76-11,666

GILBERT, Robert Miles, 1944-
THE EFFECTS OF STIMULUS DURATION AND REINFORCEMENT PROBABILITY ON AN OPERANT DISCRIMINATION.

The City University of New York
Ph.D., 1976
Psychology, experimental

Xerox University Microfilms, Ann Arbor, Michigan 48106

THE EFFECTS OF STIMULUS DURATION AND REINFORCEMENT PROBABILITY ON AN OPERANT DISCRIMINATION

by

Robert M. Gilbert

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.

1976

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.

14 December 1975 Robert W. Lanson
date Chairman of Examining Committee

January 5, 1976 Florence L. Denmark
date Executive Officer

Examining Committee: Dr. William N. Schoenfeld

Dr. Brett K. Cole

Dr. George Gourevitch

Dr. Ronald Kadden

The City University of New York

Abstract

THE EFFECTS OF STIMULUS DURATION
AND REINFORCEMENT PROBABILITY
ON AN OPERANT DISCRIMINATION

by

Robert M. Gilbert

Adviser: Professor Robert N. Lanson

An experiment was conducted investigating the effects of two variables in a multiple schedule of reinforcement on discriminative stimulus control. One independent variable was the duration of the alternating periods of reinforcement and nonreinforcement, which were always equal to each other. The range of durations covered was 1.6 sec to 320 sec, varied between blocks of five sessions. The other independent variable was the probability of reinforcement for responding during periods when reinforcement was available. The range of this variable was 1.00 to 0.06, also varied between blocks of sessions.

The response was lever pressing by the hooded rat. Six subjects were used, and all rats were run in a single subject design across combinations of stimulus duration and reinforcement probability. The discriminative stimulus indicating periods of reinforcement was the illumination of a light, and the light was off during periods of nonreinforcement. Water served as the reinforcer. The data recorded were the number of responses in each session during the reinforced and nonreinforced periods and the local response rates during tenths of each period.

The results were a decrease in responding during the nonreinforced periods with increasing period duration and an increase in responding during the reinforced periods with decreasing probability of reinforcement. Systematic changes within a period were obtained with changes in component duration. The elevation of response rate during the briefest nonreinforced periods was not uniform over the period but showed a distinctive pattern of deceleration followed by acceleration. Results were also presented in terms of the proportion of total responding occurring during the reinforced periods (discrimination ratio). The discrimination ratio increased with increasing stimulus duration and showed little change with reinforcement probability except at the shortest duration. The relevance of the results to multiple schedule component interactions and to discriminative stimulus control are discussed.

Acknowledgements

The author wishes to express his gratitude to his sponsor, Dr. Robert N. Lanson, and to Dr. William N. Schoenfeld, director of the Conditioning Subprogram in Psychology at the City University of New York, for the support and direction they provided during this investigation and over the several preceding years. Special thanks are due to Dr. Brett K. Cole for encouragement, help, and advice. His unstinting generosity went quite beyond the call of duty.

Dr. Daniel M. Sussman contributed valuable advice during the design and conduct of the research, and he lent his technical skills to the production of this manuscript. Jeffrey and Nancy Shamow offered advice and insights; they both receive my deep gratitude. Dr. Gustave M. and Matilda S. Gilbert gave the sort of loving support and encouragement that could only come from parents with the understanding of fellow academicians.

Dr. Ronald Kadden and Dr. George Gourevitch were generous in promptly and thoroughly reviewing the manuscript and assisting in the examination. Many other friends and colleagues, too numerous to mention by name, also contributed to the successful completion of this dissertation. To all of them I offer my thanks and wish them well in their own endeavors.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Discrimination is the tendency to respond in the presence of one stimulus and not to respond in the presence of another. Pavlov (1927) referred to this as "differentiation." He demonstrated differentiation experimentally by pairing one stimulus with food and alternately presenting another stimulus without pairing. He called this the method of contrasts, and he noted that salivation to the stimulus paired with food would continue unabated. He asserted that the use of the method of contrasts was necessary for the establishment of differential responding (Pavlov, 1927, p. 117).

A similar method is applicable to the differential conditioning of skeletal responses. A neutral stimulus may serve as a signal, or cue, for the availability of a reinforcing stimulus, the latter being presented when a response is made. Another stimulus is used as a cue for periods when reinforcement is unavailable, regardless of whether the organism responds. The stimulus for the availability of reinforcement may be denoted S+, and the stimulus for nonreinforcement may be denoted S-. An operant discrimination is said to have been established when there is a higher rate of responding in the presence of S+ than in the presence of S-.

A demonstration of such an operant discrimination was provided by Skinner (1933). Rats were trained to press a lever by reinforcing each occurrence of this response with a pellet of food. After three days of this training, the rats were switched to a schedule on which they were reinforced for the first response occurring five minutes after the previous reinforcement. Three sessions of this fixed interval five minute (FI 5 min) training established each rat's characteristic rate of responding on this schedule. Then the discriminative stimulus was introduced. For two rats it was the illumination of a three candlepower electric bulb above the lever, and for two others it was the double click of the solenoid latch on the chamber door. The stimulus was presented each time the reinforcer became available, and in the case of the light, it was extinguished with the occurrence of reinforcement. The result was a reduction in the rate of responding in the absence of the cue, while the rats never failed to respond promptly when the cue was presented. Whereas Pavlov (1927, p. 119) drew an analogy between differentiation and conditioned inhibition, Skinner (1933) interpreted discrimination as a selective extinction phenomenon.

A study by Frick (1948) provided further support to the theory that discrimination was a function of extinction during S-. Rats were given minimal preliminary lever press training to a criterion of three lever presses followed immediately by eating. Then the rats were given discrimination training consisting of alternating 2.5 minute periods of S+ and S-. S+ consisted of illuminating the chamber at an intensity of 20 foot candles. S- was a lower level of illumination, with various groups of rats getting 10, 7.5, 5, 2, and .02 foot candles, respectively. A control group was run with no change in illumination from the S+ level. For the experimental groups, S+ indicated the availability of reinforcement (powdered food) for each response (continuous reinforcement, or CRF). S- was a cue for the nonavailability of food (extinction). The control group got alternating periods of CRF and extinction without benefit of a differential cue.

Since S+ and S- stayed on for periods of time independent of the animals' responding, it was possible to obtain separate and comparable response rates in the presence of S+ and S-. The control group yielded an unreinforced rate in the presence of the S- stimulus indiscriminable from S+. Frick found that S- response rate decreased within and across sessions, much as one would expect for an extinction curve. The lower the intensity of the S-, the greater was the rate of decrease of response rate in S-. Responding in S+ remained at a high rate, as did the unreinforced responding of the control group. Frick suggested that the best measure of discrimination was S- response rate, and he showed that a psychophysical function could be generated by plotting S- rate as a function of S- intensity. By comparing S- rate to the unreinforced rate of the control group, Frick was able to control for the induction of reflex strength from S+ to S- noted by Skinner (1938, p. 227).

At this point it might be well to introduce the contemporary, conventional nomenclature for the sort of reinforcement schedule used by Frick (Ferster & Skinner, 1957, pp. 525-529). A multiple schedule is one in which two or more simple schedules (such as CRF and extinction) are presented successively, with an exteroceptive stimulus or stimuli to indicate which schedule is in effect during each period of time. Each of the simple schedules is called a component of the multiple schedule. The same procedure without an exteroceptive stimulus change is called a mixed schedule. Thus, Frick (1948) ran a multiple CRF, extinction schedule with equal, 2.5 minute component durations, cued by changes in illumination from high (in S+) to low (in S-). The control group received a mixed CRF, extinction schedule with equal, 2.5 minute component durations. There is no convention requiring that the component durations be equal, nor even that they be fixed. For that matter, the components need not be different schedules; as long as there is a periodic change in an exteroceptive stimulus, that establishes a multiple schedule. As is the case with most organizational systems, the conventions of the Ferster and Skinner (1957) taxonomy are arbitrary; an alternative system will be discussed later.

Dinsmoor (1951) noted that Frick's (1948) procedure yielded separate response rate measures during S+ and S-, unlike Skinner's (1933, 1938) procedures for establishing operant discriminations. But Dinsmoor objected to the use of response rate during CRF, because that rate is confounded with eating time. Also, Dinsmoor felt that testing the S+ rate with an extinction trial in the presence of the previously reinforced S+ would confound the rate with the onset of extinction. Dinsmoor suggested the establishment of a discrimination with a multiple schedule, but only reinforcing the last response in S+, thus combining elements of Frick's (1948) study and Skinner's (1933) demonstration. Dinsmoor ran a multiple fixed interval one minute, extinction schedule (<u>mult</u> FI 1 min, <u>ext</u>) with component durations of one minute for FI 1 min, and two minutes for extinction. S+ was light for some rats, darkness for others, and S- was the opposite for each rat. The last response in S+ would produce reinforcement and terminate S+, so the rate of responding in S+ was not confounded by reinforcement. Eating time would intrude into S-, but that could be ignored by taking the S- response rate during the second minute of S-. As a control, Dinsmoor ran a group on a procedure similar to Skinner's, where a three minute interval of S- would end with S+, and the next response would be reinforced and terminate S+.

Dinsmoor (1951) found that the discrimination improved steadily over cycles of presentation of the multiple schedule. Whereas, at first, the rats made only 1/3 of their responses in S+ (a rate indicative of no discrimination, since 1/3 of the time was spent in S+), after 125 cycles of training the rats made 2/3 of their responses in S+. The control group responded even less in the third minute of S- than the experimental group did in the second minute of S-. Dinsmoor explained that by citing the longer period for extinction of S- responding in the control group and resistance to extinction brought about by intermittent reinforcement in the experimental group. It could also be held, however, that the control procedure was not so much a multiple schedule as it was a discrete trial regular reinforcement paradigm, or a simple FI 3 min schedule with an exteroceptive clock to sharpen the temporal discrimination. In any event, Dinsmoor showed that discrimination could be established with intermittent reinforcement in S+. In addition, he advocated the use of response rate ratios as an index of the progress of discrimination in a free operant situation.

Earlier, Dinsmoor (1950) had done a study which suggested an interrelation between the discriminative and secondary reinforcing function of S+. Rats were reinforced for the first response in S+, which would also terminate S+. S- would stay on until the rat had not responded for thirty seconds. In effect, the rat was reinforced with S+ for thirty seconds of any activity other than lever pressing (a schedule that Ferster and Skinner, 1957, later called DRO 30 sec, for the differential reinforcement of other behavior). After 200 cycles of discrimination training, rats which had light as the S+ pressed more to produce three second periods of light in extinction, and rats which had darkness as the S+ worked harder to produce darkness than vice versa. This demonstrated the secondary reinforcing properties of S+. It was proposed (Dinsmoor, 1950; Schoenfeld, Antonitis, & Bersh, 1950; Keller & Schoenfeld, 1950, p. 236) that the establishment of a discriminative stimulus was a necessary and sufficient condition for the establishment of a secondary reinforcer. Subsequent experimentation, however, revealed that the connection between cue and reinforcing properties of the stimulus was perhaps not a necessary one (Kelleher & Gollub, 1962; Wike, 1966, pp. 462-465). The interrelation notedby Dinsmoor (1950) may have resulted from the fact that stimulus change was response-dependent during discrimination training, thus confounding the functions of the stimulus at the outset.

As we have seen, multiple schedules have played a role in the study of discrimination learning. Ferster and Skinner (1957) also advocated their use in studying the effects of various schedules of reinforcement as a within-subjects repeated measures design. In this application, the discriminability of the cue is assumed, and Ferster and Skinner (1957) asserted that the behavior exhibited during the various component schedules would be indicative of the effects of each schedule. The stimulus control exerted by the cues would provide for the relative independence of the various components associated with each cue. The fallacy of this assumption was soon demonstrated (Herrnstein & Brady, 1958). The study of the interactions among components of multiple schedules became a matter of interest in its own right.

Skinner (1938, pp. 174-175) had long acknowledged sequential interactions, and Reynolds (1961a) borrowed some of Skinner's terminology in defining four possible types of interactions among components in multiple schedules:

> In the classification based on the rate of responding in the component in which it occurs, an interaction is called <u>positive</u> if it is an increase in responding or <u>negative</u> if it is a decrease in responding. In the classification based on the rate prevailing in the <u>other</u> component, an interaction

is called a contrast if it is a change in rate in a direction away from the rate prevailing in the other component (cf., Skinner, 1938), or an induction if it is a change in a direction toward the rate prevailing in the other component. A positive contrast, for example, would be an increase in the rate of responding in one component in a direction away from the rate prevailing in the other component. (p. 115)

Reynolds (1961b) sought to determine the conditions under which behavioral contrast or induction would occur. By manipulating the reinforcement density parameters of variable interval, fixed ratio multiple schedules, he noted an apparent relation between the response rate in each component and the frequencies of reinforcement in that and the alternating component. Varying one component and keeping the other constant, Reynolds (1961b) suggested that the rate of responding in the constant component would increase as the relative frequency of reinforcement in that component increased, and the response rate in the variable component would increase as the absolute frequency of reinforcement in that component increased. Freeman (1971), reviewing the research on behavioral contrast, observed:

> Contrast occurs when the relative frequency of reinforcement is altered and when responding is sup-

pressed in one component of a multiple schedule. While both of these conditions are sufficient to produce contrast, it has not been clearly demonstrated that either of these two variables alone provides the necessary conditions. Before this question can be answered, a technique must be developed which allows the independent manipulation of response rate and reinforcement frequency. As is evident from this review, no such technique is yet available. (p. 354)

Unfortunately, Freeman was not privy to an unpublished study by Cumming and Schoenfeld (1962) in which response rate was elevated in one component of a multiple schedule without changing either the relative or absolute frequencies of reinforcement in either component. This was accomplished by placing a limited hold over reinforcement availability in the variable component and varying the duration of the limited hold. As the limited hold decreased, response rate increased in both the variable and constant components, the proportionate increase being even greater in the constant component than in the variable one.

Terrace (1966) observed that behavioral contrast did not occur following the errorless acquisition of a discrimination. He hypothesized that since the subject never made unreinforced responses in the presence of S-, the cue for extinction would not acquire negative emotional associations. Contrast, according to this theory, is an emotional response to relief from an aversive situation (S-). A similar idea was voiced by Bloomfield (1969), who cited S- as a condition of frustration (Amsel, 1962). The "disappointment" expressed by the subject during S- is followed by "relief" with the onset of S+, expressive of emotional "elation." Schaub (1969) questioned whether S- could be considered a negatively reinforcing stimulus, however. Although S- does tend to suppress responding in its presence, its onset can be used to reinforce observing responses. The informative value of the stimulus was positive even if the condition cued thereby was aversive.

Terrace (1966) also noted temporal changes of both a long-term and a short-term nature in the magnitude of behavioral contrast. Citing his own data and those of Boneau and Axelrod (1962) and Catania and Gill (1964), he postulated that ". . . the magnitude of the contrast effect might depend on the temporal proximity of a given S+ to the previous appearance of an S-" (Terrace, 1966, p. 319). Futhermore, contrast effects tended to diminish over a two-month period of extended discrimination training. This was taken as an indication of adaptation to the emotional effects of nonreinforced responding. In further support of the theory that discrimination and contrast arose from the aversive suppression of S- responding, Terrace (1968) cited evidence that punishment and negative reinforcement in S- would produce effects equivalent to unreinforced responding. Whether contrast and peak shift are convergent phenomena is still a matter subject to investigation. Hearst, Besley, and Farthing (1970) advocated that a distinction be retained between an inhibitory stimulus and inhibitory dimensional control, while Yarczower (1970) demonstrated that overtraining on a line tilt discrimination abolished both contrast and the inhibitory generalization gradient.

Another approach to the subject of component interactions arose from a consideration of how an animal would choose among various responses that differed in their reinforcing consequences. If the various responses are simultaneously available, the situation is termed a concurrent schedule (Ferster & Skinner, 1957). Herrnstein (1970) proposed that the distribution of responses would be directly proportional to the relative frequency of reinforcement for each response class, and this relationship was called the "matching law." By extension, the "matching law" might be applied to non-simultaneous, or successive, discriminations, as in multiple schedules, but it was thought that deviations from "matching" would increase with increasing component duration or deviation from simultaneity. For example, Lander and Irwin (1968) ran pigeons on a multiple variable interval, variable interval schedule, with various mean interreinforcement intervals in the two components. The component duration was three minutes for each component. The resulting ratio of responses between the two components was equal to the cube root of the ratio of reinforcements between them.

The question of the relationship between component duration and "matching" was addressed directly by Shimp and Wheatley (1971). They placed pigeons on various multiple VI, VI schedules with the ratio between mean interreinforcement intervals always 4:1. Component duration was varied from 2 sec to 180 sec. They found that the pigeons made 80% of their responses in the richer component and 20% in the leaner when component duration was 2 sec or 5 sec. With increasing component duration beyond 5 sec, there was increasing convergence of the relative response rates in the two components. A similar experiment was reported by Todorov (1972). He ran pigeons on a multiple VI 30 sec, VI 90 sec schedule with variable component duration within sessions. Average component duration, ranging from 5 to 300 sec, was varied between blocks of sessions. The relative response rates most closely approached "matching" at average component durations between 5 sec and 10 sec, and the rates converged with increasing component duration. At the 300 sec average component duration the pigeons averaged 60% of their responses under VI 30 sec, even though the reinforcement rate ratio was 3:1.

Killeen (1972) performed an experiment to determine whether "matching" was a function of the temporal proximity of the two components, or whether it related to the ability of a subject on a concurrent schedule to control the choice of component by switching from one to the other. He used a yoked-chamber control procedure. In the master chamber one key would be green or red, indicating whether food was available for pecking that key on a VI 30 sec or a VI 60 sec schedule. A second key (the changeover key) caused the schedule on the first key to change each time the changeover key was pecked. In the yoked chamber there was no changeover key, and the schedule on the food key was whatever the pigeon in the master chamber had selected. In effect, the master pigeon was on a concurrent schedule, and the yoked pigeon was on a multiple schedule with component durations determined by the master pigeon. The resulting distribution of response rates between the two components was quite similar for both birds, and this similarity held up over repeated discrimination reversals and alternations of pigeons between master and yoked roles. In a second experiment, Killeen (1972) made component change noncontingent and varied component duration. He found that "matching" was affected by the relative amount of time spent in each component, and that longer component durations brought about greater deviations from "matching."

Silberberg and Schrot (1974) also used a yoked-chamber control to study the difference between concurrent and multiple schedule performance. They manipulated component duration in both the concurrent and multiple schedules by varying the changeover delay programmed to prolong the chosen component after the changeover key had been pecked. The result was that "matching" tended to improve with increasing component duration for pigeons on the concurrent schedule, but pigeons on the corresponding multiple schedule showed increasing deviation from "matching" with increasing component duration, similar to the findings of Shimp and Wheatley (1971) and Todorov (1972). The findings of Silberberg and Schrot (1974) cast into doubt Killeen's (1972) conclusion that "matching" was independent of choice.

The investigations of the influence of component duration on multiple schedules have tended to use interval schedule components because they permit the manipulation of reinforcement rate. It will be recalled that Frick's (1948) study of stimulus control reinforced S+ responding on a CRF schedule, that is, a ratio schedule. In ratio schedules, by definition, reinforcement rate is proportional to response rate; thus, it is under control of the subject. One way to program intermittent ratio schedules is to assign a uniform probability of reinforcement to each response. Brandauer (1958) called this a "random ratio" (RR) schedule. He demonstrated that very stable rates of responding were generated by such schedules, and that response rate tended to increase with reduction in the probability of reinforcement from 1.0 to 0.02. Further reductions in probability had little effect on overall response rate. Sidley and Schoenfeld (1964) and Farmer and Schoenfeld (1967) obtained similar data, but the latter study failed to find any appreciable reduction in rate at the highest probabilities. One clear finding was that post-reinforcement pause increased sharply with decreasing probability of reinforcement. Thus, it appears that the function relating response rate to reinforcement probability will be highly dependent upon the time constants chosen to correct response rate for reinforcement time. This factor may account for the differences between Sidley and Schoenfeld (1964) and Farmer and Schoenfeld (1967).

A study using random ratio schedules as components in a multiple schedule was performed by Branch (1973). He placed pigeons on a mixed RR 50, extinction schedule. A mixed schedule is a multiple schedule without an exteroceptive cue to indicate which component is in effect. In order to produce the stimulus to turn the mixed schedule into a multiple schedule, the pigeons had to make five responses on a second key (the observing key). Meeting the observing criterion produced 25 sec of color change on the food key. The nondifferential color (mixed schedule) stimulus was blue; under the multiple schedule the food key turned red during RR 50 components and green during extinction components. The ratio component was varied in duration from 1.25 sec to 320 sec. At each reinforced component duration, _t_, the extinction component duration was randomly varied from _t_ to 4 _t_, with an expected value of 1.625 _t_. Observing response rate as a function of _t_ was fairly constant from 5 sec to 320 sec, but dropped sharply at _t_=1.25 sec. When the multiple schedule was in effect, response rates in S+ and S- didn't vary reliably with _t_, except that S- response rates were elevated at 1.25 sec. The same results obtained when the reinforced component was RR 100 and RR 200. Decreasing reinforcement probability to RR 400 brought about a marked reduction in observing behavior.

Random ratio schedules occupy a central position in the _tau_ system of specifying stimulus schedules (Schoenfeld & Cumming, 1960; Schoenfeld & Cole, 1972). In this system, two time periods alternate. Each of the time periods is characterized by a specified probability of reinforcement, given a response. The period with the higher probability of reinforcement is called _tau_-dee, and the one with the lower probability is called _tau_-_delta_. The two periods, taken together, comprise the _tau_ cycle.

The proportion of the _tau_ cycle occupied by _tau_-dee is a variable denoted _tau_-bar. _Tau_-dee and _tau_-_delta_ may or may not be cued by an exteroceptive stimulus. An example of this sort of schedule is Frick's (1948) experiment. He ran what in the _tau_ system would be a _tau_ cycle with a cycle length of 5 min; _tau_-bar was 0.5; probability of reinforcement in _tau_-dee was 1.0, and probability of reinforcement in _tau_-_delta_ was 0.0. _Tau_-dee was cued by bright illumination, and _tau_-_delta_ was cued by dimmer illumination.

Snapper (1962) investigated the behavioral effects of the variable _tau_-bar, with _tau_ cycle length kept constant at 10 min, and no differential cue within the cycle. He found that as _tau_-bar decreased, response rate in _tau_-dee remained fairly constant, while the rate in _tau_-_delta_ decreased. Of particular interest here is the response rate pattern found within _tau_-_delta_, where the probability of reinforcement was kept constant at 0.0. With the onset of _tau_-_delta_, response rate dropped rapidly from the high rate in _tau_-dee, but about one-third of the way through _tau_-_delta_ response rates began to climb again, and continued to climb until the onset of _tau_-dee. This temporal pattern of responding was evident even when the probability of reinforcement in _tau_-dee was varied from 0.08 to 0.0125. Cumming and Schoenfeld (1963) kept _tau_-bar constant at 0.20 and varied _tau_ cycle length from 7.5 sec to 600 sec. Response rate decreased as cycle length increased, and this effect seemed to be largely due to decreasing *tau-delta* responding as cycle length increased. Vickery (1971) varied *tau* cycle length from 10 to 500 sec, and probability of reinforcement in *tau-delta* from 0.0 to 0.1. Probability of reinforcement in *tau*-dee was either 1.0 or 0.1. Response rate in both *tau*-dee and *tau-delta* increased with increasing probability of reinforcement in *tau-delta*. This is similar to a finding by Reynolds (1963) which was termed induction. Vickery (1971) also found the temporal pattern of responding within *tau-delta* that Snapper (1962) had obtained, as long as the probability of reinforcement in *tau-delta* was less than the probability of reinforcement in *tau*-dee.

In the experiments by Snapper (1962), Cumming and Schoenfeld (1963), and Vickery (1971) there was no cue to distinguish between *tau*-dee and *tau-delta*. Nevertheless, the applicability of their procedures to psychophysics was not lost on those authors. As Vickery (1971) suggested, "Threshold for two stimulus conditions could be given by the maximum alternation rate which supports some arbitrary level of differential responding to the two conditions" (p. 17). In a related system of temporally defined stimulus schedules, Weissman (1961) used a green key to cue the interval in which reinforcement was available, and a white key to indicate a period of extinction. Cycle length was held constant at 90 sec, and the duration of S+ was reduced from 30 sec to 0.5 sec. S+ response rate decreased with decreasing S+ duration, while S- response rate was always near zero. The result shows the sensitivity of discrimination to temporal changes in the cycle.

Multiple schedules in which one component is extinction are of particular interest to psychophysicists when the discriminability of the stimulus is in question. For example, Pierrel (1958) obtained maintained auditory generalization gradients using a multiple VI 1 min, extinction schedule. In order to avoid temporal discrimination, however, one minute samples of each component were assigned to alternate according to a Gellerman series. S+ and S- were both 4 kHz tones, differing in intensity by 40 dB. Goff (1961) used a multiple schedule to obtain olfactory thresholds for various hydrocarbons in rats. A variable ratio (VR) 10 schedule was in effect in the absence of odor. A 10 sec puff of the odorant at a given concentration signalled the onset of at least 45 sec of extinction, with the added requirement that the rat not respond for at least 5 sec before the resumption of reinforcement availability. The ratio of responses in the first 10 sec of odor stimulation to responses in the first 10 sec of an odor-free blank trial was taken as the indicator of detection. A more sophisticated control for extraneous discriminations was proposed by Raslaer, Pierrel-Sorrentino, and Brissey (1975). They compared the performance of chinchillas on a tone-cued multiple schedule to an uncued mixed schedule component to determine the degree of auditory stimulus control. Nevertheless, the Gellerman series was used to vary component durations as a control for temporal discrimination.

The experiment reported here was designed to test the effects on discrimination of component duration and probability of reinforcement in a multiple schedule. The results are discussed with relation to behavioral contrast and induction, conditioned suppression, the tau system of stimulus schedules, and psychophysical methods. A modification of traditional stimulus control concepts is suggested.

METHOD

Subjects

Six Long-Evans strain hooded female rats were obtained from Blue Spruce Farms. The rats were housed in individual cages and given free access to Purina Lab Chow except during experimental sessions. Five of the rats were approximately ten months old at the beginning of the experiment. Rat F was approximately five months old at that time, and all rats were experimentally naive at the outset of the experiment. For the duration of the experiment, each rat was given one hour's daily access to water from a licking spout. This access was given immediately after the experimental session, so each animal was approximately 22 hours water deprived at the start of the next day's session.

