, .5, 1, 2, and 4 sec. The portion of the distribution of R-SC intervals in which R-SC intervals preceding contingent SCs overlapped the distribution of R-SC intervals preceding non-contingent SCs we call the range of abolishment. Creation of this range of abolishment introduced a delay between the subject's effective response (the one that produced the contingent SC) and the SC itself, obscuring the temporal cues distinguishing contingent from non-contingent SCs. Since it was possible for responses to occur after the effective response and prior to the SC, the R-SC interval was informative about the cause of the SC only when it exceeded the length of the programmed delay.

These longer R-SC intervals reliably preceded non-contingent SCs. Any R-SC interval less than or equal to the programmed delay was uninformative. The cues signifying contingent, or caused, events (originally followed by the immediate occurrence of the effect) and the cues signifying non-contingent, or uncaused, events (previously distinguishable by an amount of time greater than zero between a response and an ensuing event) were partially, systematically, abolished. Some of the non-contingent events were rendered indistinguishable from the contingent events.

The abolishment of the discriminative temporal properties of R-SC intervals that fell short of the programmed delay was effected without disturbing the contingent or non-contingent source of the SCs. As the range of abolishment was increased, choice responses on the right (contingent) side key were reinforced following longer R-SC intervals. This manipulation was expected to reveal corresponding changes in the subject's ability to discriminate contingent from non-contingent SCs, and should yield changes in the way the subject distributed its choice responses on the left or right key in regard to the R-SC interval length. As the subject experienced more trials in which R-SC intervals greater than zero were followed by reinforced right side key responses, his temporal criteria for voting "caused" *versus* "uncaused" should shift. Specifically, it was expected that responses would be made on the right following longer R-SC intervals as the programmed delay for contingent SCs was increased.

Within the realm of human experience we often encounter situations in which the attribution of causality is, at best, probabilistic in both the prediction and the _a posteriori_ explanation of event-relationships. People act upon hypotheses about outcomes or causes of events often with less than complete confidence, and the degree of confidence may be affected by the amount of time between the perceived cause and its effect. In the present study the temporal intervals (prior to contingent SCs only) were extended while the programmed payoff for being correct on either choice key remained equal and invariant throughout the experiment. Therefore, the subjects were required to discriminate differences in the events preceding their choice responses without consideration of the additional differences imposed by manipulations of payoff (as required of Killeen's subjects) and/or the relative ratio of contingent to non-contingent SCs (as required of subjects in an experiment of similar design reported by Benassi, Lanson, Shipley and Wilder, 1976).

In summary, the purposes of this study were (a) to relate the perception of causality to objective temporal parameters, (b) to examine the effects of manipulating the delay between the contingent response and the resulting SC, and (c) to develop a procedure whereby contingency and non-contingency can be studied with the number of contingent and non-contingent trials equated.

METHOD

Subjects. Eight female White Carneaux pigeons, five to seven years old at the beginning of the experiment, served as subjects. They were obtained from the Palmetto Pigeon Plant in Sumter, South Carolina, and weighed between 530 and 735 grams. All were experimentally naive. Each was housed individually in a wire mesh cage and given free access to grit and water when not in the experimental chamber.

Ad libitum weight was determined by monitoring each bird's weight for approximately one month prior to deprivation and calculating the mean. Then each bird was reduced to 80% of that mean by one week prior to shaping and maintained at 80% (±5%) from then on.

Apparatus. A standard three-key Lehigh Valley Electronics operant conditioning chamber, model 1519C, was used. The circular keys were 2.5cm in diameter, 3.8cm apart, and 23.8cm from the mesh floor, and were capable of being transilluminated with white, red, or green light. Each key required a minimum force of approximately 0.12 N to activate the microswitch behind it. Mixed grain was provided from a hopper 6cm wide and 4.8cm high, located 10cm from the chamber floor. This grain was available only during the 2.5 sec. reinforcement periods during which time the hopper was illuminated from within. An overhead houselight was on throughout each experimental session except during the 2.5 sec. blackout periods. A fan provided ventilation and some masking noise. Experimental conditions were programmed by BRS (Digi-Bit) solid state circuitry, a precision clock (BRS MV-4S), and a probability generator (BRS PP1). Data were recorded on Sodeco counters and parallel input printers.

Procedure. Magazine training and shaping, using the method of successive approximations, were accomplished for all subjects within five one-hour sessions. Each subject received 100 regular reinforcements for pecking the center key. This key was transilluminated with a white light which went out during the delivery of the reinforcer. The two side keys remained darkened and inoperative during shaping.

On Sessions 1 through 43 following shaping, pecking on the center key an average of 20 times would complete the first component of the forward chaining procedure that was in effect for the remainder of the experiment. During this component the center key was white and the side keys darkened. Upon completion of the first component the terminal component of the chain began consisting of a SC in which the center key became dark and inoperative as the side keys were lighted. The left side key was transilluminated with a red light and the right side key with a green light for Birds 301, 302, 303, and 304; for

Birds 305, 306, 307, and 308 red was on the right and green on the left.

Concurrent with the random ratio (RR) 20 schedule on the center key during the first component was a "non-contingent" random time schedule producing SCs at approximately the same frequency as the subject-produced SCs. Thus, the actual ratio of responses to SCs was, on the average, ten to one. This was accomplished using an independent, 10 sec. cycle in which the subject's responses served an additional function. As well as causing SCs according to the RR20 schedule, each response was incrementing the probability of the occurrence of future non-contingent SCs. Responses were accumulated separately in each 10 sec. segment of the repeating cycle. The number of responses in each 10 sec. segment were then entered into a probability gate (BRS PP-1) which gated approximately the same number of "machine-produced responses" and distributed them randomly through the succeeding 10 sec. segment.

In other words, as the subject responded during 10 sec. segment N, each of its responses would have an *a priori* probability of .05 of causing a SC in segment N. Simultaneously, these responses were being stored for the probability gate that gated independent clock-generated pulses for the concurrent non-contingent schedule. At the beginning of segment N+1 the probability gate began allowing pulses through at irregular intervals. By the end of segment N+1 approximately the same number of these independently generated pulses would have occurred as had responses in segment N, each of which had the same _a priori_ probability of .05 of causing a SC. The number of subject-produced responses occurring in segment N+1 then determined the number of machine-produced pulses in segment N+2. Therefore, the distribution of machine-produced SCs was of equal stimulus change density to the distribution of subject-produced SCs across each session. And, SCs were produced with equal probability by either the pigeon or the machine across trials.

The subject's task, when a SC occurred, was to respond on one of the side keys. If the SC was machine-produced, a response on the left key was reinforced with 2.5 sec. access to grain. A response on the right-side key was reinforced for a subject-produced change. Incorrect responses, that is, to the left following a contingent SC, or to the right following a non-contingent SC, caused a 2.5 sec. blackout. During the blackout period the houselight went off as did all key lights. Following blackout the houselight and center key light came on simultaneously. During reinforcement the houselight remained on and the key lights went off. The center key light came on as reinforcement ended. During the first 1.5 sec. following reinforcement or blackout, reponses on the center key were unable to produce a SC but were counted. Non-contingent SCs were also prevented during the first 1.5 sec. of each trial. The reason for this restriction was the same as the rationale elaborated by Herrnstein in his description of the change-over delay procedure (1961).

Each session was terminated following the delivery of 30 reinforcements.

On Session 44 the random ratio requirement on the center key was changed to RR50; actually 25 responses to one SC, on the average, since the machine produced 50% of the SCs. It remained at that value throughout the rest of the experiment.

One pigeon, Bird 303, stopped responding after 76 sessions. Data for this bird were not included in any of the analyses because it was not exposed to any manipulation of the independent variable.

The independent variable in this experiment was the programmed delay of the contingent SC. That is, the time from the response of the subject which produced the SC to the actual SC. Therefore, only contingent SCs were directly manipulated. The SC was programmed to occur immediately following the effective response in Sessions 1 through 120. Thereafter, a series of 30-session blocks was run in which the programmed delay was increased systematically through the sequence .5 sec., 1 sec., 2 sec., and 4 sec., thereby increasing the time from the occurrence of the effective response to its resulting SC. The 0-delay condition was reinstated for 10 sessions following each 30-session block, and for the final 30 sessions of the experiment (see Table 1). All 300 sessions were run on consecutive days except for occasional one or two day interruptions. Responses that occurred between the response that produced the SC and the change itself had no consequences other than advancing counters, and the center key remained illuminated until the .5, 1, 2. or 4 sec. programmed delay terminated in the various delay conditions.

Delay data were collected in .199 sec. bins. That is, a SC following a response by .199 sec. or less was recorded in bin 1. A delay of .200 sec. to .399 sec. was recorded in bin 2, etc. There were 27 bins allowing for the collection of empirical R-SC intervals in .199 sec. bins up to 5 sec. The last bin counted any R-SC intervals greater than 5 sec.

The procedure produced occasional non-contingent SCs during the post-reinforcement pause or post-blackout periods without a response having occurred on the center key. Since there were no empirical R-SC intervals on these trials, they were excluded from the data analysis of those intervals. They were, however, included in the rate analyses.

Table 1

SEQUENCE OF PROGRAMMED DELAY CONDITIONS ACROSS SESSIONS

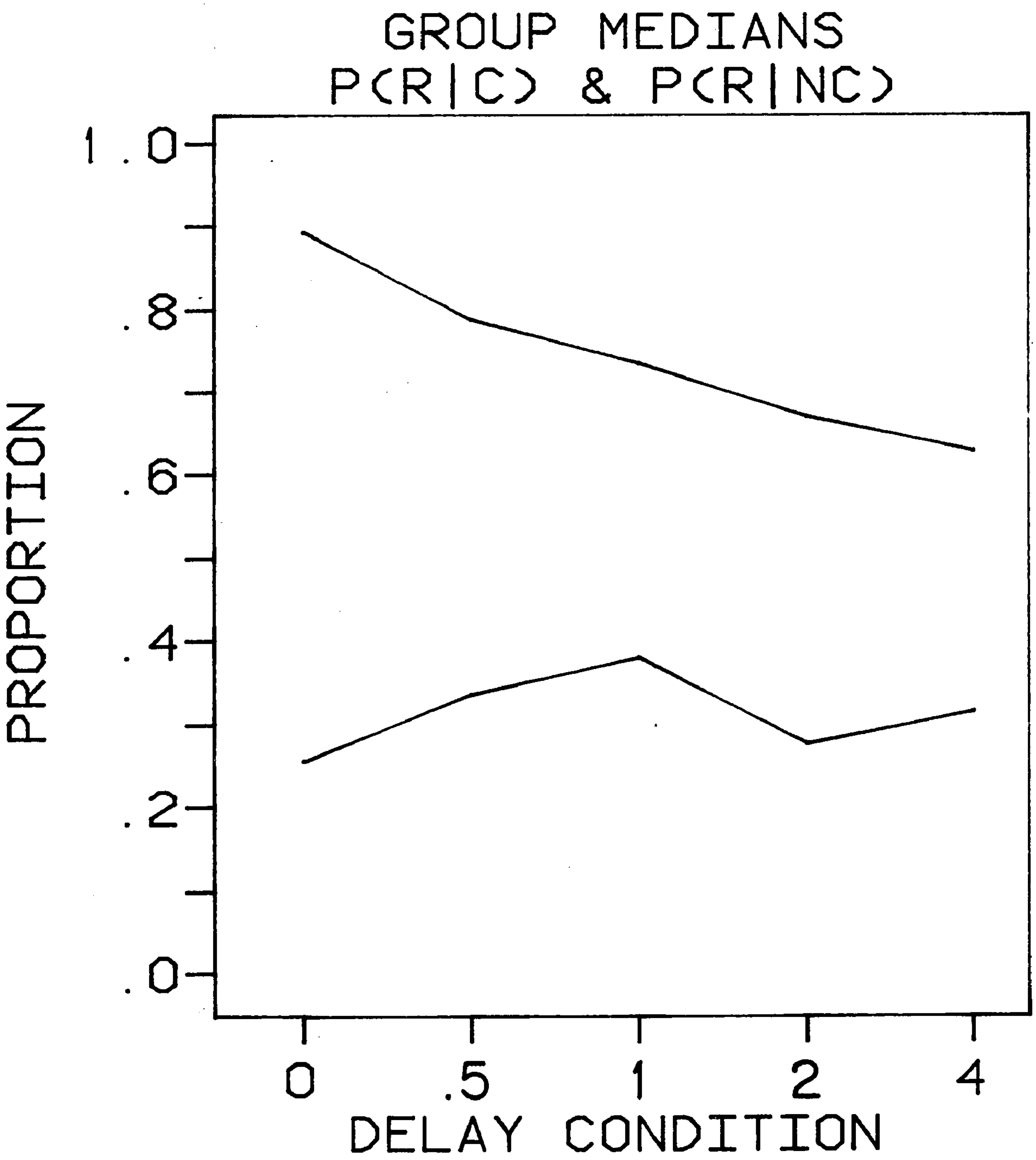
Sessions	Programmed Delay
1 through 120	no delay
(change RR20 to RR50 on Session 44)	
121 through 150	.5 sec.
151 through 160	no delay
161 through 190	1 sec.
191 through 200	no delay
201 through 230	2 sec.
231 through 240	no delay
241 through 270	4 sec.
271 through 300	no delay

RESULTS AND DISCUSSION

Two measures most common in conditional discrimination analyses such as this one have been the probability of responding on the right side key, for example, and being correct, and the probability of responding on that same side and being incorrect. These measures are known, respectively, as hits and false alarms in the parlance of signal detection theory (Green and Swets, 1966). The corresponding measures on the opposite side, left for example, are called correct rejections and misses. The designation of which side is to be labelled "hits" and "false alarms" and which is to be "correct rejections" and "misses" would, in the present case, be arbitrary. In order to avoid ambiguity, the following convention will be used to refer to each of the four possible situations: A response on the right side key following a contingent SC is designated as R|C (meaning, Right key response following a Contingent SC). A response on the right following a non-contingent SC is R|NC. A (reinforced) response on the left side key following a non-contingent SC is L|NC (meaning Left key response following a Non-Contingent SC), and a left response following a contingent SC is L|C.

The upper function in Figure 1 shows the proportion of (correct) responses on the right side key following a contingent SC: P(R|C). The lower function shows P(R|NC),

Figure 1. Proportion of right-side key responses following contingent SCs (upper function), and proportion of right-side key responses following non-contingent SCs. Each point represents the group median of each subject's mean performance.

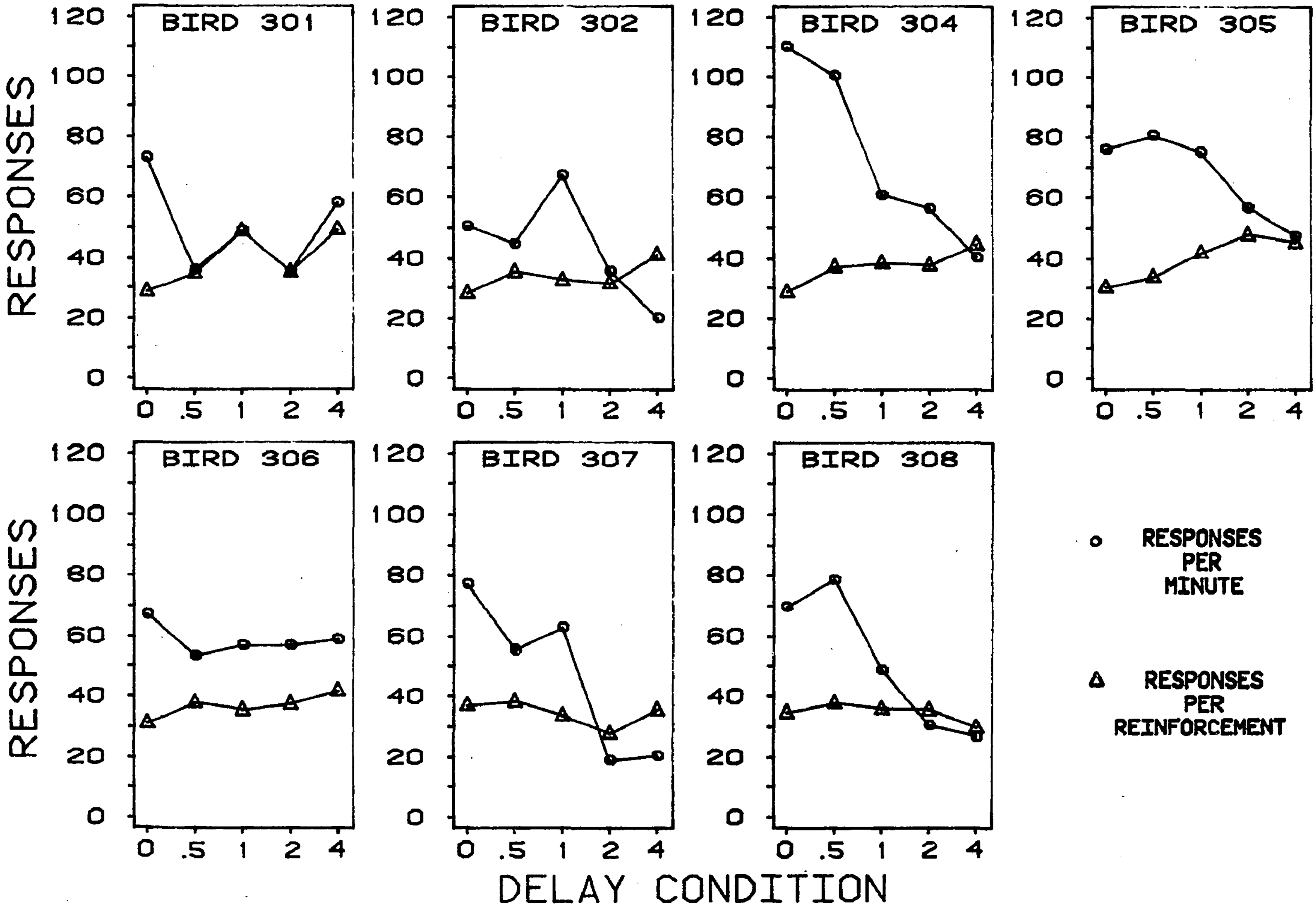

GROUP MEDIANS
P(R|C) & P(R|NC)
1.0
.8
.6
.4
.2
.0
PROPORTION
0
.5
1
2
4
DELAY CONDITION

which is the proportion of incorrect responses on the right side key. Each data point represents the group median of the individual bird mean performance for the last five sessions of each delay condition. (All subsequent data in this report are from the last five sessions of each condition except where otherwise specified.) Group data are presented here to illustrate a general tendency shown across subjects in response to the independent variable manipulation. Generally, as the programmed delay from the effective response on the center key to the contingent SC was increased the proportion of correct responses decreased.

The circles in Figure 2 show each subject's rate of responding on the center key for each condition. These rates were calculated by dividing the number of responses in each sample by the number of minutes that the white center key light was on. Generally, rates decreased as programmed delay increased.

The proportion of trials in which the subject was correct (accurate) in judging the occurrence of immediate *versus* delayed stimulus changes was determined by dividing the number of reinforced trials by the total number of trials for blocks of five consecutive sessions. When the subjects' accuracy began to consistently exceed 75% it was taken as an arbitrary indication that they were learning the contingencies of the task (see Sidman's discussion of conditional discrimination analysis, 1980). All subjects

Figure 2. Each subject's mean number of responses per minute (circles), and mean number of responses per reinforcement (triangles) at each programmed delay condition.


BIRD 301
BIRD 302
BIRD 304
BIRD 305
BIRD 306
BIRD 307
BIRD 308
RESPONSES
0
20
40
60
80
100
120
0
.5
1
2
4
DELAY CONDITION
○ RESPONSES PER MINUTE
△ RESPONSES PER REINFORCEMENT

were correct on more than 75% of the trials for two successive determinations of accuracy by Session 78. The earliest bird to pass the 75% level, Bird 306, did so by Session 33, and the last was Bird 308. Only minor disruptions occurred when the random ratio requirement on the center key was changed from RR20 to RR50 on Session 44. This change was implemented when it was thought desirable to lower the subjects' rates of responding on the center key. Killeen (1978) used a RR20 schedule on the center key and found that, "Most of the false alarms occurred within 0.5 ... to 2.0 ... seconds of a response (p. 89, 1978)". It was reasoned that lower rates would produce longer R-SC intervals. These would be more easily discriminable, and this would be reflected in the subjects' accuracy. The left-most circles in Figure 3 show that three birds, 301, 302, and 305 were correct on more than 85% of the trials, while Bird 307 was about 76% accurate in the first 0-delay condition. The remaining three averaged around 80% as did Killeen's (1978) birds. Although the change in the random ratio requirement did not appreciably change overall accuracy, the subjects' false alarm rates, i.e., P(R|NC), occurred within a much smaller range of empirical delay values than did those of Killeen's birds. From 65% (Bird 308) to 100% (Birds 301 and 304) of all R|NC responses were made following delays of less than .5 sec. during the first 0-delay condition.

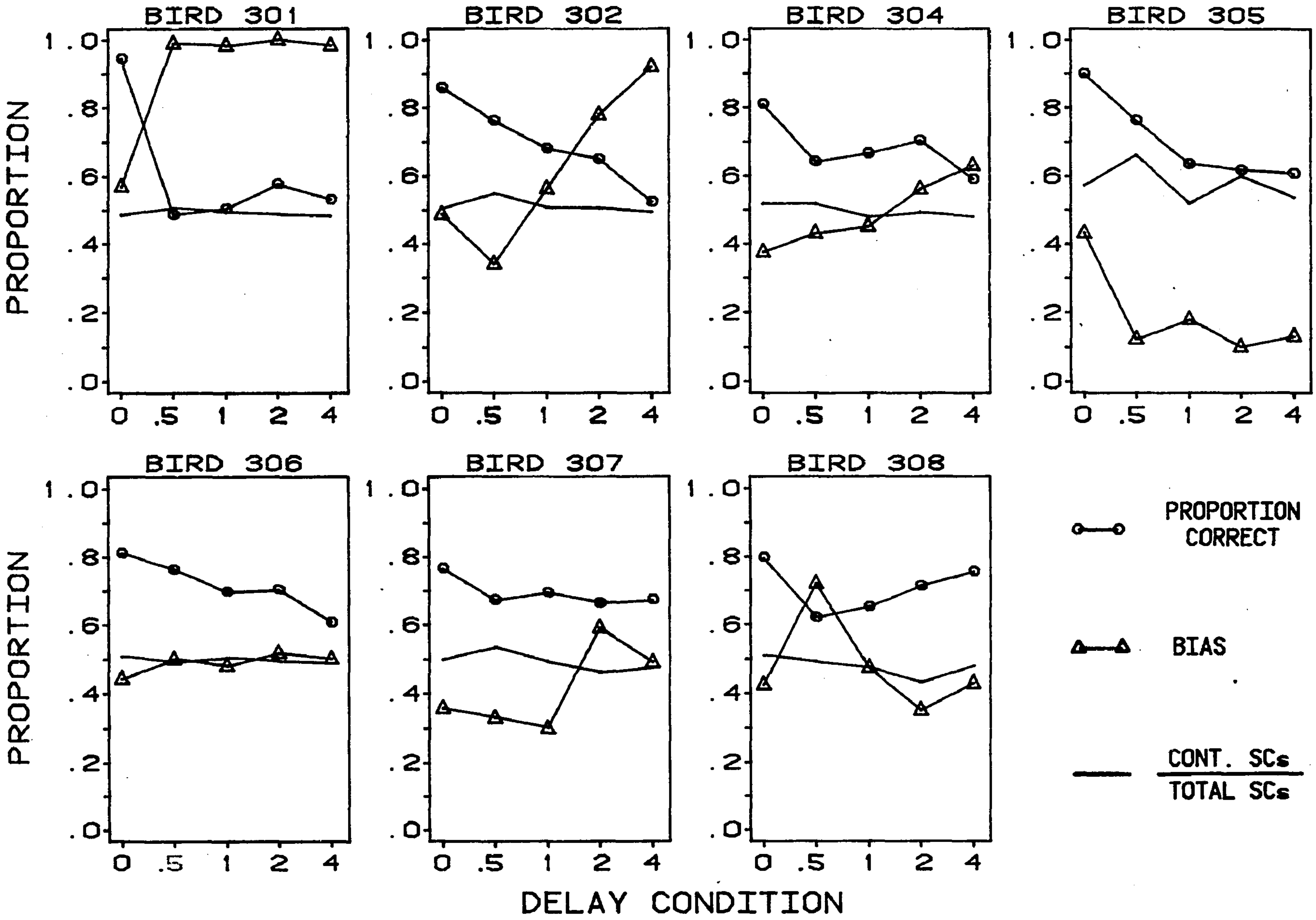
The triangles in Figure 3 show the degree to which the subject weighted its choice responses to one side. A value of .50 on the ordinate indicates that the subject had distributed its choices equally to either side key. A value of 1.00 shows that all choice responses were on the left side key and none on the right.

Although the titrating nature of the schedule allowed frequent and periodic correction for imbalance of contingencies so that reinforcement remained equally likely on either side over the course of a session, the trial by trial production of contingent and non-contingent SCs was truly random, and did not achieve a 50-50 split in every session. An even split was, however, approximated over sessions and within conditions. The actual contingent SC to total SC ratios, averaged across all trials in each condition, fall on the unmarked line in Figure 3.

The number of trials per session ranged from 30 to 105 across all conditions. Both extremes occurred during the 0-delay recovery sessions following the 4 sec. delay condition. Bird 302 was correct on every trial on Session 297, and Bird 307 responded through 105 trials before accumulating 30 reinforcements on the first 0-delay session following the 4 sec. delay condition (Session 271). Also, Bird 301 was correct on every trial on Session 118.

The number of trials in which the SC occurred before the subject had begun responding ranged from zero to six in a session with a median of less than 1.5. The proportion

Figure 3. Proportion of correct side key responses (circles), proportion of responses on the left side key (triangles), and proportion of contingent SCs at each programmed delay condition.


BIRD 301
BIRD 302
BIRD 304
BIRD 305
BIRD 306
BIRD 307
BIRD 308
PROPORTION
PROPORTION
1.0
.8
.6
.4
.2
.0
0
.5
1
2
4
DELAY CONDITION
PROPORTION CORRECT
BIAS
CONT. SCs / TOTAL SCs

of correct responses on these trials was no different from trials in which the SC followed responding on the center key.

The most general conclusion of this study was that pigeons were accurate in discriminating caused from uncaused events only when caused events were reliably cued by the immediacy of the SC. The relative proportion of contingent to non-contingent SCs was not affected by the introduction of a delay between the effective contingent response and its subsequent SC. The only changes that occurred were along temporal dimensions that had no bearing on the source of the SCs. The fact that percent correct, response rates, and biases varied as a function of programmed delay was taken as evidence that the subjects were discriminating causality on the basis of contiguity.

The R-SC interval. Figures 4 through 8 show the distributions of empirical R-SC intervals at 0 sec., .5 sec., 1 sec., 2 sec., and 4 sec. points for each delay condition. The distributions are expressed as cumulative proportions to facilitate their comparison across conditions. This conversion preserves important topographical characteristics of distributions with different Ns. All functions ultimately reach a value of 1.0 on the ordinates. In all but the 0-delay condition (Figure 4) 1.0 was attained beyond the 4 sec. limits of the figure. The vertical dashed lines in Figures 5 through 8

Figure 4. Cumulative proportion of R-SC intervals at 0, .5, 1, 2, and 4 sec. during the 0-delay condition. Each point shows the group median and range of subject means.

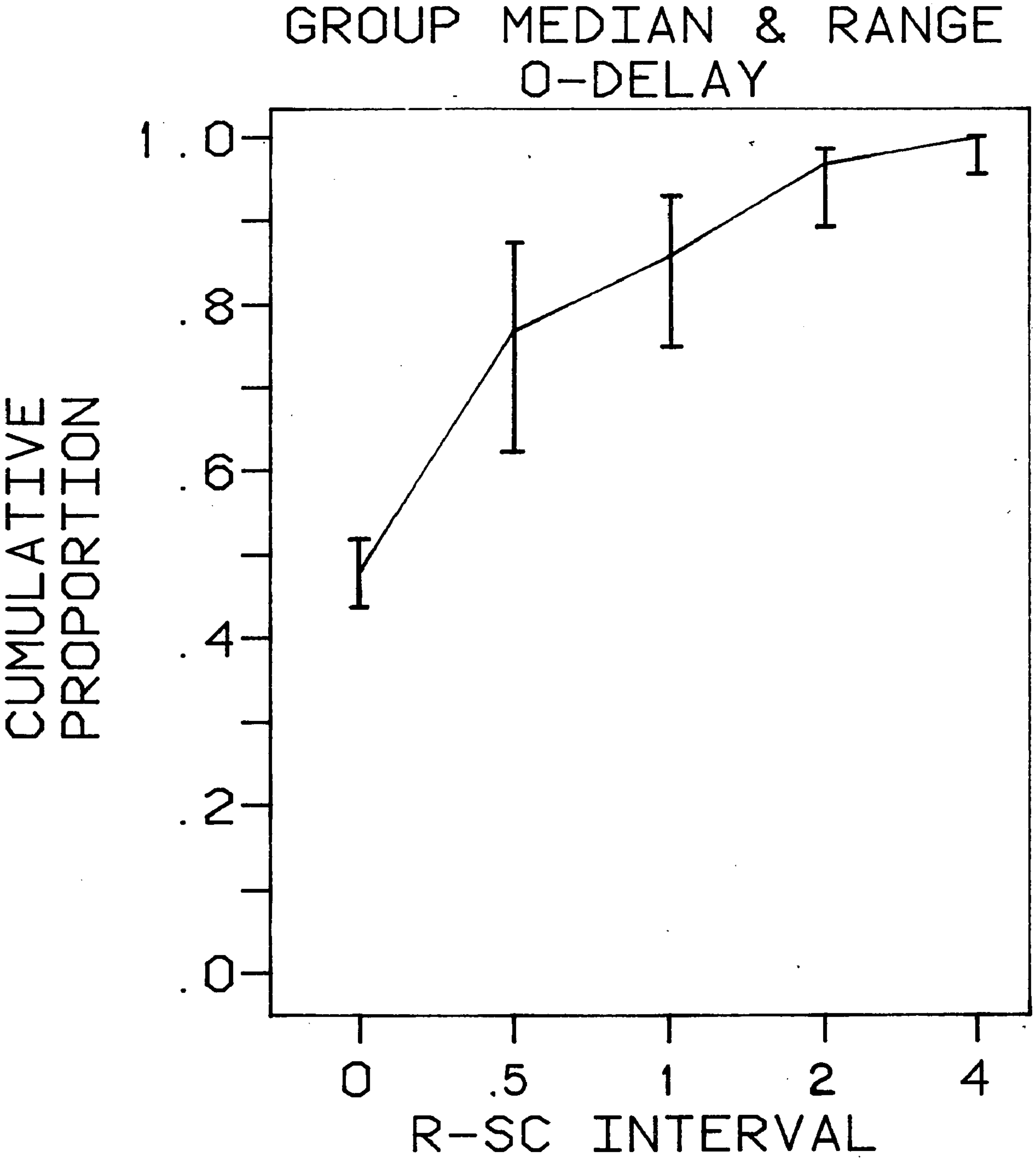

GROUP MEDIAN & RANGE
0-DELAY
CUMULATIVE PROPORTION
1.0
.8
.6
.4
.2
.0
0
.5
1
2
4
R-SC INTERVAL

Figure 5. Cumulative proportion of R-SC intervals at 0, .5, 1, 2, and 4 sec. during the .5 sec. programmed delay condition. Each point shows the group median and range of the subject means. The dashed lines represent the range of uncertainty.

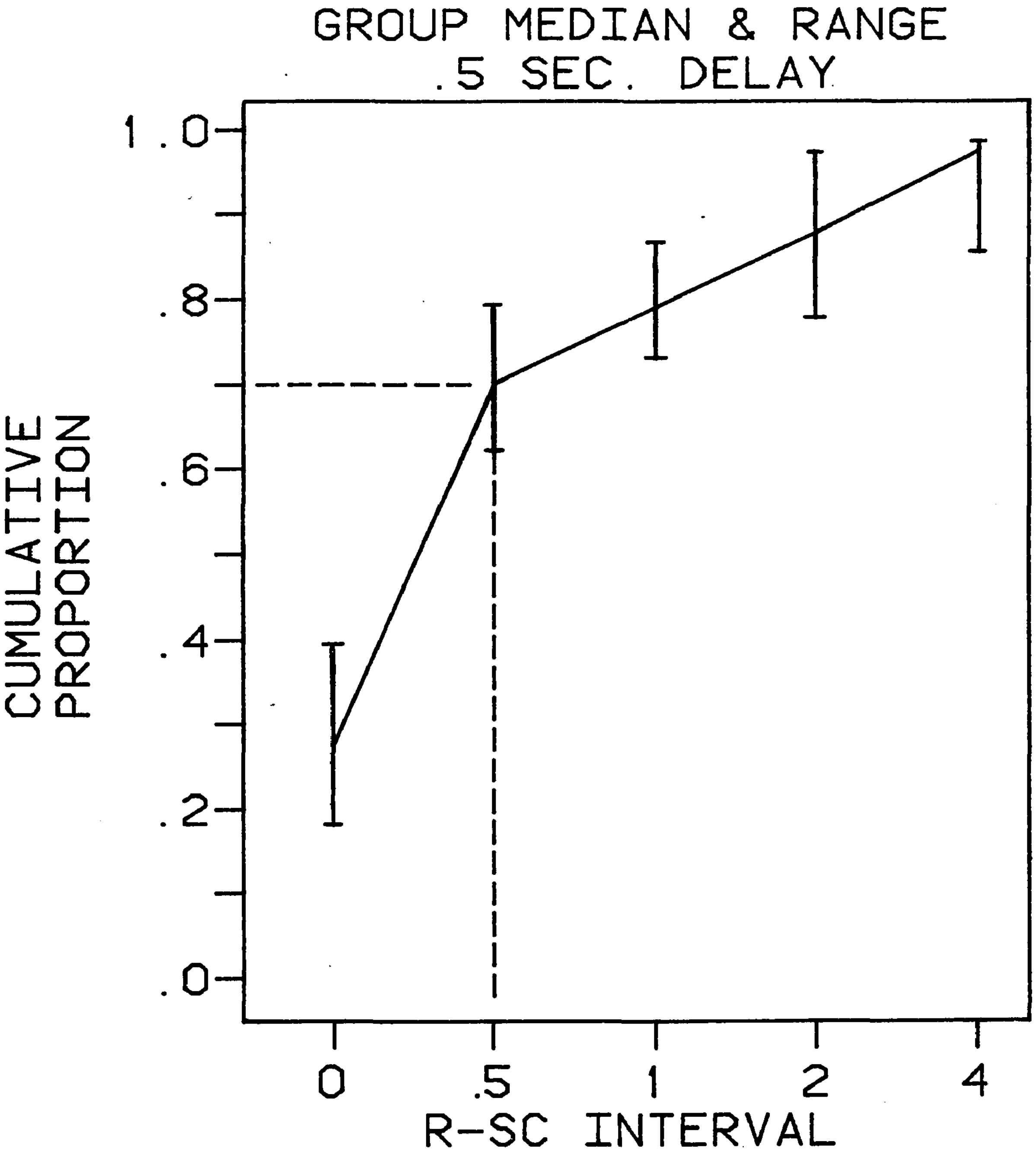

GROUP MEDIAN & RANGE
.5 SEC. DELAY
1.0
.8
.6
.4
.2
.0
CUMULATIVE PROPORTION
0
.5
1
2
4
R-SC INTERVAL

Figure 6. Cumulative proportion of R-SC intervals at 0, .5, 1, 2, and 4 sec. during the 1 sec. programmed delay condition. Each point shows the group median and range of the subject means. The dashed lines represent the range of uncertainty.

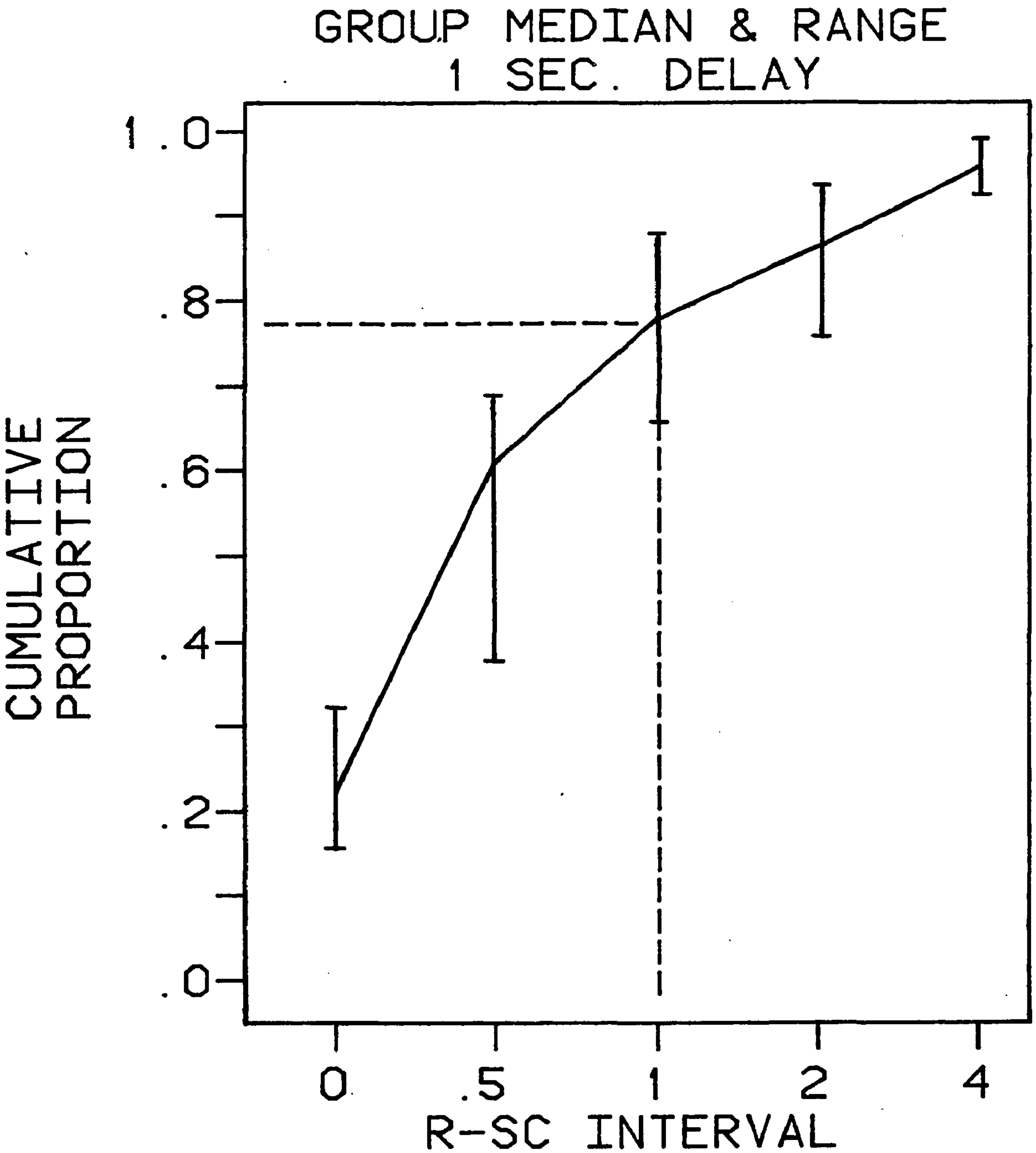

GROUP MEDIAN & RANGE
1 SEC. DELAY
CUMULATIVE PROPORTION
1.0
.8
.6
.4
.2
.0
0
.5
1
2
4
R-SC INTERVAL

Figure 7. Cumulative proportion of R-SC intervals at 0, .5, 1, 2, and 4 sec. during the 2 sec. programmed delay condition. Each point shows the group median and range of the subject means. The dashed lines represent the range of uncertainty.

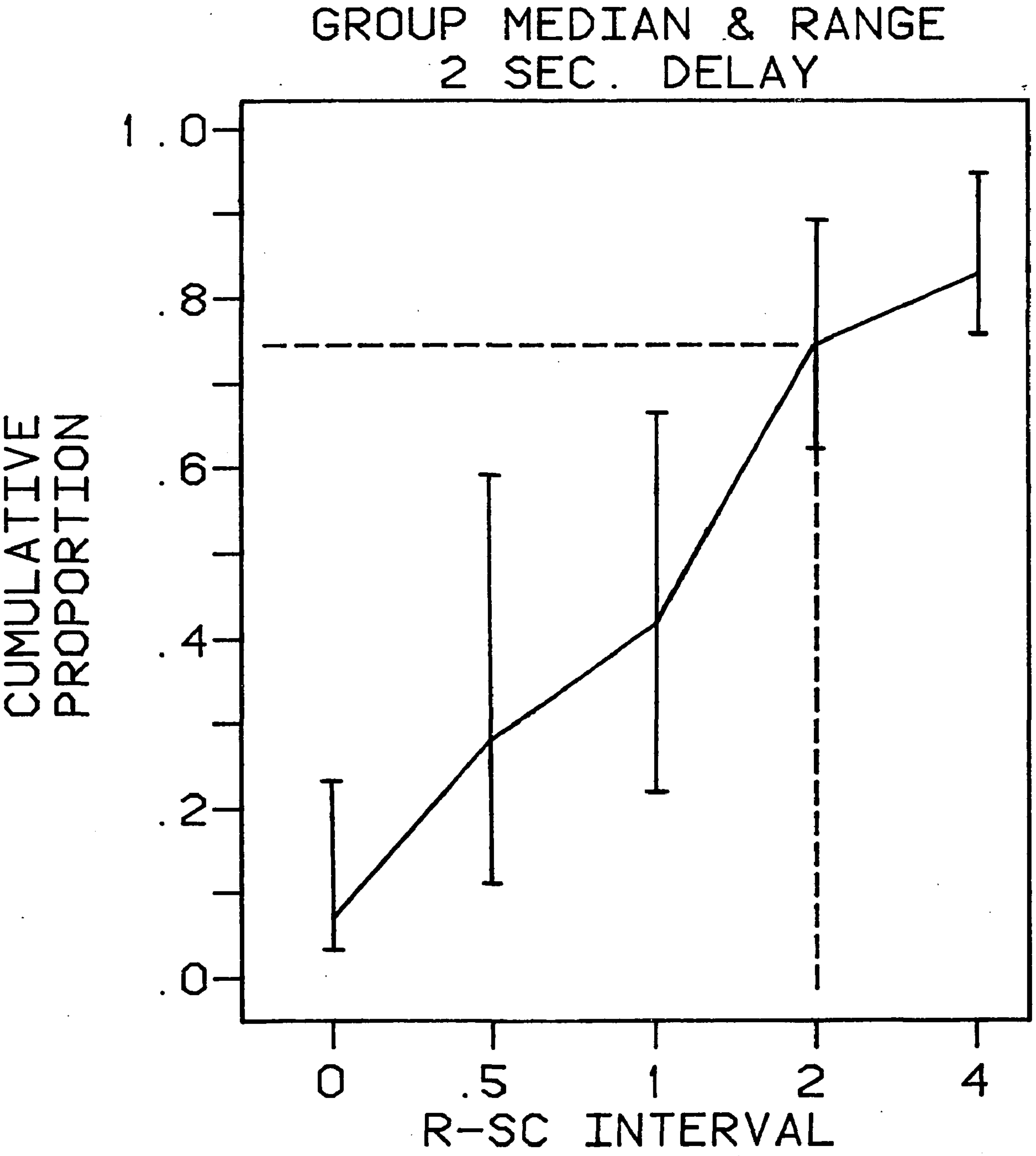
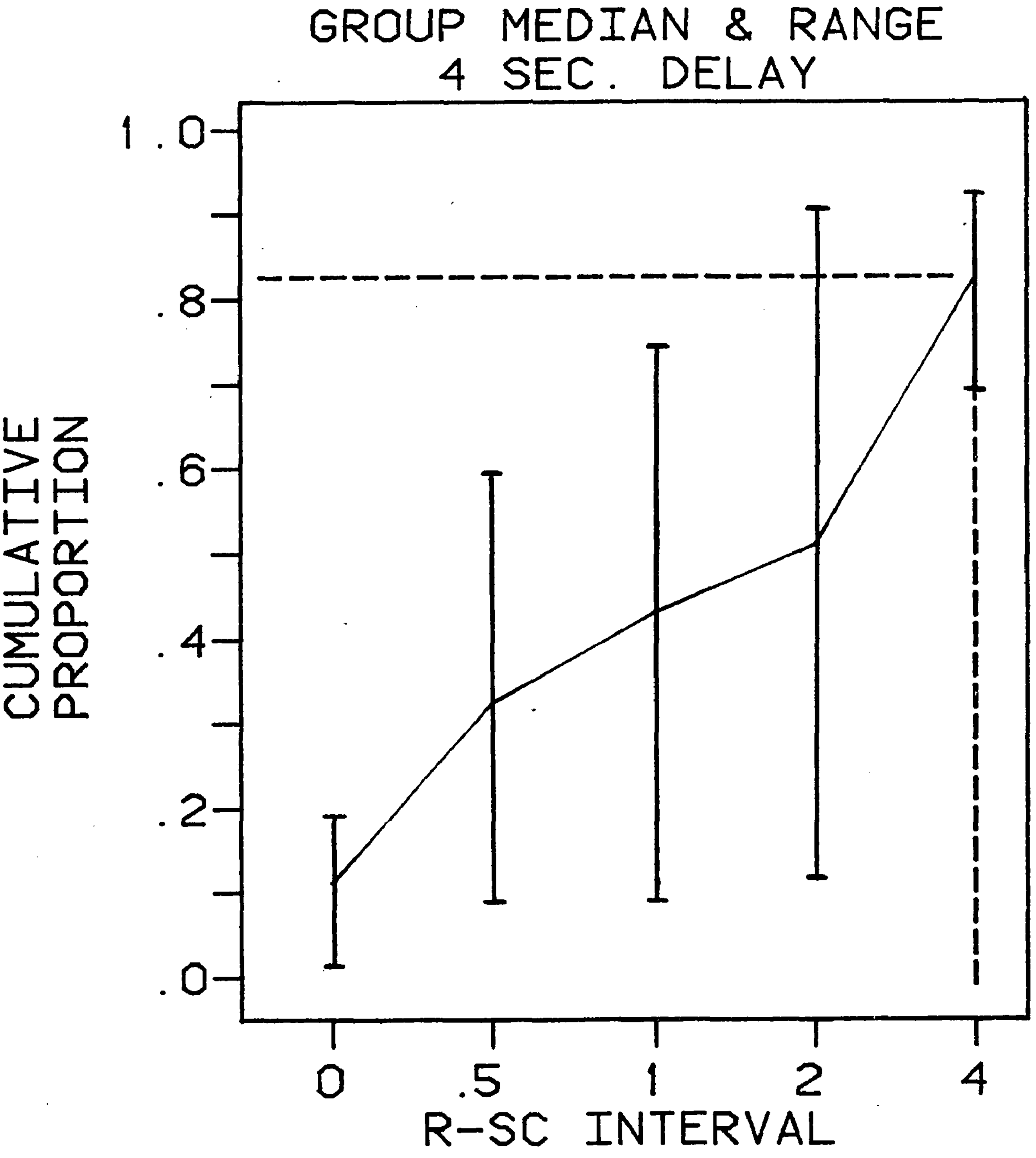

GROUP MEDIAN & RANGE
2 SEC. DELAY
1.0
.8
.6
.4
.2
.0
CUMULATIVE PROPORTION
0
.5
1
2
4
R-SC INTERVAL

Figure 8. Cumulaltive proportion of R-SC intervals at 0, .5, 1, 2, and 4 sec. during the 4 sec. programmed delay condition. Each point shows the group median and range of the subject means. The dashed lines represent the range of uncertainty.


GROUP MEDIAN & RANGE
4 SEC. DELAY
1.0
.8
.6
.4
.2
.0
CUMULATIVE PROPORTION
0
.5
1
2
4
R-SC INTERVAL

are drawn at the programmed delay values. The horizontal dashed lines show the proportion of trials for which the R-SC intervals were equal to, or less than, the programmed delay. Together, the dashed lines represent the range of abolishment.

The distributions of R-SC intervals changed so that the average R-SC interval increased as the programmed delay was increased. The average R-SC interval was a direct function of the subject's rate of responding. As a subject's rate dropped and the R-SC intervals lengthened, there was greater variability in R-SC intervals, and a greater proportion of them were beyond the range of abolishment, within a given condition, than would have been had the rates not decreased. This was interpreted to mean that slow responding was instrumental in accessing more cued R-SC intervals than fast responding, in the sense that an R-SC interval longer than the programmed delay value was a cue that a response on the left key was correct. Figures 5 through 8 show that lower rates of responding maintained a substantial portion (from 30% to 18%) of the R-SC intervals beyond the range of abolishment as the programmed delay was increased. This interpretation assumes that the cuing properties of an R-SC interval are reinforcing, thereby differentially reinforcing slow responding on the center key with longer, more discriminable, R-SC intervals. In agreement with this assumption was the tendency for biases which showed systematic changes, to develop toward the left as is evident for Birds 302 and 304 (Figure 3). One exception to this tendency to be biased toward the left was Bird 305 whose bias was toward the right. The unmarked line in Figure 3 for Bird 305 shows that the ratio of contingent SCs to total SCs deviated, by chance, so that there were more contingent trials than non-contingent trials for this bird. Its bias probably reflected a sensitivity to this imbalance.

The R-SC intervals with putative cuing properties were only those longer than the programmed delay so only some of the non-contingent SCs were cued. If non-contingent SCs were the only kind that were cued, then the subject was likely to be more accurate on the left. In turn, greater accuracy produced a higher rate of reinforcement for left key choices. With this reasoning in mind, it may be noted that the center key response rates of Birds 304, 307, and 308 generally decreased as the programmed delay was increased (Figure 2) while the proportion of correct trials remained about the same (Figure 3).

Further evidence for the putative value of the cuing properties of long R-SC intervals is revealed in the empirical values of $P(L|NC)$. These values are obtained by subtracting $P(R|NC)$ (Figure 1) from unity:

$$P(L|NC)=1-P(R|NC)$$

The diminishing accuracy associated with increases in programmed delay were far less apparent for P(L|NC) than for P(R|C). Slower responding, by producing more cued R-SC intervals, had the effect of countering the abolishment operation, and became progressively more advantageous as the range of abolishment was increased. In the 0-delay condition both contingent and non-contingent SCs were temporally cued, and the proportion of trials in which the subject was correct reflected its ability to discriminate immediate from delayed SCs. When there were no longer temporal cues signalling contingent SCs, many of the non-contingent SCs maintained their cuing properties if the subject's rate of responding decreased enough to allow a substantial proportion of R-SC intervals to exceed the programmed delay value. In addition, any variability in strength of the R-SC interval as a discriminative stimulus could only be derived from its cuing properties signifying which choice key was most likely to produce the grain hopper, and it is likely that the effectiveness of the cuing properties increased as a function of the degree to which the R-SC interval exceeded the range of abolishment.

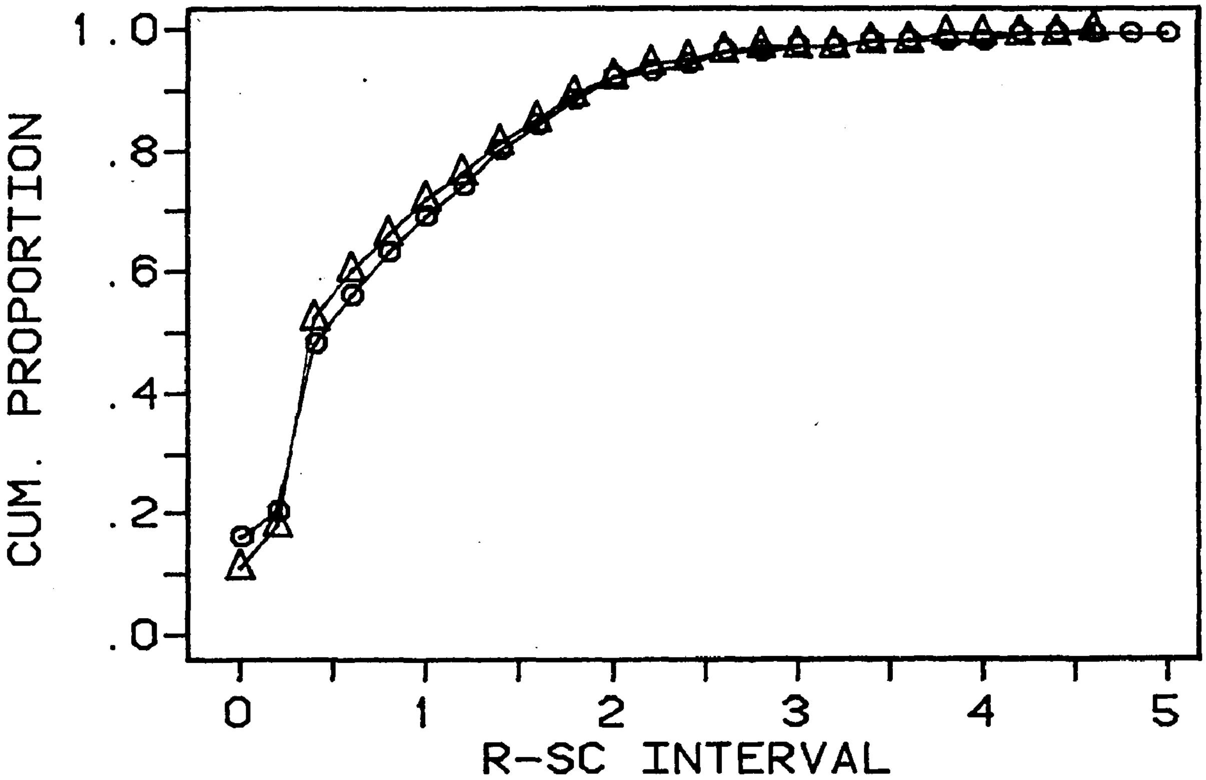
<u>Delay and choice</u>. When the distributions of R-SC intervals were categorized according to left and right choice responses, it was apparent that the frequency of errors rapidly decreased as the R-SC intervals increased when the 0-delay condition was in effect. The proportion of choice

responses following R-SC intervals of less than .5 sec. on the right side key ranged from 94% for Birds 307 and 308, to 100% for Birds 301 and 304. The proportion of left key responses following R-SC intervals of less than .5 sec. ranged from 29% (Bird 302) to 75% (Bird 304) during the same condition. At this point it should be noted that the metric of proportion of choice responses is not equally sensitive to rate changes. Changes in response rate have a greater effect on the distributions of R-SC intervals preceding left key responses than those preceding right key responses. This may be because the R-SC intervals preceding non-contingent SCs were free to vary over a relatively wide range, while those preceding contingent SCs were contained within the range of abolishment.