Apparatus

All sessions were run in a modified Lehigh Valley rat chamber, model 143-04. The left-hand lever was removed, and its slot in the intelligence panel covered. The right-hand lever was used as the only manipulandum. A solenoid dipper, normally inaccessible, presented water at a hole near the center of the intelligence panel. The discriminative stimulus was a light viewed through a round hole, 2.5 cm in diameter, cut in the intelligence panel 2.5 cm above the top of the lever. Behind the hole a 2.5 cm inside diameter tube extended 7 cm to a cap that sealed the end of the tube. The inside of the tube and cap were painted flat black. A light-emitting diode (LED) was mounted in the cap on the axis of the tube. When illuminated, the LED (Monsanto cat. # MV 5222) produced light with a wavelength of 570 nm ("green") and a half-power bandwidth of 35 nm. The LED may be assumed to be a point source, and at the current used here the irradiance was 2.04×10^{-9} W/cm^2-nm, as determined by an EG&G model 580/585-66 radiometer. The tube mounting of the LED served three purposes. First, minimum viewing distance was limited to 7 cm. A rat could place her snout into the tube, but could not insert the head as far as the eyes. The light was thus kept at a distance beyond the near point of focus of the rat eye. Second, viewing angle was restricted to a solid angle of approximately 20°, an area over which the polar radiation pattern of this model LED provided a relatively constant intensity for all angles of regard. Third, the tube kept the LED at a sufficient distance that the rat could not gnaw, lick, paw, or soil the lens of the LED.

The chamber was contained within a fan-ventilated enclosure which, in turn, was located in a dark room, separated from the control apparatus by a solid door. No house light was used in the chamber following initial lever press training. Thus, when the LED was off the rat was in complete darkness. A loudspeaker in the enclosure provided continuous white noise, and that, together with the sound of the fan, provided some acoustical masking. Control functions were provided by a system of solid state logic modules (BRS Digi-Bits). The time base for all intervals was a tuning fork controlled multivibrator with a base frequency of 1 kHz, and a BRS probability generator programmed reinforcement probability. Response and reinforcement data were recorded on electromechanical counters.

Procedure

Reinforcement consisted of access to one drop (approximately .01 cc) of tap water. During initial lever press training, access time was as long as 2 sec, and was gradually reduced to 0.8 sec as the rats learned to respond quickly to the dipper. The rats were trained to press the lever by reinforcing successive approximations to lever pressing, as determined by the experimenter. Rats A, B, C, and D were given two to five days of preliminary training. Rat E required twelve days of initial training, and rat F learned to press the lever in only one session. Following initial lever press training, rats A, B, C, and D received five sessions of regular reinforcement (CRF); rat E received two days of CRF, and rat F received one day of CRF. Because of the differences in acquisition time, rats A, B, C, D, E, and F received 4152, 3589, 1712, 2384, 2224, and 912 reinforcements, respectively, in preexperimental training. All initial training was performed with the LED on, but no deliberate attempt was made to train the rats to monitor the light.

Each experimental session started with the first response and lasted 64 minutes. During that time the cue light was alternately illuminated and extinguished for equal periods of time. The duration of the periods was one of the two variables in the experiment, as will be discussed below. Each session began with a light-off period, and the light went off at the end of the session. When the light was on (S+), a random ratio schedule of reinforcement was in effect, the probability of reinforcement being an independent variable, and when the light was off (S-), extinction was always in effect.

Each experimental condition, or point, was run for five sessions on consecutive days. Each condition was a combination of a particular probability of reinforcement during S+ and duration of S+ and S-. The various nominal probabilities of reinforcement were: 1.00 (CRF), 0.50 (random ratio 2), 0.25 (RR4), 0.13 (RR8), and 0.06 (RR16). Reinforcement frequency was monitored daily, and there was never any notable deviation from the nominal probabilities. At each step, the duration of S+ and S- were equal. An even, integral number of these periods made up the constant 64 minute duration of each session. Periods were timed "by the clock," and component change was independent of the rat's behavior. The order in which the points were run is given in Table 1. Each point at the 320 sec component duration was redetermined after intervening points had been run, as a test of behavioral stability and a demonstration that the results did not depend upon the order in which the points were run. All six rats covered the same points at the same time.

To summarize the procedure, each point was a multiple random ratio (or CRF), extinction schedule. S+ was light-on, and S- was light-off. Lever pressing during S+ was reinforced with water. Component duration and ratio requirement were varied between blocks of five sessions. The schedule may also be regarded as a *tau* cycle with *tau*-bar constant at 0.5. Probability of reinforcement in *tau*-*delta* was constant at 0.00. *Tau* cycle length and probability of reinforcement in *tau*-dee were varied between points. *Tau*-dee was cued by light-on, and *tau*-*delta* was cued by light-off (Schoenfeld & Cole, 1972).

Table 1.

Order in which points were run.

		COMPONENT DURATION (sec)					
		320	320	160	64	16	1.6
	1.00	1	6	7	8	9	10
REINFORCEMENT	0.50	2	11				
PROBABILITY	0.25	3	12	13	14	15	16
IN S+	0.13	4	17	18	19	20	21
	0.06	5	22	23	24	25	26

RESULTS AND DISCUSSION

The principal effect of increasing component duration was a decrease in S- response rate. By comparison, S+ response rate showed no regular trend over component durations. These relations held true for all six rats, as can be seen in Figures 1-6. Absolute average deviations from the plotted medians are given in the Appendix: Table 3. The effect of reducing the probability of reinforcement in S+ was generally to increase response rates in both S+ and S- components of the schedule. An exception to the latter finding was that rat E showed a decrease in S+ response rate when the ratio requirement was increased from RR8 to RR16. Most of the change in the S- rate occurred over the component duration range of 1.6 to 64 sec. Relative to the changes between CRF, RR4, and RR8, the increase in S+ rates between RR8 and RR16 was small for the five rats that showed such an increase. The effect of the probability variable on S+ rates was in accord with the general findings of Brandauer (1958) and Sidley and Schoenfeld (1964), who noted that the response rates on a random ratio schedule were depressed at a probability of 1.0 (CRF), but there was very little change in response rates at lower probabilities. Farmer and Schoenfeld (1967) found no systematic change in "running" rate as a function of probability, but post-reinforcement pause increased with decreasing probability. The "running" rate measure subtracts the time of the post-reinforcement pause from the response rate calculation.

All response rates reported in the present study are "uncorrected" for reinforcement time and post-reinforcement pause. It was felt that an attempt at such a correction would be inappropriate here. Corrected rate calculations are arbitrary in that they depend on the time base chosen (Schoenfeld & Cole, 1972, p. 62). The choice of a given time base may be justified where there is a rational basis for its selection. If, for example, the time spent consuming the reinforcer can be specified, as with a pigeon given two seconds' access to a food hopper, or if the clock is stopped with reinforcement and restarted with the first response following reinforcement, there are clear criteria for the period disregarded in the rate calculations. In the present study, the rat could consume the drop of water in less time than the dipper stayed up. Responses were sometimes heard during the time that the dipper was up. No post-reinforcement pause data were collected, and the session clock ran continuously from the first response to the end of the session. Since a rational basis for a correction factor was lacking, no correction was made.

The most notable difference among the six rats may be seen in comparing the S- rates at the 16 sec component duration. Rats B and E responded as little during a 16 sec S- as they did at longer component durations. All other rats gave S- rates at 16 sec intermediate between those at 1.6 sec and 64 sec. It was also the case that rats B and E gave near zero S- response rates at component durations other than 1.6 sec for all values of reinforcement probability in the alternating component. Rats A, C, D, and F showed a more general tendency for S- response rates to increase where S+ response rates increased (positive induction, as Reynolds, 1961a, would call it).

Following the suggestion of Dinsmoor (1951), the data may also be plotted in terms of responding during the positive stimulus as a proportion of total responses. The means of the daily discrimination ratios calculated by this definition are shown as a function of component duration for the individual rats in Figures 7-10. There are other ways to calculate a discrimination ratio. For example, response rate in S- may be plotted as a proportion of response rate in S+. This type of discrimination ratio is often used in conditioned suppression paradigms, where it is called a suppression ratio (Hoffman, 1969, p. 66). The question of the appropriate denominator for a discrimination ratio can become complicated where there are several different stimulus conditions (Raslaer, Pierrel-Sorrentino, & Brissey, 1975). Where there are only two stimulus conditions and two response rates, any rate ratio may be directly derived from any other. The ratio used here was convenient in that it provided a scale from 0.0 to 1.0, with better discriminations approaching the top of the scale. In the absence of a discrimination, the expected value of the ratio would be 0.5, but that assumption oversimplifies the matter, as the data will show and as will be discussed later.

Figures 7-10 show that discrimination ratio increased with increasing component duration. That result followed directly from the finding that S- response rate decreased with increasing component duration. Rats B and E exceed a discrimination ratio of 0.9 at the 16 sec component duration, while the other rats approach that level of accuracy only at component durations of 64 sec and greater. As noted above, one would not predict discrimination ratios less than 0.5, but all rats gave ratios less than 0.5 when the probability of reinforcement in S+ was 1.0 and the component duration was 1.6 sec. When reinforcement was available on random ratio 4, rats A, C, D, and E gave ratios below 0.5 at 1.6 sec. With RR8 and 1.6 sec as the parameters, rats A, C, and E produced ratios below 0.5. On the leanest schedule of reinforcement, RR16, all rats gave ratios around 0.5 at the 1.6 sec component duration. One possible explanation for ratios below 0.5 is that response rate in S+ is depressed by the time required to obtain reinforcement. As the schedule becomes leaner, fewer reinforcements are obtained, and the uncorrected rate more closely approximates the "running" rate. Whether discrimination ratios of 0.5 or less are really indicative of failure to discriminate is a matter to be discussed more fully below, in the light of data on the temporal distribution of responses within cycles.

The S+ and S- response rate data of Figures 1-6 are very similar to the findings of Branch (1973, Fig. 2) for periods when a multiple schedule was in effect for his pigeons. The discrimination ratio data of Figures 7-10 of the present study closely parallel functions Branch obtained relating percentage of the session spent observing the multiple schedule cue to component duration (Fig. 1 of the cited study). Branch also presented "discrimination" ratios as a function of component duration for periods when the mixed schedule was in effect (Fig. 3 of the cited paper). The only cues to be discriminated in the latter case were the relative frequencies of reinforcement in RR50 and extinction. The ratios increased gradually from 0.5 to 0.65, with most of the change taking place between 160 sec and 320 sec of component duration. Although there are similarities in the data between Branch (1973) and the present study, there are reasons to doubt that the findings here at the 1.6 sec component duration resulted from failure of the rats to monitor the light.

If the rats were ignoring the light when component duration was brief, one would expect to find a relatively constant rate of responding within components, with the exception of the depressive effect of reinforcement in S+, discussed above. Figures 11-40 show that such is not the case. In these figures responses have been partitioned into time divisions, or bins, within components, so as to illustrate the local response rate relative to component change. The data in these figures were obtained from the second half (32 min) of each session, in order to avoid warmup effects and biases accompanying changes in schedule parameters. Behavioral stability did not turn out to be a problem, and the precaution of recording the time bin data from the second half of the session was probably unnecessary. As obtained, each point in Figures 11-40 represents the mean response rate in each one-tenth of a component. Since all component durations were sampled repeatedly for a constant period of time, each point represents the average rate over a total time period of eight minutes. The number of occurrences of each bin was inversely proportional to component duration. The first and second determinations at the 320 sec component durations are plotted separately (open and filled circles). The first determination generally shows a lower S+ rate than the redetermination at 320 sec. This result is consistent with a finding by Cumming and Schoenfeld (1959) that absolute rates tend to rise with successive alternations of schedules.

The general features of the response pattern within components may be characterized as follows: For component durations of 64, 160, and 320 sec there was a brief increase in rate at the onset of S+ and then, especially in CRF, a gradual decrease in rate through S+ (shown in Figures 11-16). Response rate dropped abruptly with the onset of S- and remained near zero through the unreinforced component. The pattern just described is characteristic of the curves plotted with circle and square data points. Figure 26 is a clear example. The pattern for the 16 sec component in S+ was similar to the longer component durations, but the decline in rate with the onset of S- was not as steep. In fact, rats A and F showed a brief increase in rate following 16 sec of CRF or RR4. Then rate dropped to a moderately low level, as in Figure 37, while some rats showed an increase in rate in the second half of S-, as in Figures 11, 14, 31, 35, and 38, the curves in question being those denoted with open triangles. For rats B and E, S- rate was near zero at the 16 sec component duration (Figs. 12, 15, 24, 27, 30, 33, 36, and 39).

For the 1.6 sec component duration, plotted with closed triangles, there are two types of patterns, depending on the probability of reinforcement in S+. In the CRF condition, response rate declined to a minimum toward the end of S+, then rose to a local peak at the onset of S-, declined to a second minimum in the middle of S-, and rose sharply to the highest rate at the end of S- (Figs. 11-16). This bicuspidate pattern reduced to a single parabola with a minimum near the end of S+ when an intermittent schedule of reinforcement was in effect in S+ (Figs. 23-33, Fig. 34 being an exception). Some curves show a dip in the sixth bin of S-. This is an artifact of the intermittent malfunction of the counter for that bin. At the leanest probability of reinforcement, RR16, the parabola becomes nearly flat (Figs. 35-39), the exception being an inversion of the parabola (Fig. 40, the same rat as Fig. 34).

Considering the temporal distribution of responding, let us return to the question of whether the rats were under discriminative stimulus control at the shorter component durations. The increase in rate just prior to S+ onset could be explained as a temporal discrimination, but the peak seen at the first bin of S- following CRF must be cued by light offset. The duration of that bin is only 0.16 sec, enough time for one response, but not enough time to adjust interresponse time to the absence of reinforcement for that first response. The overall discrimination ratio indicated the absence of a discrimination, or even the paradoxical reversal of discrimination, but the temporal distribution of responses showed that the rat's response rate was being modulated by even the most rapid component change.

Component duration had a far greater effect on discrimination than did the probability of reinforcement in S+. Figures 41-46 show that for most rats, at most component durations, discrimination ratio did not vary across reinforcement probabilities. Where a difference did exist, it was in the direction of a depression in the ratio at RR1 (CRF), RR2, and RR4. This is consistent with the finding that S+ rates were lower at the higher probabilities of reinforcement in the present study, and it is also in accord with the observations by Brandauer (1958) and Sidley and Schoenfeld (1964) that rate changes as a function of reinforcement probability in random ratio schedules occur only at the highest probabilities. The data obtained by Branch (1973) in extending the probability of reinforcement from RR50 to RR400 indicated that discriminative stimulus control held up through RR200, and only at RR400 did the pigeons fail to keep the multiple schedule in effect through at least 80% of the session.

The computation of the median response rates presented in Figures 1-6 and the mean discrimination ratios presented in Figures 7-10 and 41-46 disregarded the data obtained in the first block of five sessions for each determination at the 320 sec component duration. The

data for the two determinations at 320 sec were presented separately in Figures 11-40, and it can be seen that the rates in S+ for the second determination were generally higher than for the first determination, and the rates in S- were sometimes higher in the first determination than in the second. The reason for not averaging the two determinations at 320 sec together was to provide data for that component duration which would not be confounded by the initial acquisition of the discrimination. There is evidence that the discrimination was acquired rapidly, and that, in fact, the rats had begun to discriminate during the first session of discrimination training. On the first day, the discrimination ratios of the six animals were 0.67, 0.54, 0.64, 0.57, 0.60, and 0.68, all above the 0.50 level expected in the absence of discrimination. By the second day the ratios were 0.88, 0.75, 0.83, 0.86, 0.89, and 0.81, respectively. The second day's data showed ratios superior to those obtained later at the 1.6 sec and 16 sec component durations.
A comparison of the mean discrimination ratios between the first and second determinations shows relatively little difference, considering that at least a month of experimentation intervened. These data are shown in Table 2.

One conclusion that may be drawn from the results presented here is that discrimination does not arise simp-

Table 2.

Mean discrimination ratios for first and second determinations at 320 sec component duration.

		REINFORCEMENT PROBABILITY				
Rat	Determin.	1.00	.50	.25	.13	.06
A	I	.828	.902	.931	.932	.900
	II	.872	.857	.929	.915	.926
B	I	.739	.916	.984	.991	.978
	II	.853	.942	.989	.960	.969
C	I	.828	.925	.949	.935	.900
	II	.773	.897	.937	.905	.895
D	I	.836	.942	.963	.943	.944
	II	.884	.931	.966	.888	.920
E	I	.850	.929	.970	.977	.981
	II	.965	.951	.986	.969	.952
F	I	.866	.946	.964	.982	.978
	II	.937	.918	.951	.938	.957

ly from the extinction of unreinforced responding in S- (Skinner, 1933; Frick, 1948). Decreasing component duration may elevate S- responding without manipulating stimulus intensity parameters (Frick, 1948) or introducing reinforcement into the leaner component (Vickery, 1971). The result may be viewed as a demonstration of "induction" in the sense used by Skinner (1938), that is, an overlap of the excitatory effects of reinforcement into a stimulus condition where reinforcement is never presented. There is certainly induction as defined by Reynolds (1961a), an increase in rate in the constant component (S-) consequent upon increasing the rate in the variable component (S+). The problem with induction as an inferred process or as a phenomenon is that it is not specific enough to predict the conditions under which the effect will or will not be in evidence. Nor can induction account for specific effects, such as the temporal pattern of responding found here.

The process of secondary reinforcement may have some bearing on the temporal relations that aroused S- responding here. Bersh (1951) investigated the temporal relation between a neutral stimulus and a primary reinforcer that would give reinforcing properties to the neutral stimulus. He paired light with food at several values of delay, then made 1 sec presentations of light contingent upon lever pressing. The greatest number of lever presses for light was shown by groups of rats which had

0.5 sec and 1.0 sec delay between light and food on the pairing trials. The secondary reinforcing effect of the light-food pairing decreased with increasing delay beyond 1.0 sec. Since S- in the present experiment was, in a sense, "paired" with S+ and with reinforcement in S+, S- may have acquired secondary reinforcing properties when the delay was brief, as when the alternation of components was most rapid.

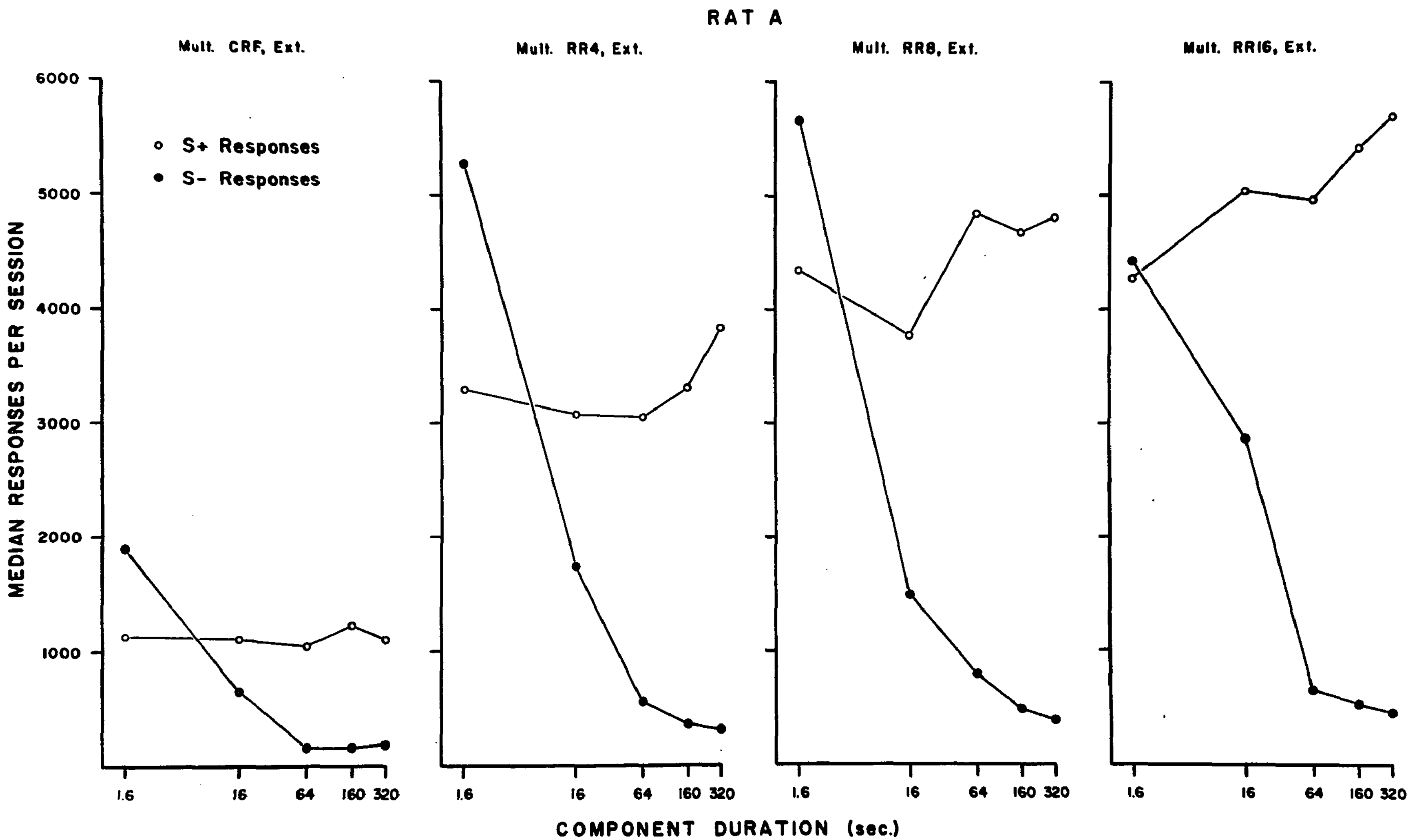
The fact that induction, rather than behavioral contrast, was obtained here has some bearing on the still unanswered question of what constitutes the necessary and sufficient conditions for contrast to occur. Reynolds (1961b) thought that increasing the absolute frequency of reinforcement in the variable component would increase response rate in that component. The opposite is true here; response rate in S+ increased when the probability of reinforcement decreased. Reynolds (1961b) also said that responding in the constant component increased when the relative frequency of reinforcement in that component increased. If the constant component is extinction, however, the frequency of reinforcement in that component is zero, and since zero divided by any number is still zero, the relative frequency of reinforcement in extinction is always the same. Yet the result here was that responding increased in the constant component as probability of reinforcement decreased in the variable component (S- curves of Figures 1, 3, 4, and 6).

Terrace's (1966) speculation that the magnitude of the behavioral contrast effect depended upon the temporal proximity of S+ and S- is contradicted by the data presented here. Figures 11-40 show that induction is enhanced by temporal proximity, both within components and with decreasing component duration. The present results are also at variance with the findings by Shimp and Wheatley (1971), Todorov (1972), Killeen (1972), Silberberg and Schrot (1974), and Merigan, Miller, and Gollub (1975) that response rate "matching" to relative frequency or duration of reinforcement improved with decreasing component duration. In the present study, discrimination ("matching") improved with increasing component duration. "Matching" performance seems to be better at short components under procedures where the frequency (or duration, in the case of Merigan, Miller & Gollub, 1975) of reinforcement is beyond the control of the subject. When the subject can manipulate reinforcement frequency, as in a ratio schedule (present study; Branch, 1973) or by changing components, as in the concurrent schedule procedure of Silberberg and Schrot (1974), improvement is "matching" occurs with longer component durations.

Vickery's (1971) suggestion that psychophysical thresholds could be produced as a function of the rate of stimulus change yielding a given level of differential responding gains support here. The present study demonstrates that as the rate of alternation between two cues increases (decreasing component duration), the differentiation of response rate to the two cues does, indeed, decrease. This is somewhat analogous to the technique of varying the frequency and amplitude of light modulation to determine flicker sensitivity in the visual system (deLange, 1952). For use as a psychophysical procedure, the next step would be to determine whether temporal manipulations of reinforcement schedules interact in some orderly way with the physical parameters of the discriminative stimulus.

If a multiple schedule with a fixed component duration were used as a psychophysical procedure, it would be desirable to maximize the number of stimulus presentations per unit time while also maximizing the range of the discrimination ratio. The number of stimuli are of interest because they would take on different physical values along some continuum under investigation, such as the radiance of a light or the frequency of a tone. The limits on the discrimination ratio would determine the possible range of the psychophysical function. The results of the present study show that there is a tradeoff between stimulus duration and the number of stimuli in a session. With the animals and apparatus used here, an optimal choice of component duration would be about one minute. Changing stimuli as often as four times a minute would prevent four out of six rats from discriminating as well as they might, and changing the stimuli less often than once a minute would unnecessarily restrict the number of stimuli in a session of reasonable length. The results of the present study show that component duration is a relatively powerful variable in determining the discrimination of a cue in a multiple schedule and that variation of probability of reinforcement has less of an effect on discriminability.

Figures 1-6. Median response rates in S+ and S- as a function of component duration under four multiple schedules.



RAT A
Mult. CRF, Ext.
Mult. RR4, Ext.
Mult. RR8, Ext.
Mult. RR16, Ext.
S+ Responses
S- Responses
MEDIAN RESPONSES PER SESSION
6000
5000
4000
3000
2000
1000
1.6
16
64
160
320
COMPONENT DURATION (sec.)

Figure 1.

Figure 2.