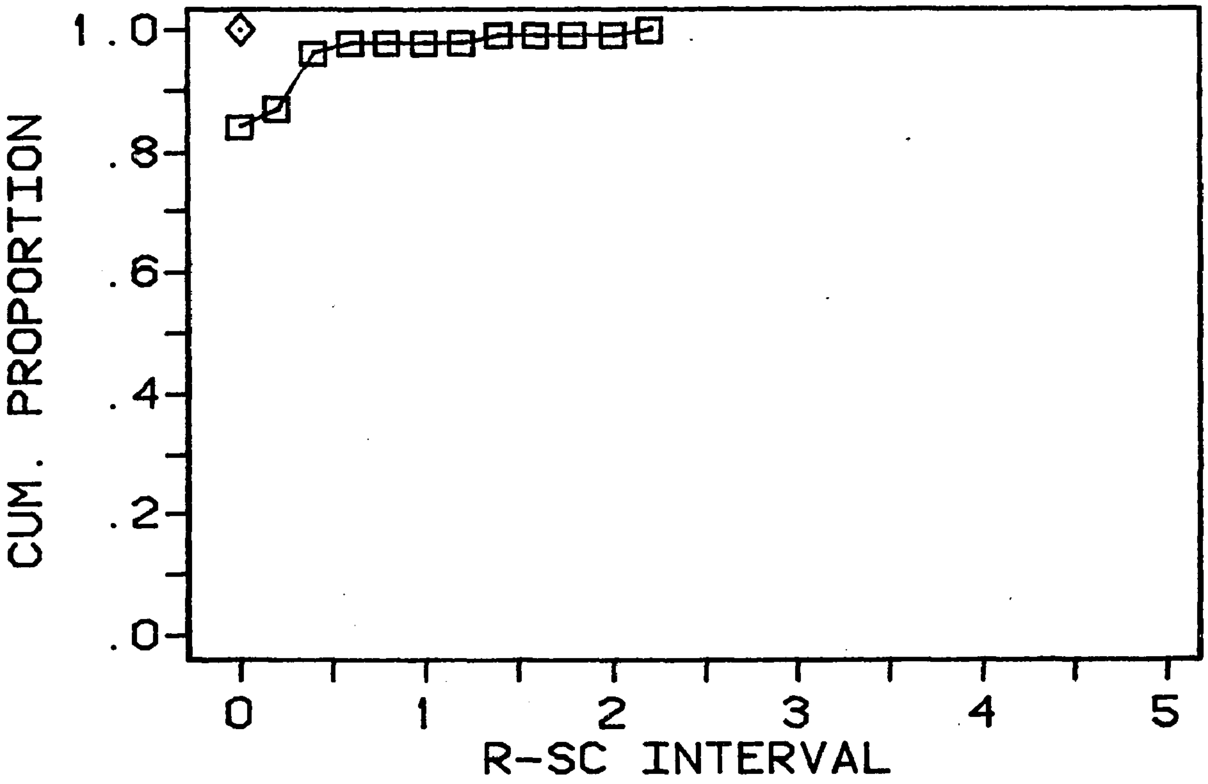
In Figures 9 through 13 the triangles and diamonds represent the same cumulative group data shown in Figures 4 through 8, separated according to the source of the SC, into distributions of R-SC intervals preceding non-contingent (upper panels) and contingent (lower panels) SCs. The plotted range of these distributions is from 0 to 5 sec. in .2 sec. increments. Any function that does not reach 1.0 on the ordinate indicates that the remaining R-SC intervals in that distribution were longer than 5 sec.

The circles and boxes in Figures 9 through 13 are, again, from the same distributions shown in Figures 4 through 8, separated according to the subjects' choice responses on the left key (upper panels) and the right key

Figure 9. Cumulative proportion of R-SC intervals in .2 sec. bins. The upper panel shows R-SC intervals preceding non-contingent SCs (triangles), and R-SC intervals preceding left side key responses (circles). The lower panel shows R-SC intervals preceding contingent SCs (diamonds), and right-side key responses (boxes). Each point represents the group mean of the subject means during the original 0-delay condition.

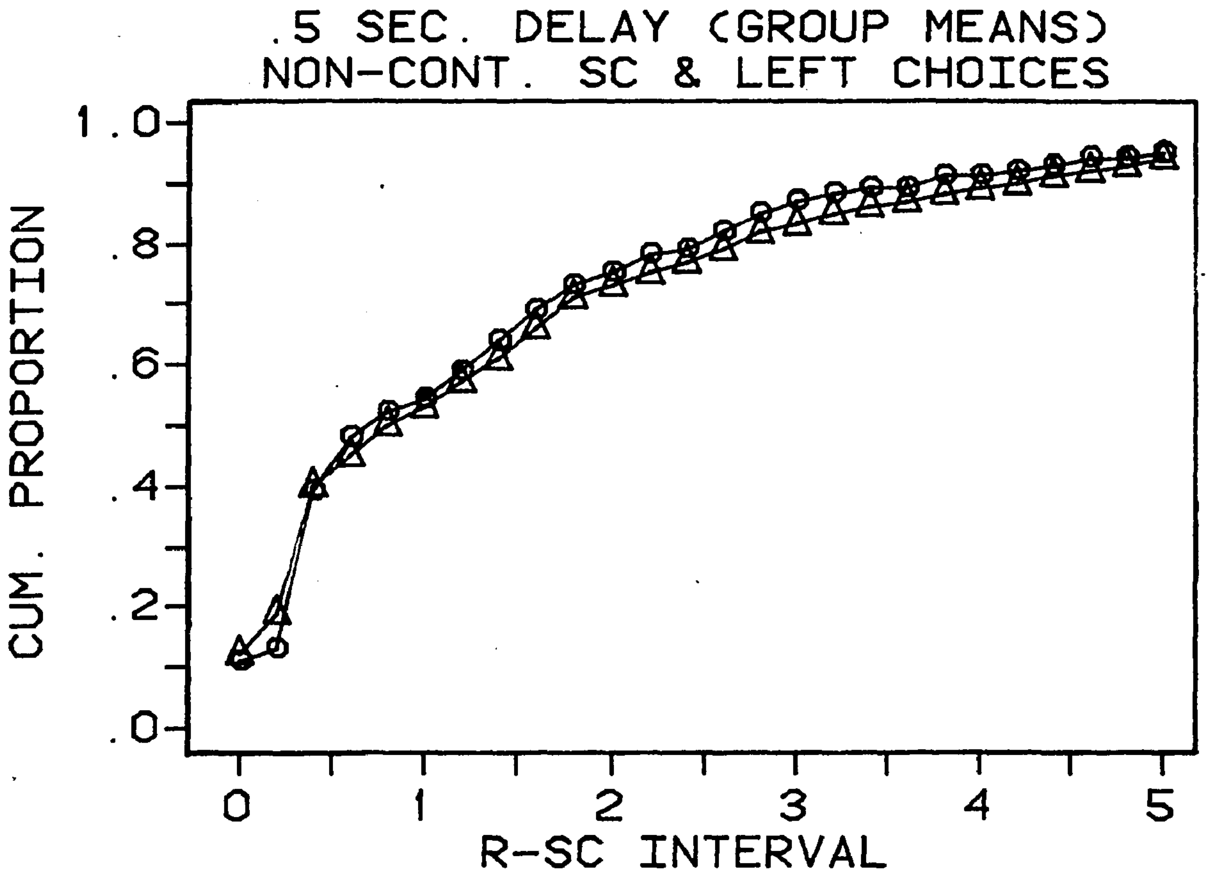


0-DELAY (GROUP MEANS)
NON-CONT. SC & LEFT CHOICES



CONTINGENT SC & RIGHT CHOICES

Figure 10. Cumulative proportion of R-SC intervals in .2 sec. bins. The upper panel shows R-SC intervals preceding non-contingent SCs (triangles), and R-SC intervals preceding left side key responses (circles). The lower panel shows R-SC intervals preceding contingent SCs (diamonds), and right-side key responses (boxes). Each point represents the group mean of the subject means during the .5 sec. programmed delay condition.


.5 SEC. DELAY (GROUP MEANS)
NON-CONT. SC & LEFT CHOICES
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

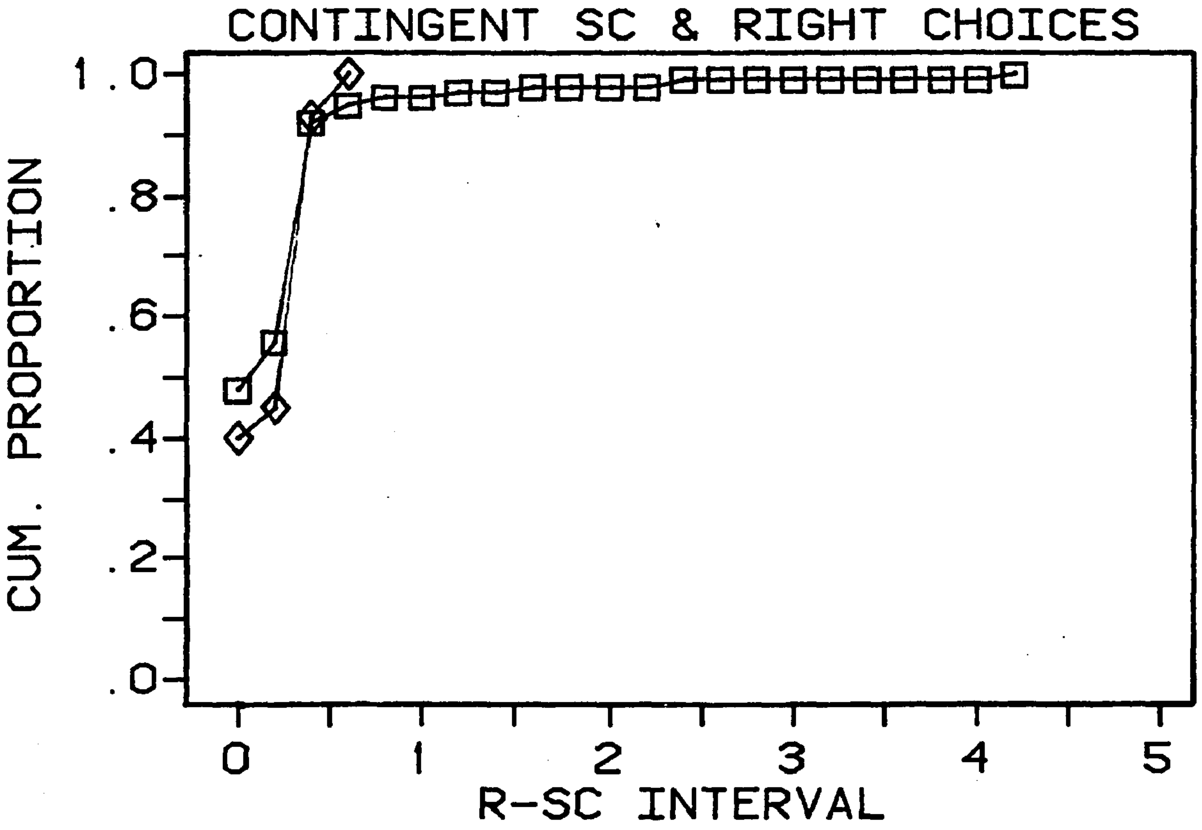
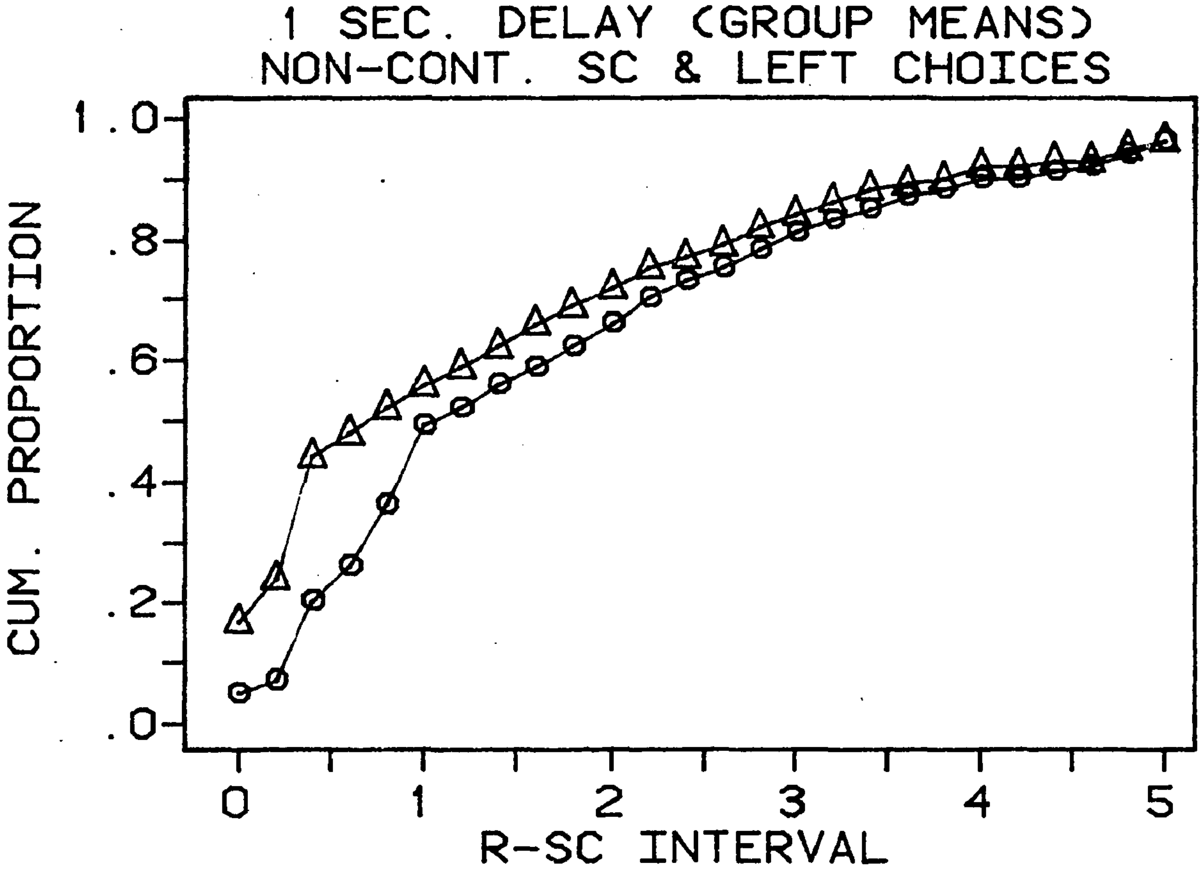

CONTINGENT SC & RIGHT CHOICES
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 11. Cumulative proportion of R-SC intervals in .2 sec. bins. The upper panel shows R-SC intervals preceding non-contingent SCs (triangles), and R-SC intervals preceding left side key responses (circles). The lower panel shows R-SC intervals preceding contingent SCs (diamonds), and right-side key responses (boxes). Each point represents the group mean of the subject means during the 1 sec. programmed delay condition.


1 SEC. DELAY (GROUP MEANS)
NON-CONT. SC & LEFT CHOICES
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

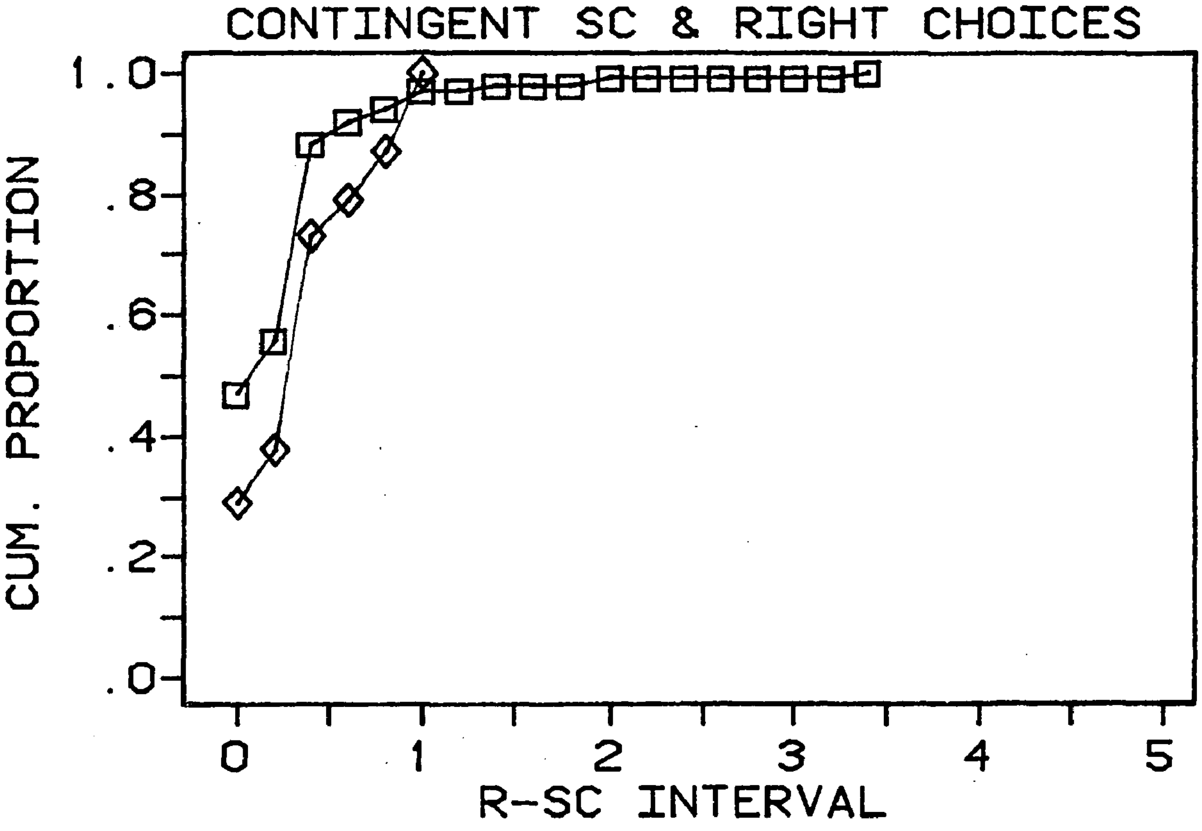
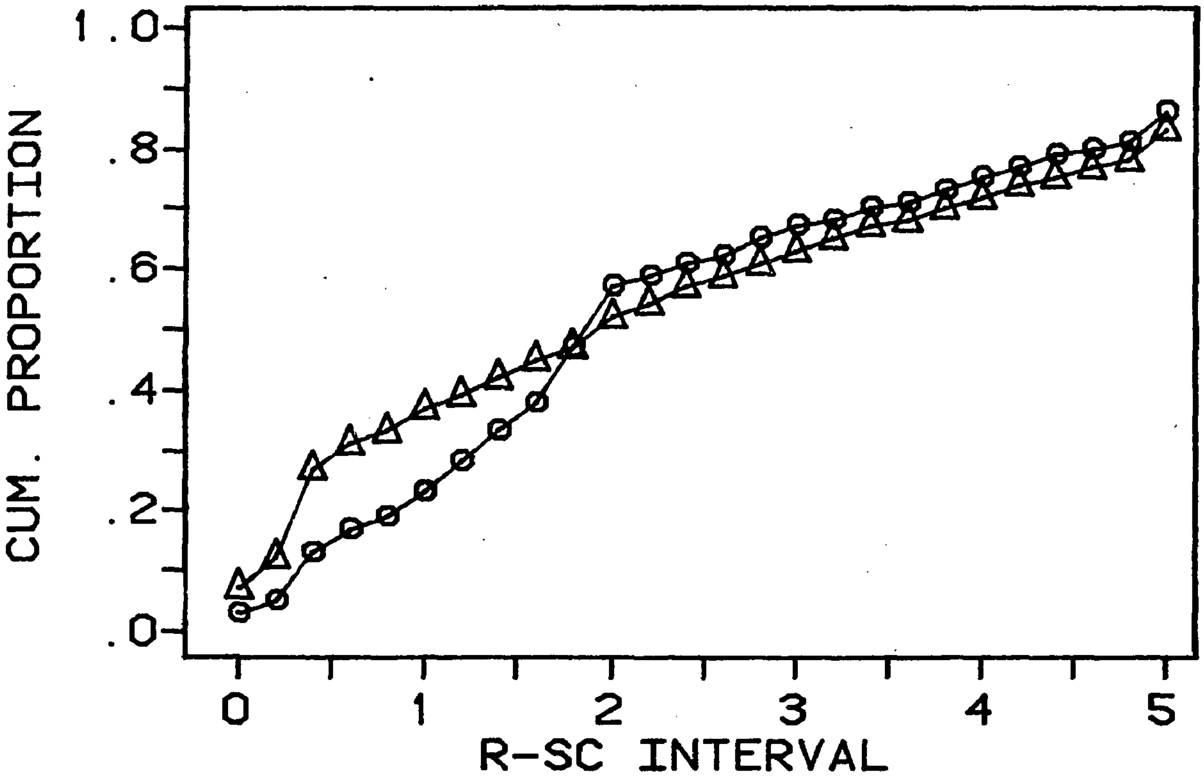

CONTINGENT SC & RIGHT CHOICES
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 12. Cumulative proportion of R-SC intervals in .2 sec. bins. The upper panel shows R-SC intervals preceding non-contingent SCs (triangles), and R-SC intervals preceding left side key responses (circles). The lower panel shows R-SC intervals preceding contingent SCs (diamonds), and right-side key responses (boxes). Each point represents the group mean of the subject means during the 2 sec. programmed delay condition.

2 SEC. DELAY (GROUP MEANS)
NON-CONT. SC & LEFT CHOICES



CONTINGENT SC & RIGHT CHOICES

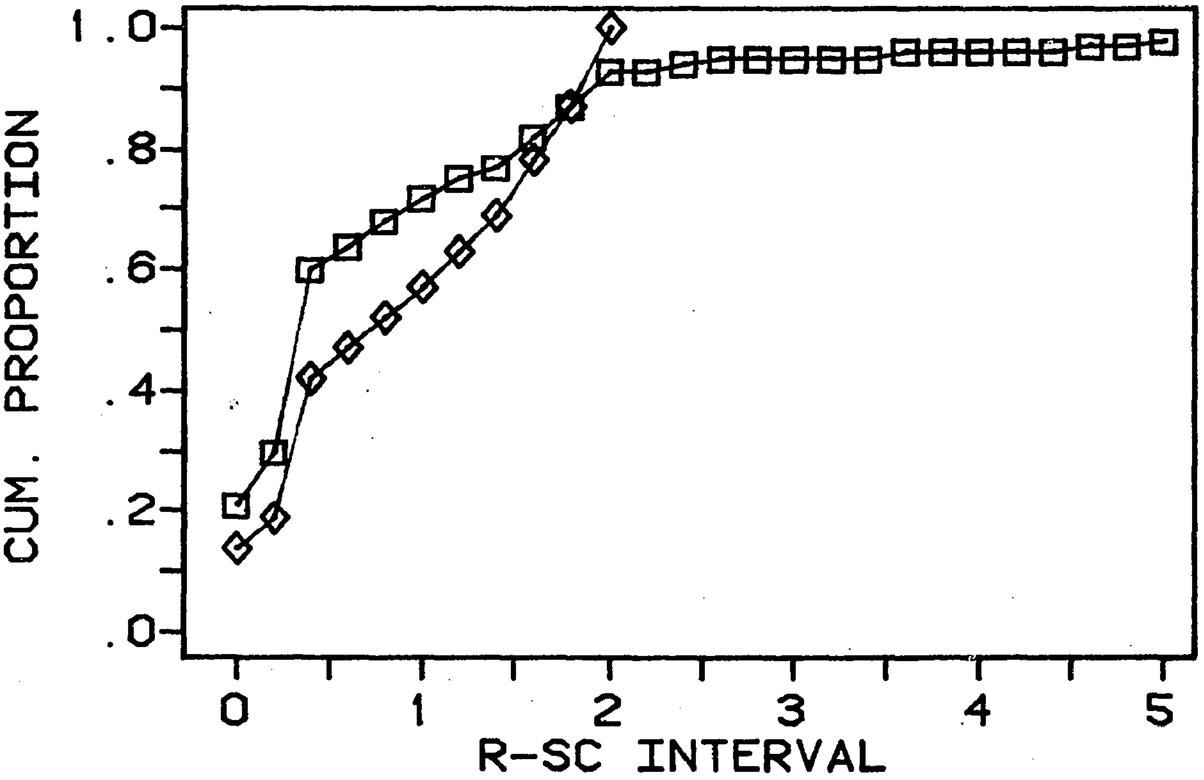
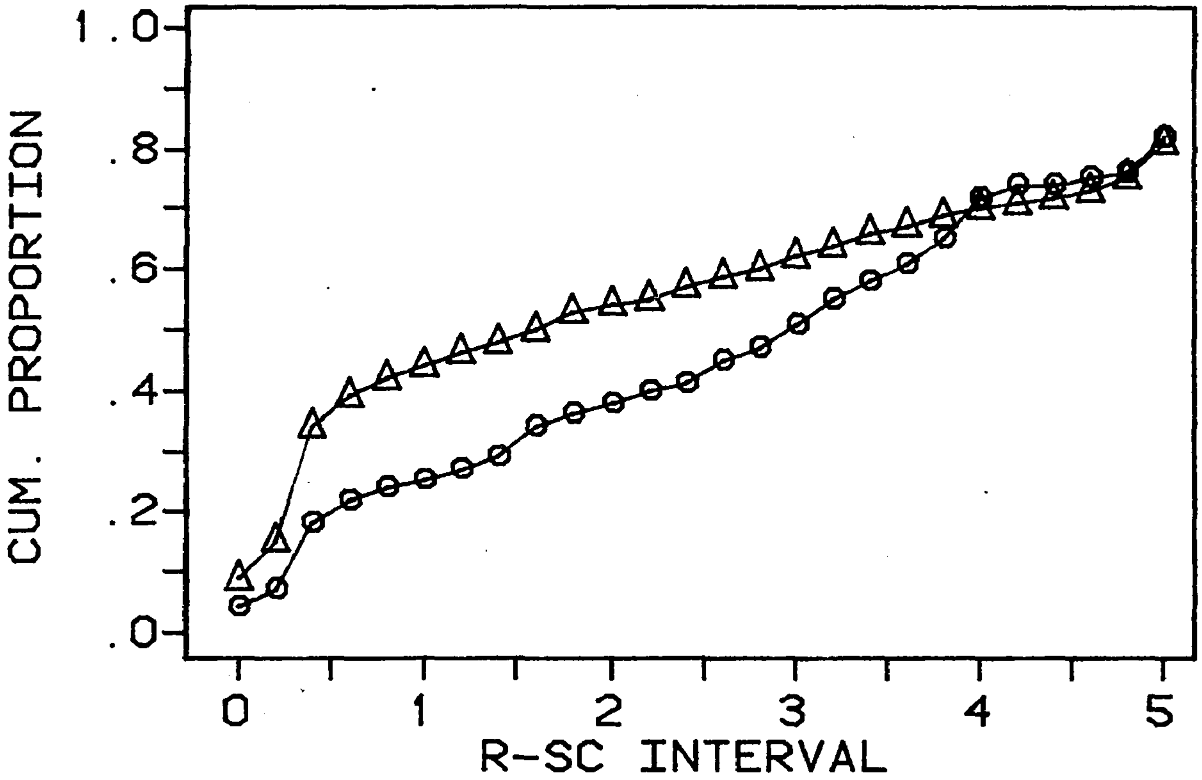
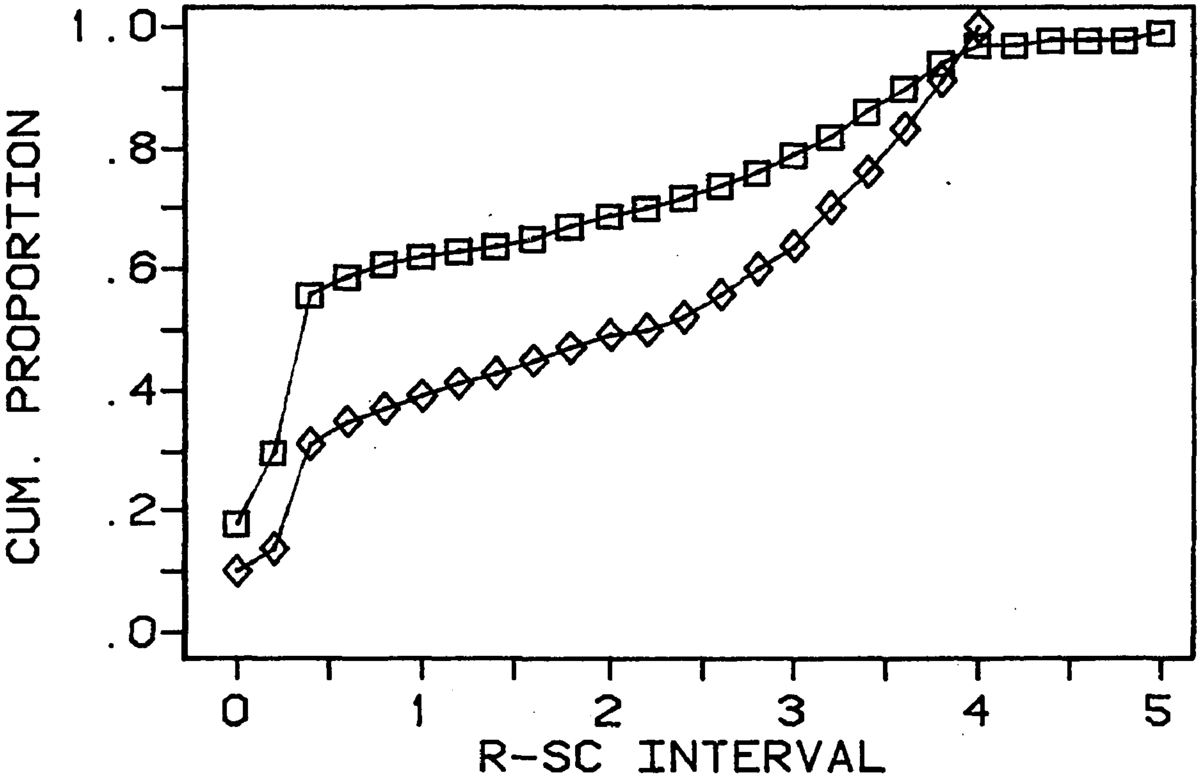


Figure 13. Cumulative proportion of R-SC intervals in .2 sec. bins. The upper panel shows R-SC intervals preceding non-contingent SCs (triangles), and R-SC intervals preceding left side key responses (circles). The lower panel shows R-SC intervals preceding contingent SCs (diamonds), and right-side key responses (boxes). Each point represents the group mean of the subject means during the 4 sec. programmed delay condition.



4 SEC. DELAY (GROUP MEANS)
NON-CONT. SC & LEFT CHOICES



CONTINGENT SC & RIGHT CHOICES

(lower panels). The choice functions in the upper panels combine L|NC and L|C responses, and R|C and R|NC responses are combined in the lower panels. Presenting objective source data and subjective choice data within the same coordinates facilitates direct comparison of each pair of functions.

The pair of source and choice functions in the upper panel of Figure 9 represents non-contingent and left key values during the initial 0-delay condition. These two functions virtually overlap, with the greatest difference between the two (5%) occurring in the first bin. This bin contained the most immediate of the R-SC intervals, and the discrepancy between functions at this point seems to indicate that the subjects' threshold of discriminability of immediate _versus_ delayed SCs averaged .2 sec. or less.

As contingent delay was introduced and increased, the magnitude and range of discrepancy between source and choice functions also increased. Figure 10, upper panel, shows the non-contingent and left choice function when the programmed delay was .5 sec. The greatest difference between this pair of functions (6%) occurs in Bin 2. Figure 11, upper panel, shows the same functions at the 1 sec. delay condition. At this value there is enough resolution to see some topographical characteristics of the discrepancy between the source function and the choice function. Specifically, the range of the largest differences is within the range of abolishment (i.e., from

0 sec. to 1 sec. at the 1 sec. delay condition). This remains true through the 2 sec. and 4 sec. delay conditions (Figures 12 and 13).

Where the functions continue beyond the range of abolishment they lie in close proximity to each other. This fact supports the contention that longer R-SC intervals maintained their discriminative properties. Also, the direction of the differences, consistent across conditions, shows that the choice distributions were weighted more toward longer R-SC intervals than the source distributions.

The magnitude, range, and direction of the differences between the two functions within the ranges of abolishment support the contention that each R-SC interval was perceived as having discriminative temporal properties upon which the subjects were basing their choices, regardless of whether or not those "cues" were reliable. A given trial was as likely to be contingent as non-contingent. When the R-SC interval, on a given trial, fell within the range of abolishment, there were no more apparent discriminative stimuli upon which to base choices. An R-SC interval at the longer end of the range of abolishment, at 3.8 sec. in the 4 sec. delay condition, for example, was no more likely to be of non-contingent (or contingent) origin than an R-SC interval at .2 sec.

The same conclusions may be drawn from the data presented in the lower panels of Figures 9 through 13.

These figures show the cumulative distributions of R-SC intervals preceding contingent SCs (diamonds) and right side key choices (boxes). Of course, the direction of the differences is opposite to those shown in the upper panels. The subjects tended to choose the right-side key following any R-SC interval that was short in comparison to the others, and the distributions tended to converge at or near the programmed delay. Although the distributions of R-SC intervals following contingent SCs were limited to a value equal to or less than the programmed delay in each condition, the distributions of right-side key choices had no constraints, and a small percent of the subjects' right-side responses occurred following long R-SC intervals. These responses, if they occurred beyond the range of abolishment, were never reinforced. Conversely, a small percent of left key choices occurred following the shortest R-SC intervals. These were occasionally reinforced.

Figures 14 through 34 show the source and choice data for each bird. All four functions are presented in each figure. The effects of bias, although not as readily apparent as when presented directly (Figure 3), can be seen in the distributions of Bird 301 (Figures 15 and 16) and Bird 305 (Figures 24 and 25). Bird 301 made only one response on the right-side choice key during the last five sessions of the .5 sec. delay condition (Figure 15, upper panel) and no responses on the right during the 2 sec.

Figure 14. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 301 during the original 0-delay condition.

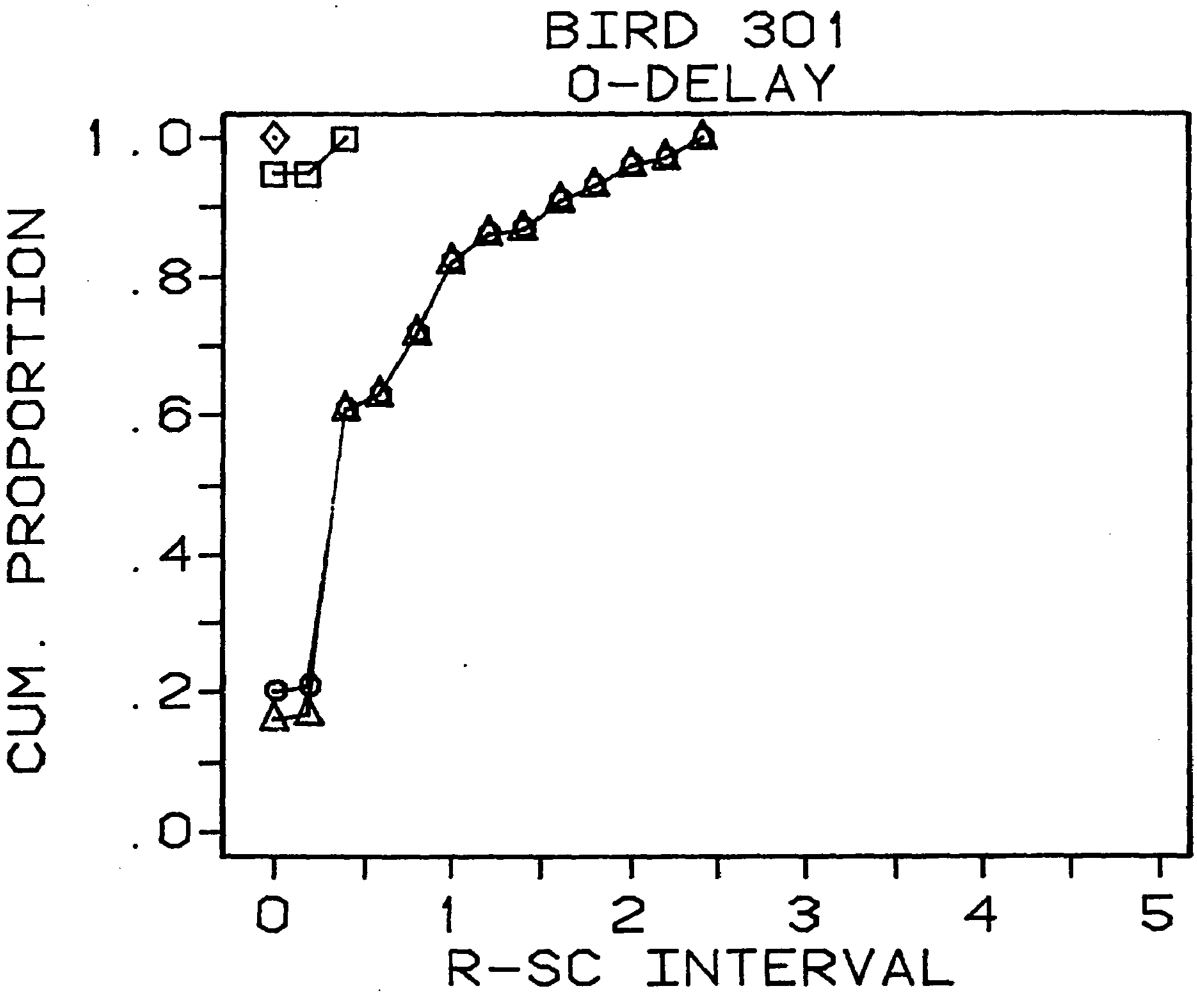
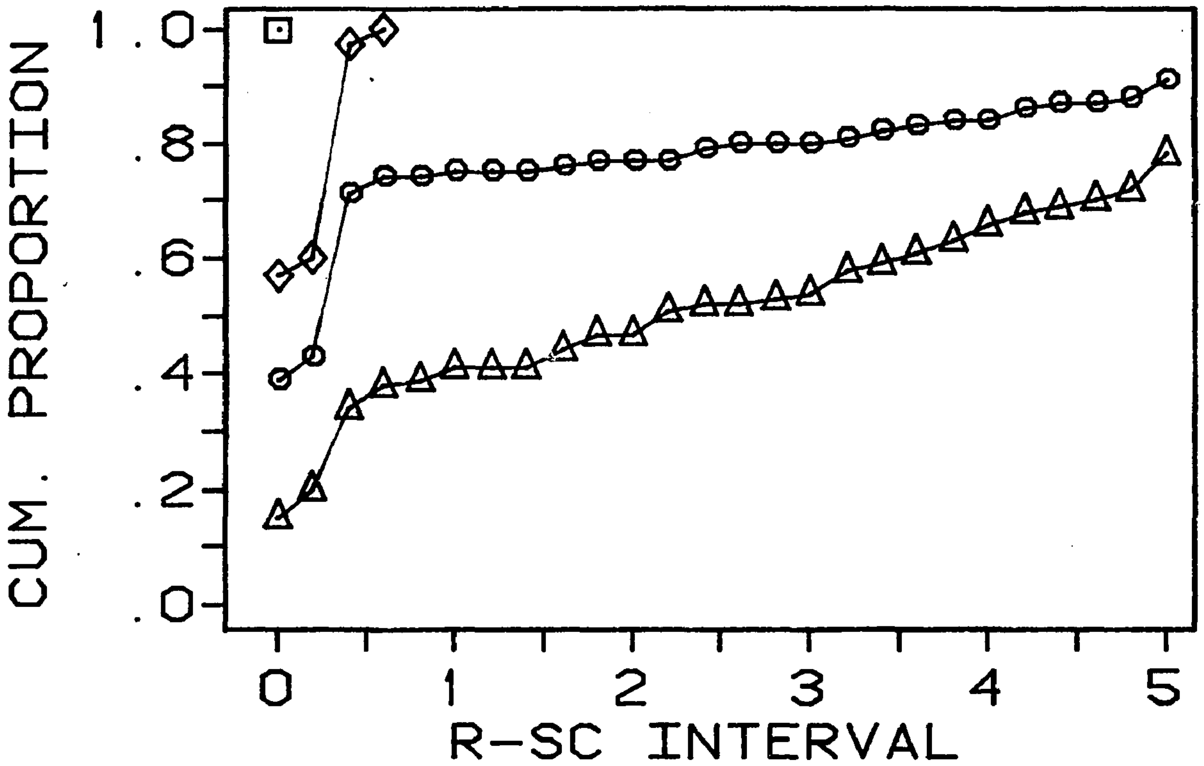

BIRD 301
0-DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 15. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 301. The upper panel represents performance during the .5 sec. programmed delay condition, and the lower panel represents performance during the 1 sec. programmed delay condition.

BIRD 301

.5 SEC. DELAY



1 SEC. DELAY

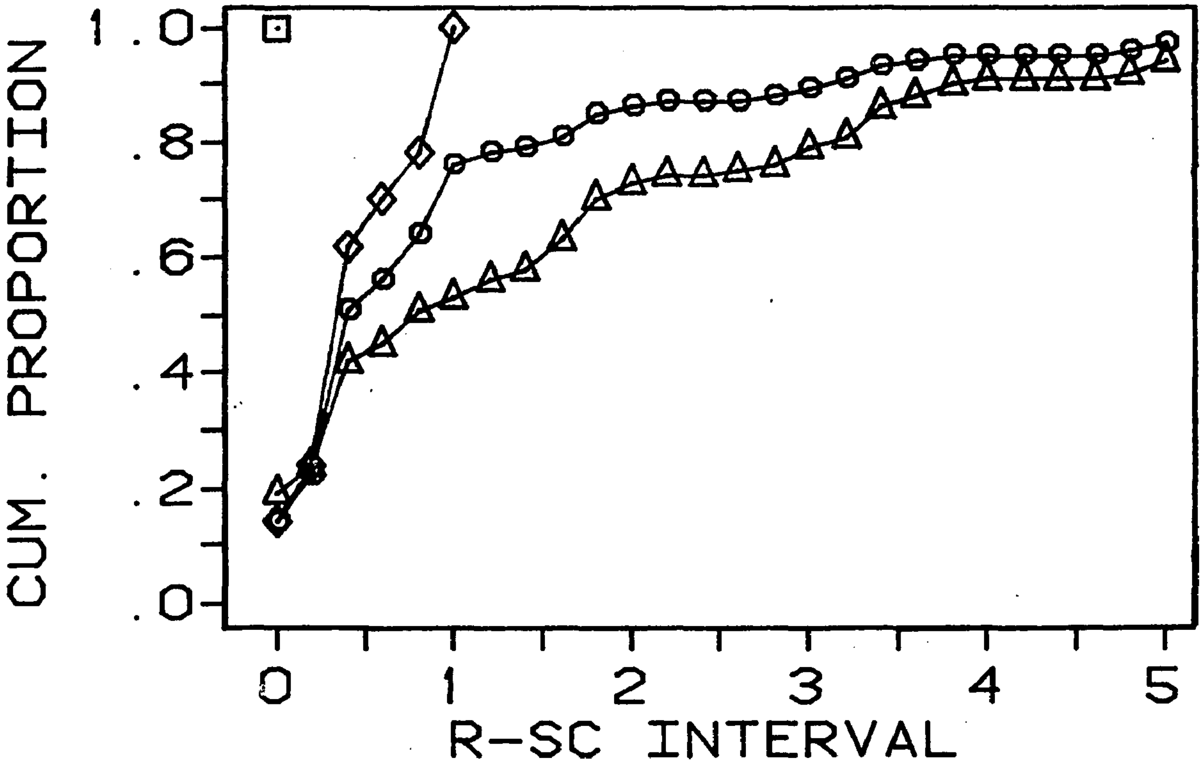
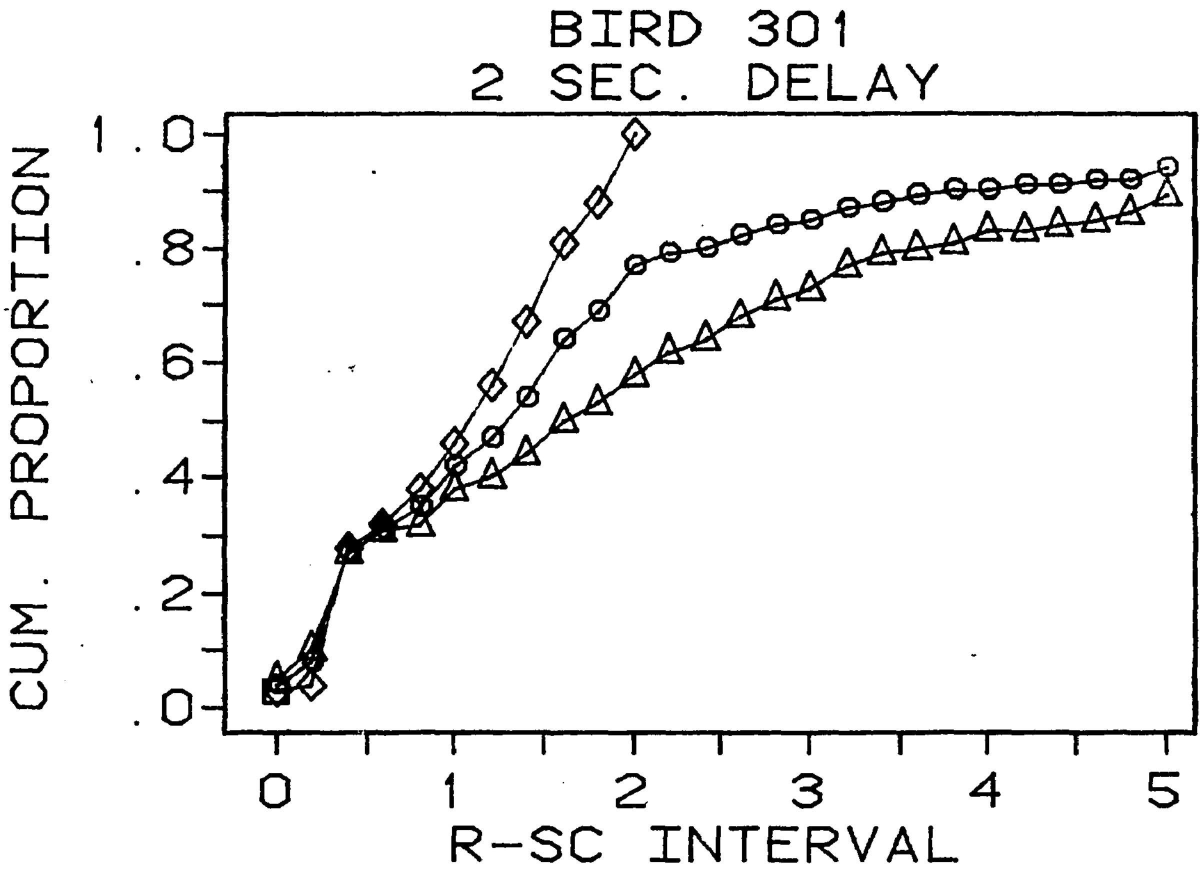


Figure 16. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 301. The upper panel represents performance during the 2 sec. programmed delay condition, and the lower panel represents performance during the 4 sec. programmed delay condition.


BIRD 301
2 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

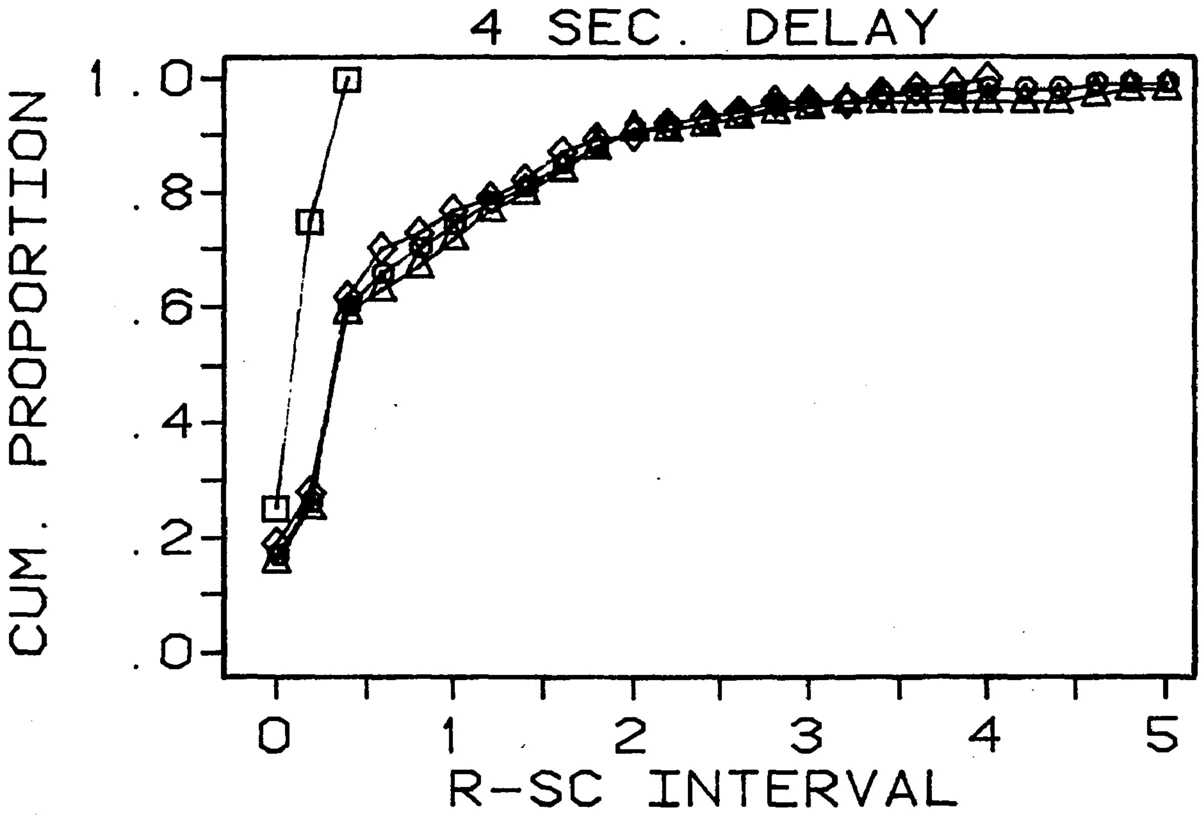

4 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 17. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 302 during the original 0-delay condition.

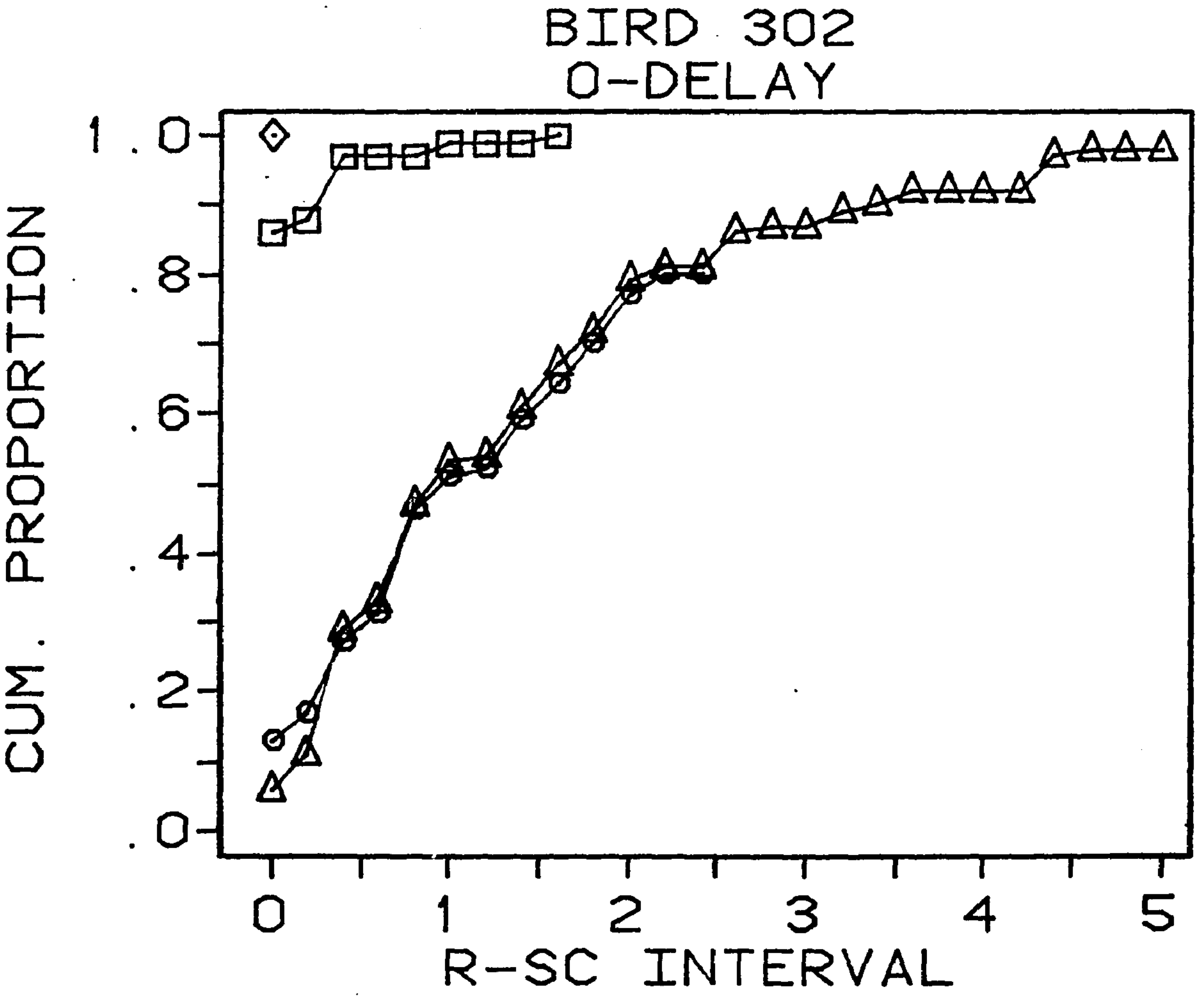
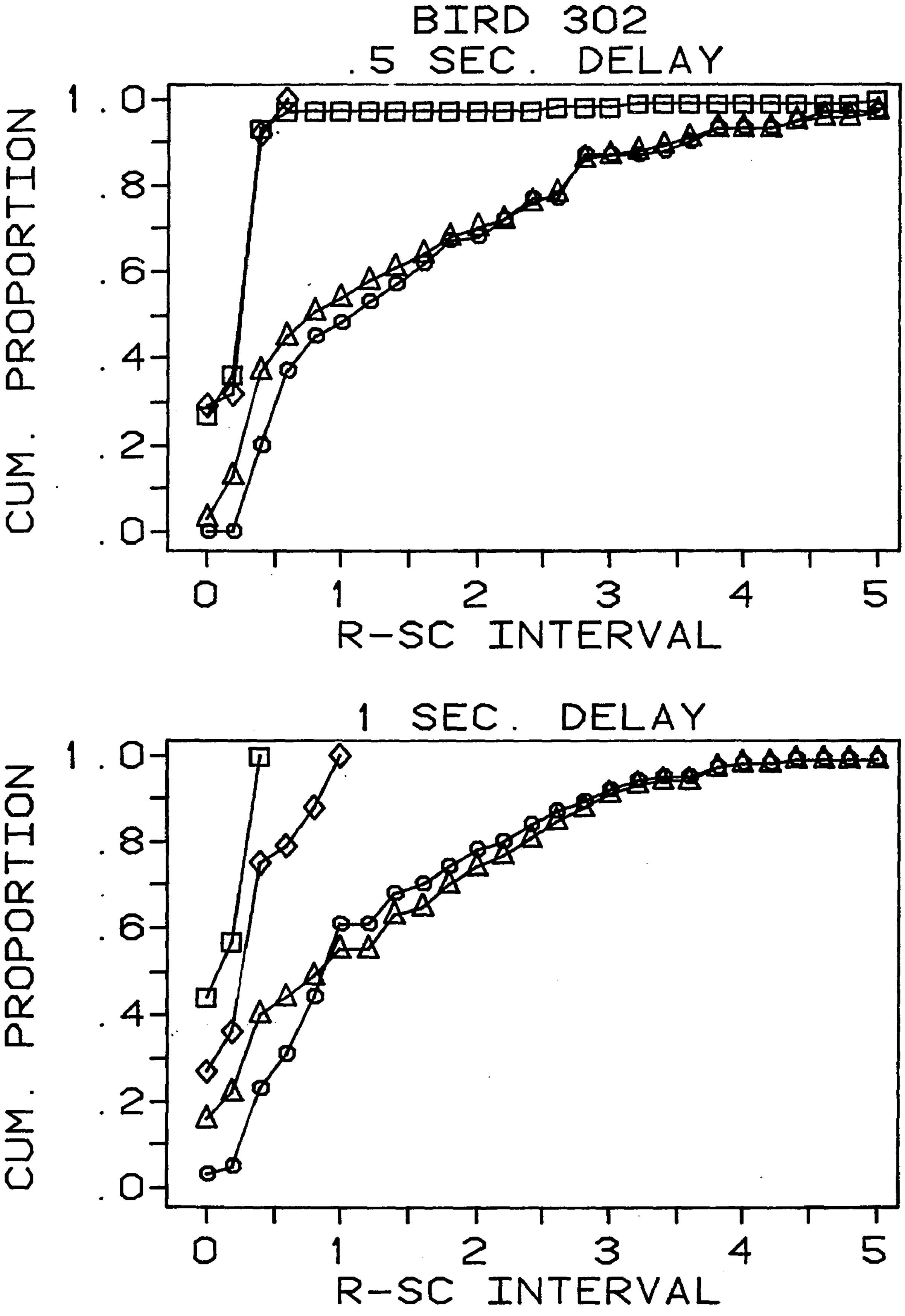