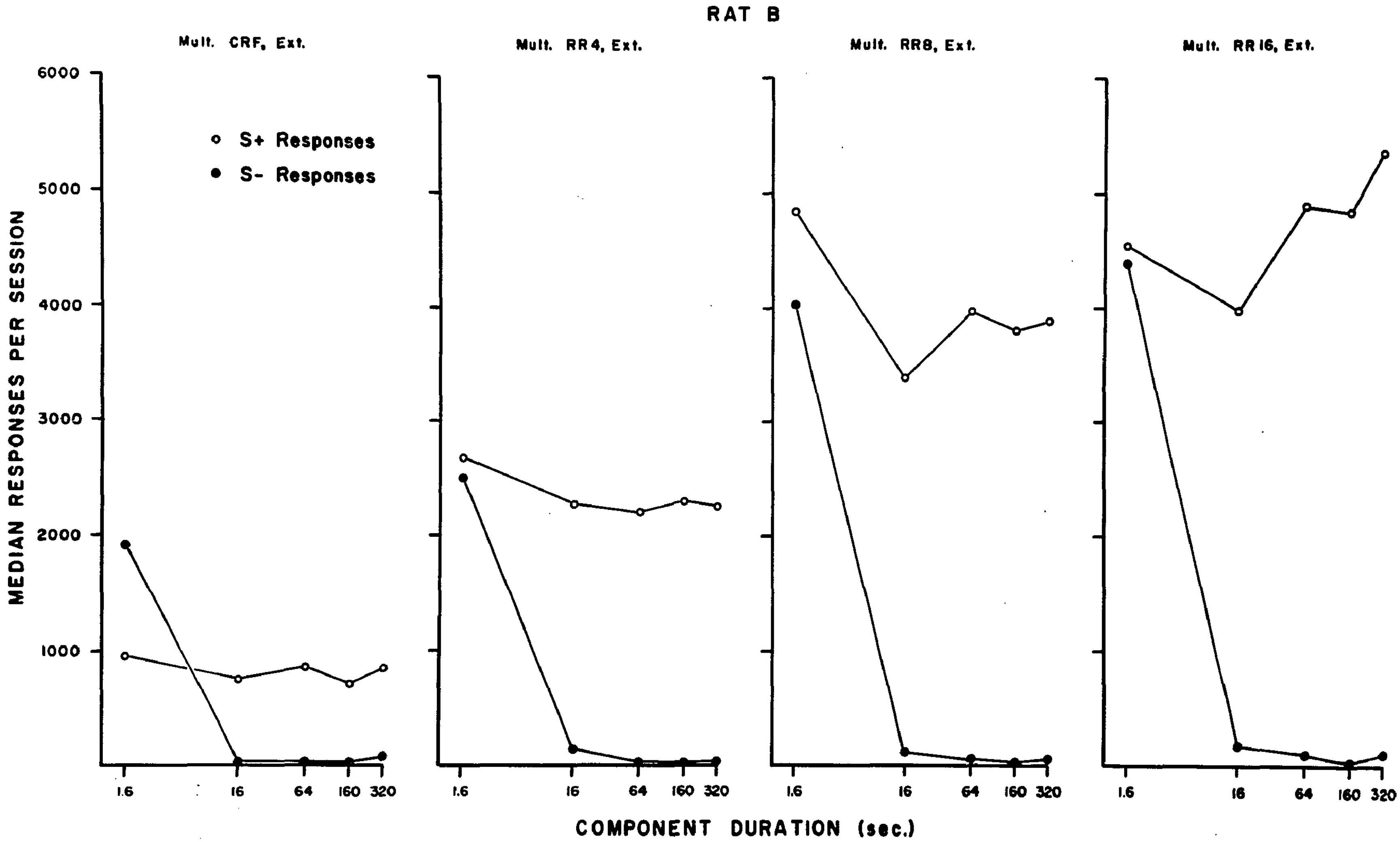

RAT B
Mult. CRF, Ext.
Mult. RR4, Ext.
Mult. RR8, Ext.
Mult. RR16, Ext.
S+ Responses
S- Responses
MEDIAN RESPONSES PER SESSION
6000
5000
4000
3000
2000
1000
1.6
16
64
160
320
COMPONENT DURATION (sec.)

Figure 3.

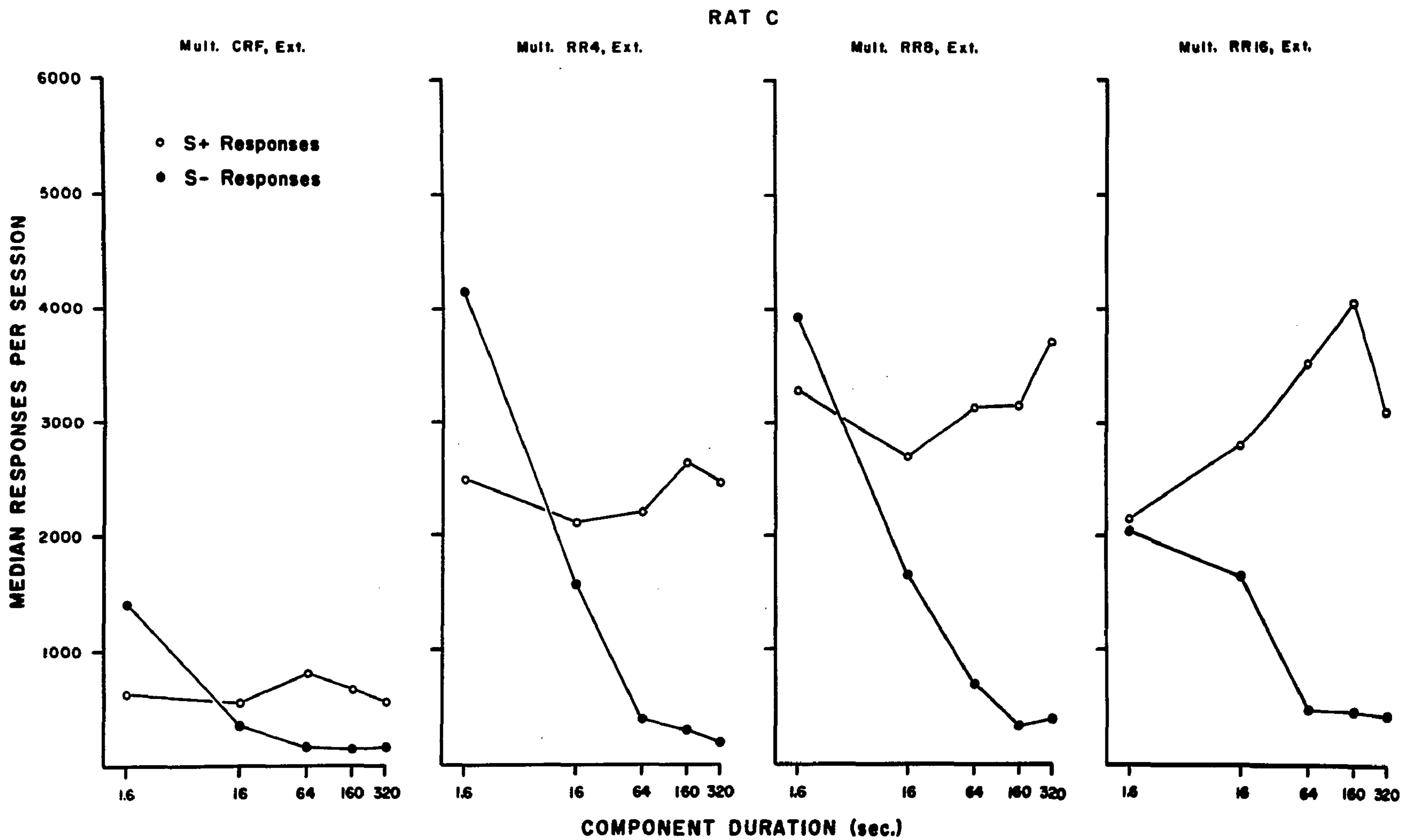

RAT C
Mult. CRF, Ext.
Mult. RR4, Ext.
Mult. RR8, Ext.
Mult. RR16, Ext.
S+ Responses
S- Responses
MEDIAN RESPONSES PER SESSION
6000
5000
4000
3000
2000
1000
1.6
16
64
160
320
COMPONENT DURATION (sec.)

Figure 4.

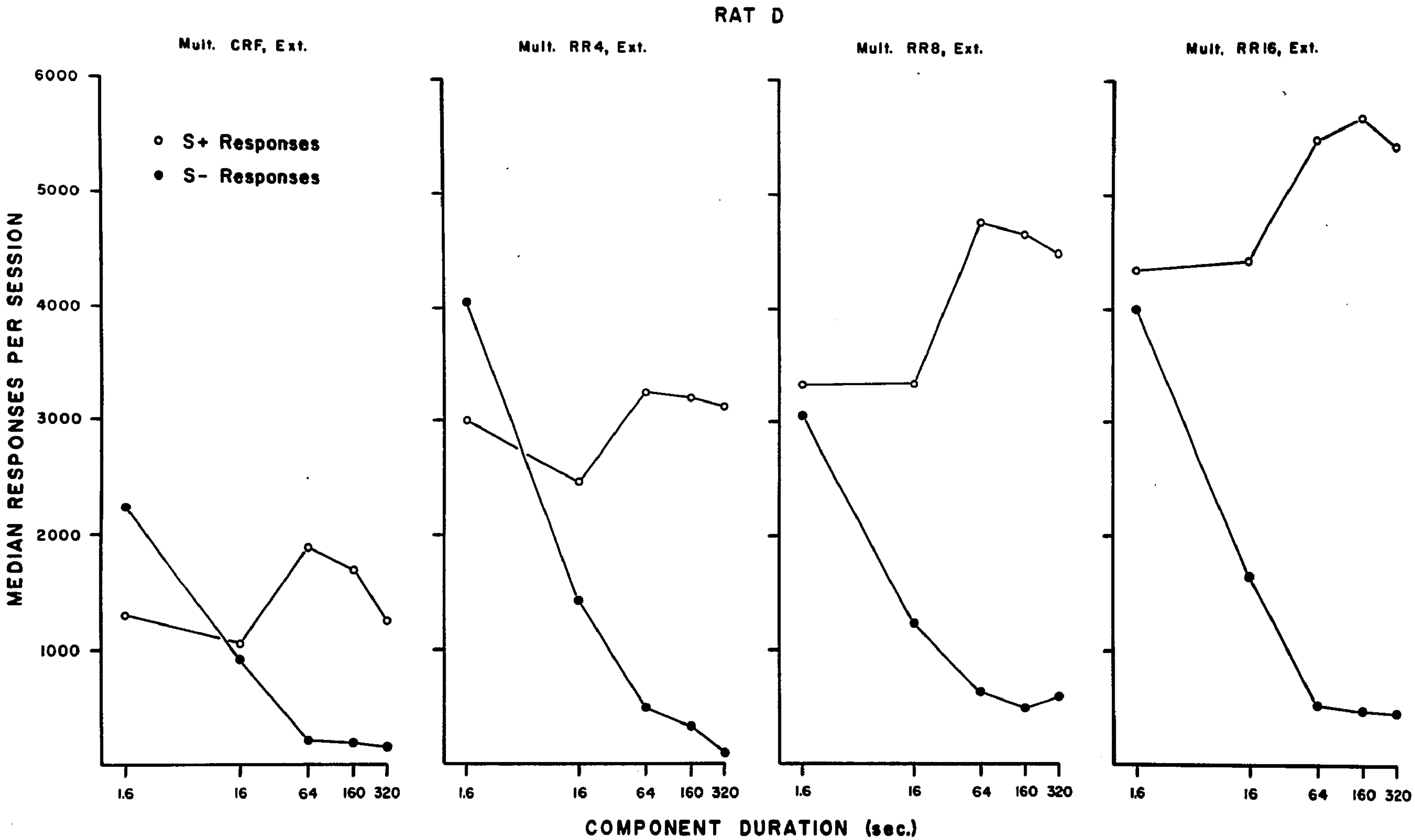

RAT D
Mult. CRF, Ext.
Mult. RR4, Ext.
Mult. RR8, Ext.
Mult. RR16, Ext.
S+ Responses
S- Responses
MEDIAN RESPONSES PER SESSION
6000
5000
4000
3000
2000
1000
1.6
16
64
160
320
COMPONENT DURATION (sec.)

Figure 5.

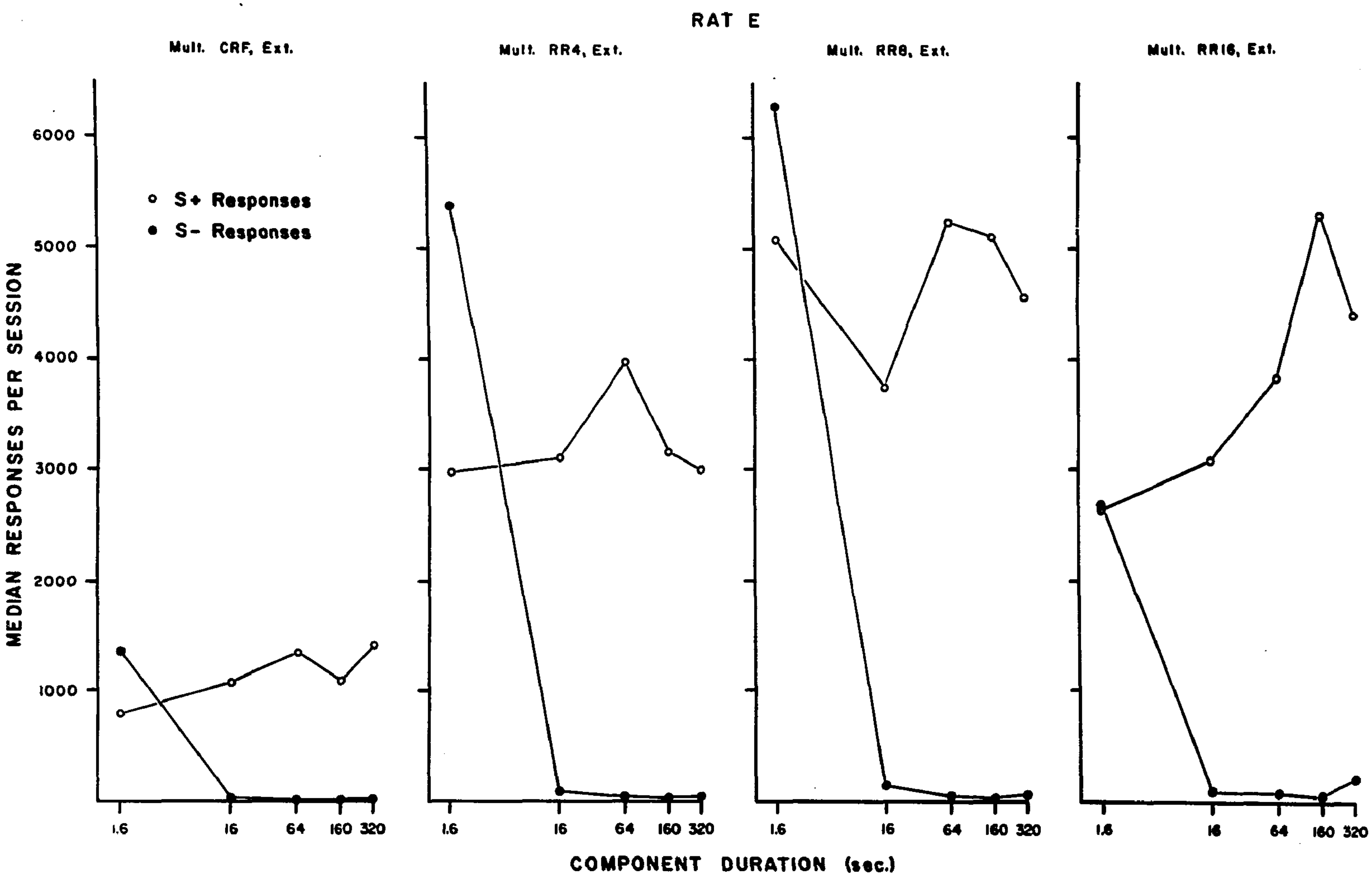
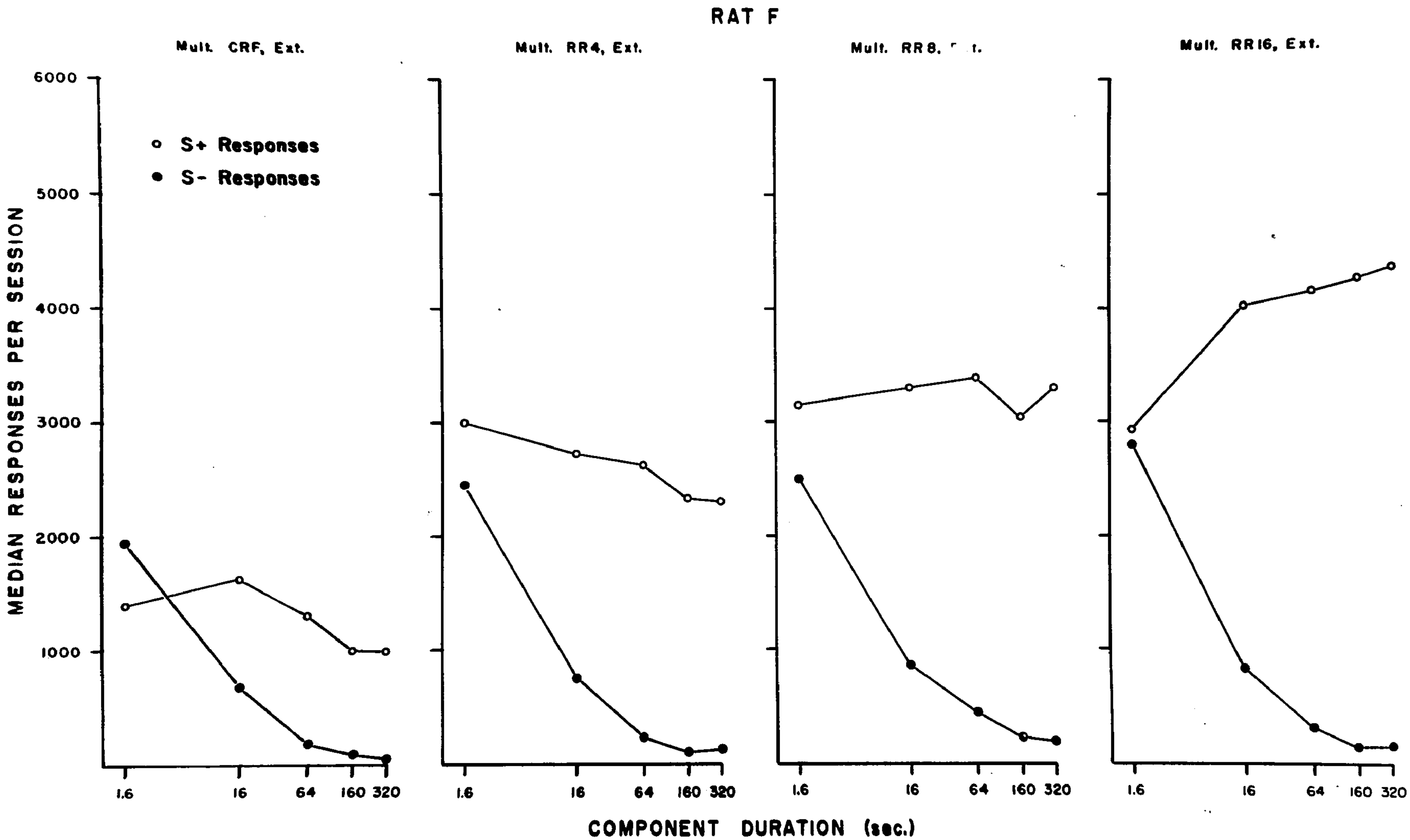

RAT E
Mult. CRF, Ext.
Mult. RR4, Ext.
Mult. RR8, Ext.
Mult. RR16, Ext.
S+ Responses
S- Responses
MEDIAN RESPONSES PER SESSION
6000
5000
4000
3000
2000
1000
1.6
16
64
160
320
COMPONENT DURATION (sec.)

Figure 6.

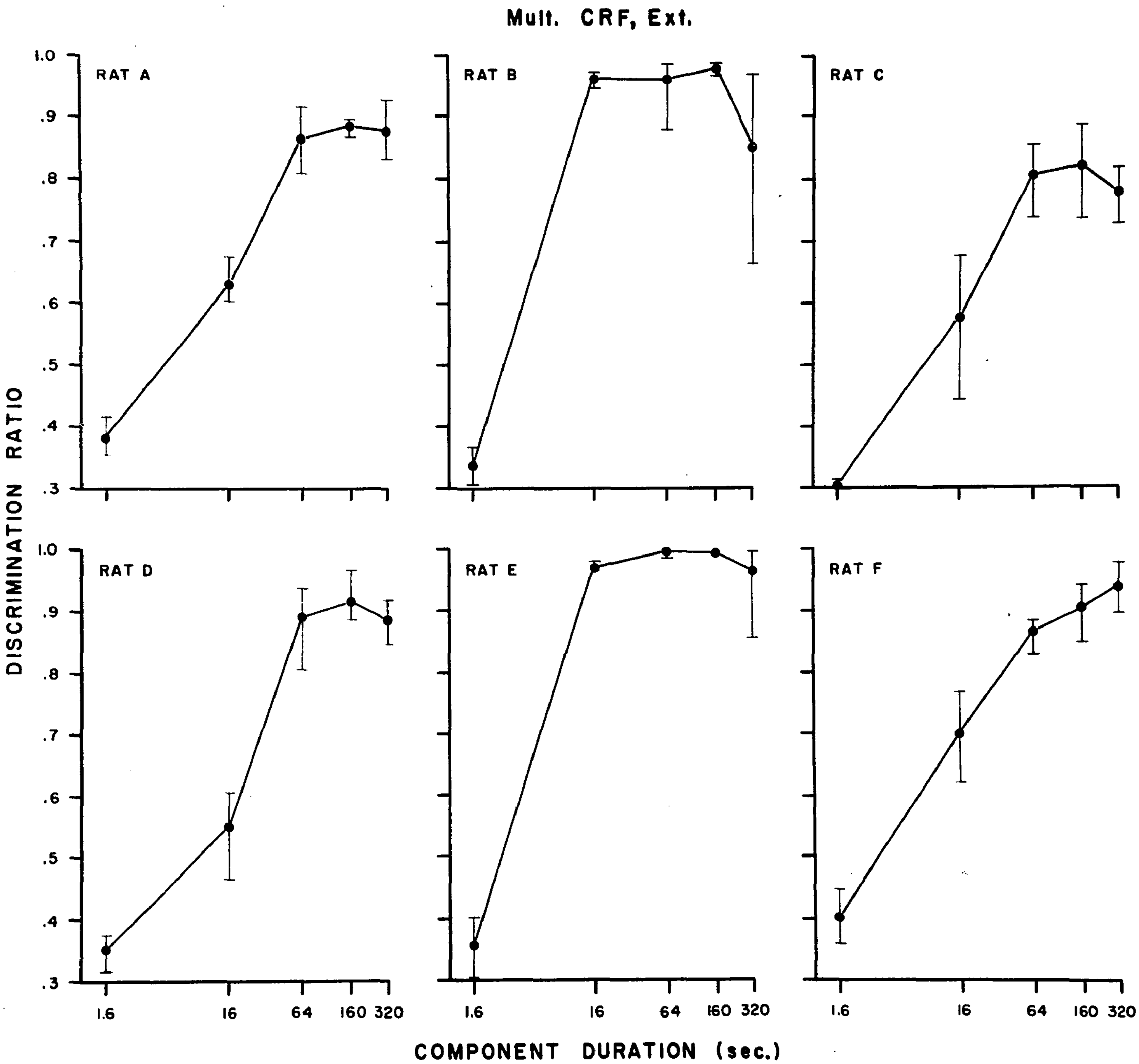

RAT F
Mult. CRF, Ext.
Mult. RR4, Ext.
Mult. RR8.
Mult. RR16, Ext.
S+ Responses
S- Responses
MEDIAN RESPONSES PER SESSION
6000
5000
4000
3000
2000
1000
1.6
16
64
160
320
COMPONENT DURATION (sec.)

Figures 7-10. Mean discrimination ratios

(S+ rate/S+ rate + S- rate)

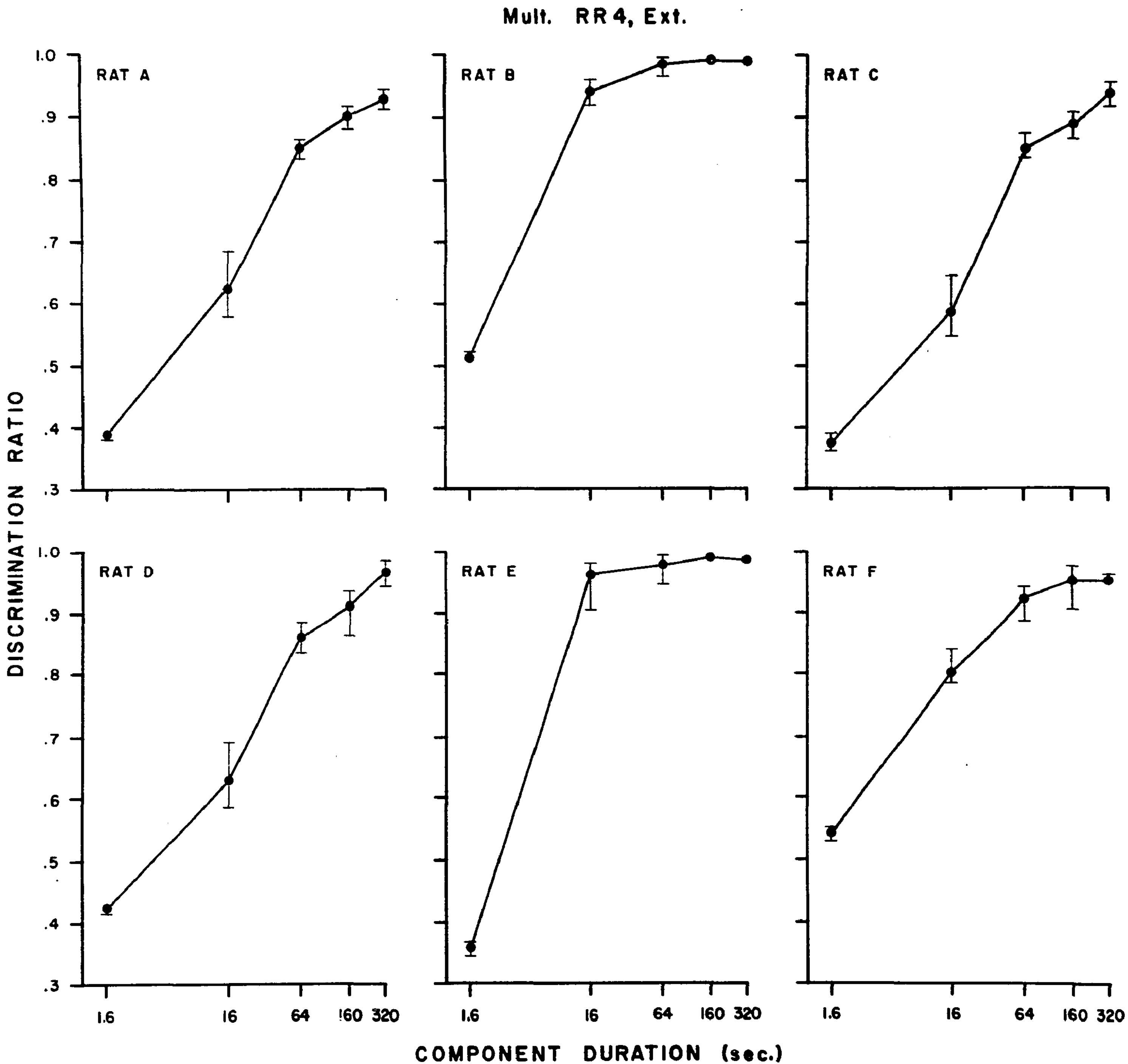
as a function of component duration for six rats. Vertical bars indicate range of five daily discrimination ratios. Where bars are missing, the range was within 0.01 from the mean.