BIRD 302
0-DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

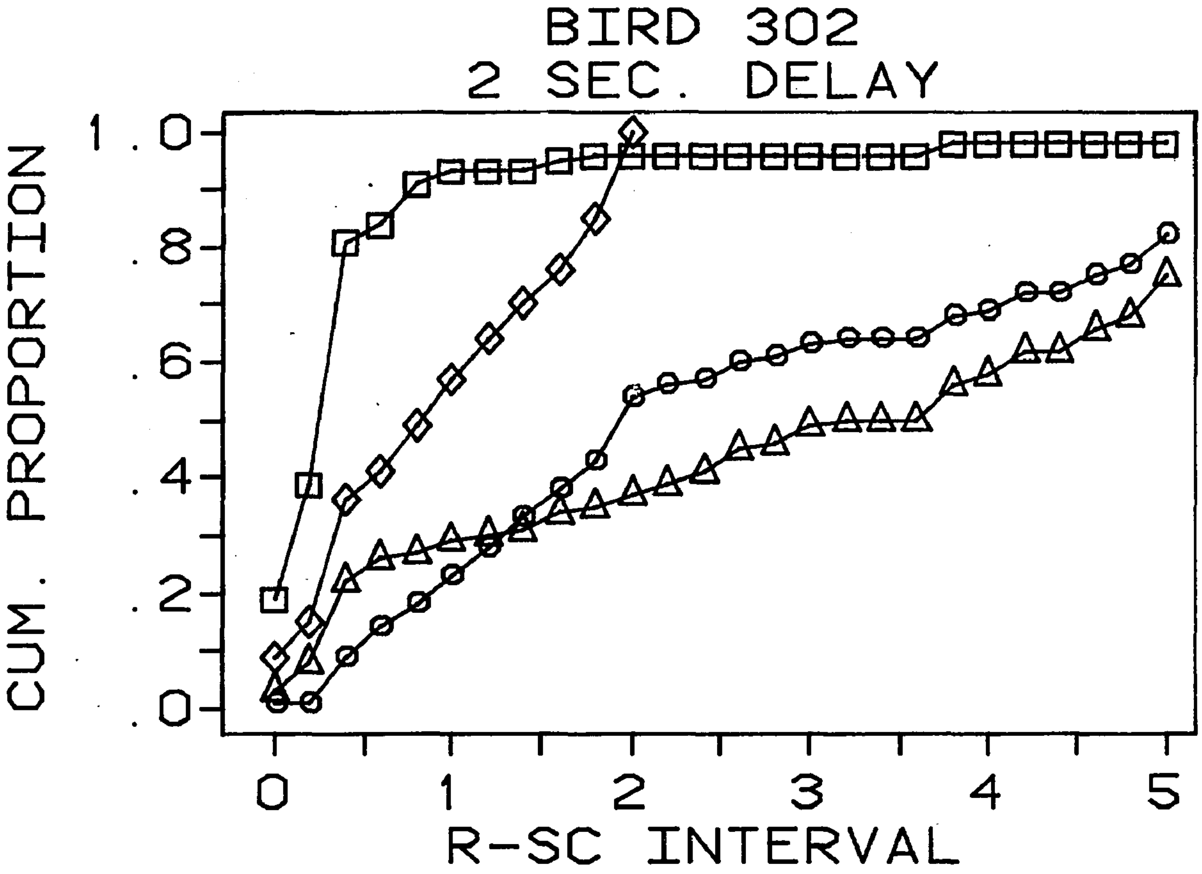
Figure 18. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 302. The upper panel represents performance during the .5 sec. programmed delay condition, and the lower panel represents performance during the 1 sec. programmed delay condition.


BIRD 302

.5 SEC. DELAY

1 SEC. DELAY

Figure 19. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 302. The upper panel represents performance during the 2 sec. programmed delay condition, and the lower panel represents performance during the 4 sec. programmed delay condition.


BIRD 302
2 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

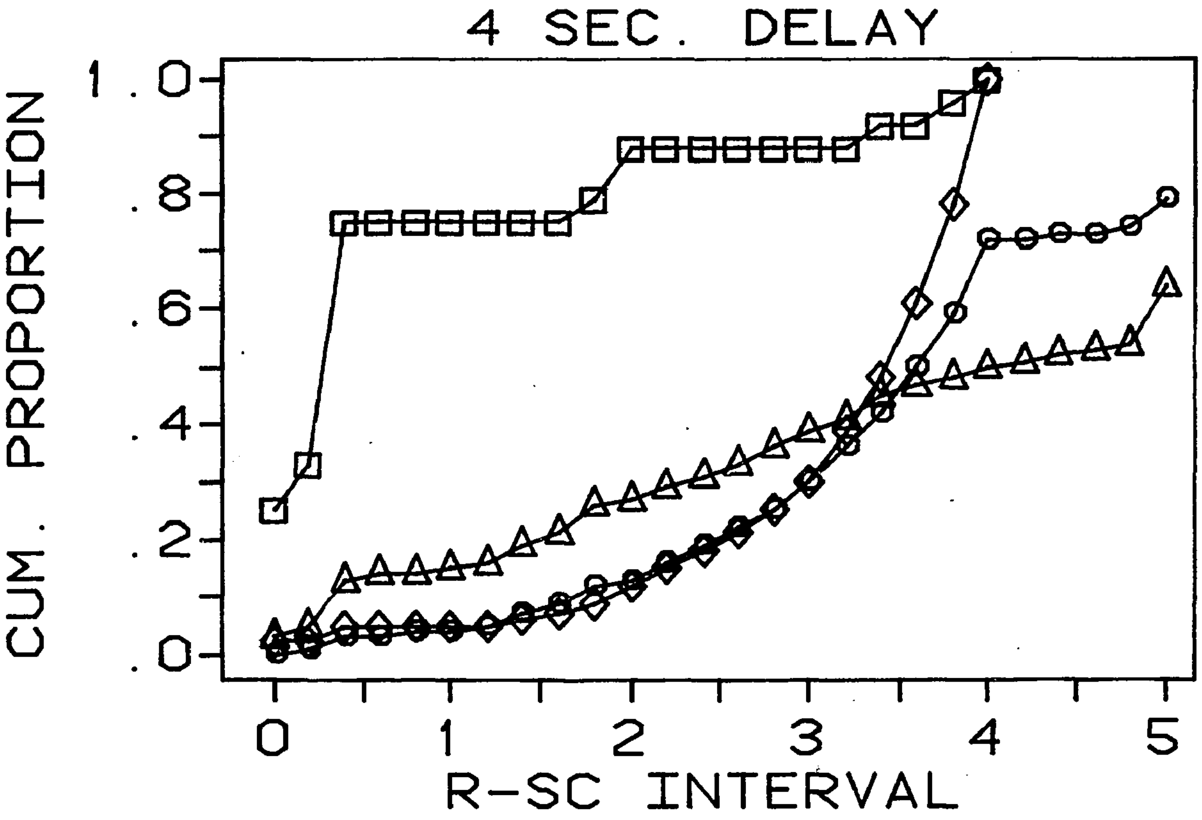

4 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 20. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 304 during the original 0-delay condition.

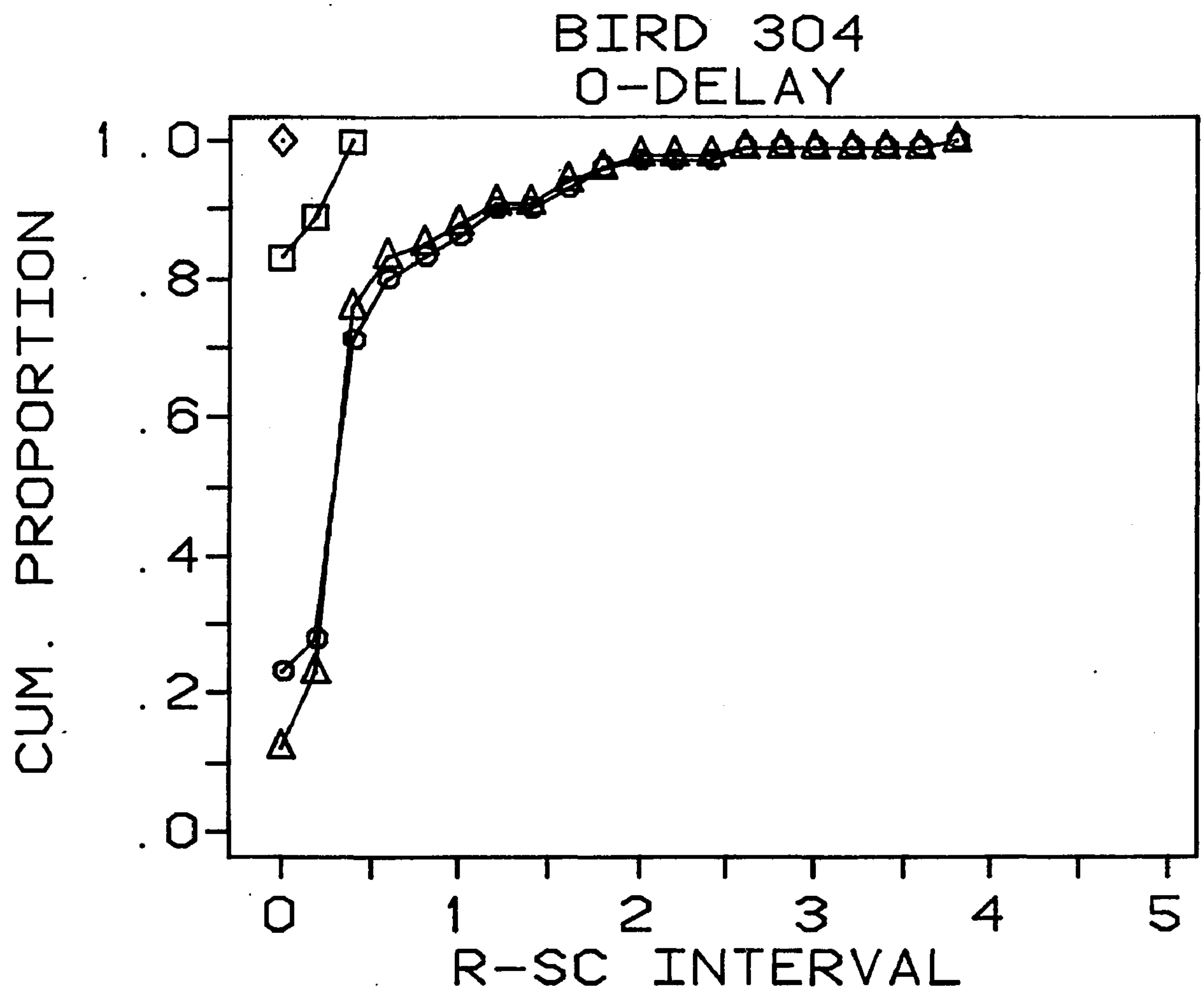
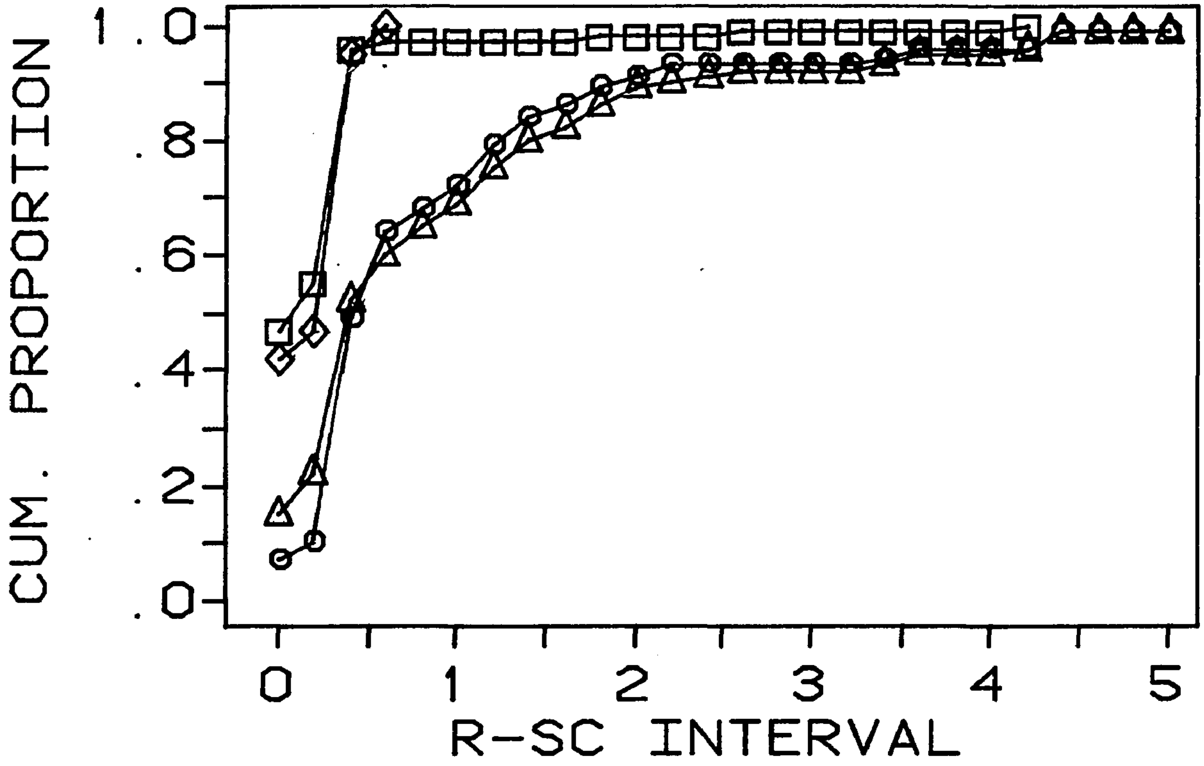

BIRD 304
0-DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 21. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 304. The upper panel represents performance during the .5 sec. programmed delay condition, and the lower panel represents performance during the 1 sec. programmed delay condition.

BIRD 304

.5 SEC. DELAY



1 SEC. DELAY

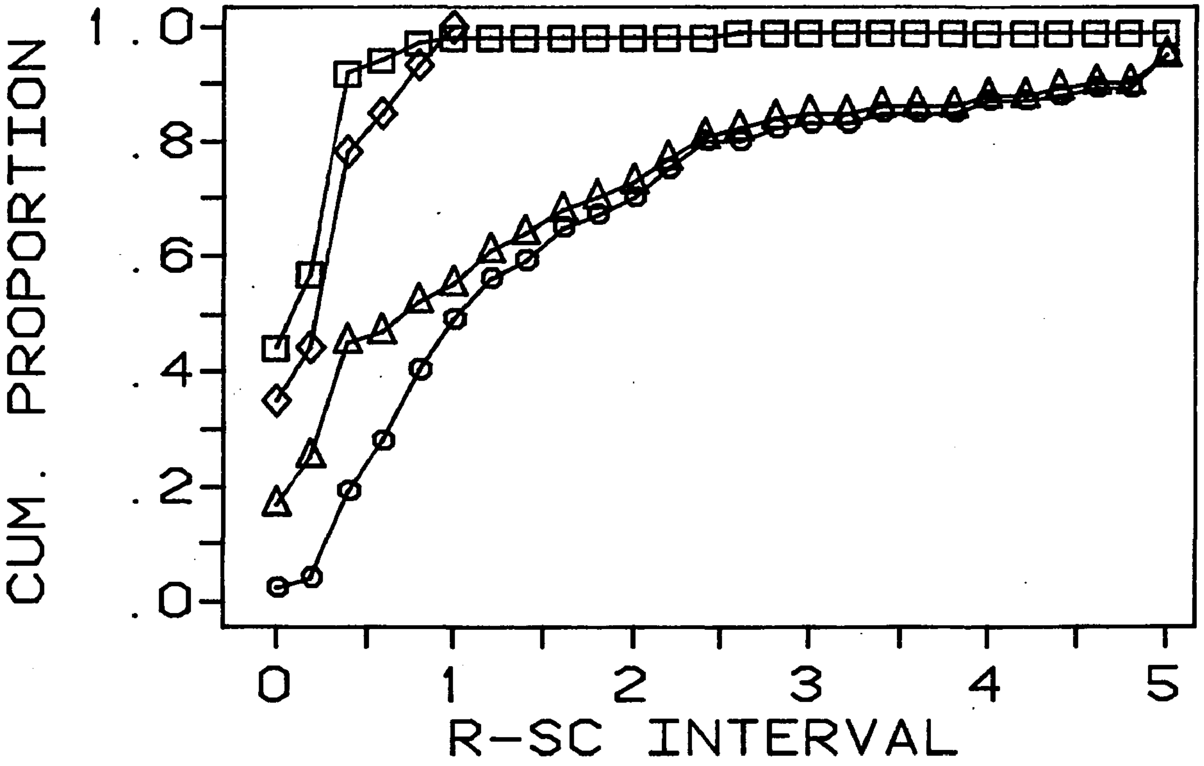
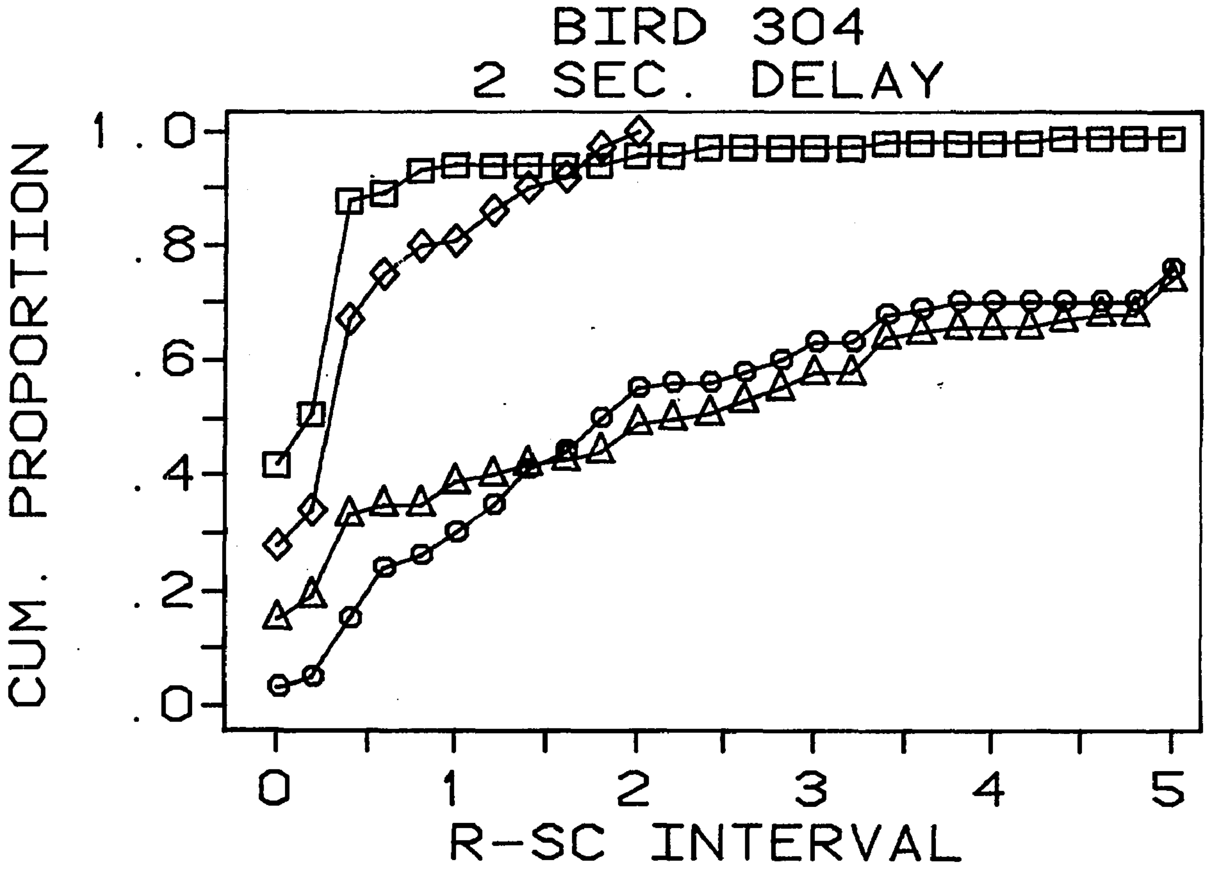


Figure 22. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 304. The upper panel represents performance during the 2 sec. programmed delay condition, and the lower panel represents performance during the 4 sec. programmed delay condition.


BIRD 304
2 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

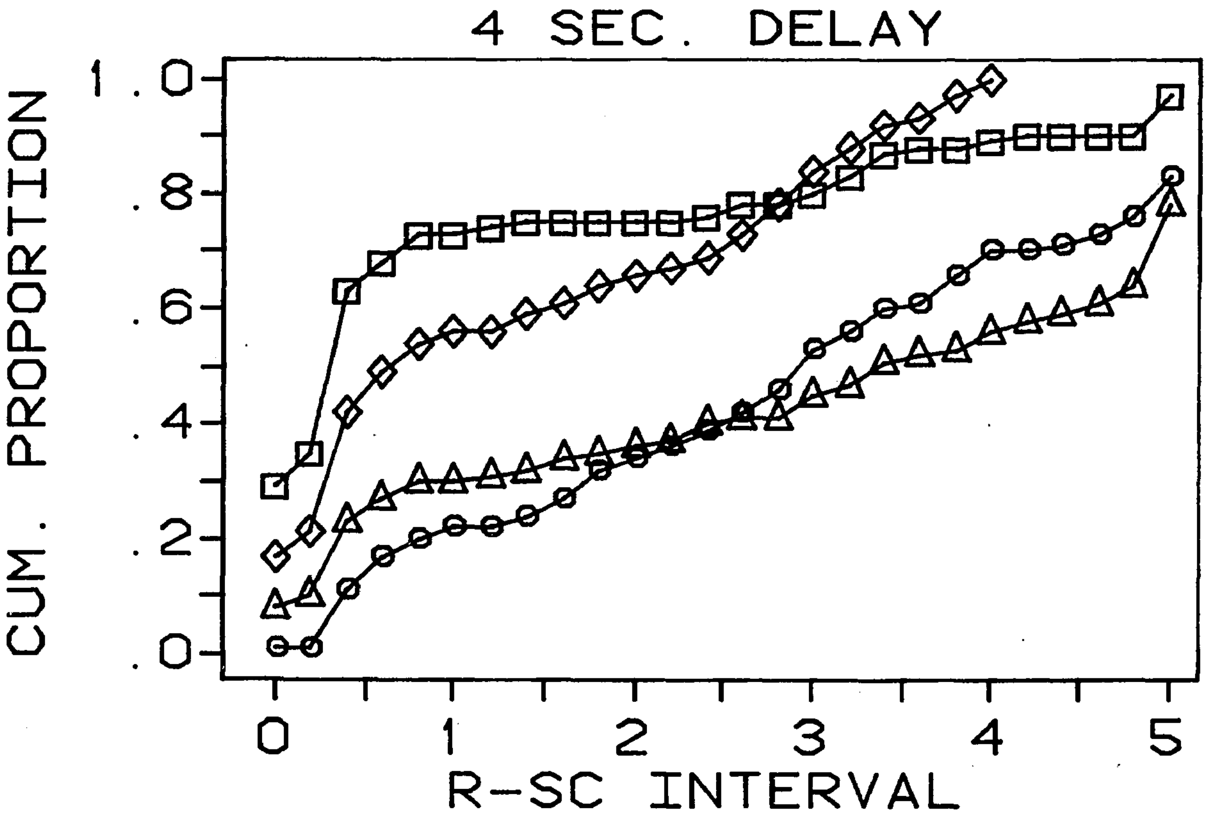
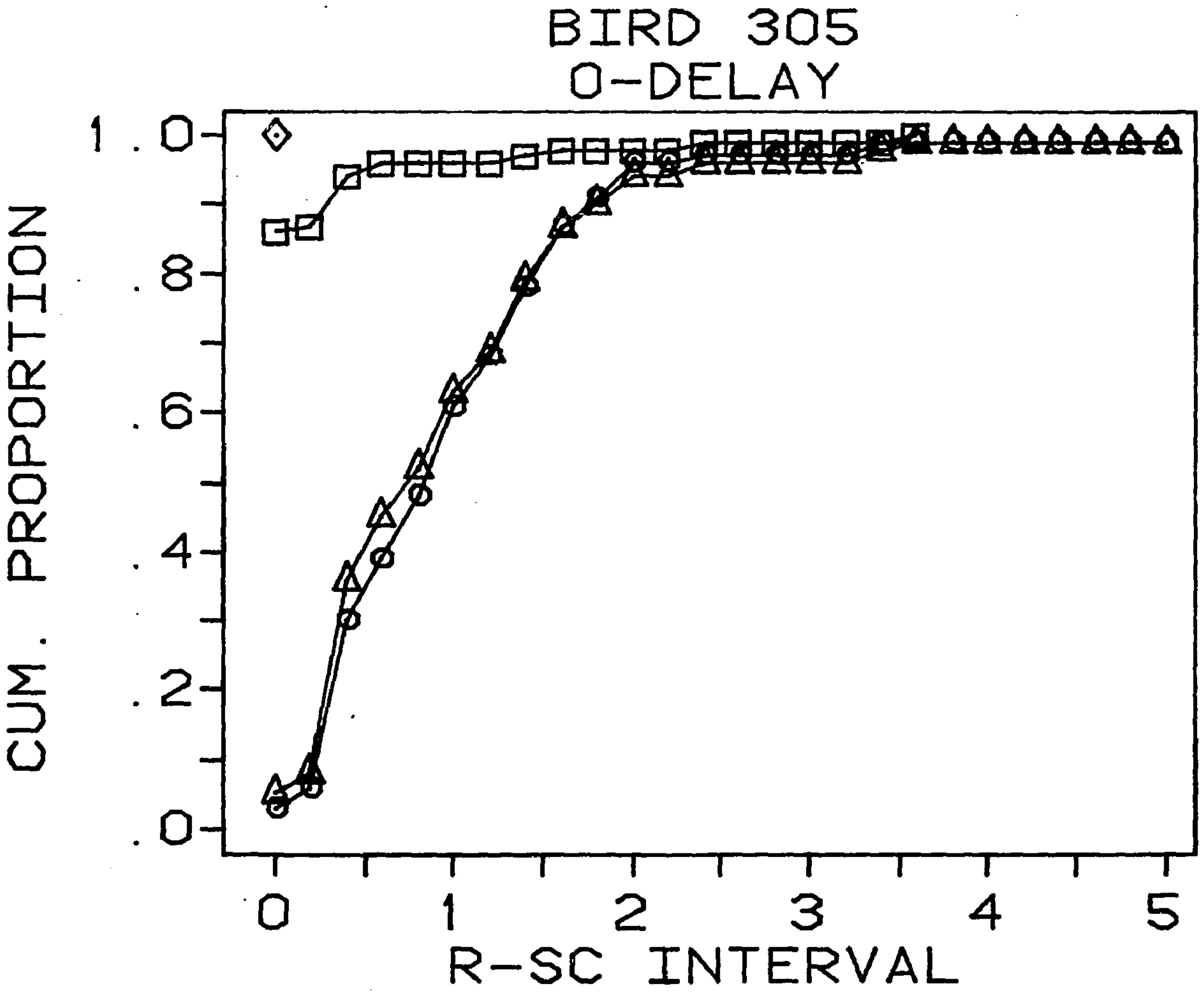

4 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 23. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 305 during the original 0-delay condition.