Figure 7.



Mult. CRF, Ext.
RAT A
RAT B
RAT C
RAT D
RAT E
RAT F
DISCRIMINATION RATIO
1.0
.9
.8
.7
.6
.5
.4
.3
1.6
16
64
160
320
COMPONENT DURATION (sec.)

Figure 8.


Mult. RR4, Ext.
RAT A
RAT B
RAT C
RAT D
RAT E
RAT F
DISCRIMINATION RATIO
1.0
.9
.8
.7
.6
.5
.4
.3
1.6
16
64
160
320
COMPONENT DURATION (sec.)

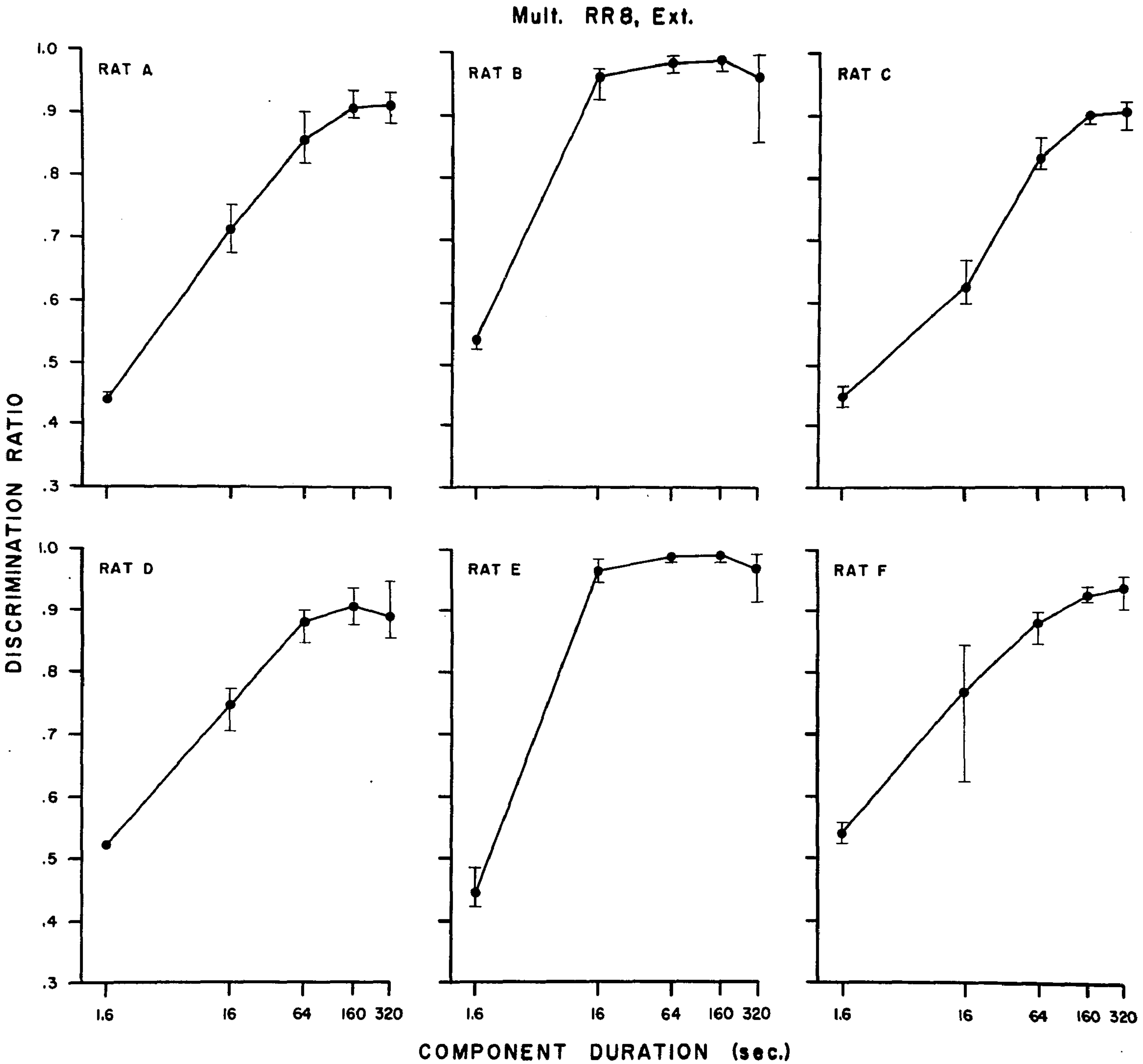
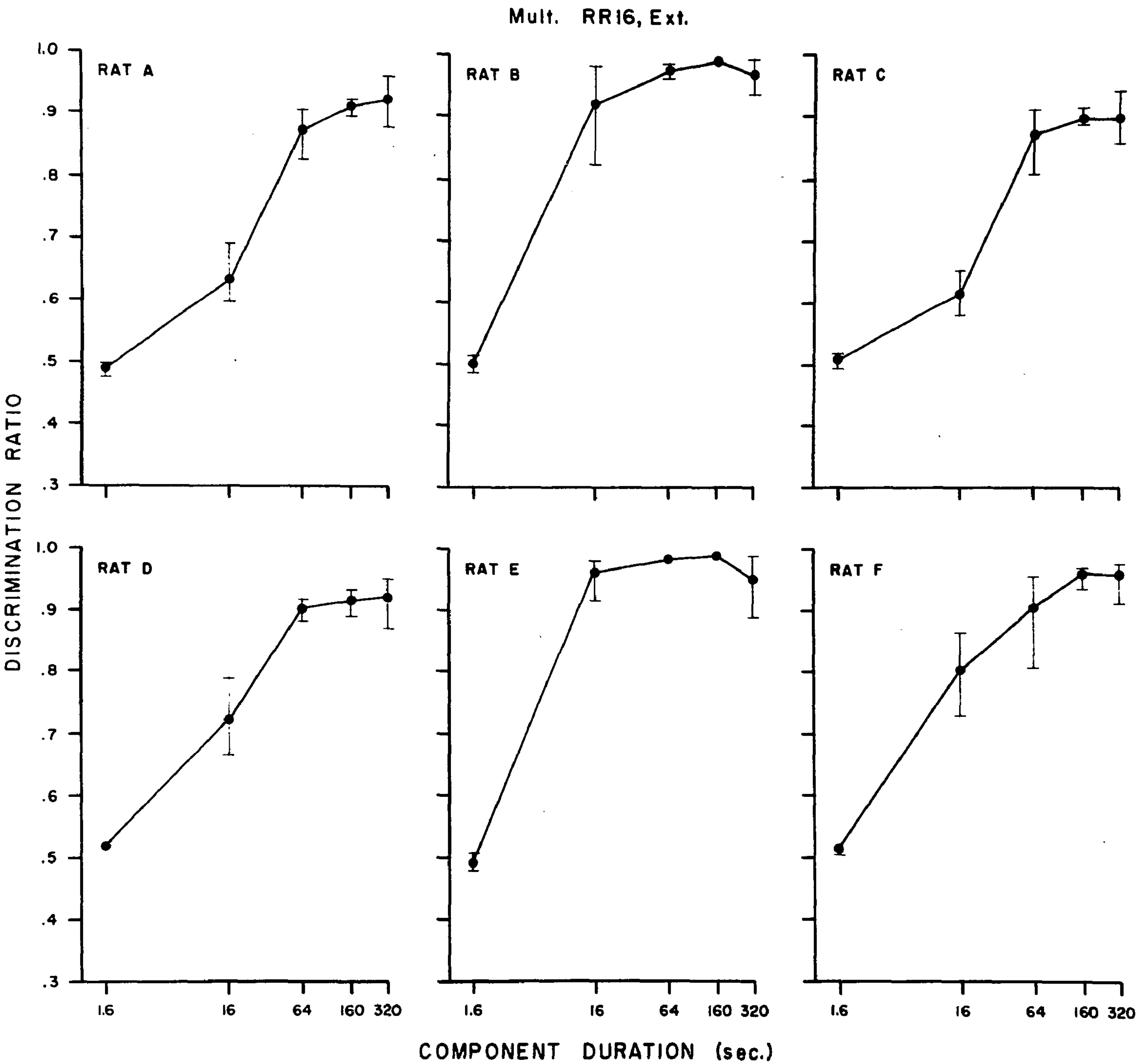

Mult. RR8, Ext.
RAT A
RAT B
RAT C
RAT D
RAT E
RAT F
DISCRIMINATION RATIO
1.0
.9
.8
.7
.6
.5
.4
.3
1.6
16
64
160
320
COMPONENT DURATION (sec.)

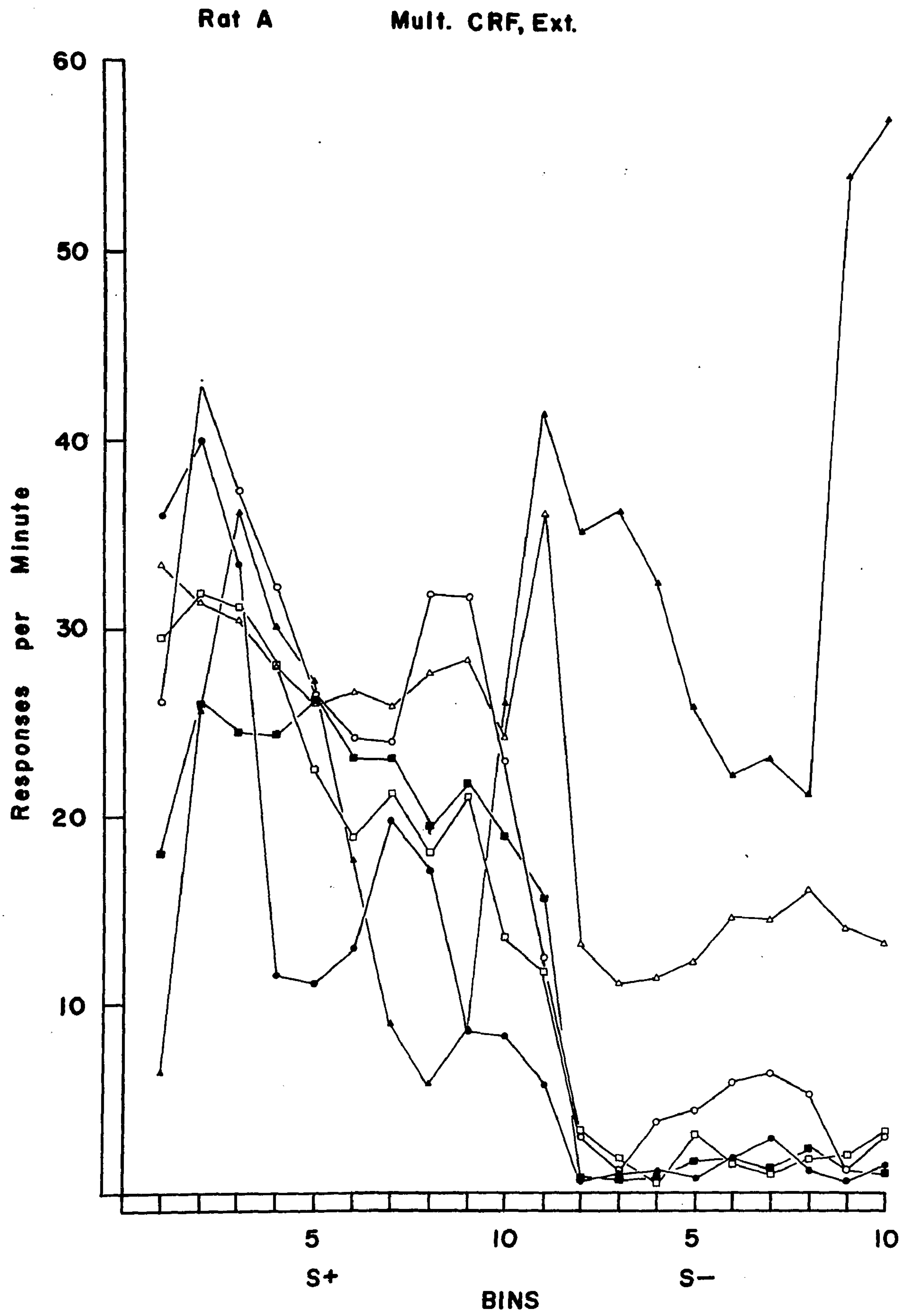
Figure 9.

Figure 10.


Mult. RR16, Ext.
RAT A
RAT B
RAT C
RAT D
RAT E
RAT F
DISCRIMINATION RATIO
1.0
.9
.8
.7
.6
.5
.4
.3
1.6
16
64
160
320
COMPONENT DURATION (sec.)

Figures 11-40. Mean response rate as a function of time division bins within components of a multiple schedule.

Key:	Symbol	Component Duration
	○	320 sec, 1st determination
	●	320 sec, 2nd determination
	□	160 sec
	■	64 sec
	△	16 sec
	▲	1.6 sec



Rat A
Mult. CRF, Ext.
Responses per Minute
60
50
40
30
20
10
5
10
5
10
S+
S−
BINS

Figure 11.

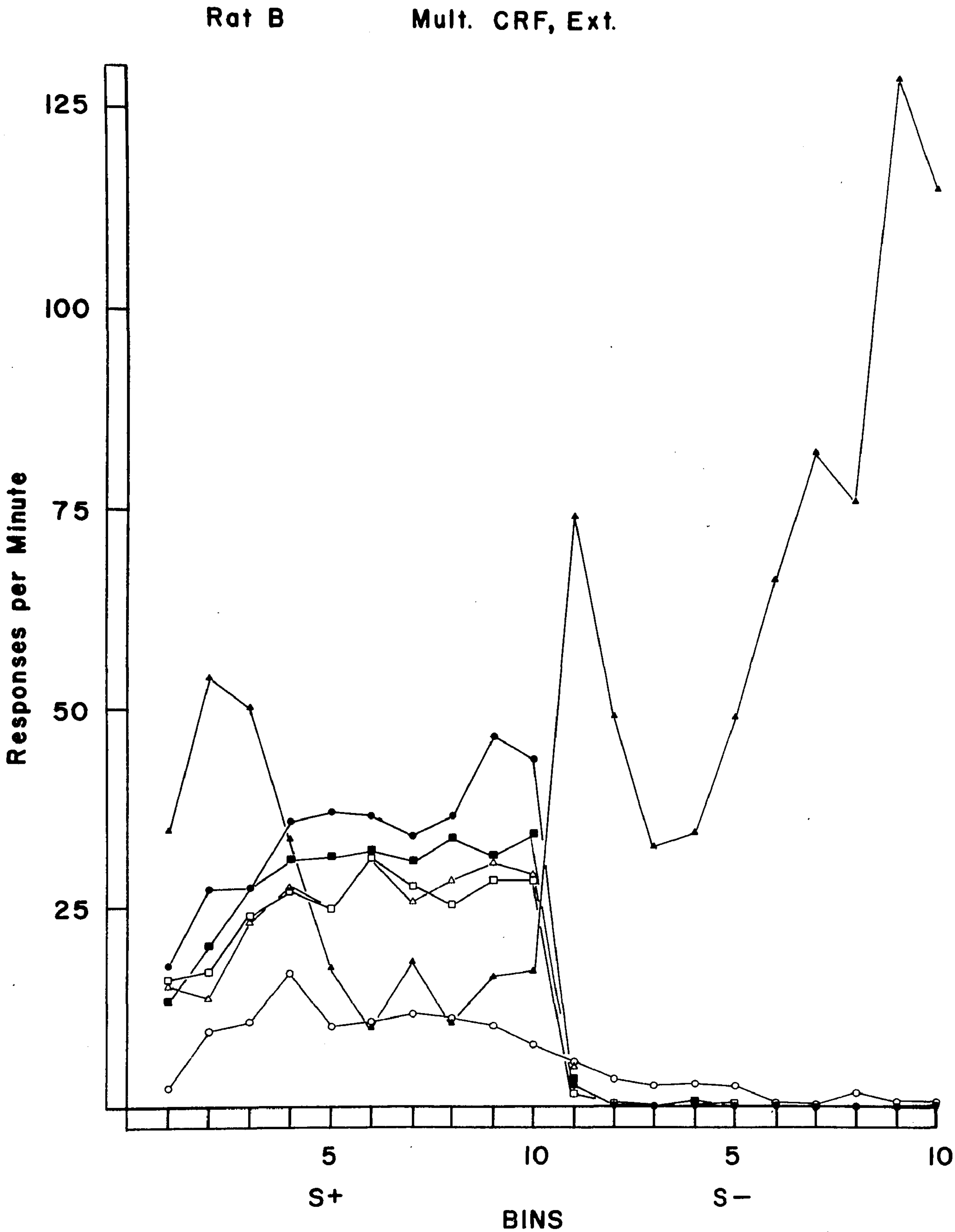

Rat B
Mult. CRF, Ext.
125
100
75
50
25
Responses per Minute
5
10
5
10
S+
S−
BINS

Figure 12.

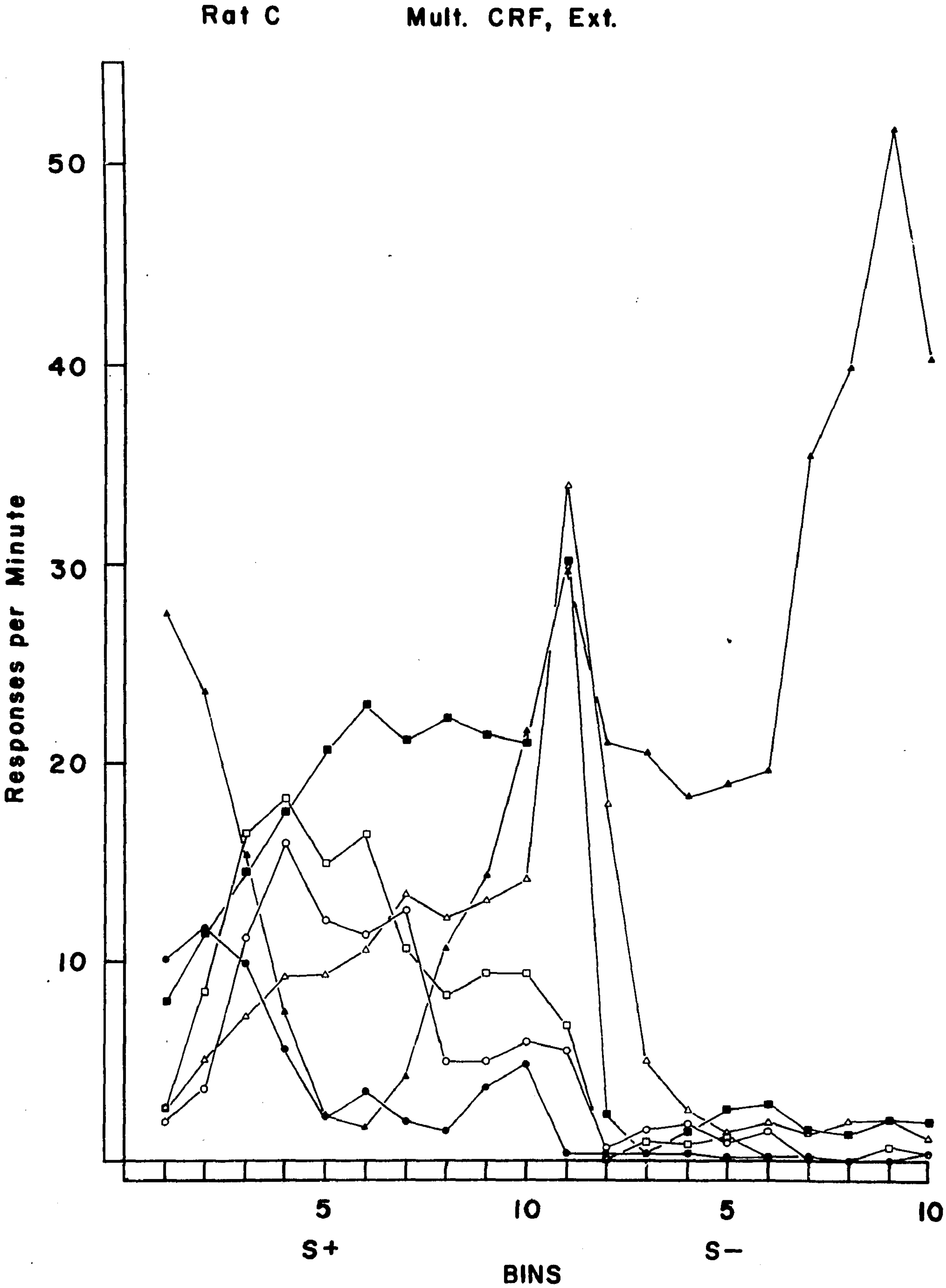

Rat C
Mult. CRF, Ext.
Responses per Minute
50
40
30
20
10
5
10
5
10
S+
S−
BINS

Figure 13.

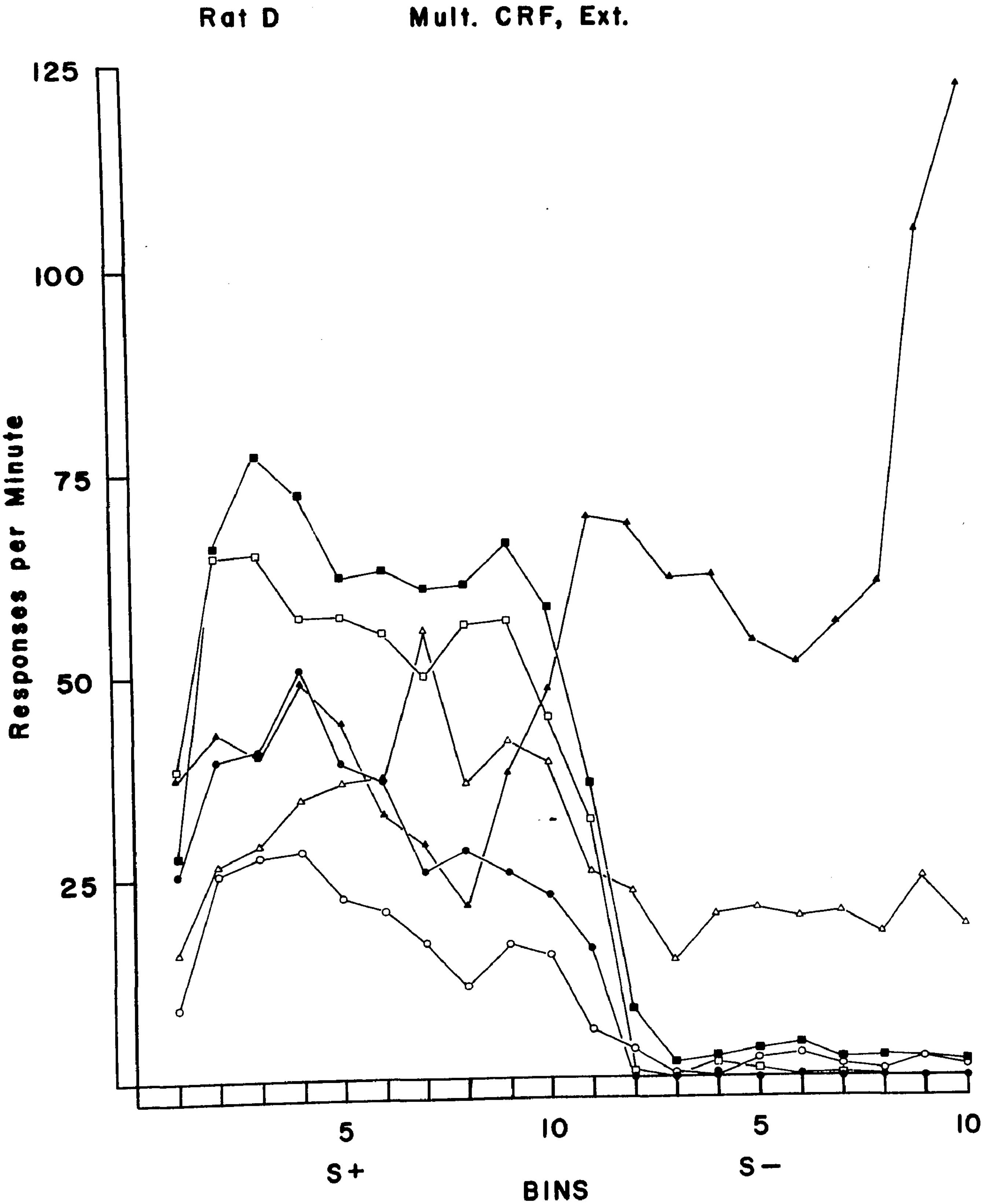

Rat D
Mult. CRF, Ext.
Responses per Minute
125
100
75
50
25
5
10
5
10
S+
S−
BINS

Figure 14.