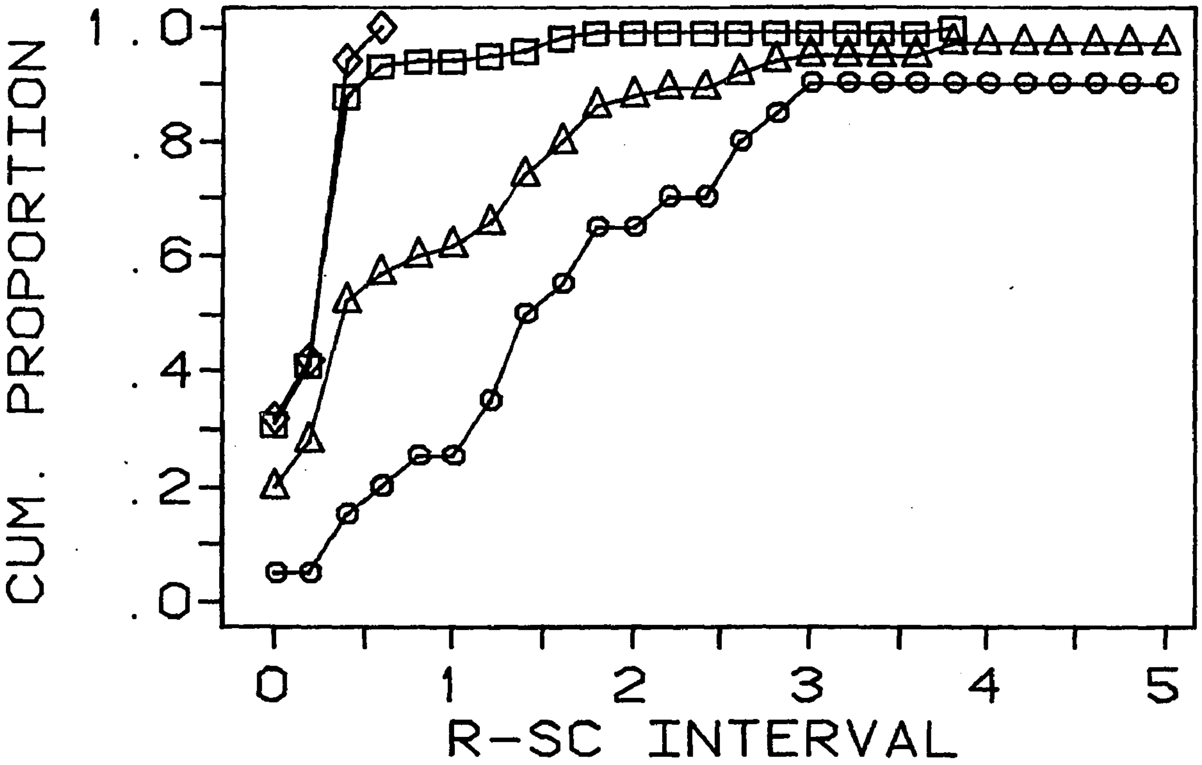


BIRD 305
O-DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 24. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 305. The upper panel represents performance during the .5 sec. programmed delay condition, and the lower panel represents performance during the 1 sec. programmed delay condition.

BIRD 305

.5 SEC. DELAY



1 SEC. DELAY

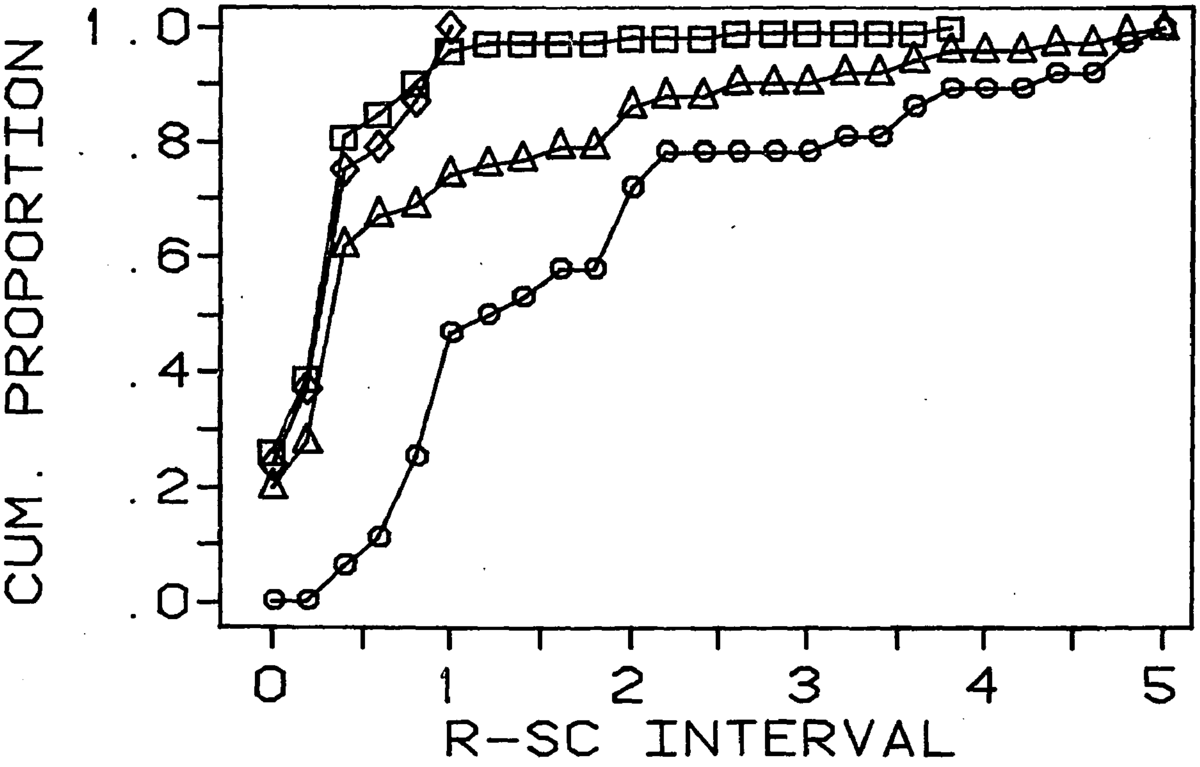
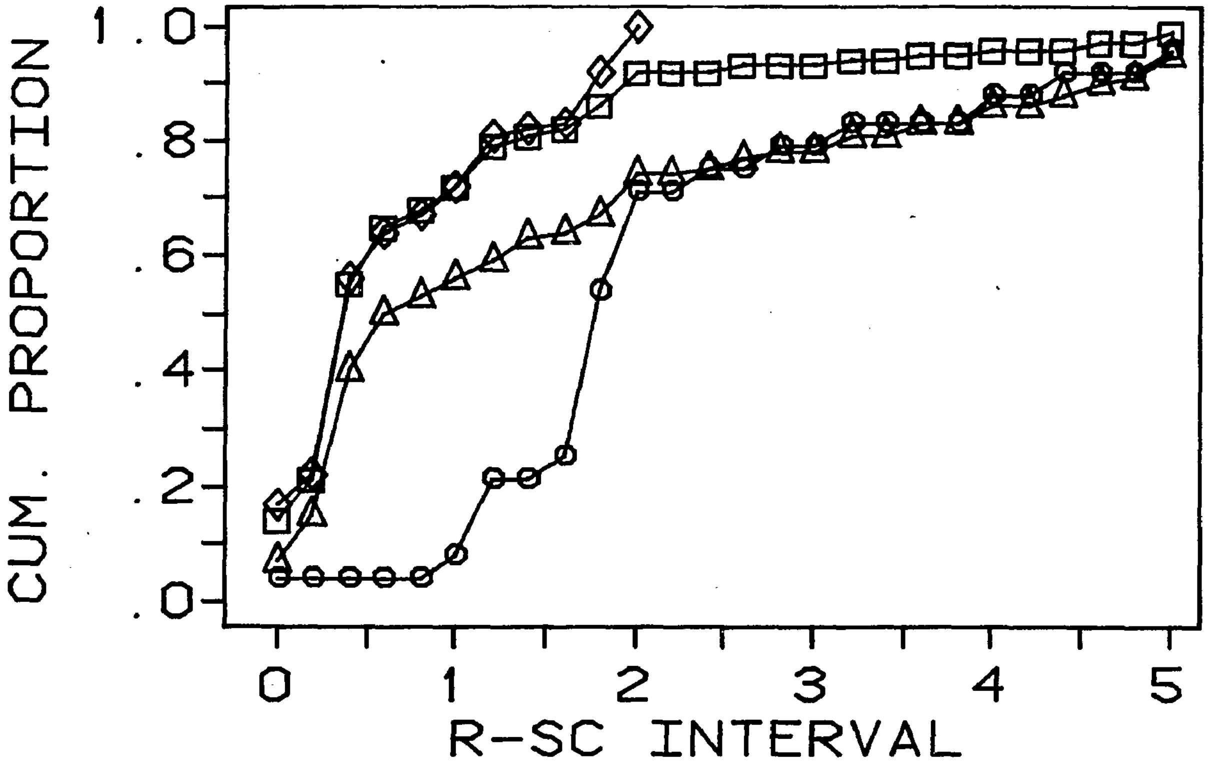


Figure 25. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 305. The upper panel represents performance during the 2 sec. programmed delay condition, and the lower panel represents performance during the 4 sec. programmed delay condition.

BIRD 305
2 SEC. DELAY



4 SEC. DELAY

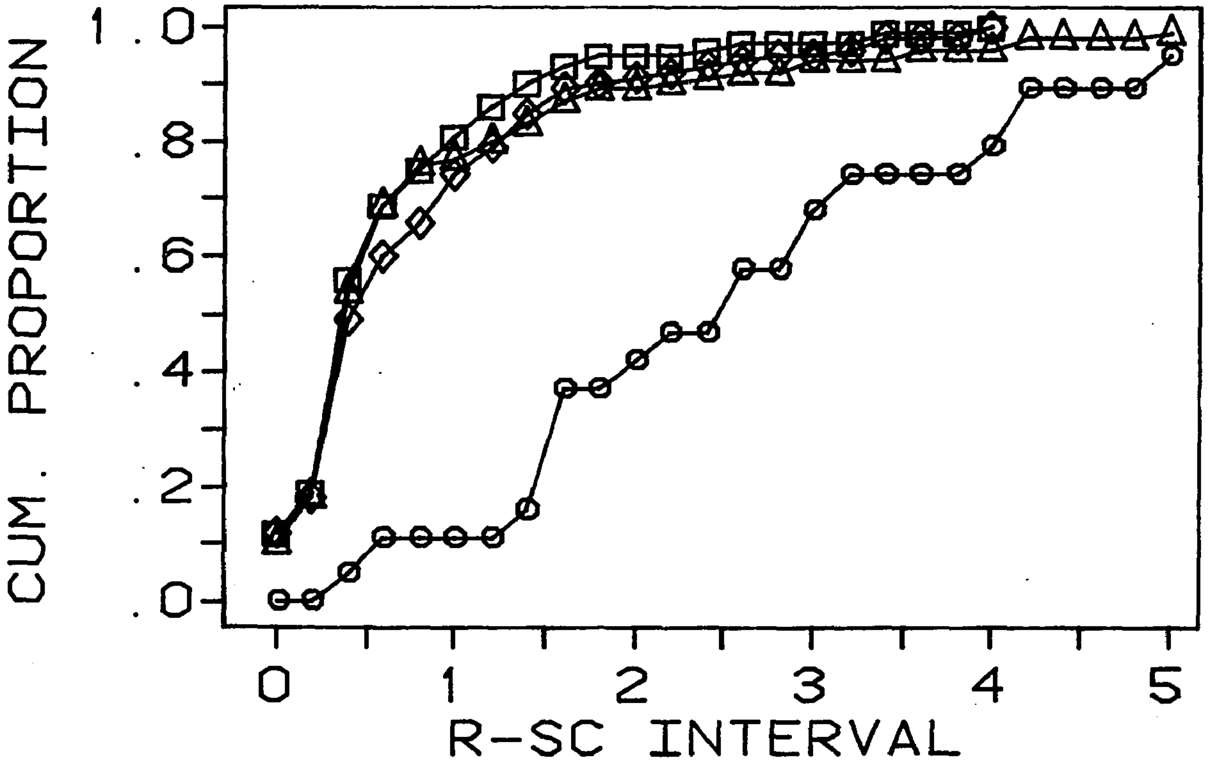


Figure 26. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 306 during the original 0-delay condition.

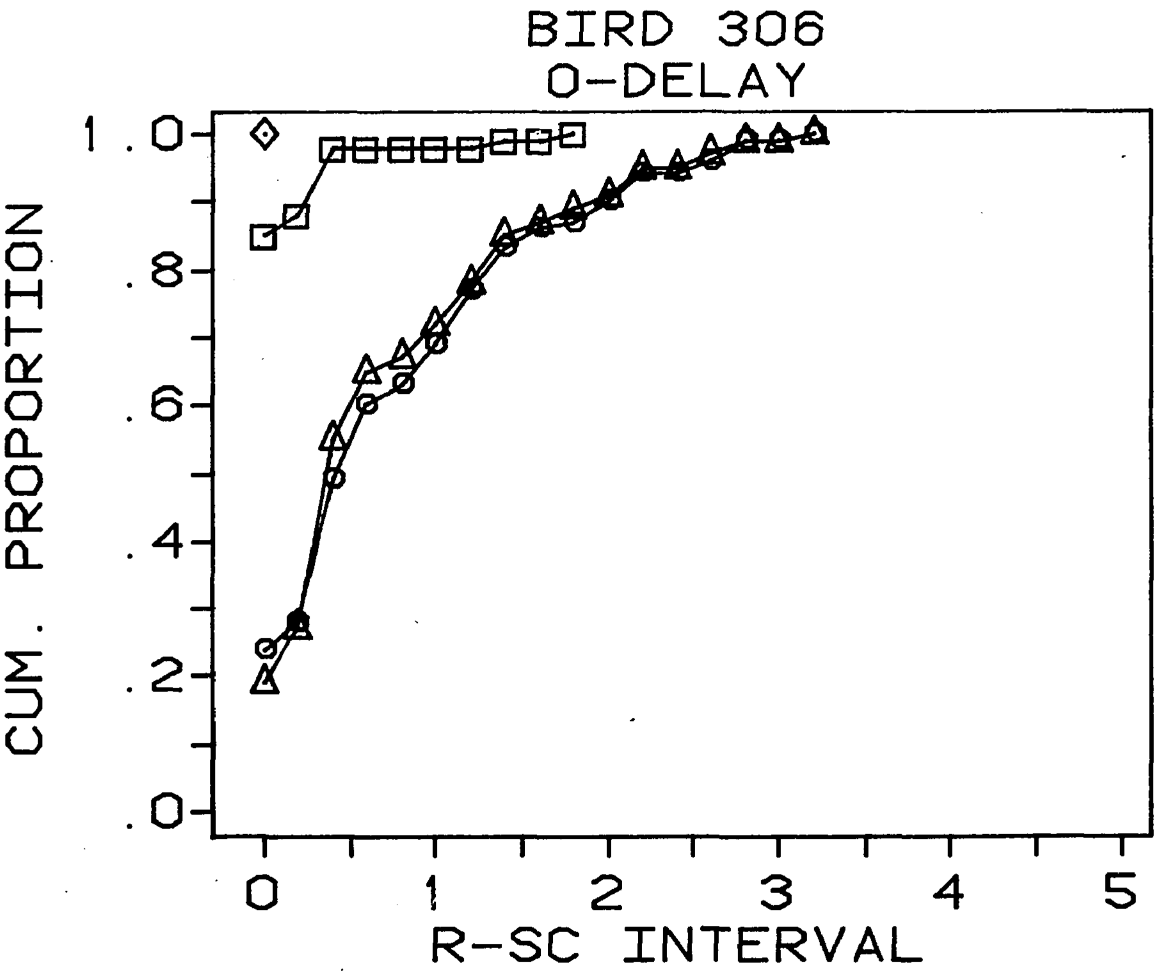
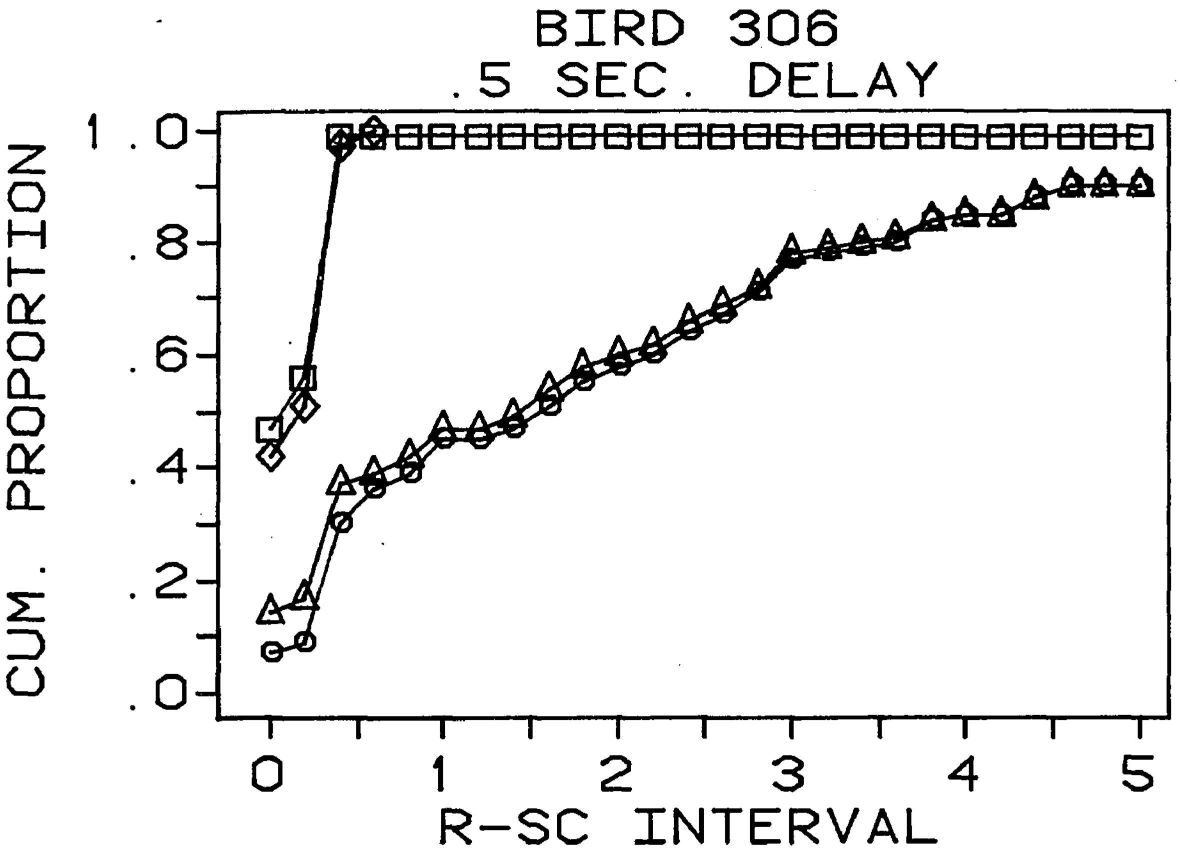

BIRD 306
0-DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 27. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 306. The upper panel represents performance during the .5 sec. programmed delay condition, and the lower panel represents performance during the 1 sec. programmed delay condition.


BIRD 306
.5 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

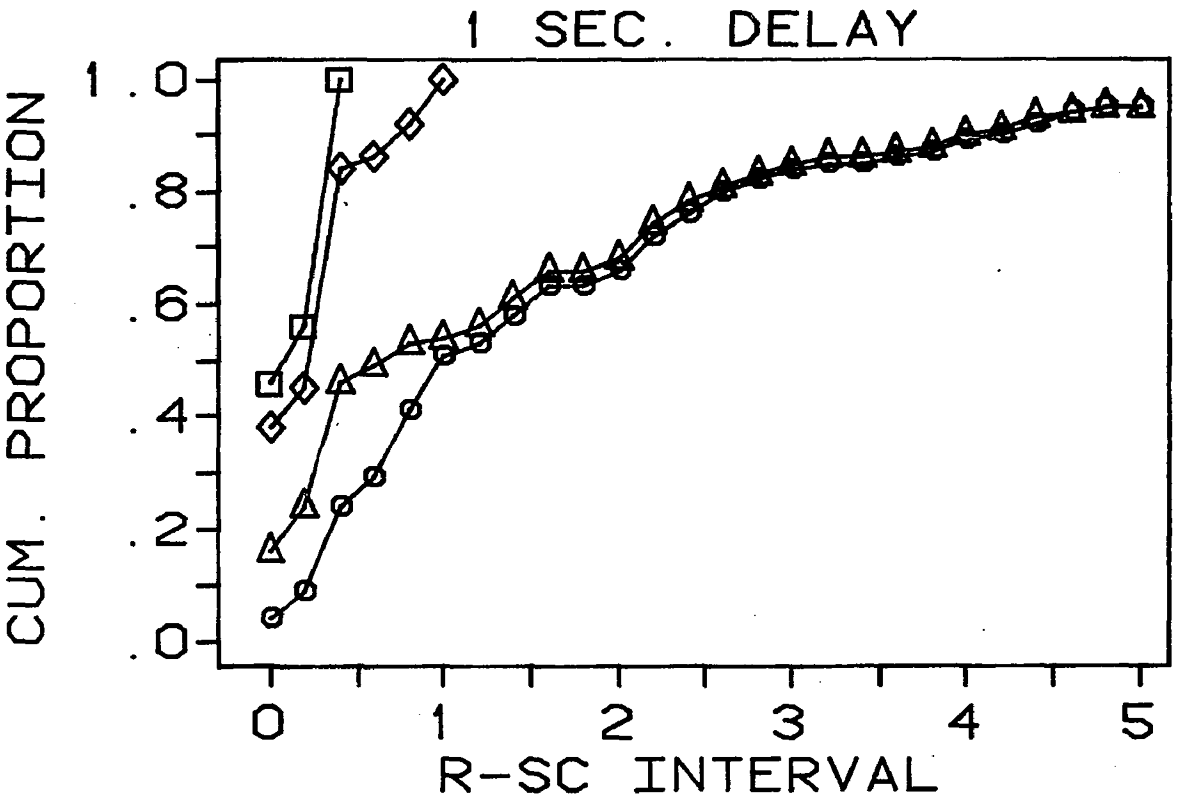
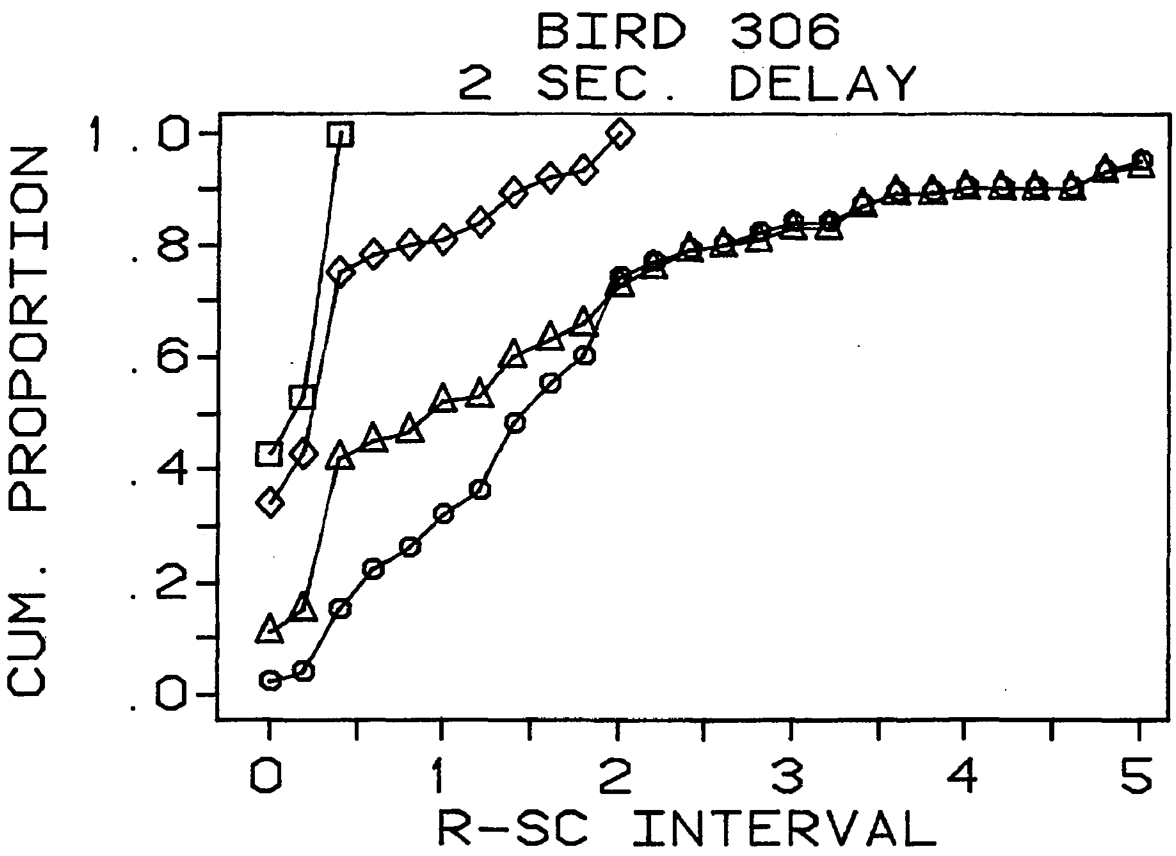

1 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 28. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 306. The upper panel represents performance during the 2 sec. programmed delay condition, and the lower panel represents performance during the 4 sec. programmed delay condition.