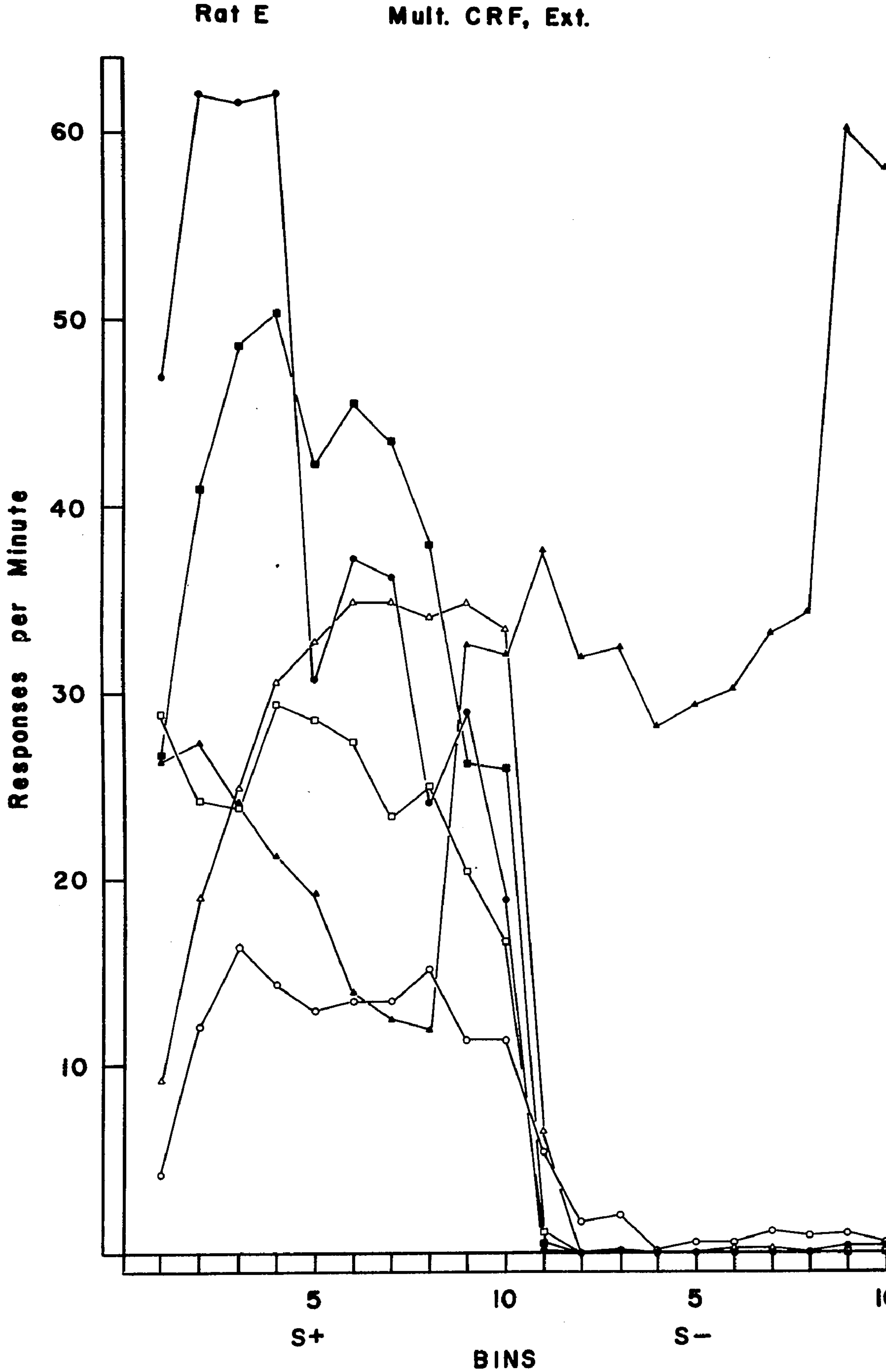

Rat E
Mult. CRF, Ext.
Responses per Minute
60
50
40
30
20
10
5
10
5
10
S+
S−
BINS

Figure 15.

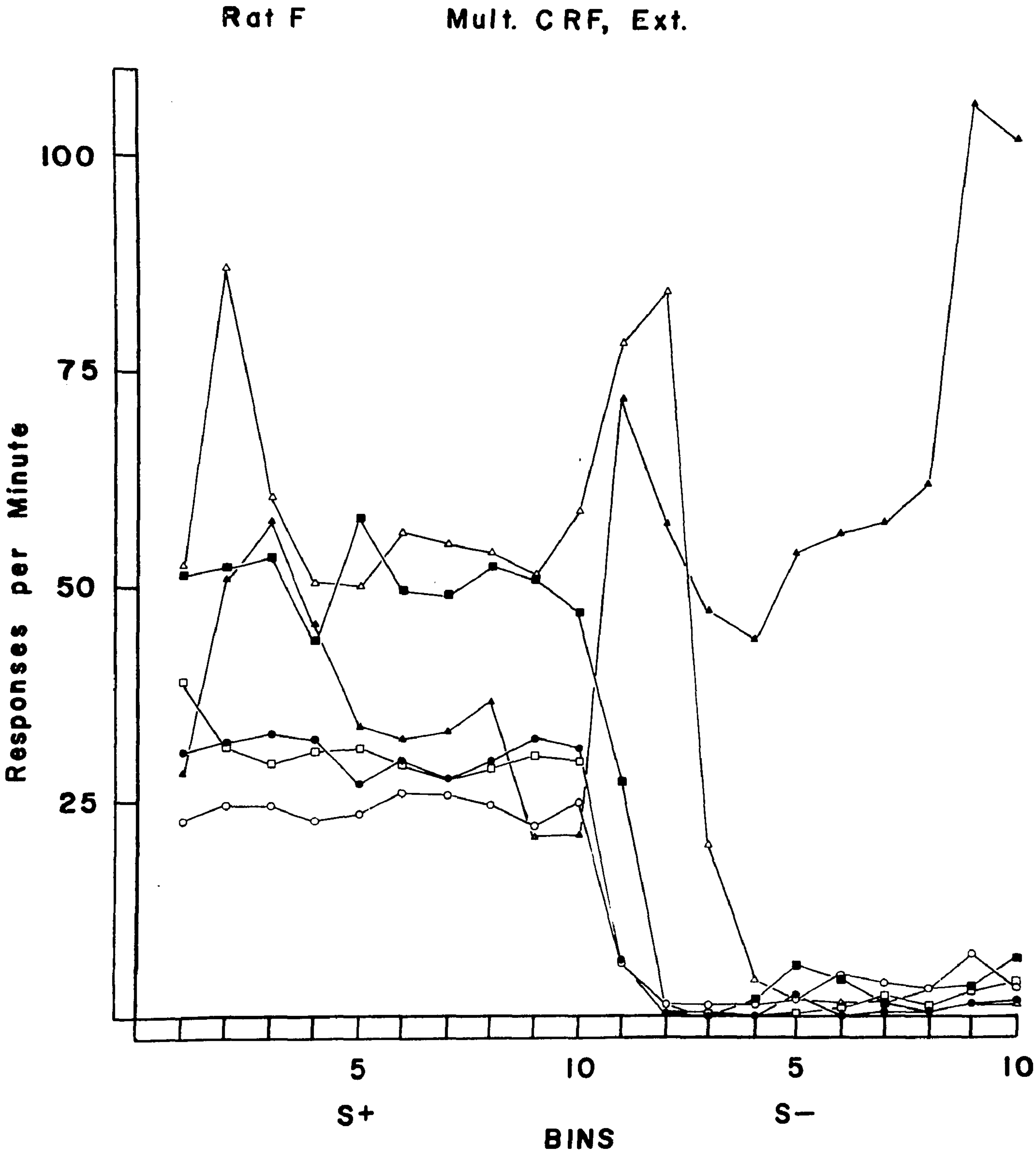

Rat F
Mult. CRF, Ext.
Responses per Minute
100
75
50
25
5
10
5
10
S+
S−
BINS

Figure 16.

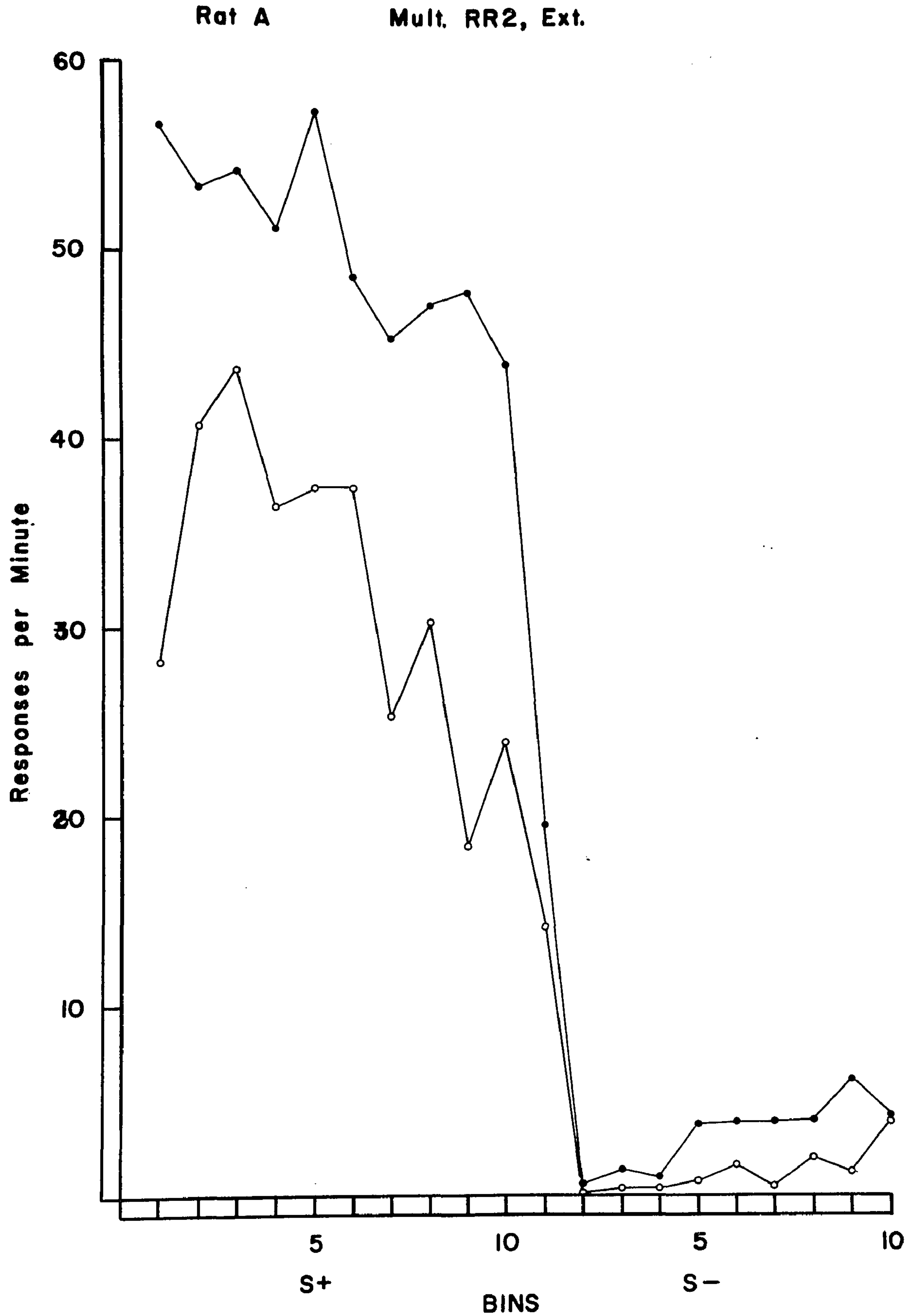

Rat A
Mult. RR2, Ext.
60
50
40
30
20
10
Responses per Minute
5
10
5
10
S+
S−
BINS

Figure 17.

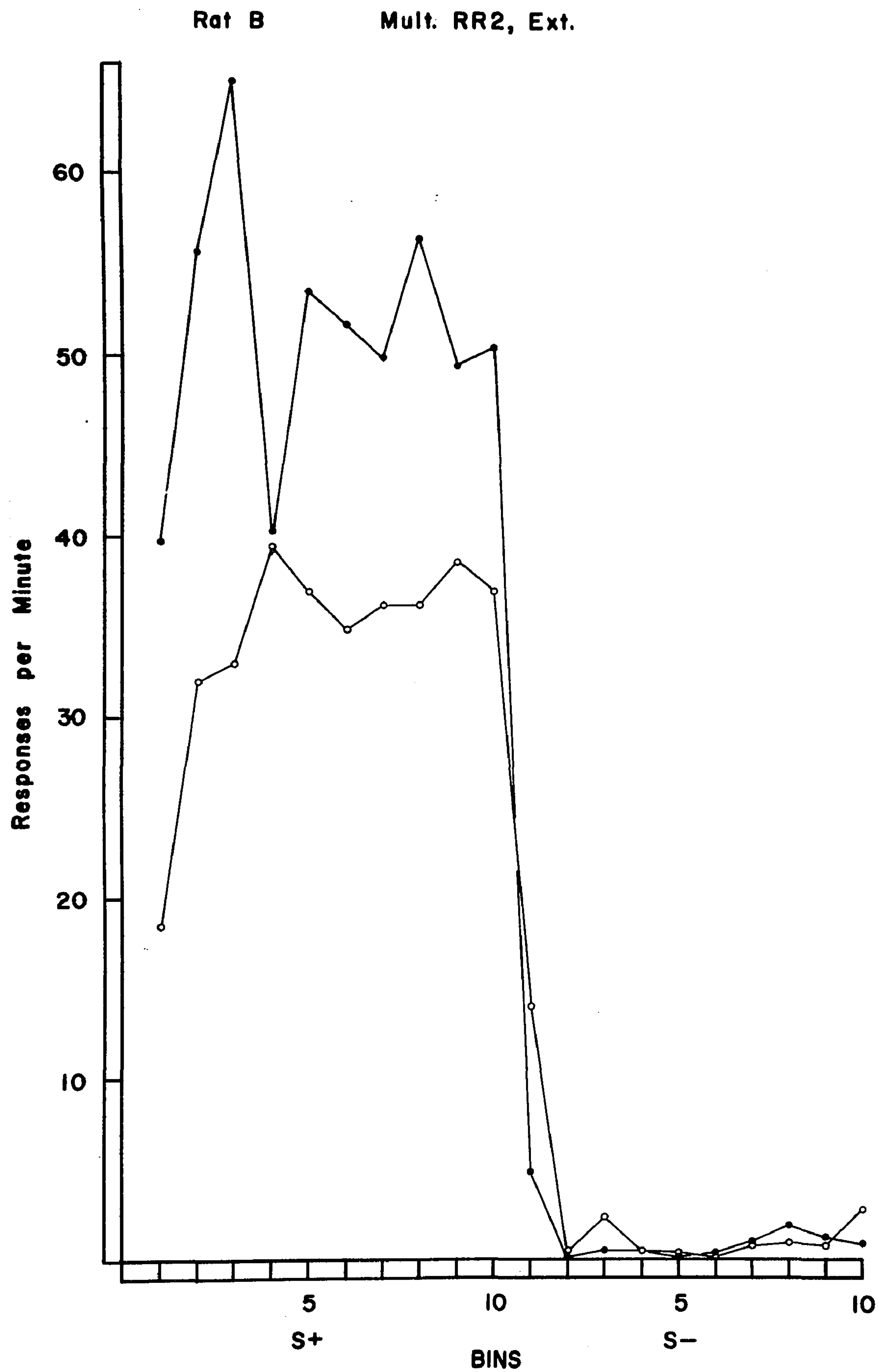

Rat B
Mult. RR2, Ext.
Responses per Minute
60
50
40
30
20
10
5
10
5
10
S+
BINS
S−

Figure 18.

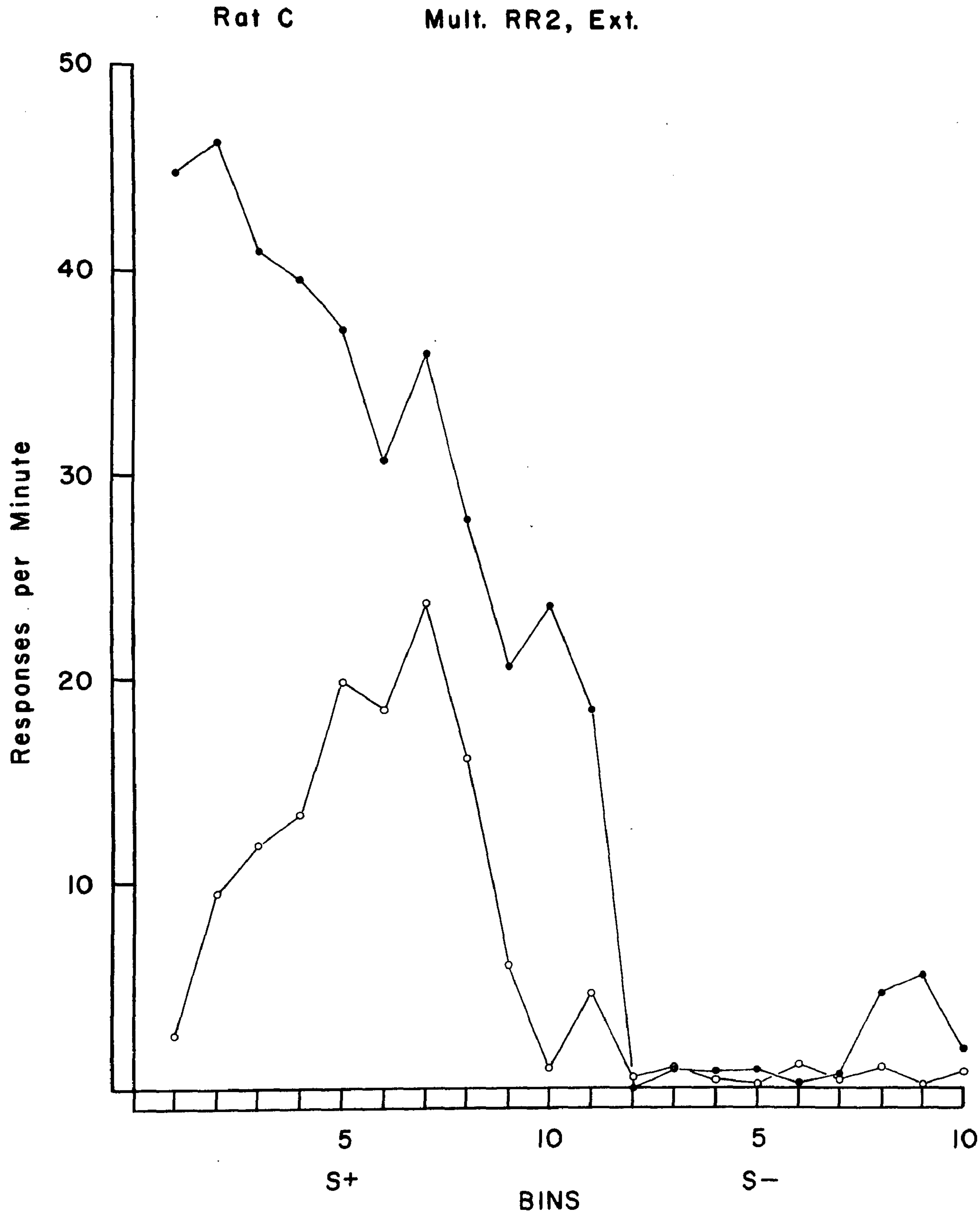

Rat C
Mult. RR2, Ext.
Responses per Minute
50
40
30
20
10
5
10
5
10
S+
BINS
S−

Figure 19.

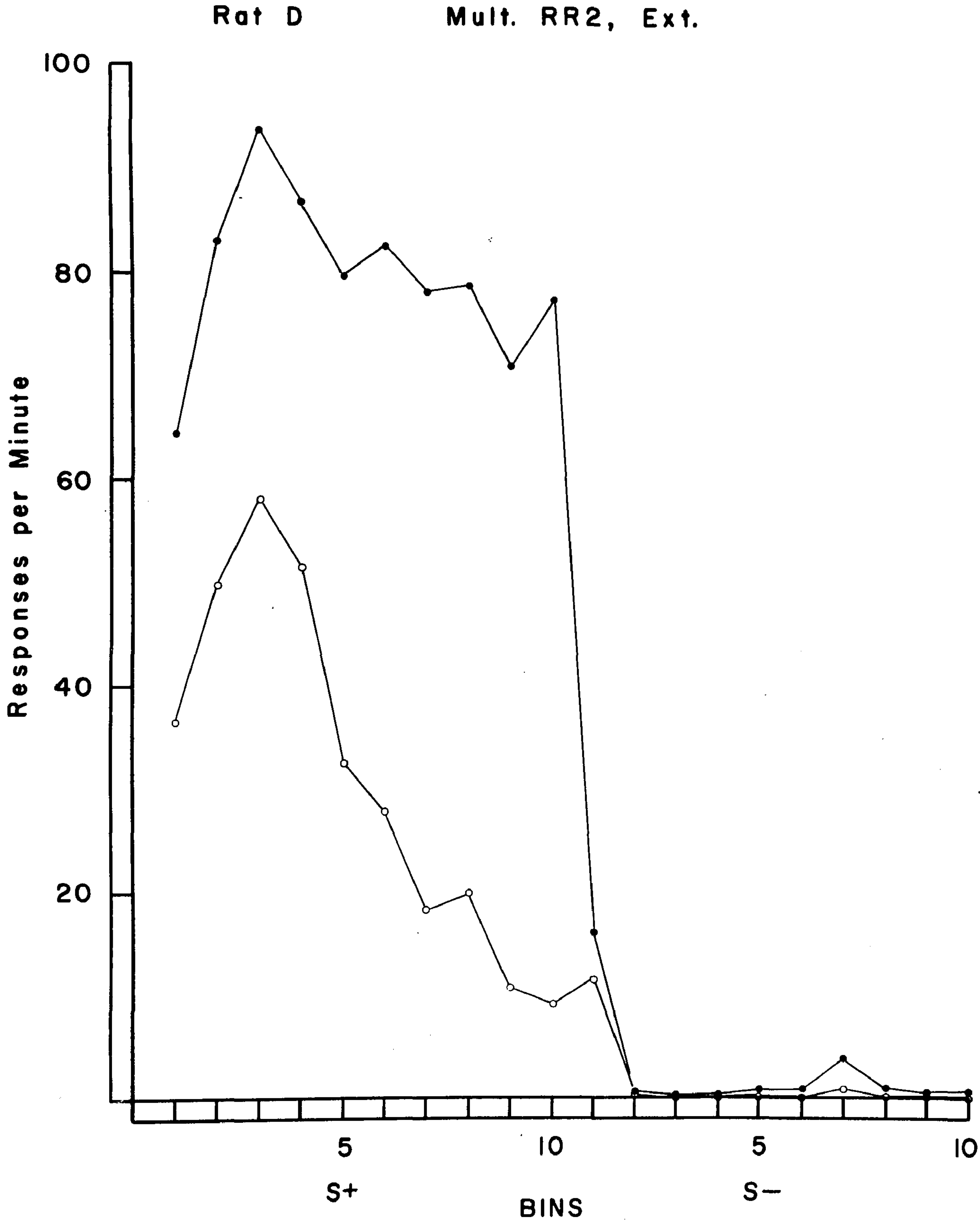
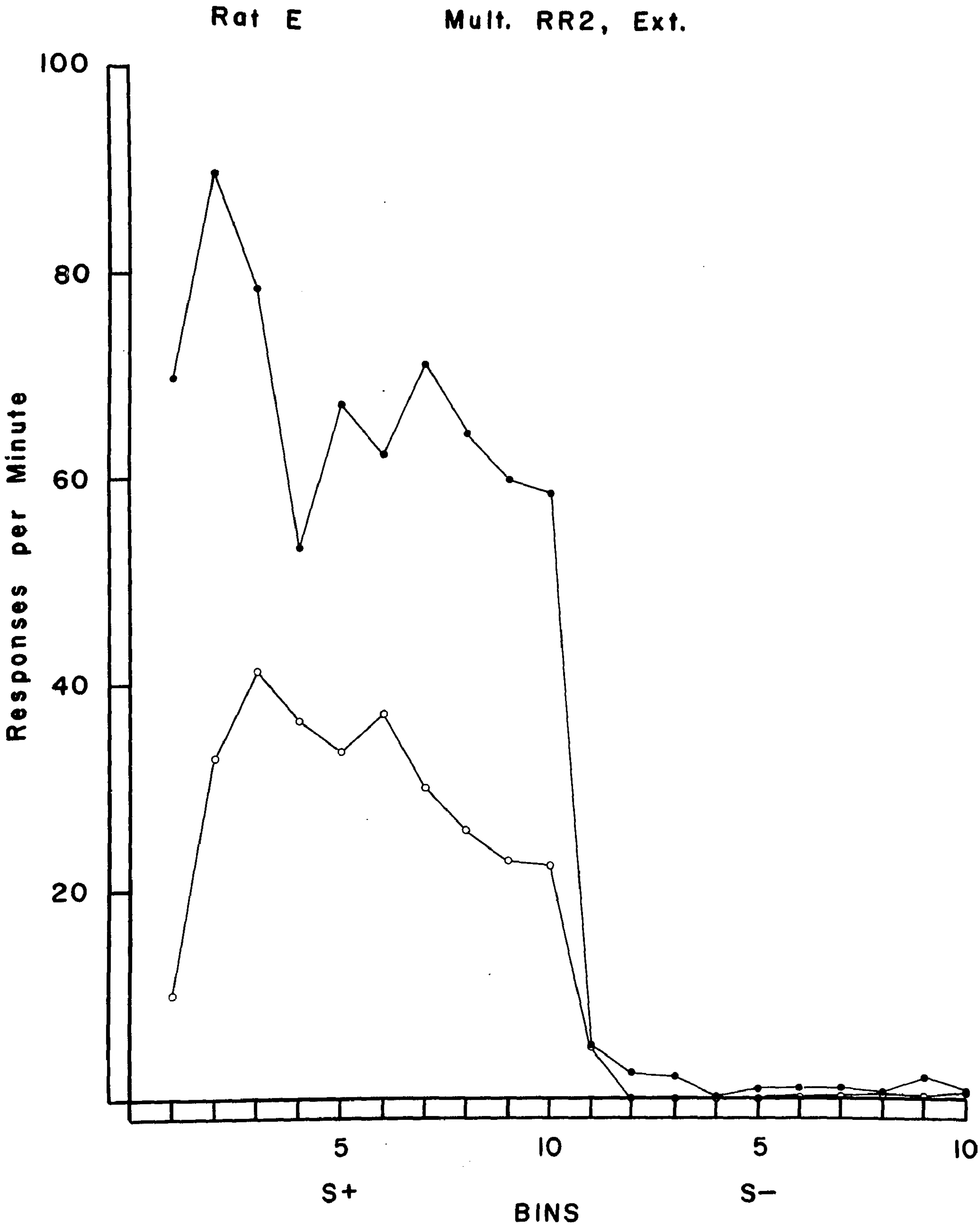

Rat D
Mult. RR2, Ext.
100
80
60
40
20
Responses per Minute
5
10
5
10
S+
BINS
S−

Figure 20.



Rat E
Mult. RR2, Ext.
100
80
60
40
20
Responses per Minute
5
10
5
10
S+
S−
BINS

Figure 21.

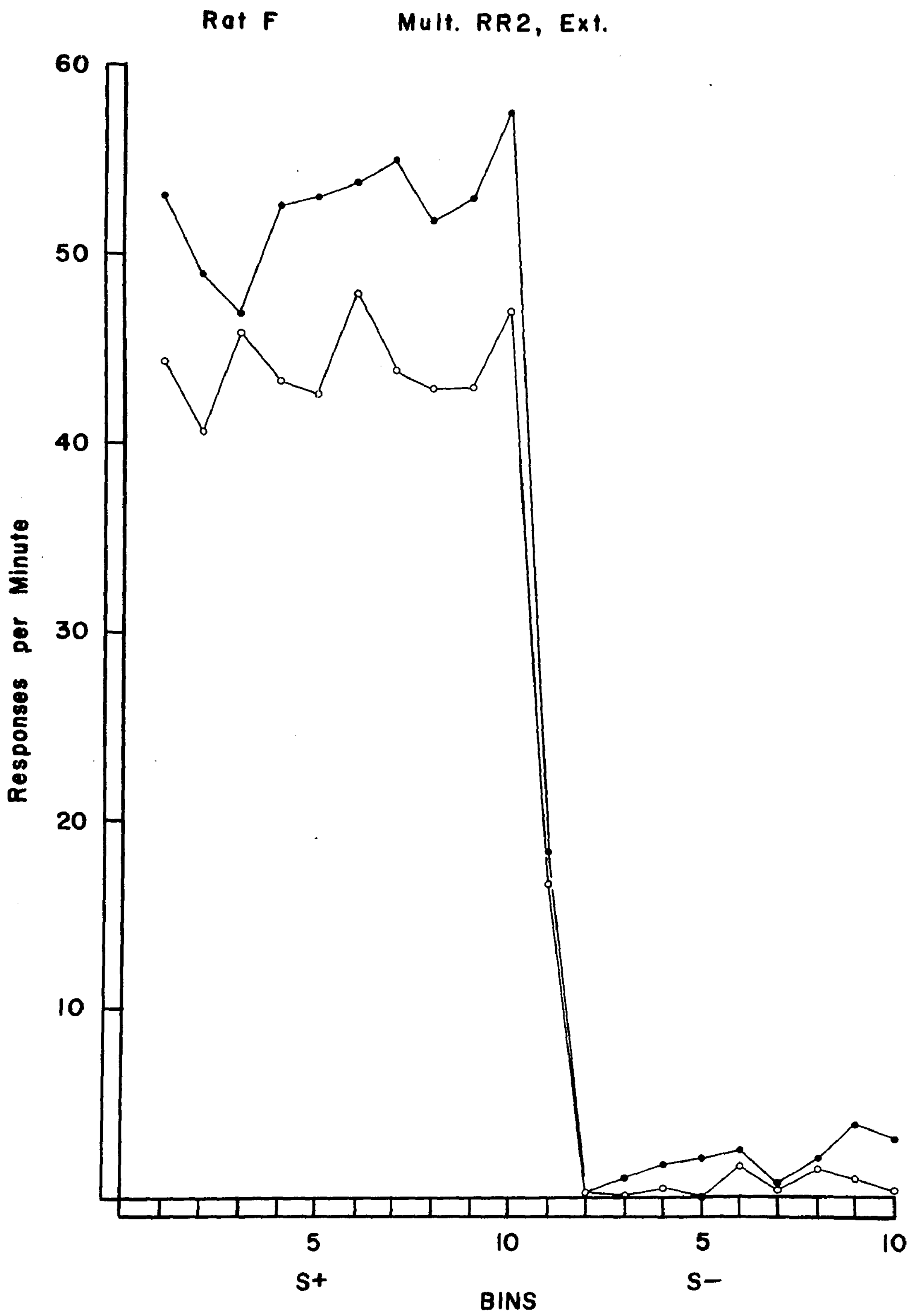

Rat F
Mult. RR2, Ext.
60
50
40
30
20
10
Responses per Minute
5
10
5
10
S+
S−
BINS

Figure 22.

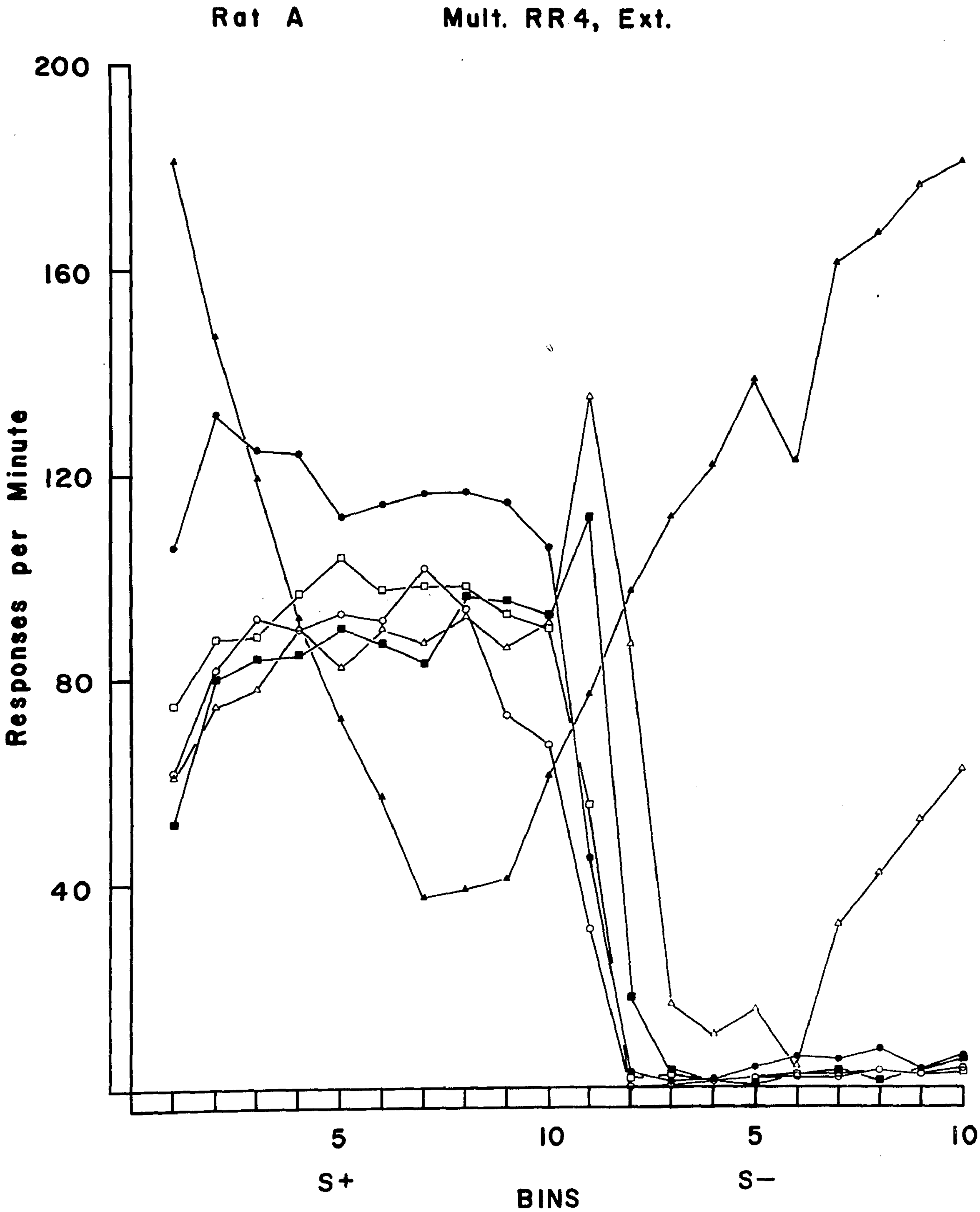
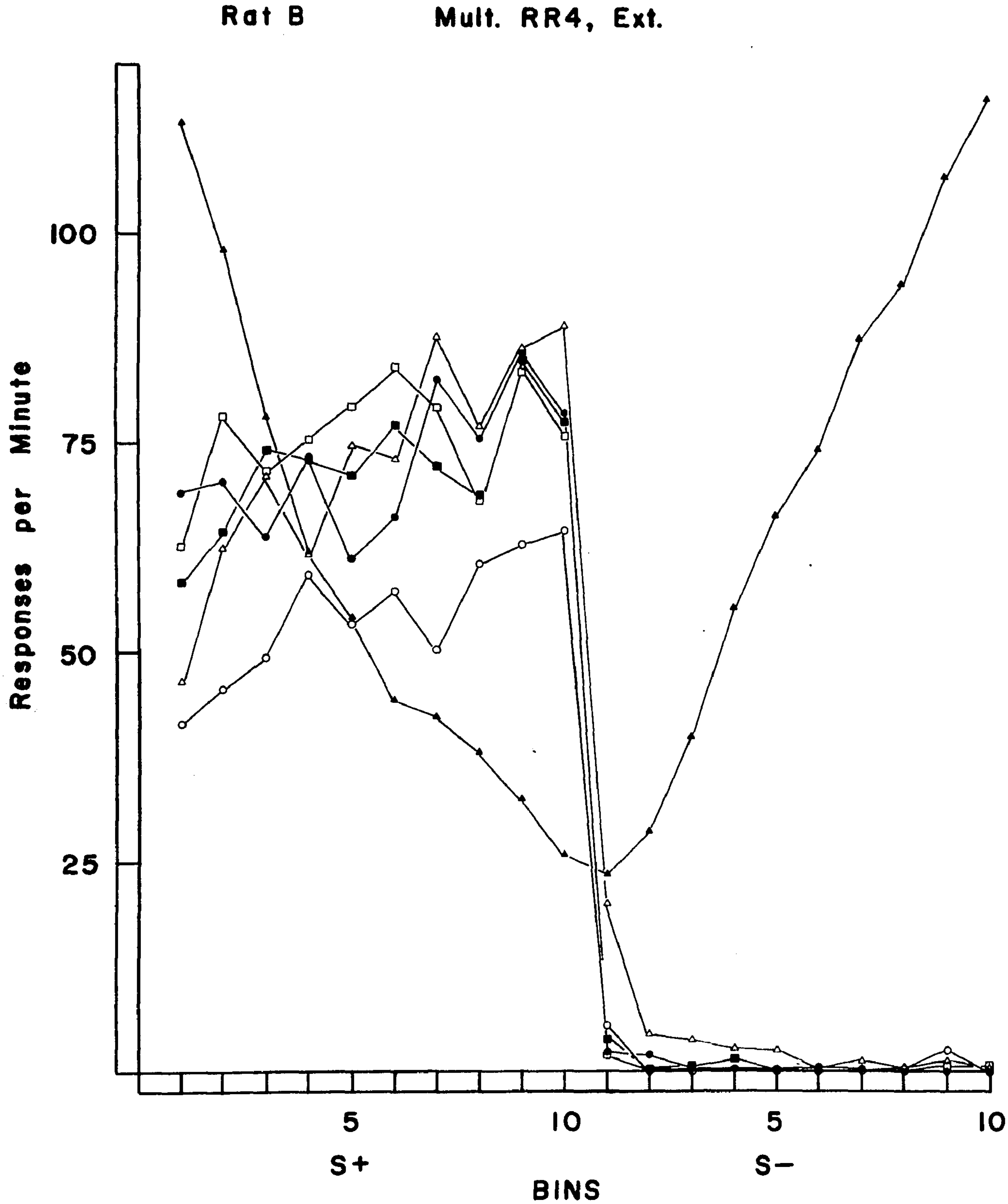

Rat A
Mult. RR 4, Ext.
Responses per Minute
200
160
120
80
40
5
10
5
10
S+
S−
BINS

Figure 23.



Rat B
Mult. RR4, Ext.
Responses per Minute
100
75
50
25
5
10
5
10
S+
S−
BINS

Figure 24.

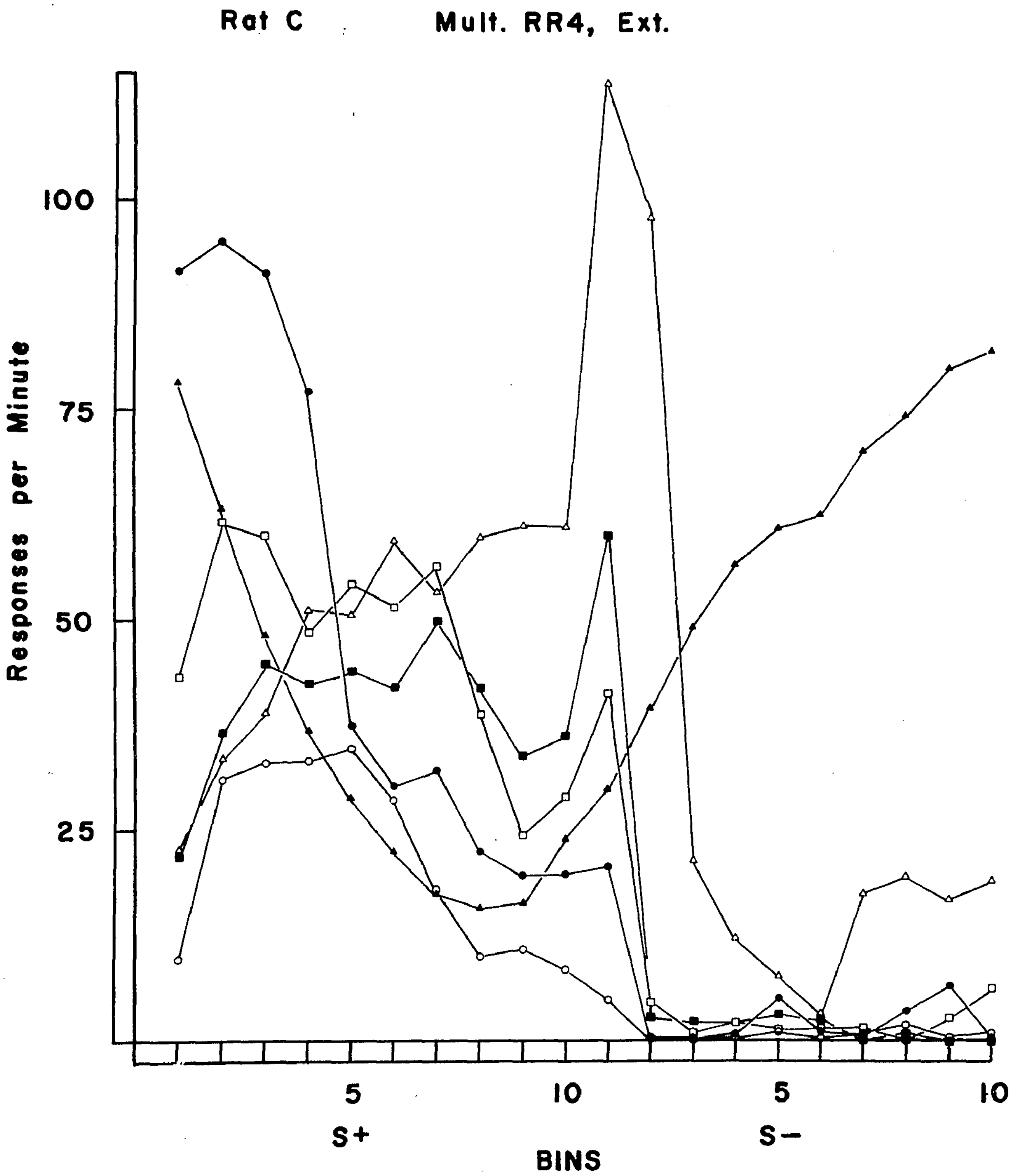

Rat C
Mult. RR4, Ext.
Responses per Minute
100
75
50
25
5
10
5
10
S+
S−
BINS

Figure 25.

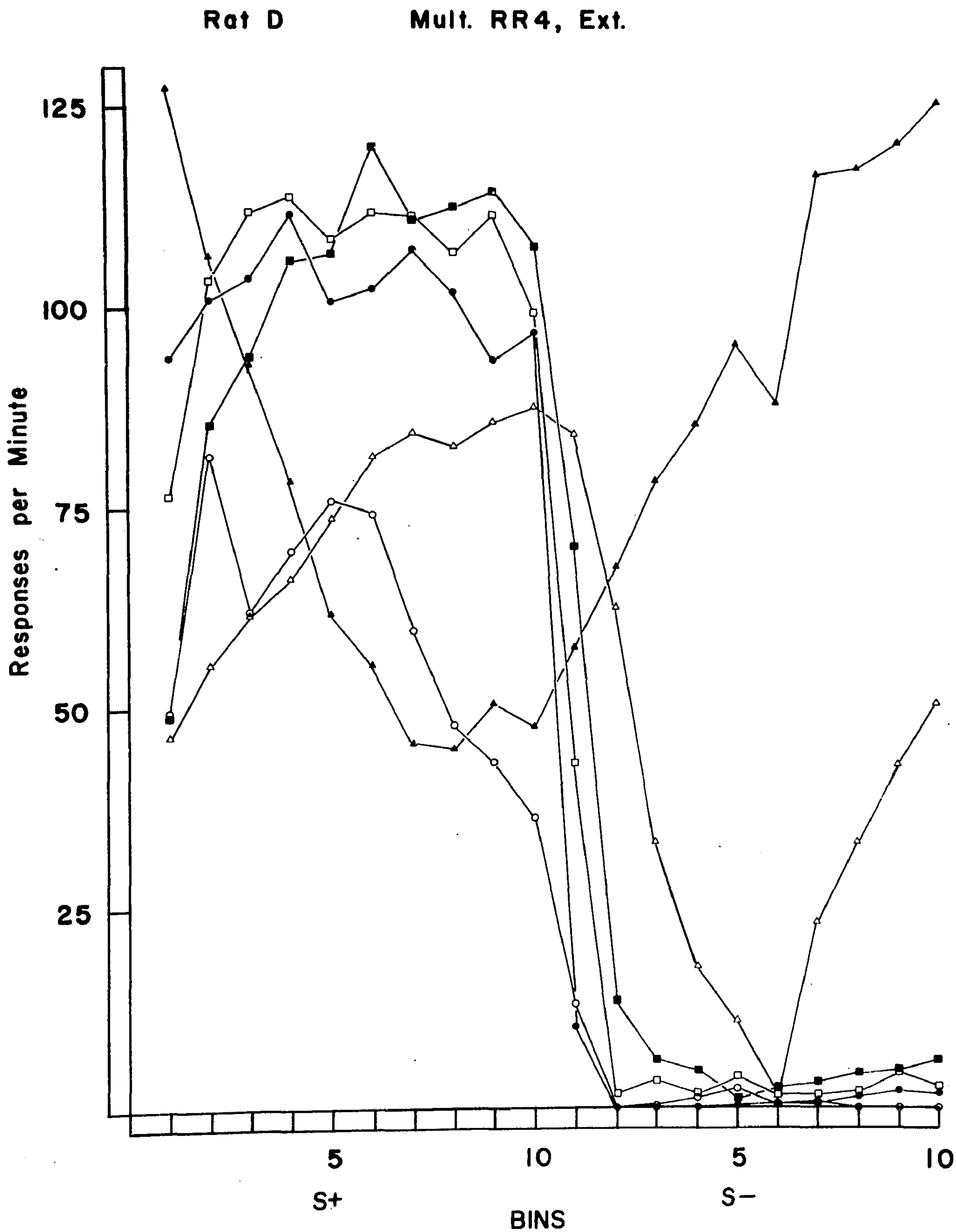
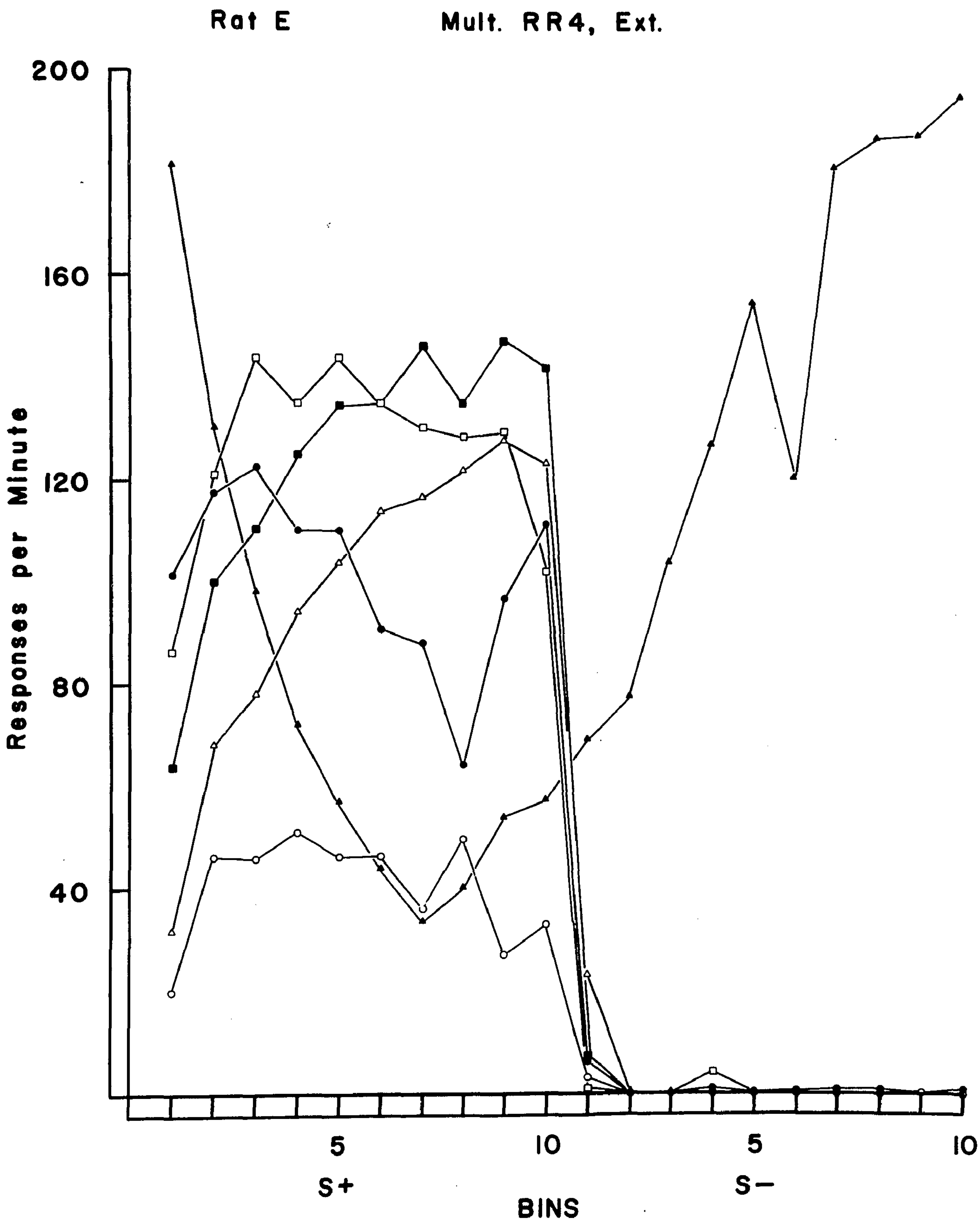
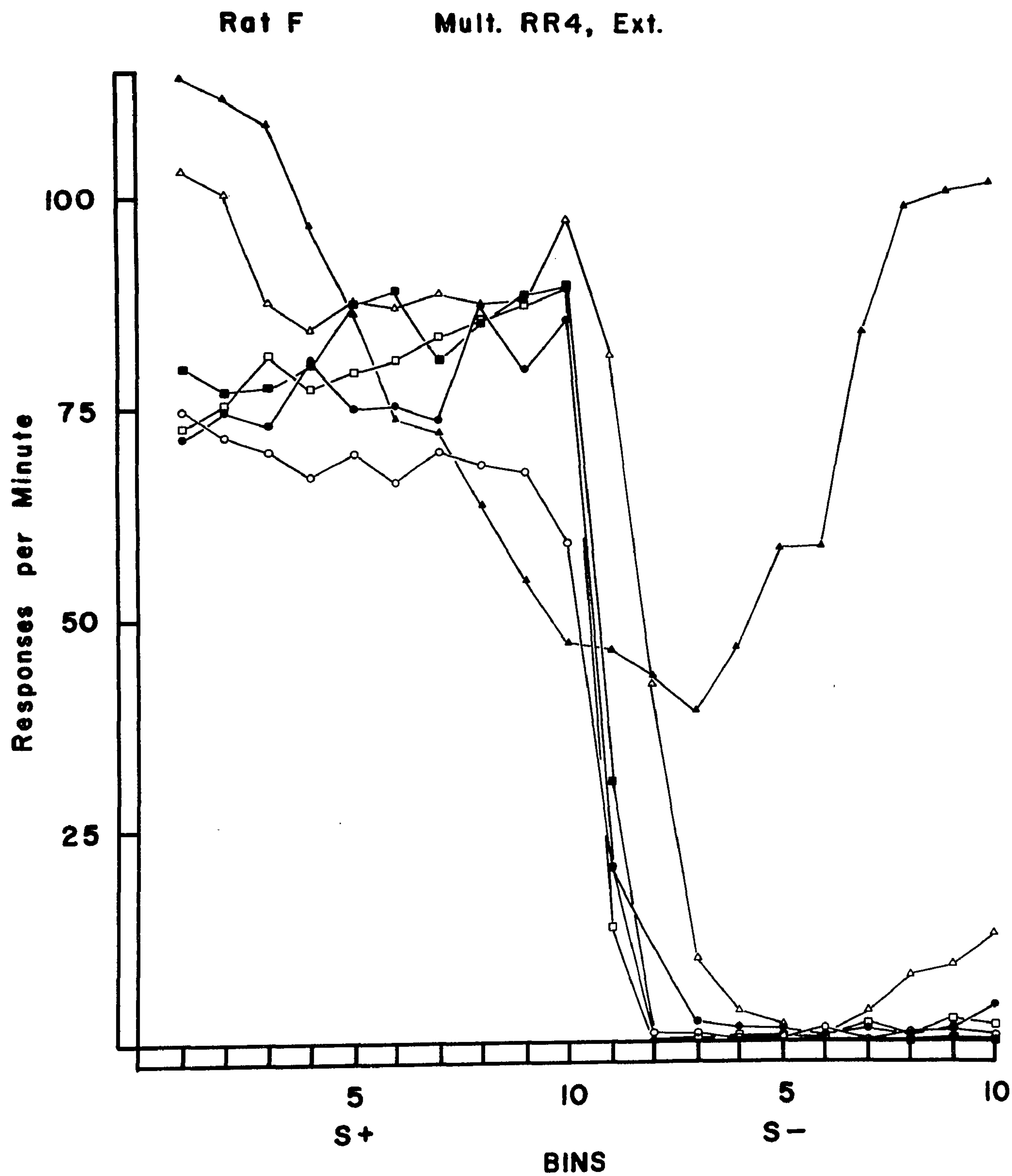

Rat D
Mult. RR4, Ext.
Responses per Minute
125
100
75
50
25
5
10
5
10
S+
S−
BINS

Figure 26.