BIRD 306
2 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

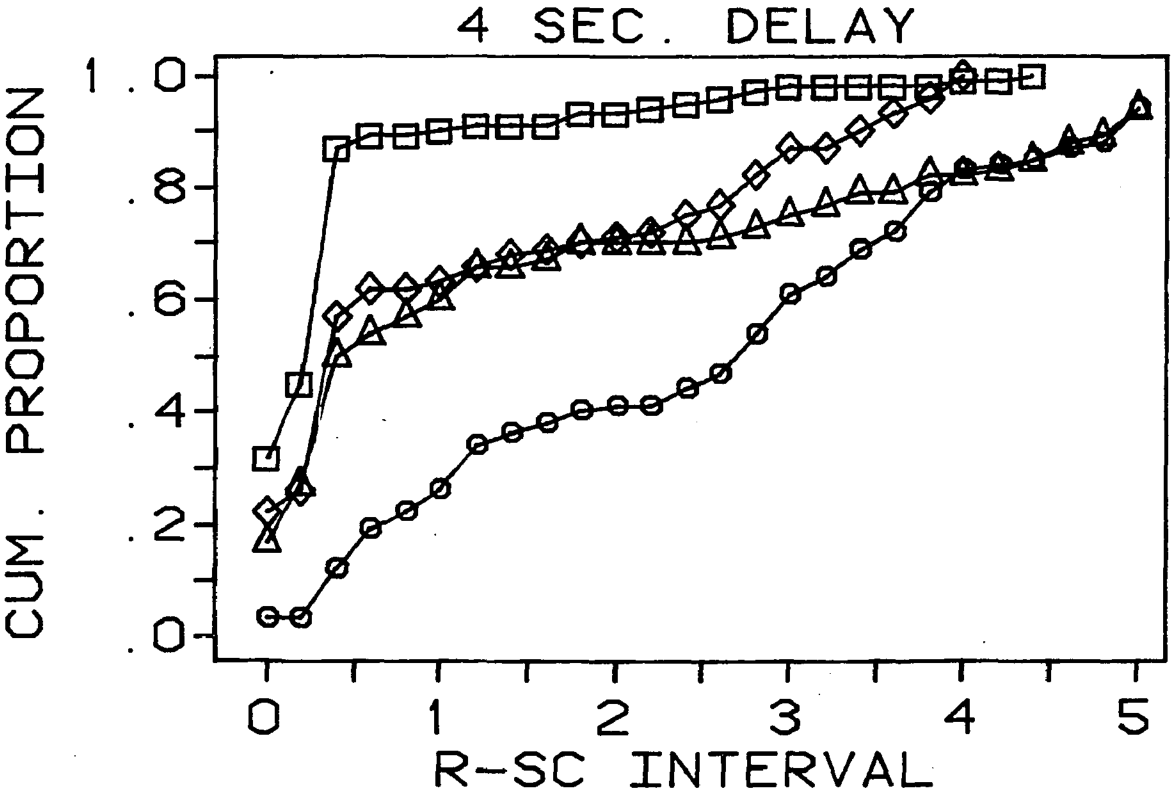

4 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 29. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 307 during the original 0-delay condition.

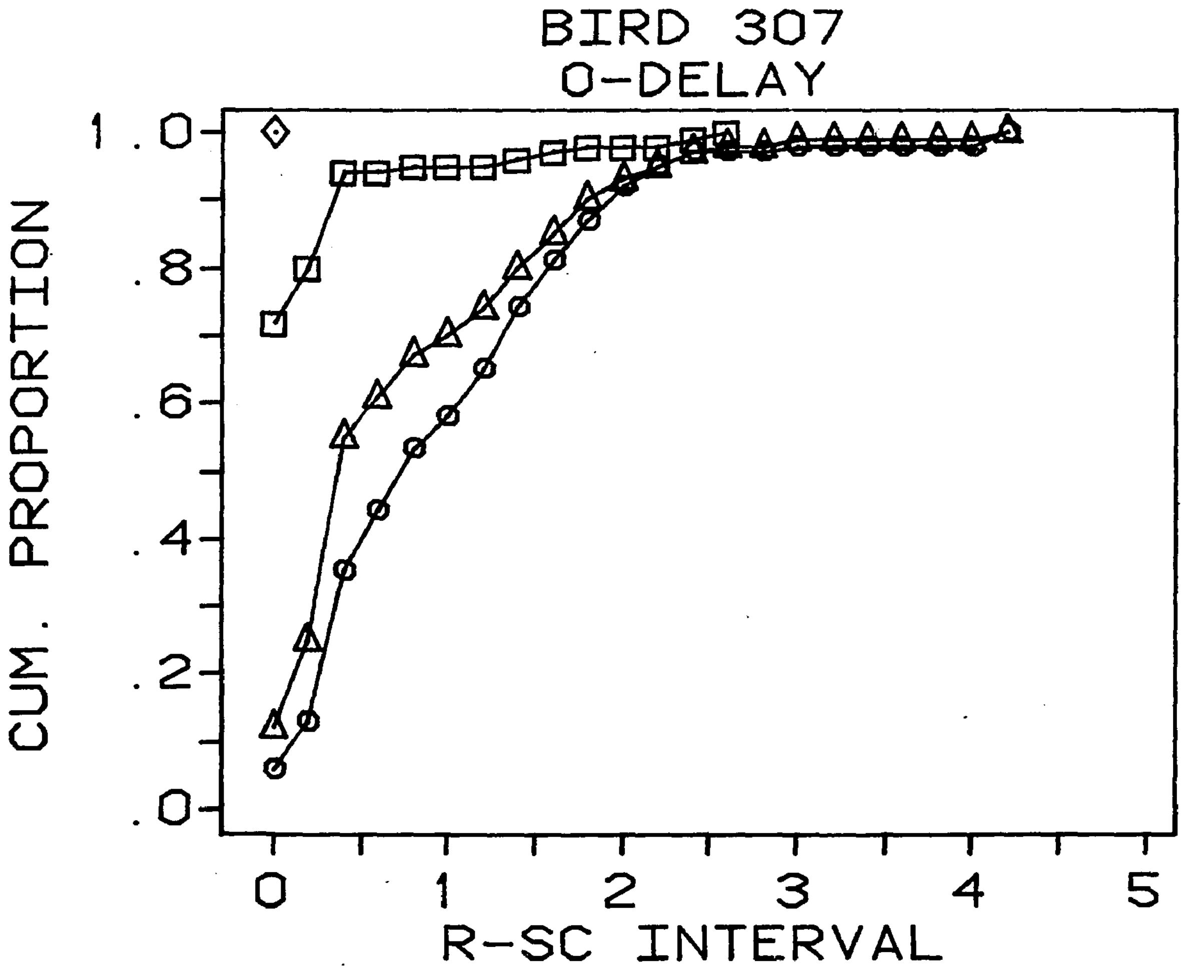
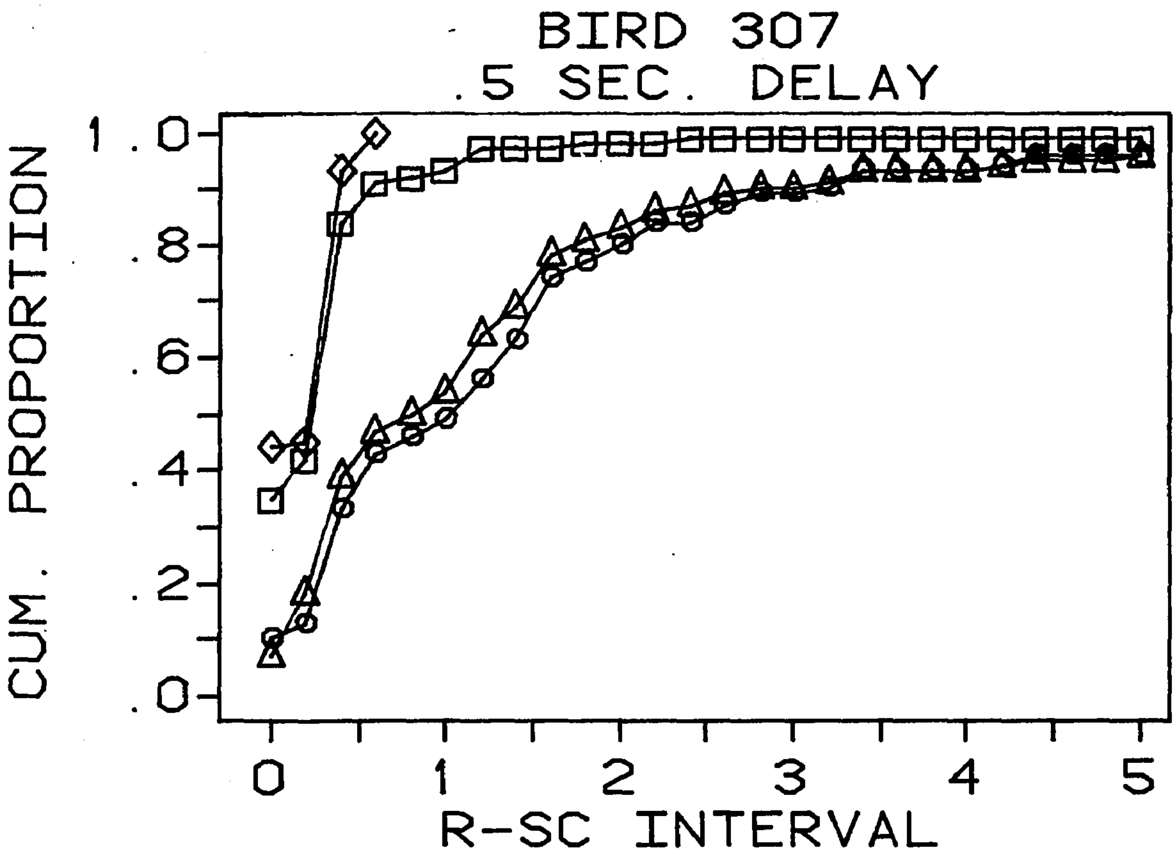

BIRD 307
0-DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 30. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 307. The upper panel represents performance during the .5 sec. programmed delay condition, and the lower panel represents performance during the 1 sec. programmed delay condition.


BIRD 307
.5 SEC. DELAY
CUM. PROPORTION
.0
.2
.4
.6
.8
1.0
0
1
2
3
4
5
R-SC INTERVAL

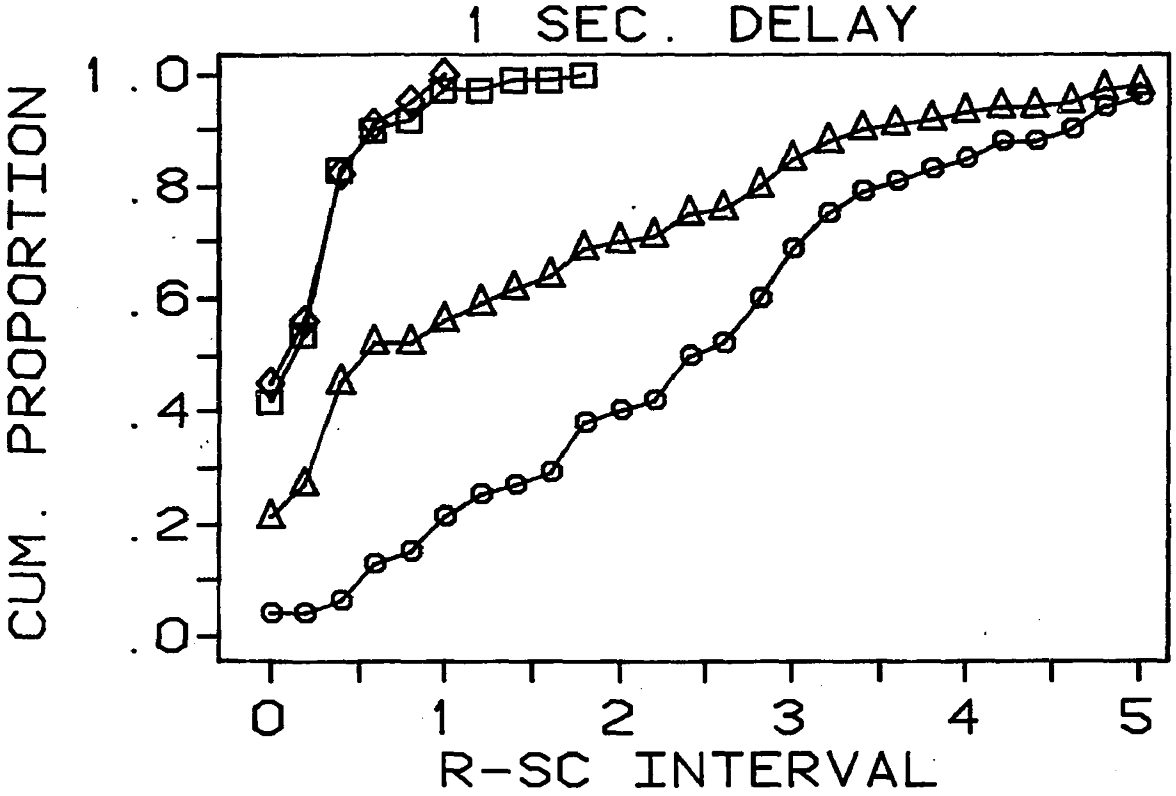
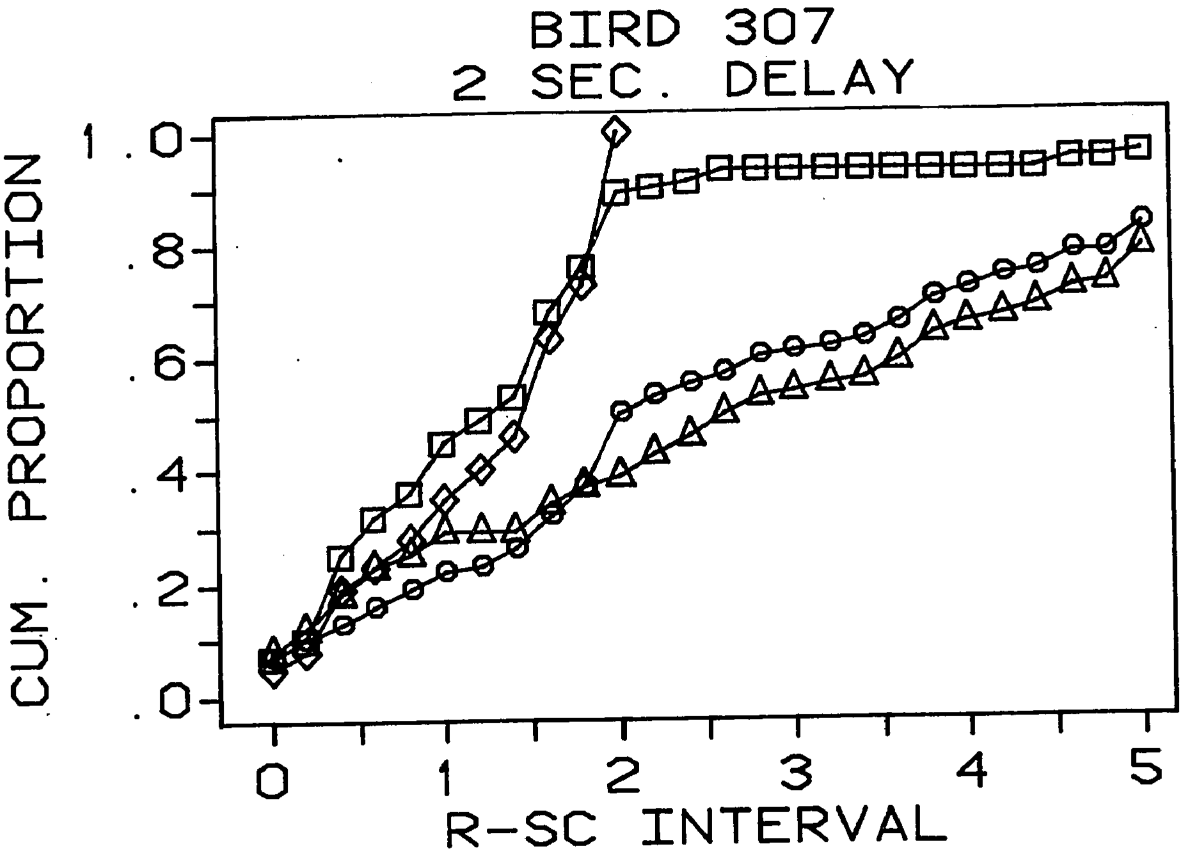

1 SEC. DELAY
CUM. PROPORTION
.0
.2
.4
.6
.8
1.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 31. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 307. The upper panel represents performance during the 2 sec. programmed delay condition, and the lower panel represents performance during the 4 sec. programmed delay condition.


BIRD 307
2 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

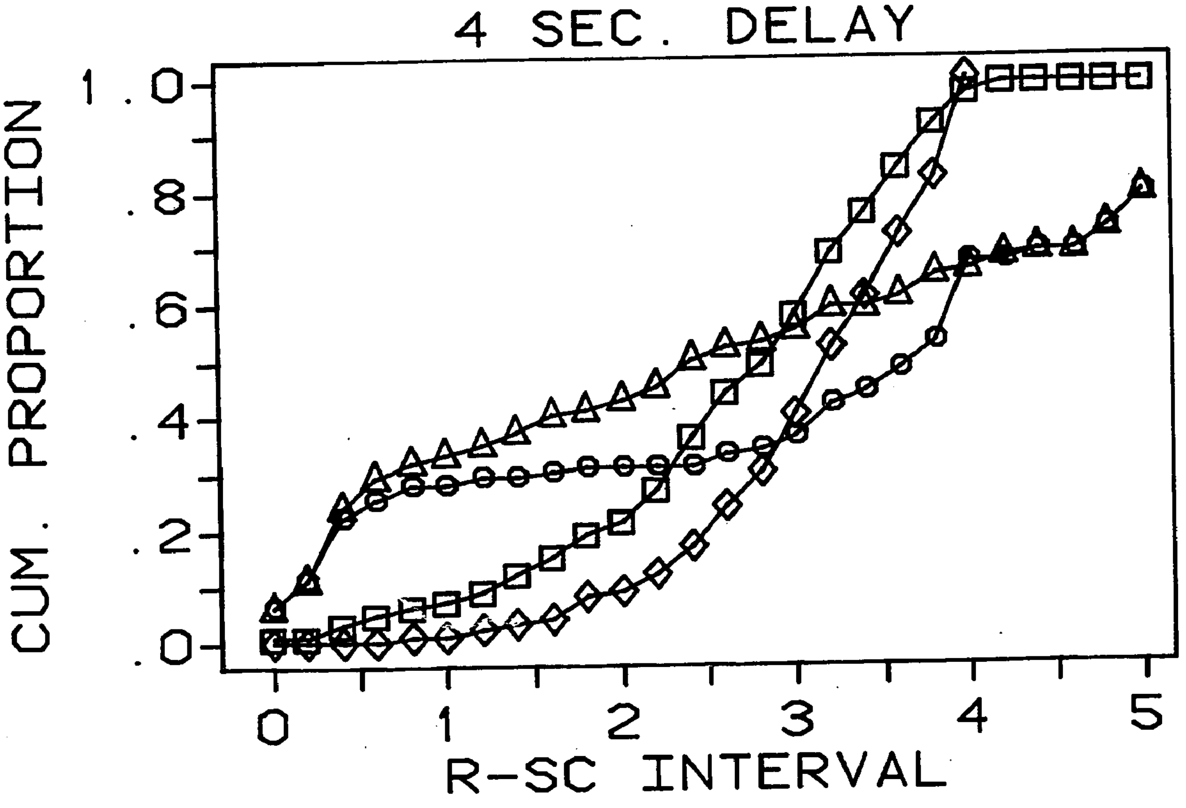

4 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 32. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 308 during the original 0-delay condition.

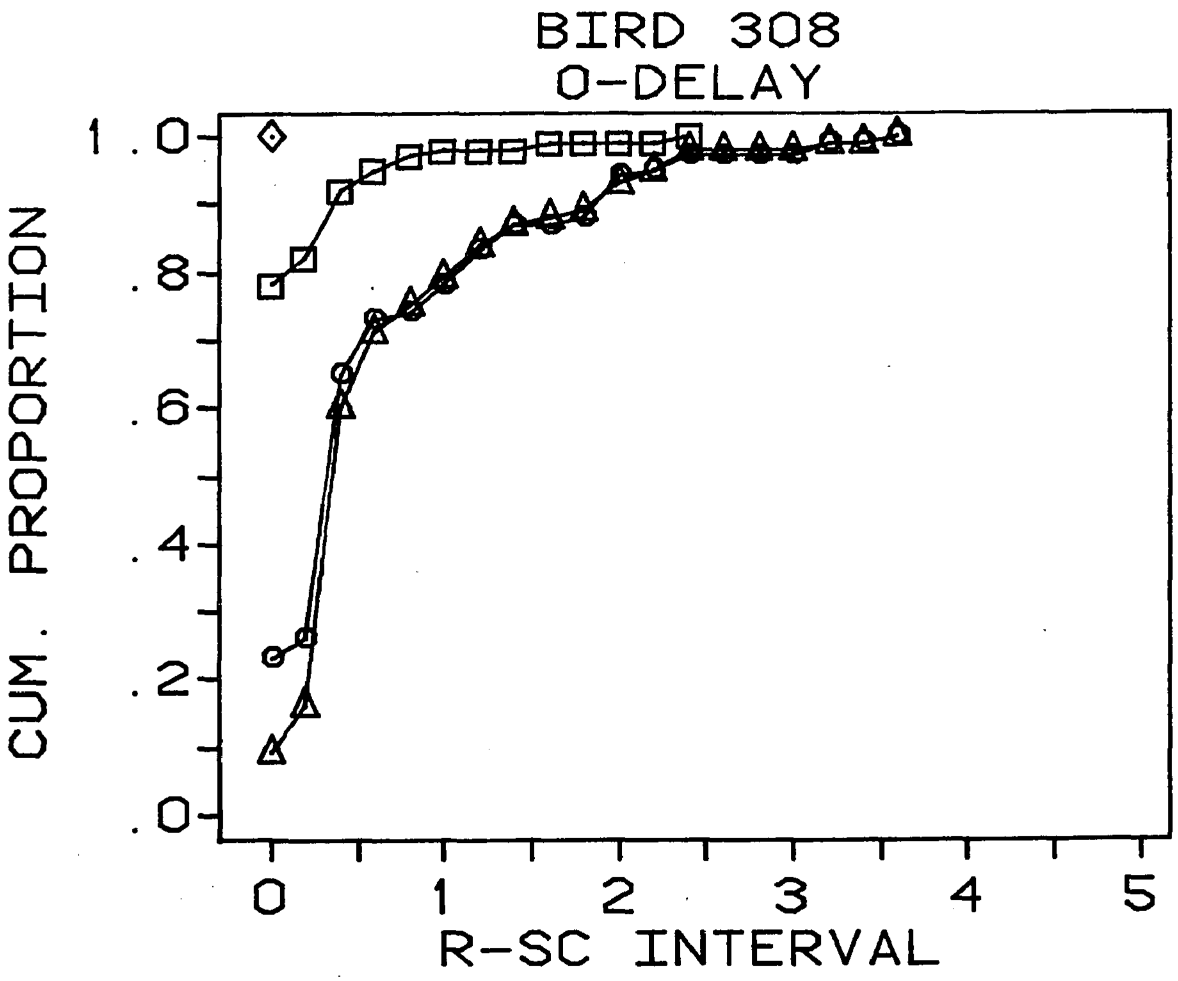
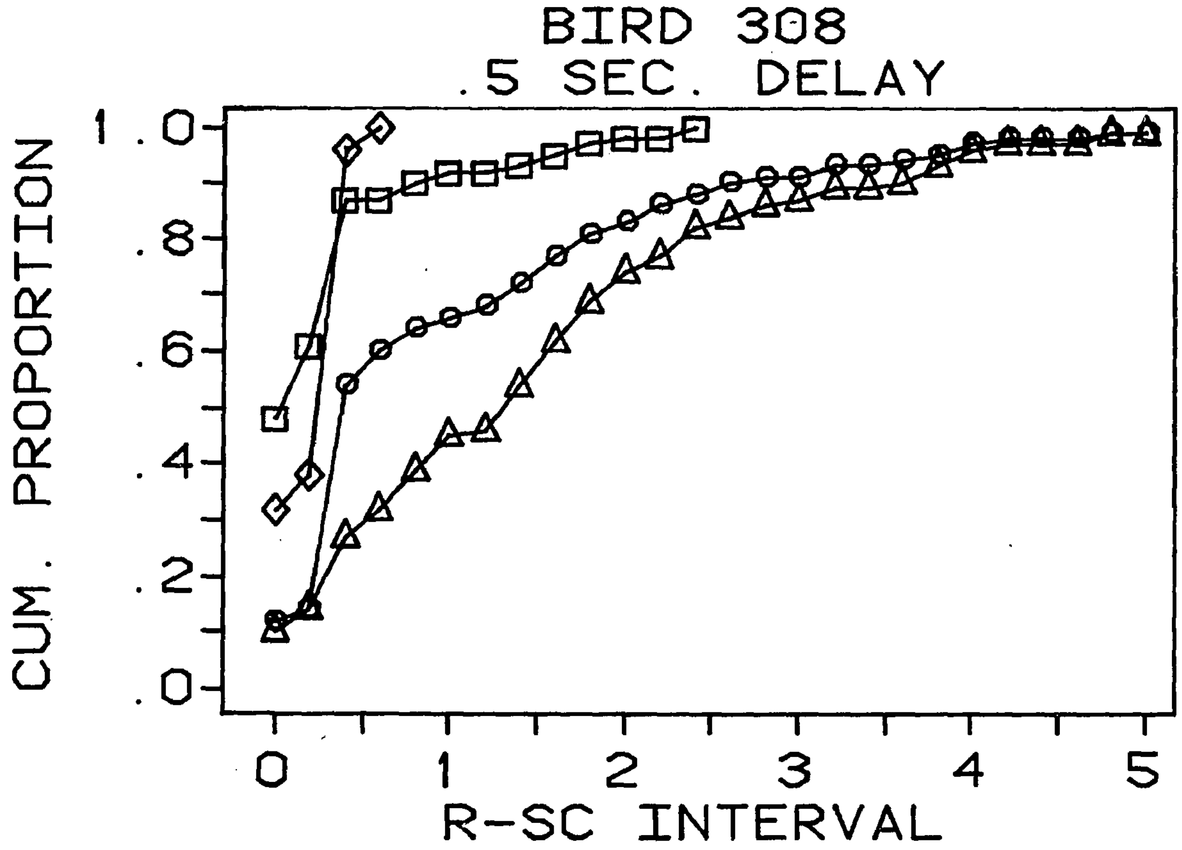

BIRD 308
0-DELAY
CUM. PROPORTION
.0
.2
.4
.6
.8
1.0
0
1
2
3
4
5
R-SC INTERVAL

Figure 33. Cumulative proportion of R-SC intervals preceding non-contingent SCs (traingles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 308. The upper panel represents performance during the .5 sec. programmed delay condition, and the lower panel represents performance during the 1 sec. programmed delay condition.