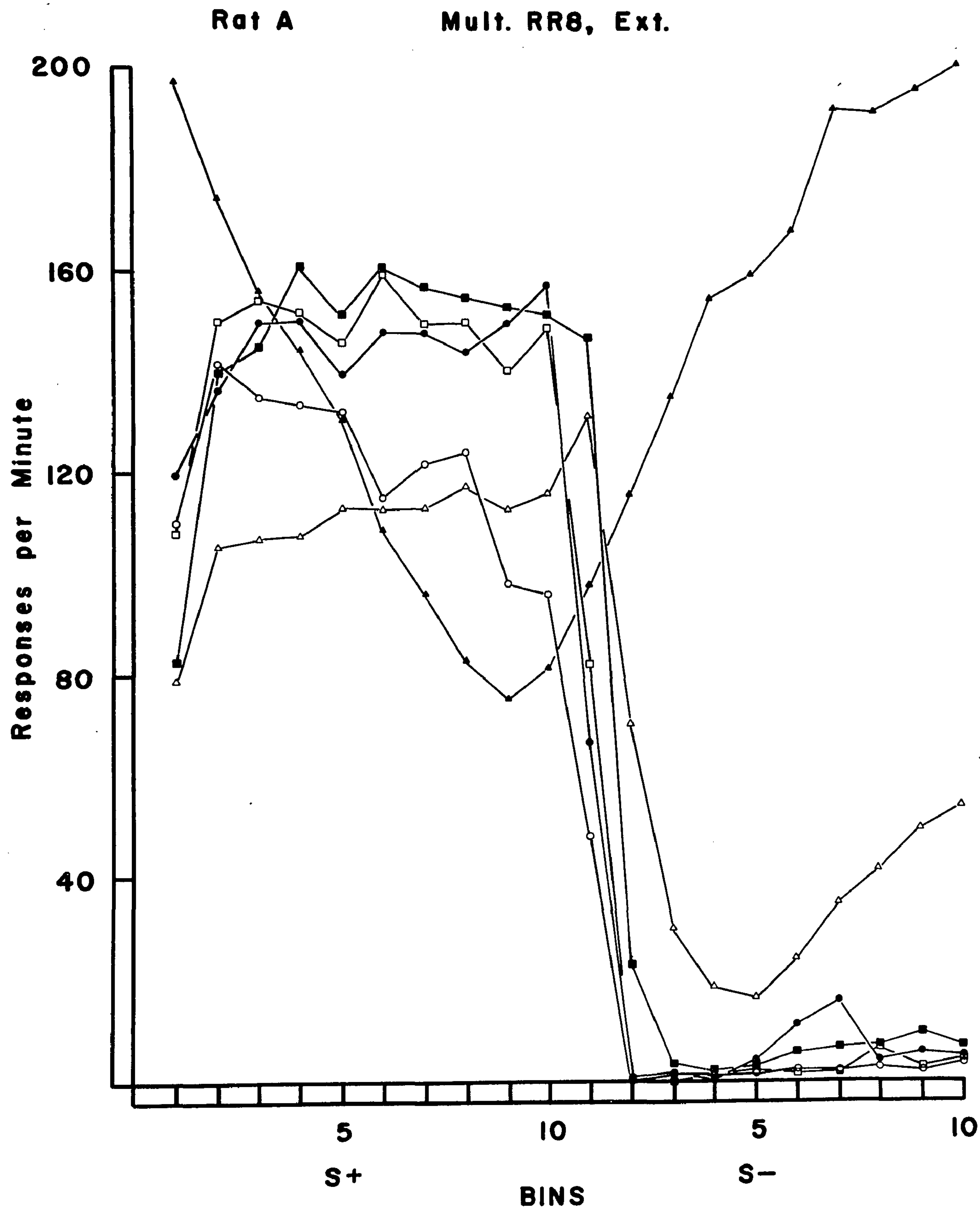
Rat E
Mult. RR4, Ext.
Responses per Minute
200
160
120
80
40
5
10
5
10
S+
S−
BINS

Figure 27.



Rat F
Mult. RR4, Ext.
Responses per Minute
100
75
50
25
5
10
5
10
S+
S-
BINS

Figure 28.



Rat A
Mult. RR8, Ext.
Responses per Minute
200
160
120
80
40
5
10
5
10
S+
S−
BINS

Figure 29.

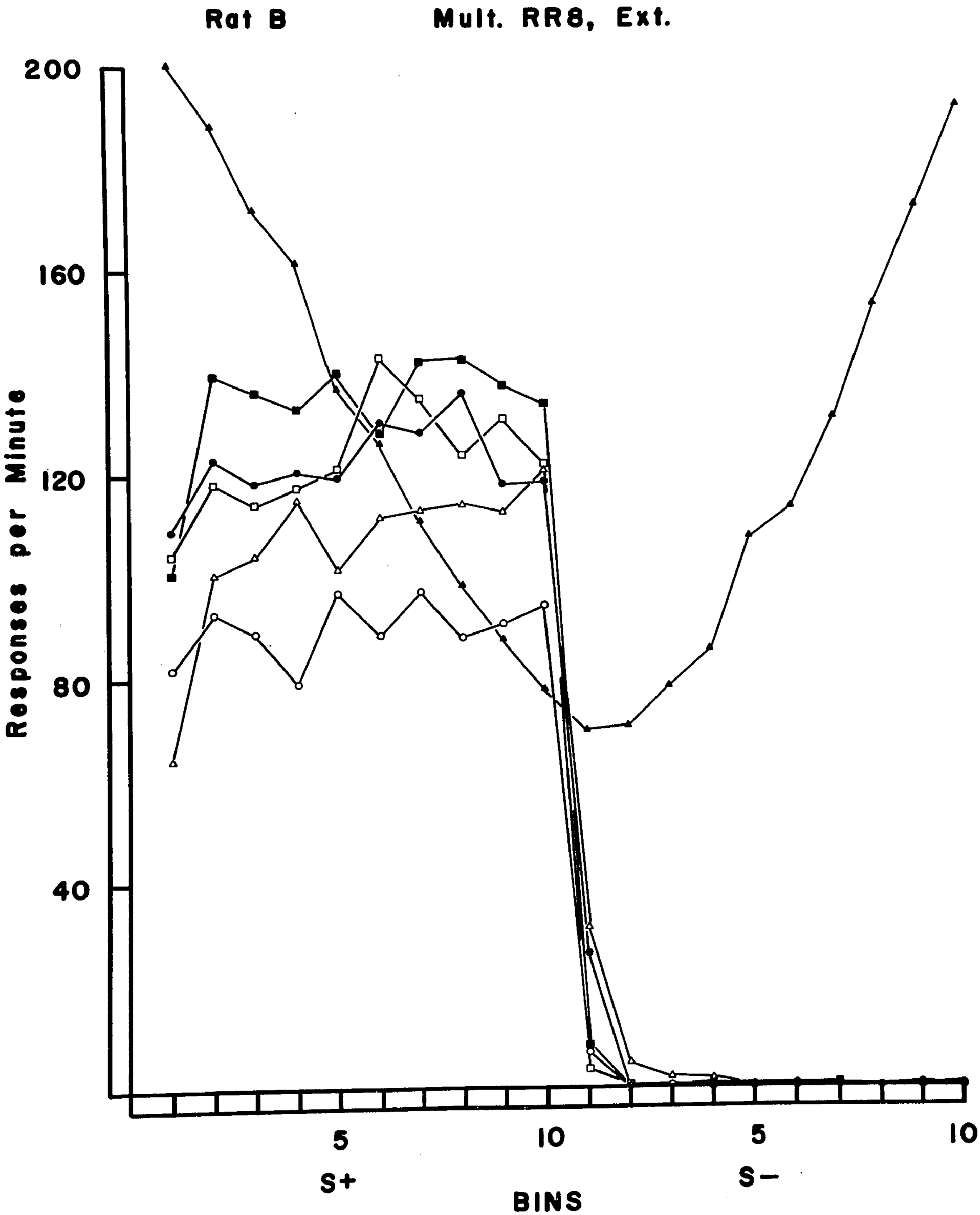

Rat B
Mult. RR8, Ext.
Responses per Minute
200
160
120
80
40
5
10
5
10
S+
S−
BINS

Figure 30.

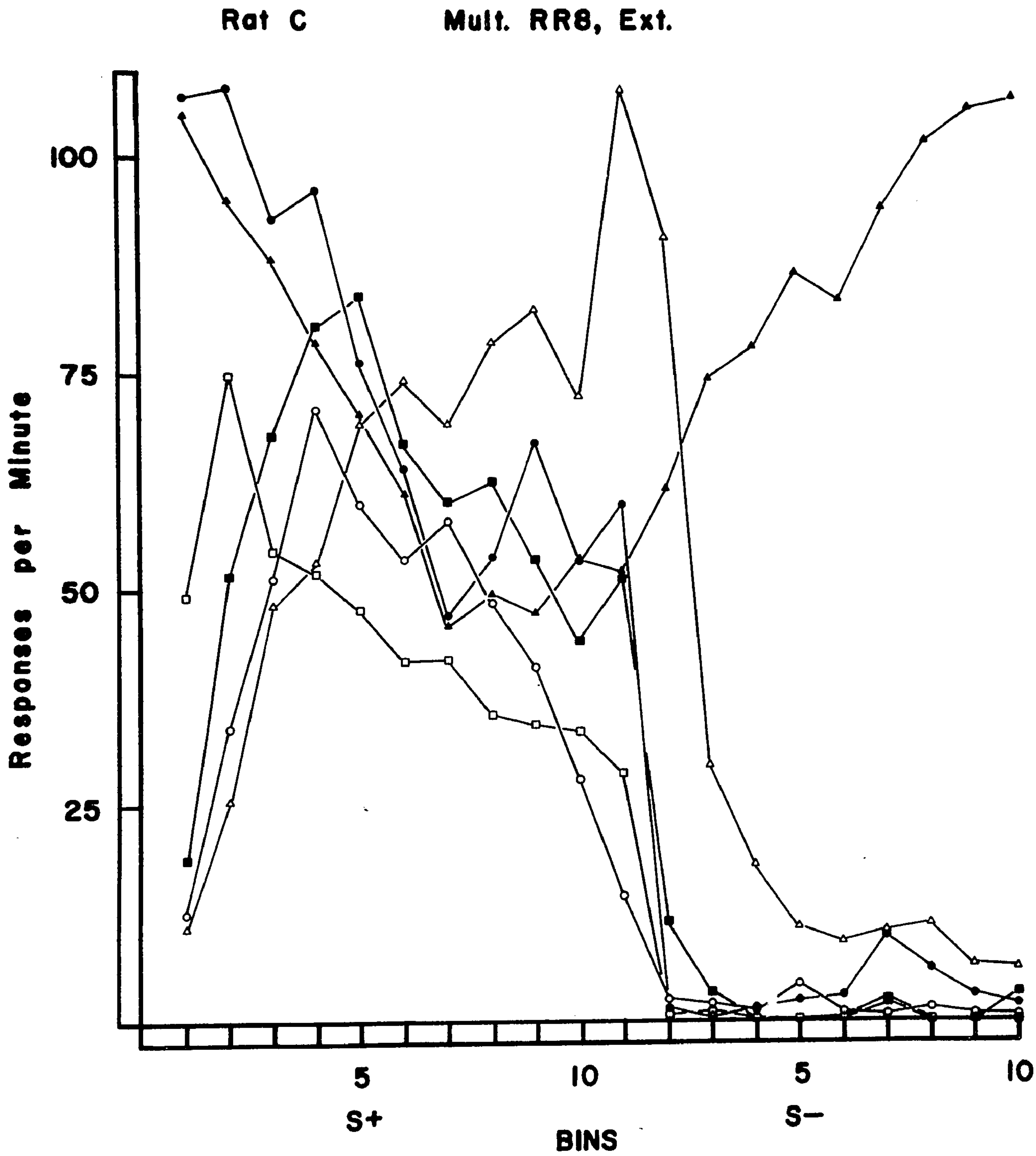

Rat C
Mult. RR8, Ext.
Responses per Minute
100
75
50
25
5
10
5
10
S+
S−
BINS

Figure 31.

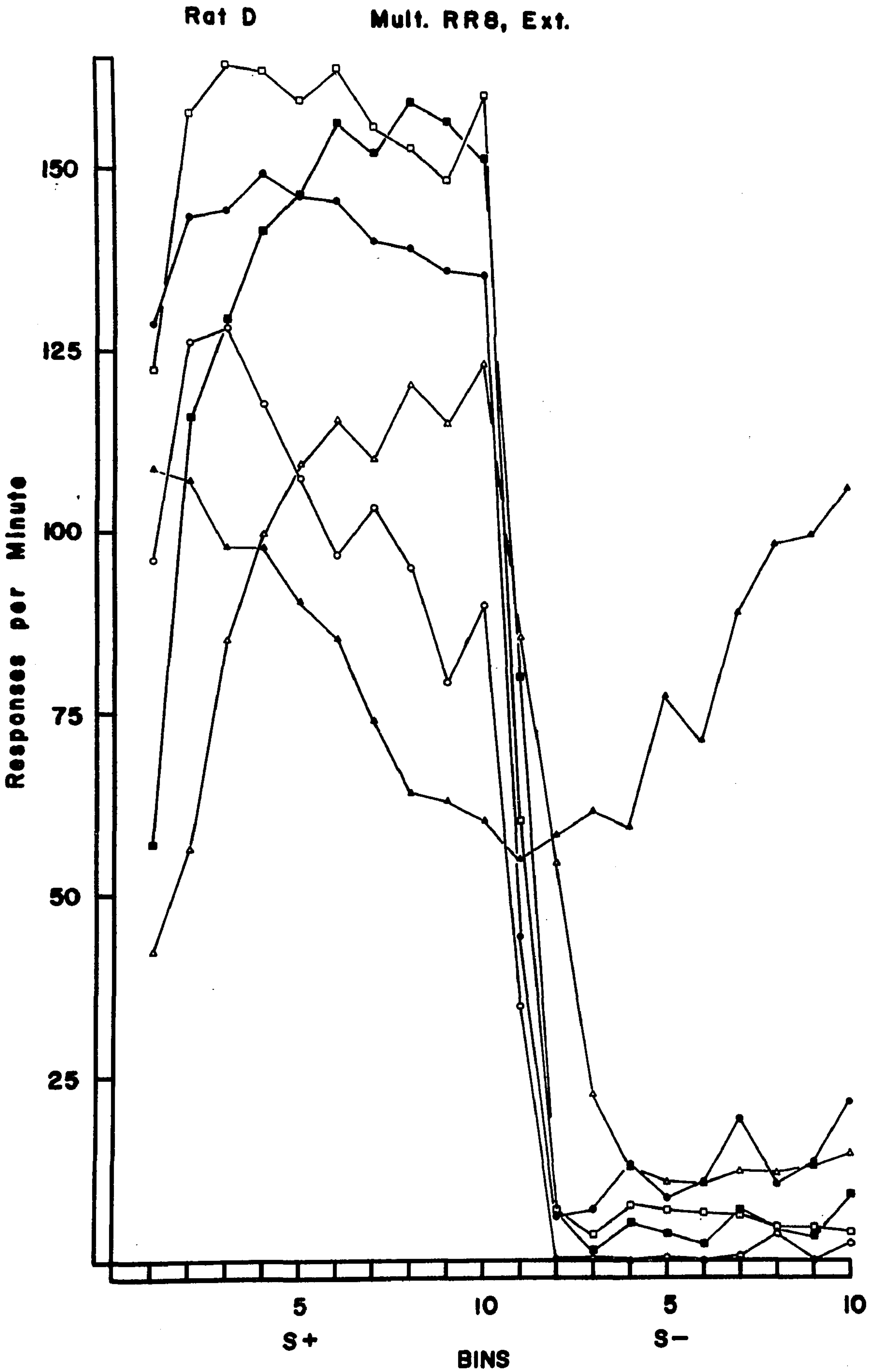

Rat D
Mult. RR8, Ext.
Responses per Minute
150
125
100
75
50
25
5
10
5
10
S+
S−
BINS

Figure 32.

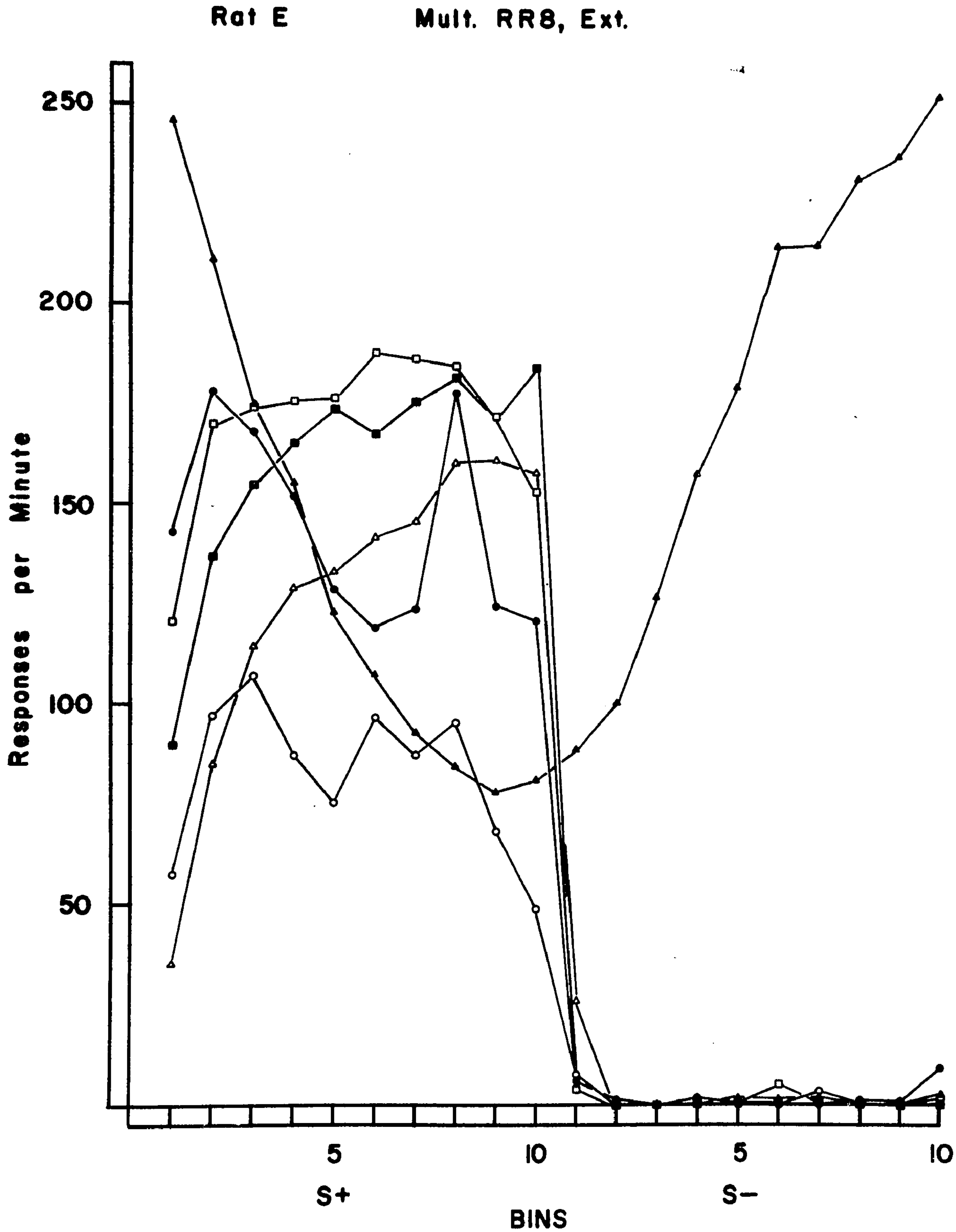
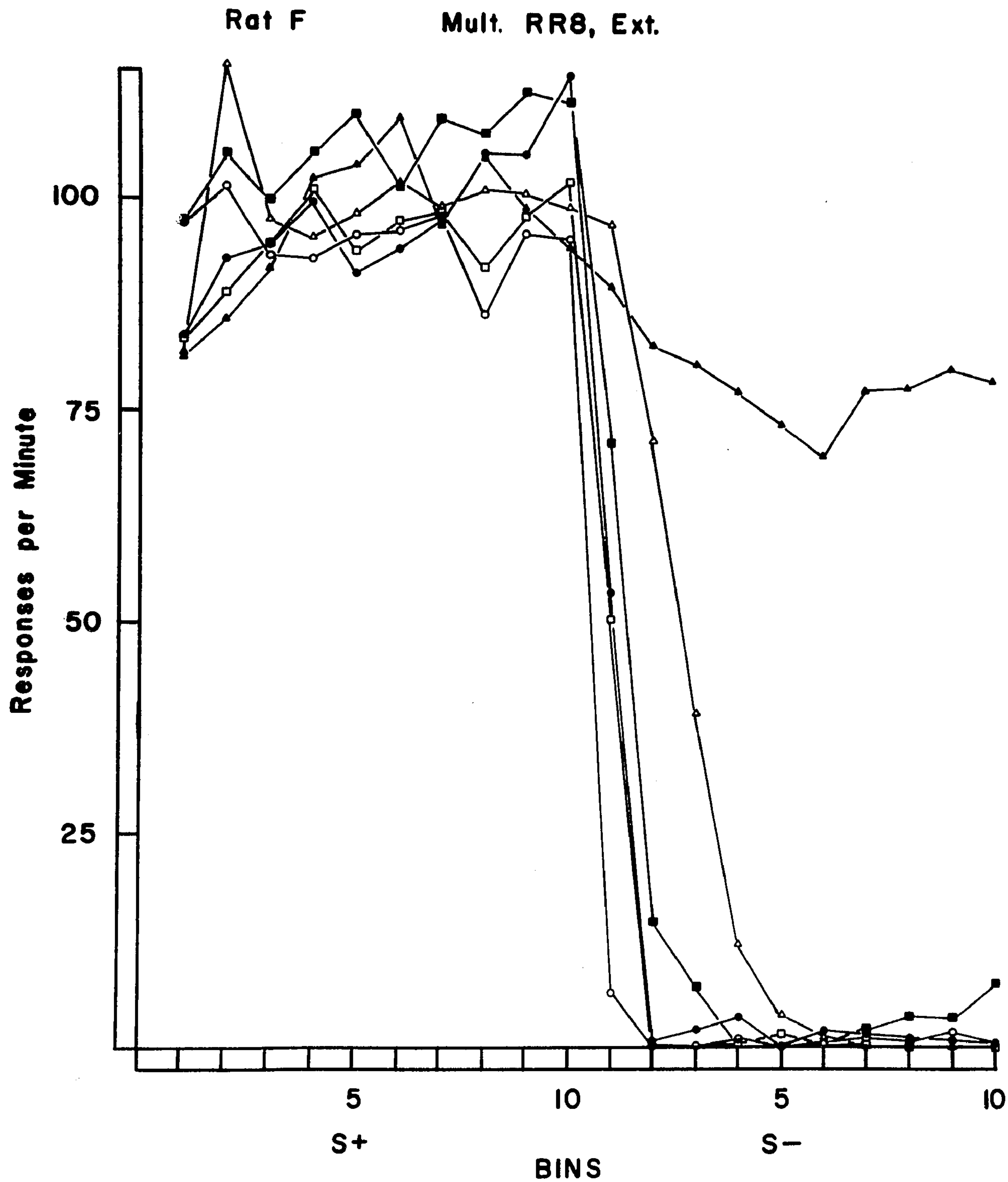

Rat E
Mult. RR8, Ext.
Responses per Minute
250
200
150
100
50
5
10
5
10
S+
S−
BINS

Figure 33.



Rat F
Mult. RR8, Ext.
Responses per Minute
100
75
50
25
5
10
5
10
S+
S−
BINS

Figure 34.