BIRD 308
.5 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

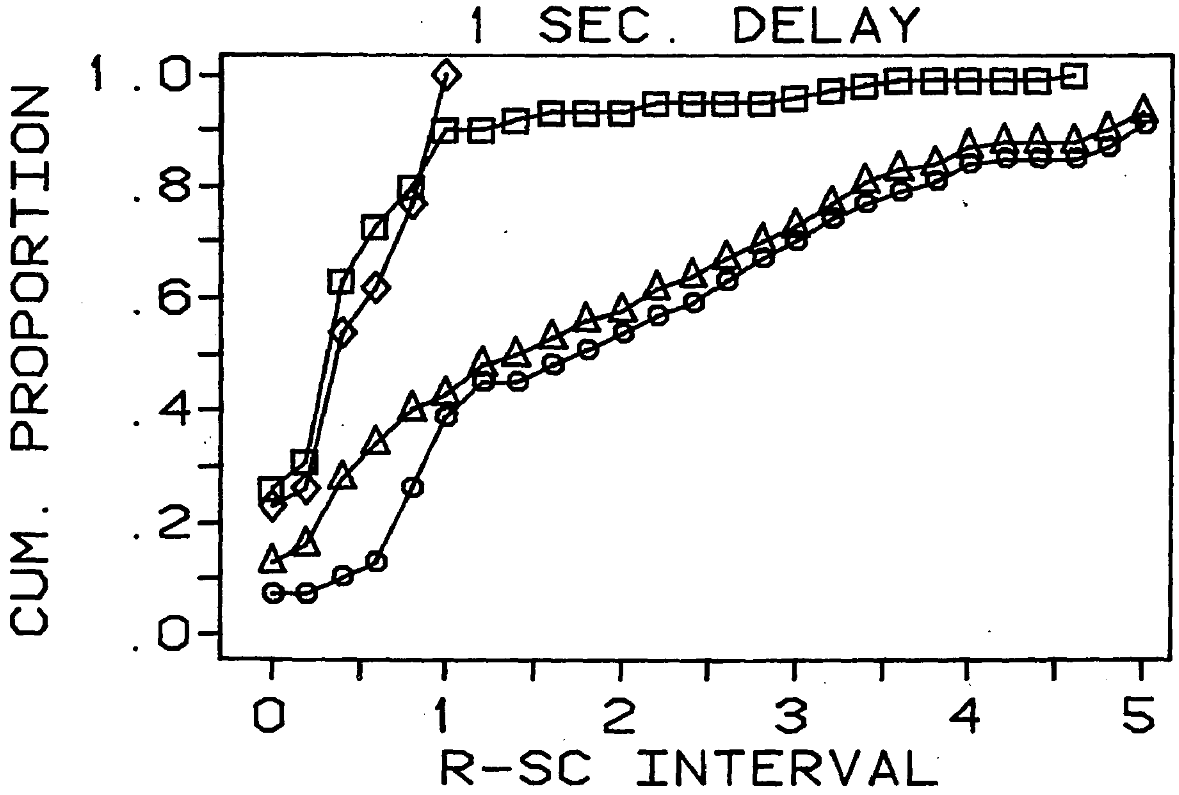
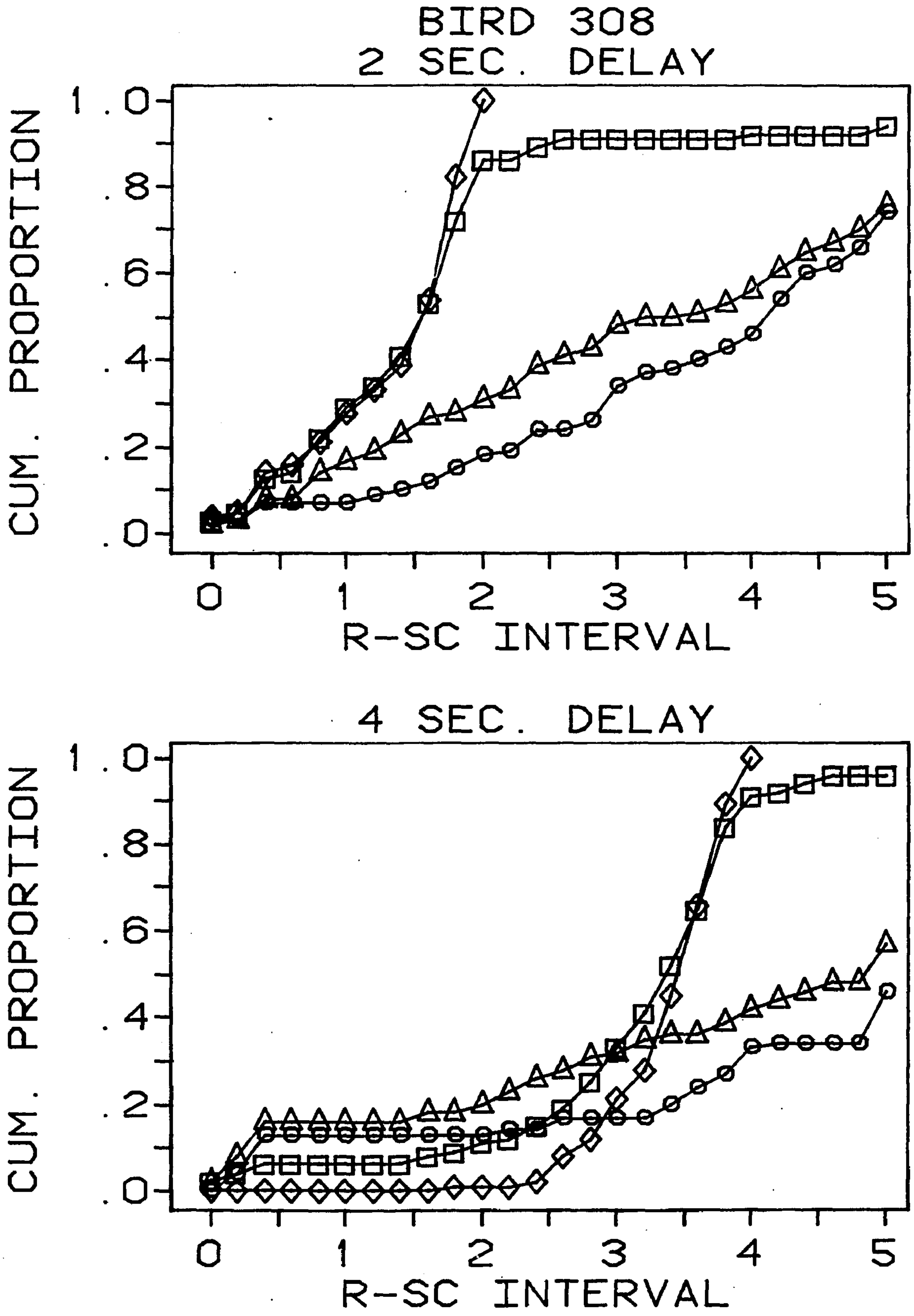

1 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

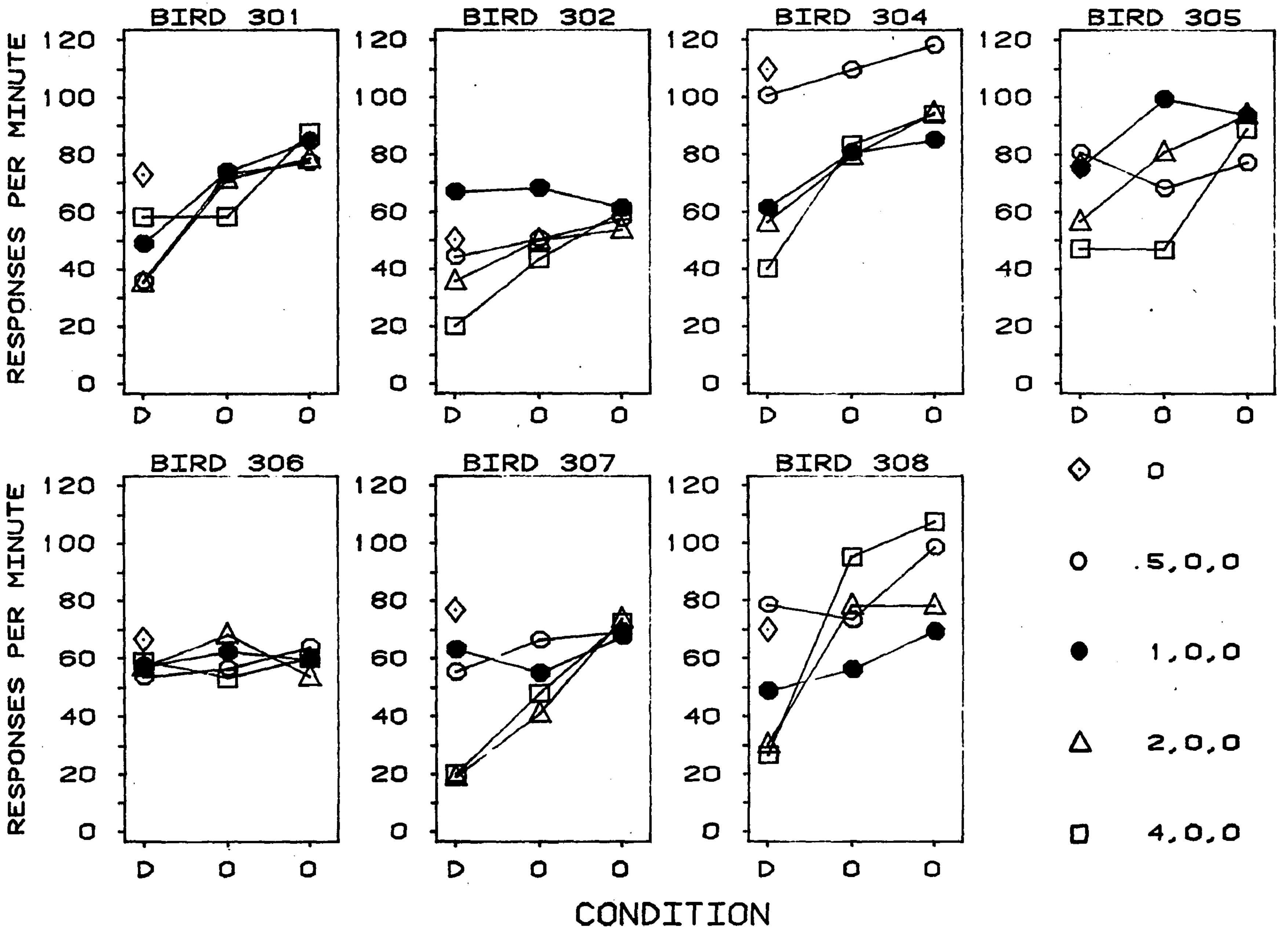
Figure 34. Cumulative proportion of R-SC intervals preceding non-contingent SCs (triangles), contingent SCs (diamonds), left side key responses (circles), and right-side key responses (boxes) for Bird 308. The upper panel represents performance during the 2 sec. programmed delay condition, and the lower panel represents performance during the 4 sec. programmed delay condition.


BIRD 308
2 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL
4 SEC. DELAY
CUM. PROPORTION
1.0
.8
.6
.4
.2
.0
0
1
2
3
4
5
R-SC INTERVAL

delay sample (Figure 16, upper panel). This extreme bias forced the choice function to fall mid way between the two source functions, or between the non-contingent function and 1.0 beyond the range of the contingent function. Bird 305, whose bias was to the right, put 10 to 18 percent of its choice responses on the left when a delay condition was in effect (see Figure 3). In spite of Bird 305's strong bias to the right, the magnitude, range, and direction of the differences between the non-contingent and left choice distibutions were consistent with those of the group, indicating that the length of the empirical R-SC intervals had enough control over choice responding to counter the bias on some trials. Birds 301 and 305 were the most deviant from the trends apparent in the group data when an abolishment condition was in effect (Figures 10 through 13), and Bird 306 was the most similar (Figures 26, 27, and 28).

Reinstatement of 0-delay. Between 30-session blocks in which a programmed delay was in effect were ten sessions in which all contingent SCs occurred immediately following the subject's effective response. Figure 35 shows the response rates for each subject. The left-most points on each function restate the response rates for each subject under each delay condition (Figure 2) to facilitate comparison with rates during the 0-delay reinstatements. The middle points show the response rates for the first five sessions

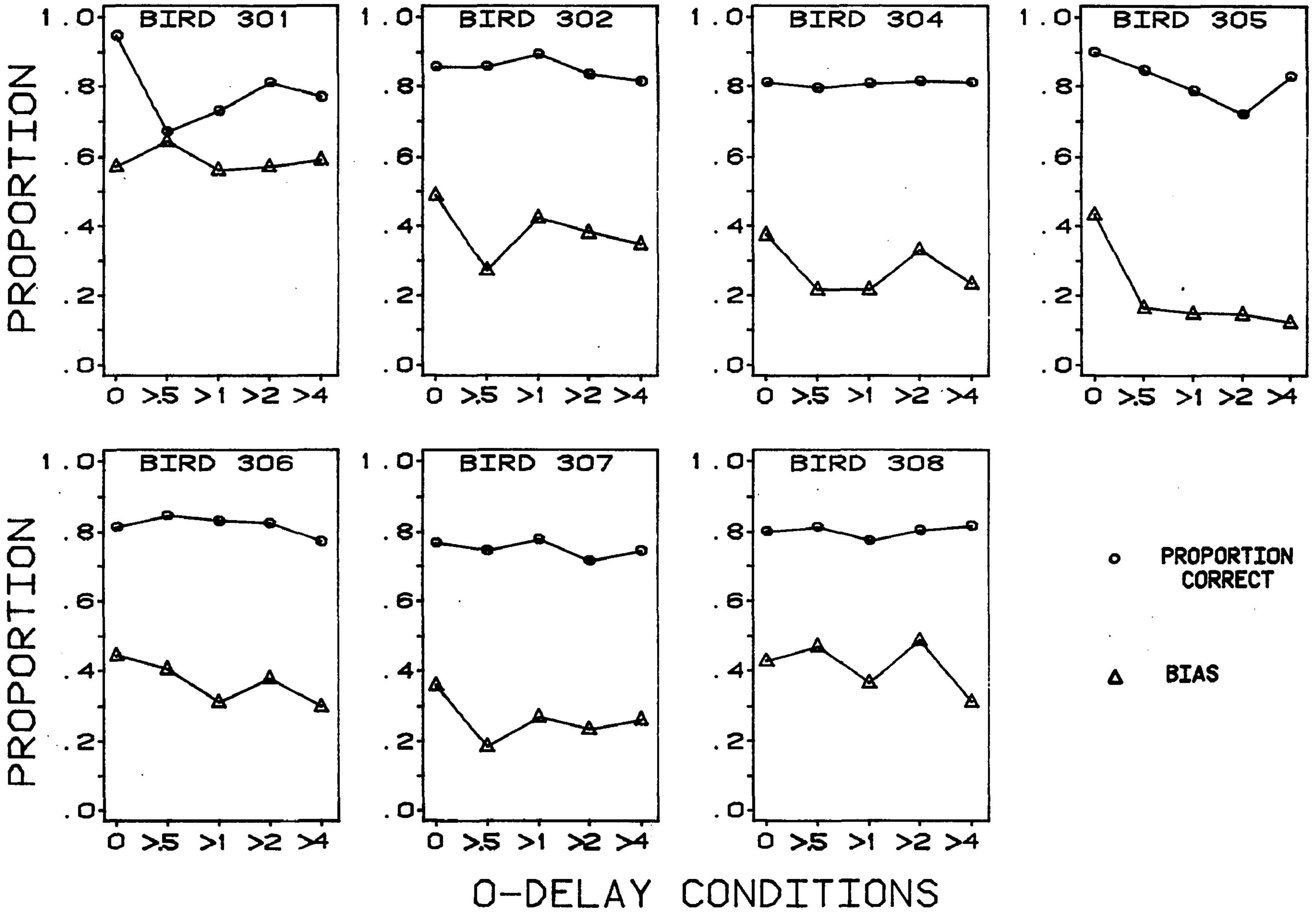
Figure 35. Responses per minute for each subject. The left-most points in each graph represent response rates at the original 0-delay condition (diamonds), and at each programmed delay condition. The center points represent response rate during the first five 0-delay reinstatement sessions following each programmed delay condition. The points on the right show response rates during the last five 0-delay reinstatement sessions. Each delay condition is represented by the following symbols: .5 sec., open circles; 1 sec., filled circles; 2 sec., triangles; 4 sec., boxes.


BIRD 301
BIRD 302
BIRD 304
BIRD 305
BIRD 306
BIRD 307
BIRD 308
RESPONSES PER MINUTE
0
20
40
60
80
100
120
D
0
0
CONDITION
◇ 0
○ .5,0,0
● 1,0,0
△ 2,0,0
□ 4,0,0

following the shift from an abolishment condition back to 0-delay, and the points on the right show rates during the last five sessions of each 0-delay condition. The tendency was for rates to increase during each reinstatement of the 0-delay condition following each delay condition.

Figure 36 shows the percent correct and bias of each subject for the last five sessions of each 0-delay condition. The left-most points are, again, those that were presented as the left-most points in Figure 3, the original 0-delay condition. The changes in accuracy and bias were greatest for Bird 301 when compared to the conditions in which a delay was imposed. The fact that this subject was extremely biased toward the left during delay conditions may be viewed as an indication of excellent temporal discriminative ability, rather than as a lack of discriminative behavior. It may be that this bird learned the original task so well that its criterion for voting contingent, or "caused", when a SC occurred was very stringent. That is, during the original 0-delay condition (Sessions 1 through 120) the rule was: immediate SCs meant a response on the right side will be reinforced; longer than immediate meant respond left for reinforcement. During subsequent sessions, whenever a programmed delay was in effect, the rule changed. Efficiency, in terms of number of responses per reinforcement, was enhanced if the rule, respond right for short, left for long, was obeyed. This is particularly likely in cases where response rates

Figure 36. Each subject's proportion of correct responses (circles) and proportion of left side key responses (triangles) at the original 0-delay condition (left-most points), and each 0-delay reinstatement condition.


BIRD 301
BIRD 302
BIRD 304
BIRD 305
BIRD 306
BIRD 307
BIRD 308
PROPORTION
PROPORTION
1.0
.8
.6
.4
.2
.0
0
>.5
>1
>2
>4
PROPORTION CORRECT
BIAS
O-DELAY CONDITIONS

decreased enough to allow a substantial proportion of R-SC intervals to exceed the range of abolishment. This rule, however, could only be evident to subjects who occasionally responded on the right following longer R-SC intervals. If, as with Bird 301, a subject never violated the first rule, the second could never be learned.

During each 0-delay condition roughly half of the SCs were immediate in each session, because roughly half were contingent. When an abolishment condition of any value was in effect virtually all R-SC intervals were greater than zero, and the only SCs that would be judged "immediate" were those with R-SC intervals approaching zero. The extremely rigid criterion of Bird 301 resulted in drops in overall percent correct and a lower rate of reinforcement, which resulted, in turn, in a drop in response rate during any abolishment condition. Bird 301 was the best at discriminating immediate from delayed SCs during the original 0-delay condition, and its percent correct was the lowest when any programmed delay was in effect. Response rate and accuracy recovered when 0-delay was reinstated as the subject experienced more immediate SCs and put a substantially larger proportion of its responses on the right.

One may speculate as to which type of R-SC interval, immediate or long, had the greatest value as a cue, and perhaps be led to different conclusions by different subjects. Although the relatively longer ones were consistently reliable in cuing the availability of reinforcement for a left response, Bird 301 obviated the cuing properties of long R-SC intervals by responding almost exclusively on the left. This subject's rate of responding seemed to be controlled directly by rate of reinforcement, as measured by number of responses per reinforcement, without the additional control source of discriminative temporal cues still available during abolishment conditions. This is supported by the data marked by triangles in Figure 2. Although the temporal frequency of SCs and, to a lesser extent, reinforcements, varied directly with rate of responding for all subjects, the number of responses per reinforcement varied the most, and was greatest during abolishment conditions, for Bird 301. When the 0-delay condition, and, along with it, the proportion of immediate SCs, was reinstated, the subject's criterion for voting "caused" was more often met, responses occurred on the right more frequently, accuracy increased, and response rates increased.

If Bird 301 was the most rigid and stringent in placing choice responses according to the criterion of immediate <u>versus</u> not immediate, then Bird 306 was the most flexible. Although Bird 301 was very sensitive to temporal differences, it appeared insensitive to differences in the programmed delay value. Bird 306 seemed sensitive to both from its ability to maintain a high level of accuracy across all conditions with minimal changes in response rate or bias (Figures 2, 3, 35, and 36). In Figures 26, 27 (upper panel), and 28 (lower panel) the right-side response functions (boxes) show that Bird 306 was occasionally responding on the right following longer R-SC intervals. This occasional sampling enabled this subject to come in contact with a greater proportion of the range of possible contingencies as they changed in each abolishment condition.

The performance of Bird 307 reveals a different aspect of the discimination of time. This subject's response rate shows a 70 percent decrease when the 2 sec. delay condition is compared to the 1 sec. delay condition. When delay was increased to 4 sec., long pauses (up to one hour) began to occur after some SCs. (Because they occurred after the SC they are not reflected in Figure 2.) These pauses affected the distributions of R-SC intervals so as to effectively reverse the contingencies of the task. Within the range of abolishment, a substantial proportion of contingently produced R-SC intervals were longer than R-SC intervals following non-contingent SCs (Figure 31, lower panel). Bird 307's sensitivity to this effective reversal of contingencies accounts for the 105 trials it took to complete the first 0-delay reinstatement session that followed the 4 sec. delay condition (p. 28).

SUMMARY AND CONCLUSIONS

When presented with a trial by trial, non-correction task in which reinforcement may be obtained by responding on one of two choice keys, seven pigeons learned to respond on the left choice key when a discriminative stimulus change event was non-contingent, and on the right when the event was contingent. The discriminative events were distinguishable on the basis of their temporal relationship to the subjects' prior responses on a key located between the two choice keys. The non-contingent events could follow the center key responses by an amount of time greater than zero. This produced a distribution of times between the subject's last response on the center key and the stimulus change, limited by coincidence at one end, and the subject's interresponse time at the other. Each contingent stimulus change was temporally contiguous with a response. When a delay was introduced between the response and the contingent SC, a distribution of times preceding contingent SCs was produced, limited by coincidence at one end, and the programmed value of the imposed delay at the other. Two variables affected the amount of overlap between the distribution of times preceding contingent SCs and the one preceding non-contingent SCs. The programmed delay (an independent variable) set the limits of the contingent distribution, and the subject's rate of responding on the center key (a dependent variable) determined the range of the non-contingent distribution. These variables determined the objective discriminability of the events, but were not the only determinants of the subjects' behavior.

Both rate of responding and percent correct tended to decrease as delay was increased, but they did not covary in any systematic way across subjects. Each subject's response rate varied with percent correct in a unique way. Sidman (1980) cautioned against depending on percent correct as a measure of discriminative performance. While it is true that differing choice behavior does indicate a difference between subjects, that difference may not be in the ability of the subjects to discriminate time.

When presented with an R-SC interval that might have come from either distribution, each subject seemed to be choosing left or right according to a criterion that varied from subject to subject. Furthermore, each subject differed in the amount that its criterion for choosing right over left shifted, as programmed delay was increased. For one subject (Bird 301) that criterion never shifted, resulting in that subject choosing the left choice key whenever any delay was perceived preceding a stimulus change. While this subject was the most accurate of all during sessions in which no contingent delay was programmed, its accuracy dropped to chance when a contingent delay of any value was in effect. For some subjects the criterion for choosing left or right changed as the value of the programmed delay was changed. In these situations the differences in percent correct were not as great between delay and no-delay conditions as they were for Bird 301.

One argument addressed by these data is the contention that time between delivery of reinforcements is a primary determinant of response rate in most conditioning situations (cf. Ferster and Skinner, 1957). Of course, the present data can in no way be construed as refuting that hypothesis, but they did result from a situation in which other sources of control seemed to exert a major influence on rate of responding.

The center key response rate of Bird 301 dropped, as did the rates of the other birds, during delay conditions. However, rather than change as a function of programmed delay, it dropped and stayed relatively low when any delay was imposed, but recovered to its pre-delay rate during all 0-delay reinstatement conditions. Bird 301 seemed to get no cues from long R-SC intervals since only virtually immediate SCs occasioned right-side key responses (see Figures 14 through 16). Those were rare when a contingent delay was in effect. Consequently, she responded left. The other subjects' rates changed when the delay condition was changed, suggesting that the value of the R-SC interval had some control, not just the lack of immediacy. That source of control was probably the relative production of long R-SC intervals, which were more discriminable, leading to greater accuracy and more reinforcements per unit time.

Most subject's response rates rose during the 0-delay recovery conditions, and probably for the same reason: Reinstatement of the 0-delay condition brought reinstatement of reliable cuing properties of all R-SC intervals. The reinforcement rate increased because percent correct increased. Percent correct increased because the temporal cues supplied by short R-SC intervals became reliable, so slower responding did not have as much instrumental value toward maintaining distinctions between distributions.

In addition to response rate, percent correct, and bias, a measure was derived which allowed direct comparison of objective non-contingent and contingent distributions of R-SC intervals preceding subjective left and right choices. This measure showed that, when faced with a choice based on the length of an R-SC interval that might have preceded either a non-contingent or a contingent SC, the subjects tended to respond on the left following longer R-SC intervals, and on the right following shorter ones, regardless of the objective source of the SC. The subjects whose criteria shifted the most as the distributions of intervals changed in percent of overlap were the ones whose criteria were most variable. That is, the subjects who occasionally responded on the right following the longer intervals, and on the left following shorter ones, were the subjects most "in contact" with the shifts in contingency effected when programmed delay was increased.

The particular interest expressed in this study was in the properties of the discriminative behavior occasioned by certain temporal parameters, and their possible relationship to the perception of causality as conceived by Michotte (1963) and others. Killeen (1978), for example, assumed that a relationship existed between his subjects' perception of causality and the temporal proximity of their responses to subsequent stimulus events. He then proceeded to explore the relative amount of control exerted by incentive on his subjects' distribution of left and right side key responses, testing the contention of "'threshold psychophysicists' who hold that motivational variables affect a judgmental stage subsequent to perception (Killeen, 1978, p. 89)." The present experiment attempted to directly manipulate the temporal contiguity between contingent responses and ensuing SCs, and thereby modify the subjects' perception of causality inasmuch as it may be determined by the temporal proximity of behavior and its consequences.

The situation arranged by the experimenter presented various distributions of temporal stimuli (R-SC intervals) to the subject. If we stand _in loco columbidae_ when a delay is first imposed between our response and its SC, we respond on the left and experience non-reinforcement as a consequence. If we are persistent in this choice pattern we might respond on the right only when the R-SC interval is so short that it is indiscriminable from immediate, and earn reinforcement for only some of our rare right key responses. Such a situation might be perceived as one in which responses on the right choice key were no longer being reinforced, and the left key was being reinforced only half the time. Although the subject is still discriminating temporal intervals quite precisely, he will get no more reinforcement than if he were dividing his responses randomly between the choice keys.

A different perspective is revealed by a subject who occasionally sampled both keys following long and short R-SC intervals. This subject would experience reinforcement on the right following intervals that were previously unreinforced, as well as extinction on the left following some intervals that had always been reinforced on the left. This could lead to a shift in criterion, and more reinforcers, because some of the longer R-SC intervals remained reliable in cuing reinforcement for responding on the left.

Finally, despite a multitude of strategies, it remains clear that all the subjects were dividing the distributions of R-SC intervals according to some criterion, and the more sensitive that criterion was to environmental changes, the more efficient the subject, as measured by overall percent correct. This is in agreement with Killeen's concluding statement in which he said, "Viewed in this light, flexible criteria for attribution of causality...are more adaptive than fixed criteria that cannot shift to optimize expected payoff (1978, p.89)."

The present study is an example in support of the contention of Killeen and others, that discriminative performance does not always reflect discriminative ability. It may also be viewed as providing clear examples of Sidman's (1980) point regarding conditional discrimination analyses, and several suggestions were made for measures to be used in conjunction with, or as alternatives to percent correct.

With regard to the perception of causality per se, compelling cognitive interpretations require caution and scrutiny. It is all too easy to bridge the gap separating objectivity and inference with logic, abundant in surface validity, that strays beyond the data. That the subjects can distinguish contingency in this experiment there is little doubt. That temporal variables determine the choices that reveal the distinction is also clear. Whether they call the event-relationships "caused" or not we cannot know. Experiments of this type encounter obvious disadvantages when infra-human subjects are unable to obey instructions or describe phenomenological "impressions". Nevertheless, there are intriguing similarities between the behavior of pigeons and that of humans confronted with analogous experimental situations. When asked to make a judgment regarding the relative impression of a causal relationship between two mechanical events, college sophomores' "thresholds of causality" varied as a function of the amount of delay imposed between the events, and as a function of previous exposure to slightly differing stimuli (Gruber, Fink, and Damm, 1957). This experiment and others using human subjects (e.g., Michotte, 1963) rely heavily on verbal reports when assessing their perceptions of causality. Although animal experimenters are not privy to this sort of information, there are no substantive differences in objective measures of choice behavior as a function of temporal contiguity and/or prior experience, between human and infra-human subjects. Yet, the generalization of findings about the impression of causality in humans to include animals is premature, if only on methodological grounds. Human subjects are typically presented with two sequential events and asked whether the first appeared to cause the second. In the present study, and others presenting contingent and non-contingent events, the first event in the event-relationship sequence is typically the subject's response and the second is some stimulus event. In future experiments more parallels may be drawn if humans are asked to judge the causal relationship between their behavior and some subsequent event. Or, a procedure may be devised in which animals are required to respond according to the contiguity of two stimulus events.

Even with this limitation the lawfulness in verbal reports correlates with the objective findings in the animal data, and Michotte's "...cardinal finding, namely that the impression of causality is dependent on specific and narrowly limited spatio-temporal features of the event observed...(Oldfield, 1963, p.vii)", may eventually be usefully applied to the results of "causality" studies in which the subjects are non-humans.

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