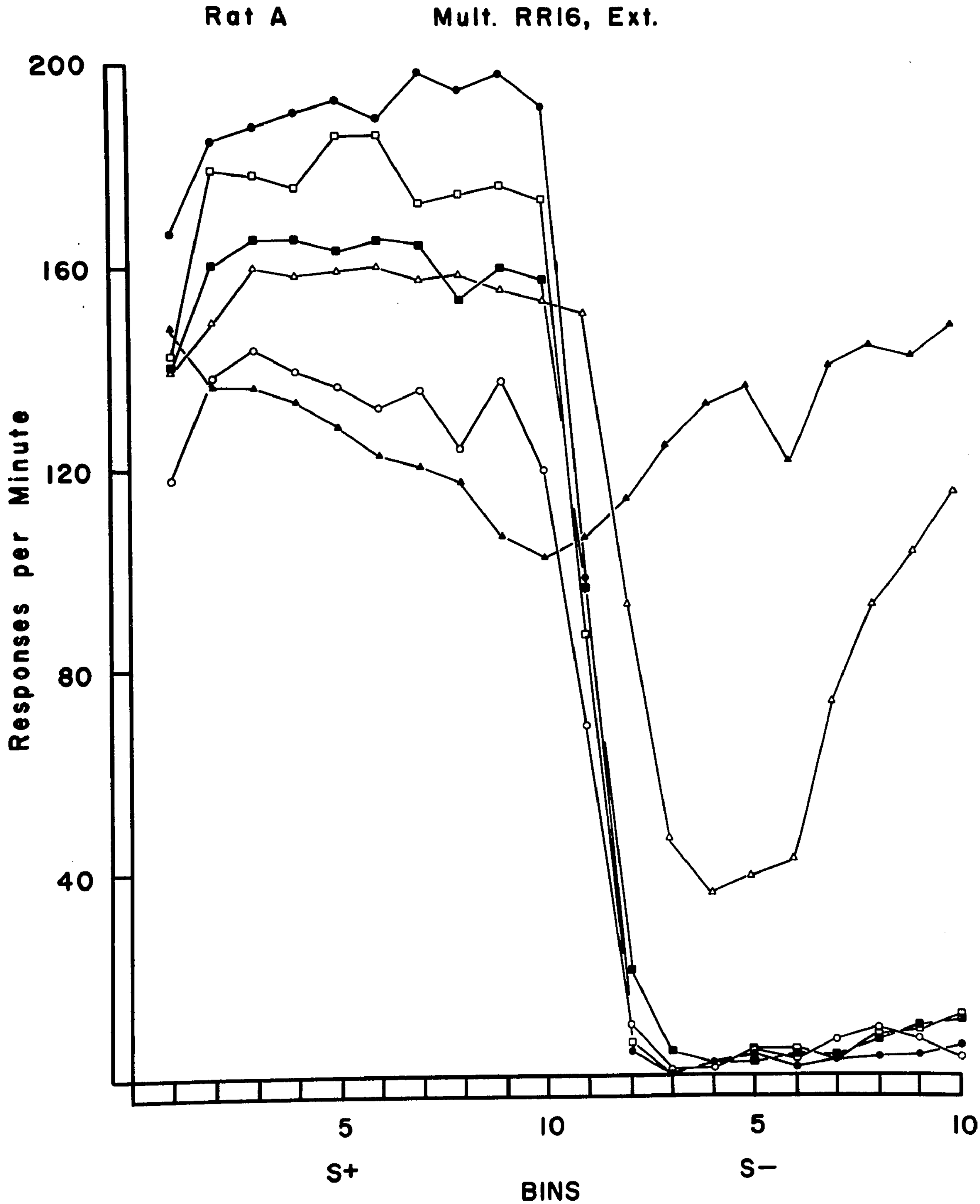
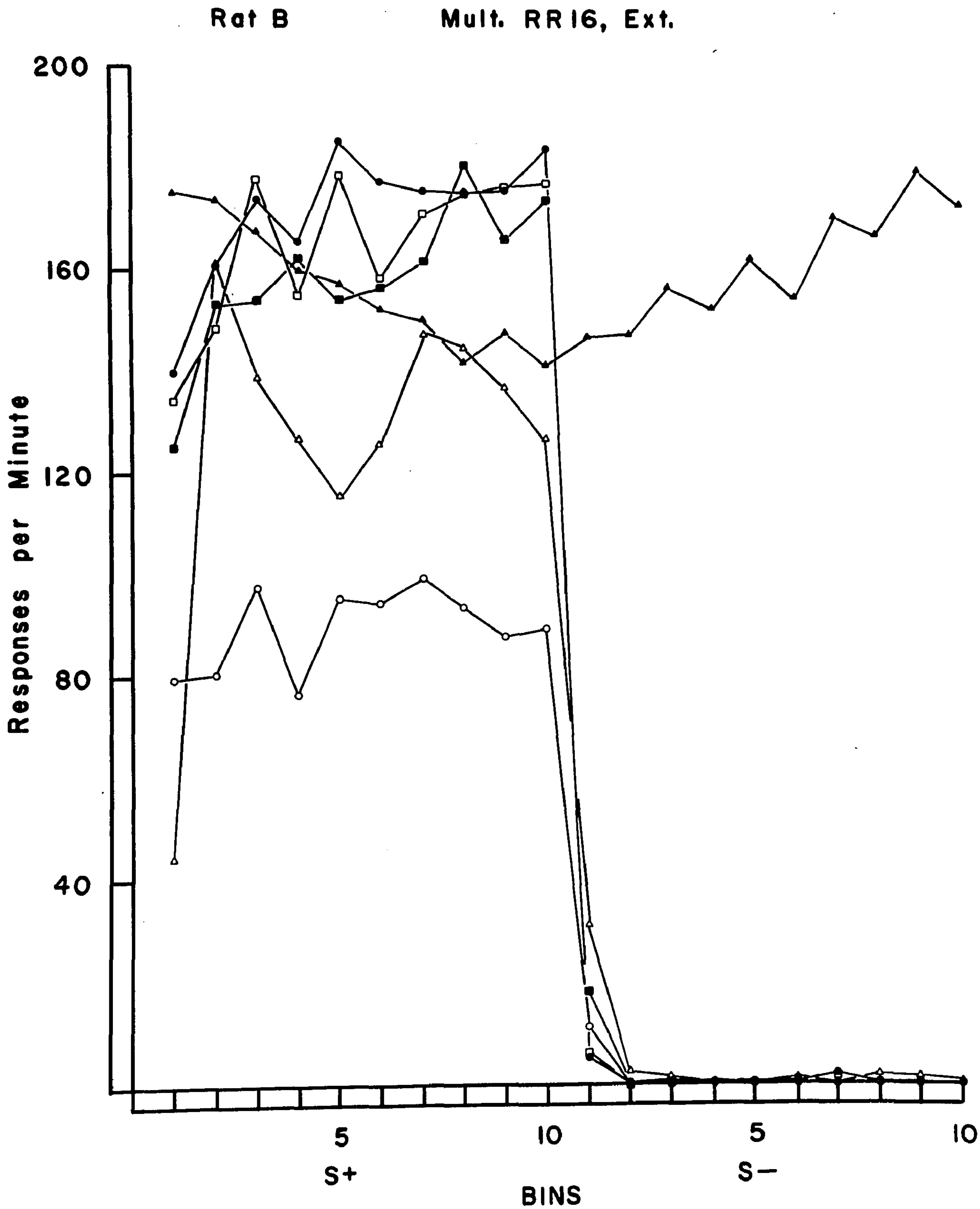

Rat A
Mult. RR16, Ext.
200
160
120
80
40
Responses per Minute
5
10
5
10
S+
S−
BINS

Figure 35.



Rat B
Mult. RR16, Ext.
200
160
120
80
40
Responses per Minute
5
10
5
10
S+
S−
BINS

Figure 36.

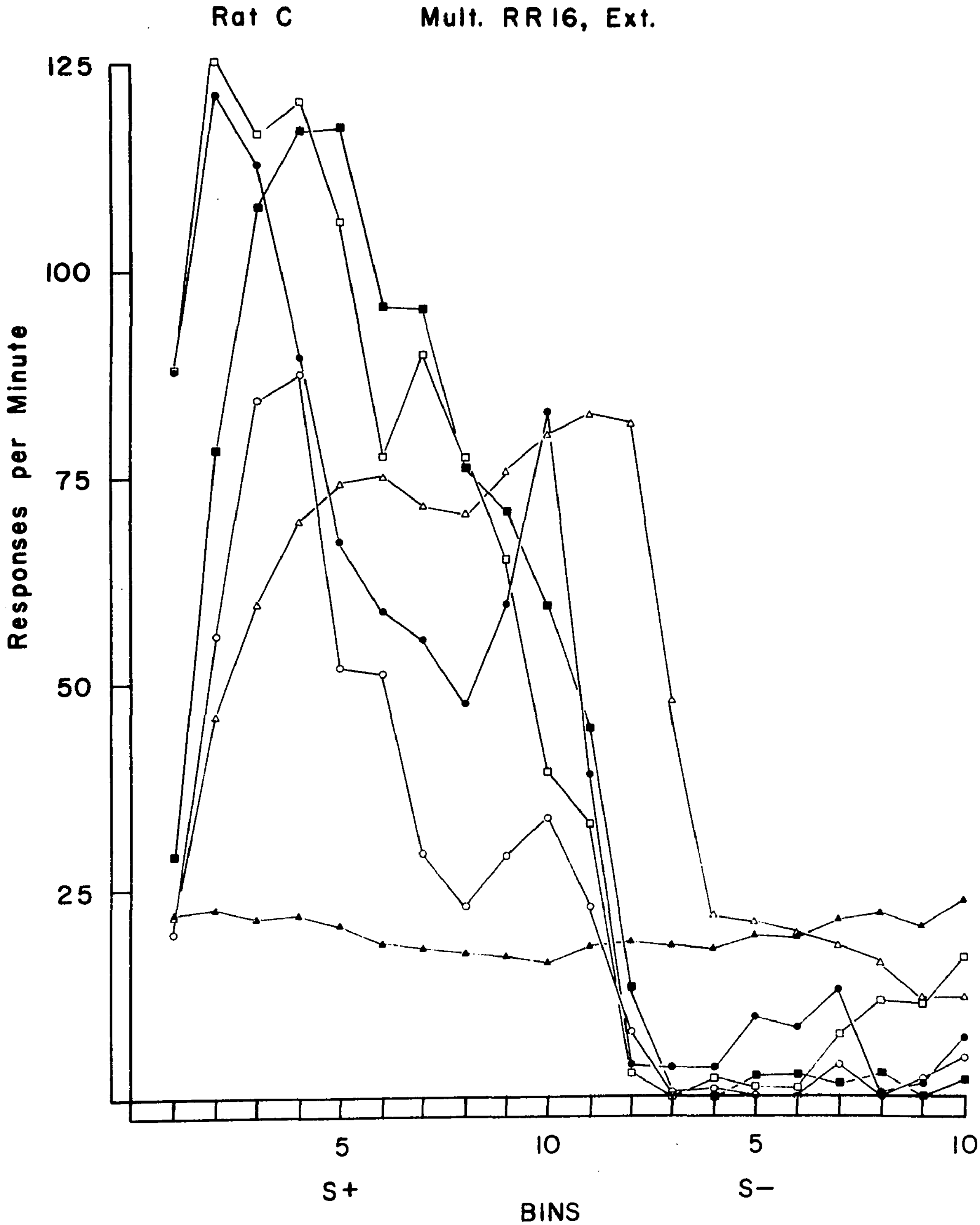

Rat C
Mult. RR16, Ext.
125
100
75
50
25
Responses per Minute
5
10
5
10
S+
S−
BINS

Figure 37.

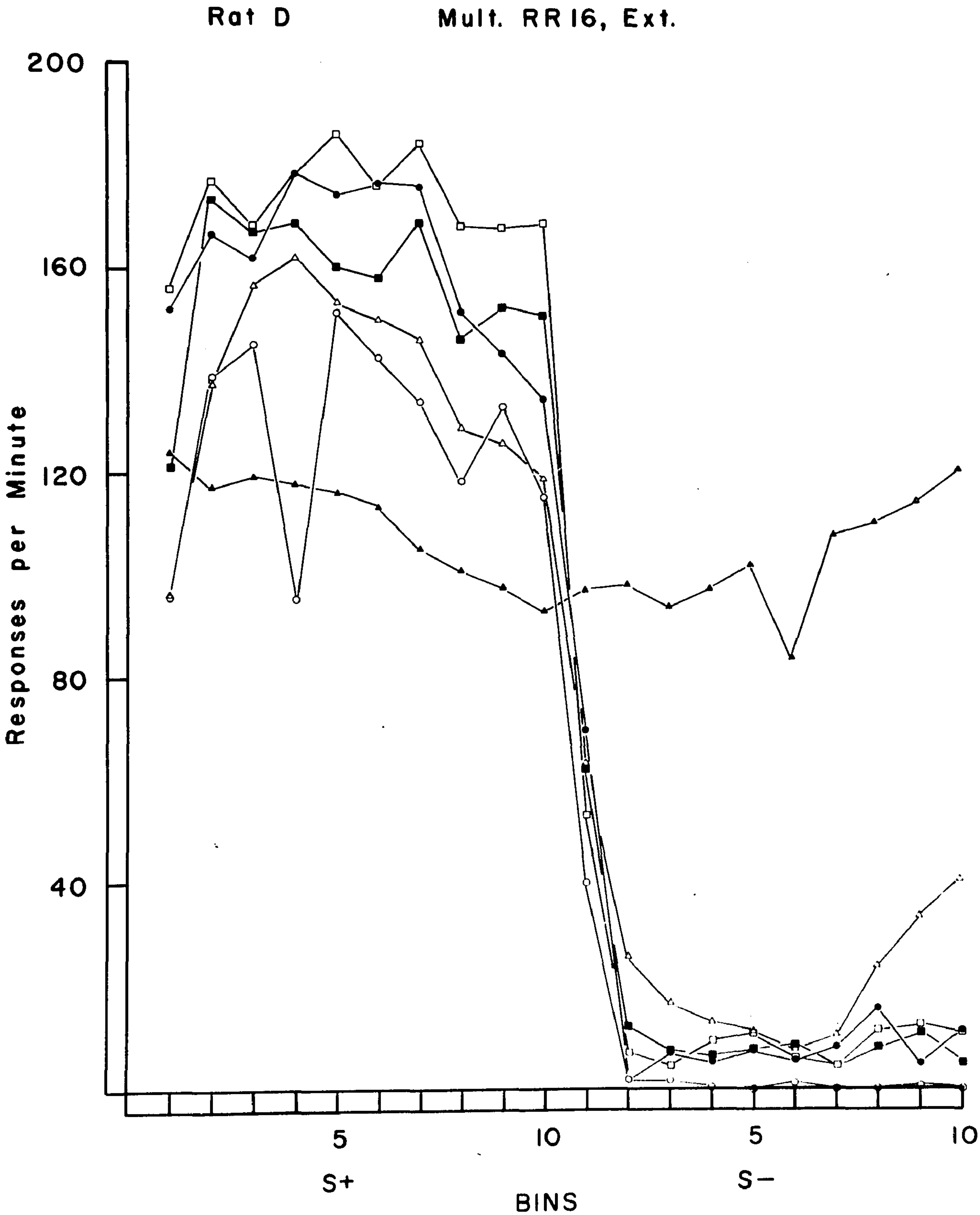

Rat D
Mult. RR 16, Ext.
200
160
120
80
40
Responses per Minute
5
10
5
10
S+
S−
BINS

Figure 38.

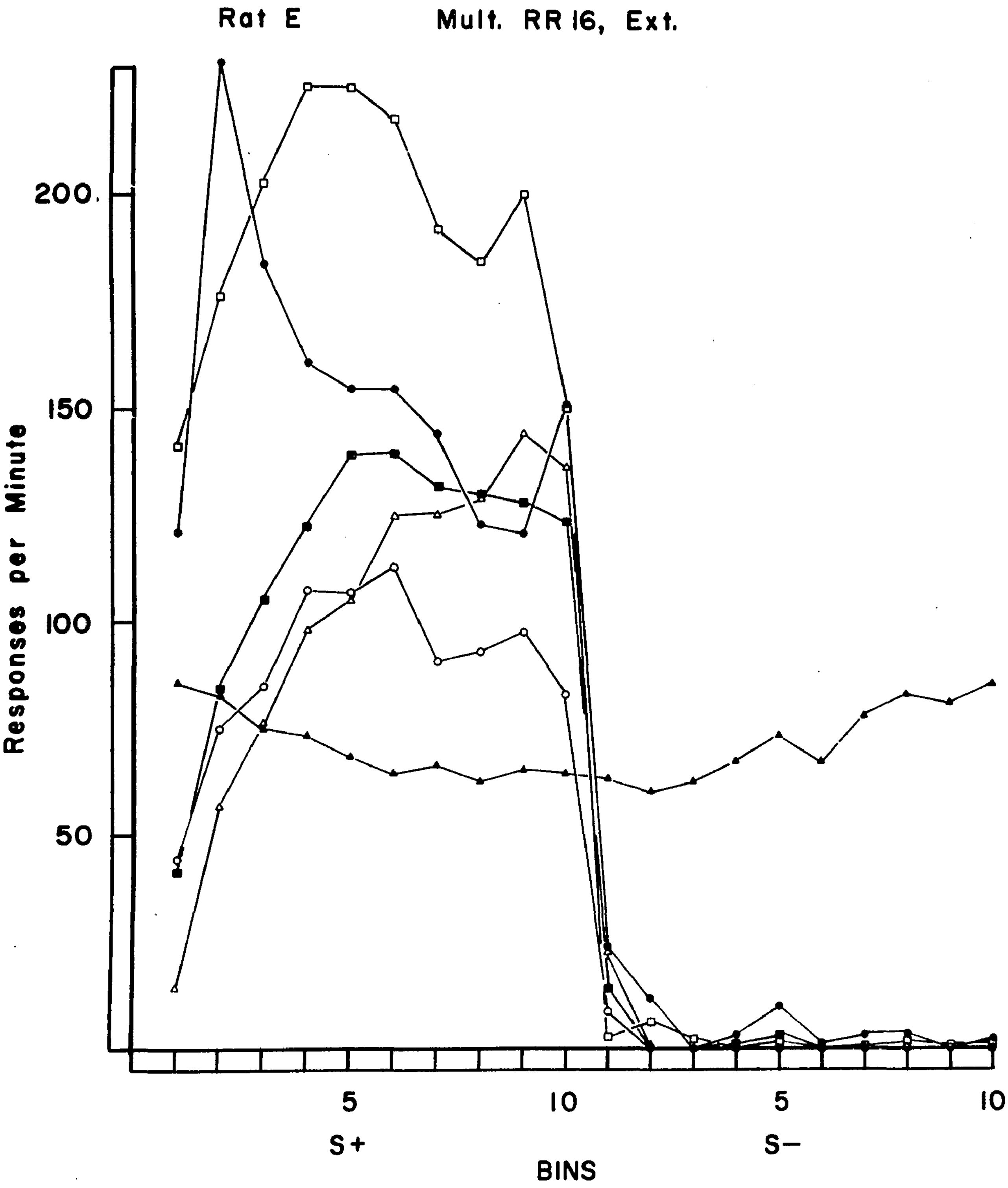

Rat E
Mult. RR 16, Ext.
Responses per Minute
200
150
100
50
5
10
5
10
S+
S−
BINS

Figure 39.

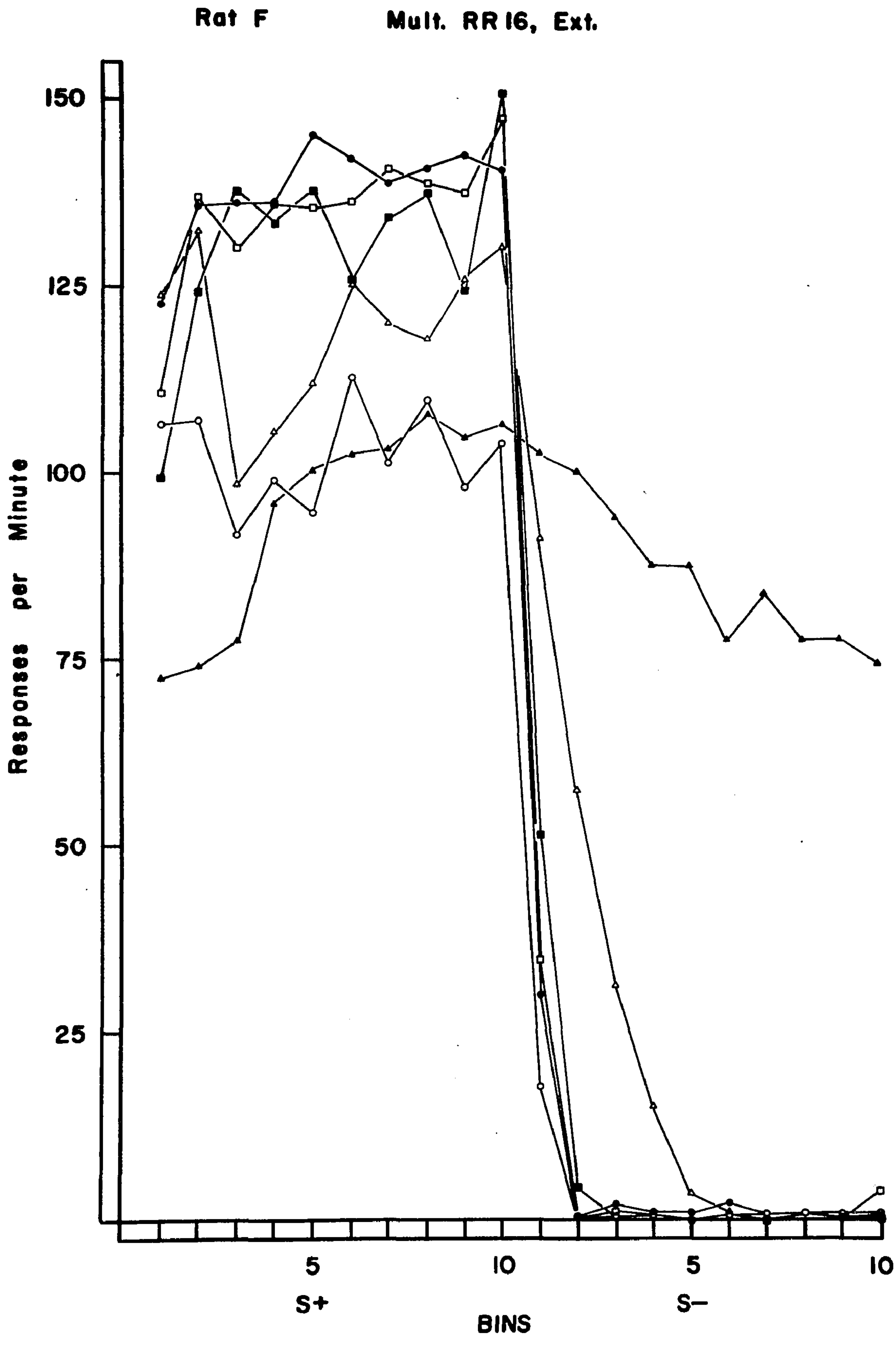

Rat F
Mult. RR 16, Ext.
150
125
100
75
50
25
Responses per Minute
5
10
5
10
S+
S−
BINS

Figure 40.

Figures 41-46. Mean discrimination ratio as a function of random ratio schedule in S+ for each component duration. Vertical bars indicate range of five daily discrimination ratios. Where bars are missing, range did not extend beyond 0.01 of the mean.

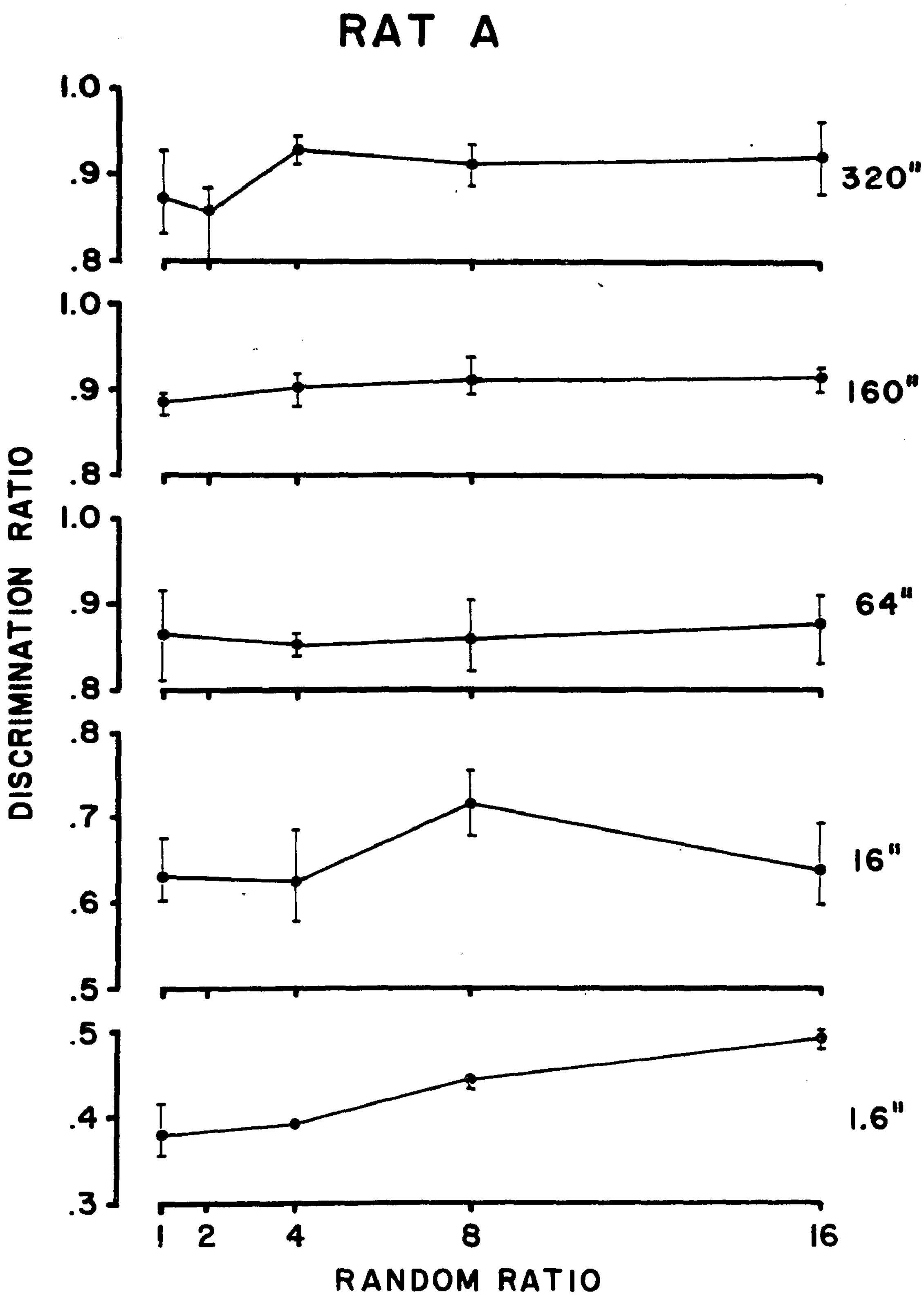

RAT A
1.0
.9
.8
320"
160"
64"
.7
.6
.5
16"
.4
.3
1.6"
DISCRIMINATION RATIO
1 2 4 8 16
RANDOM RATIO

Figure 41.

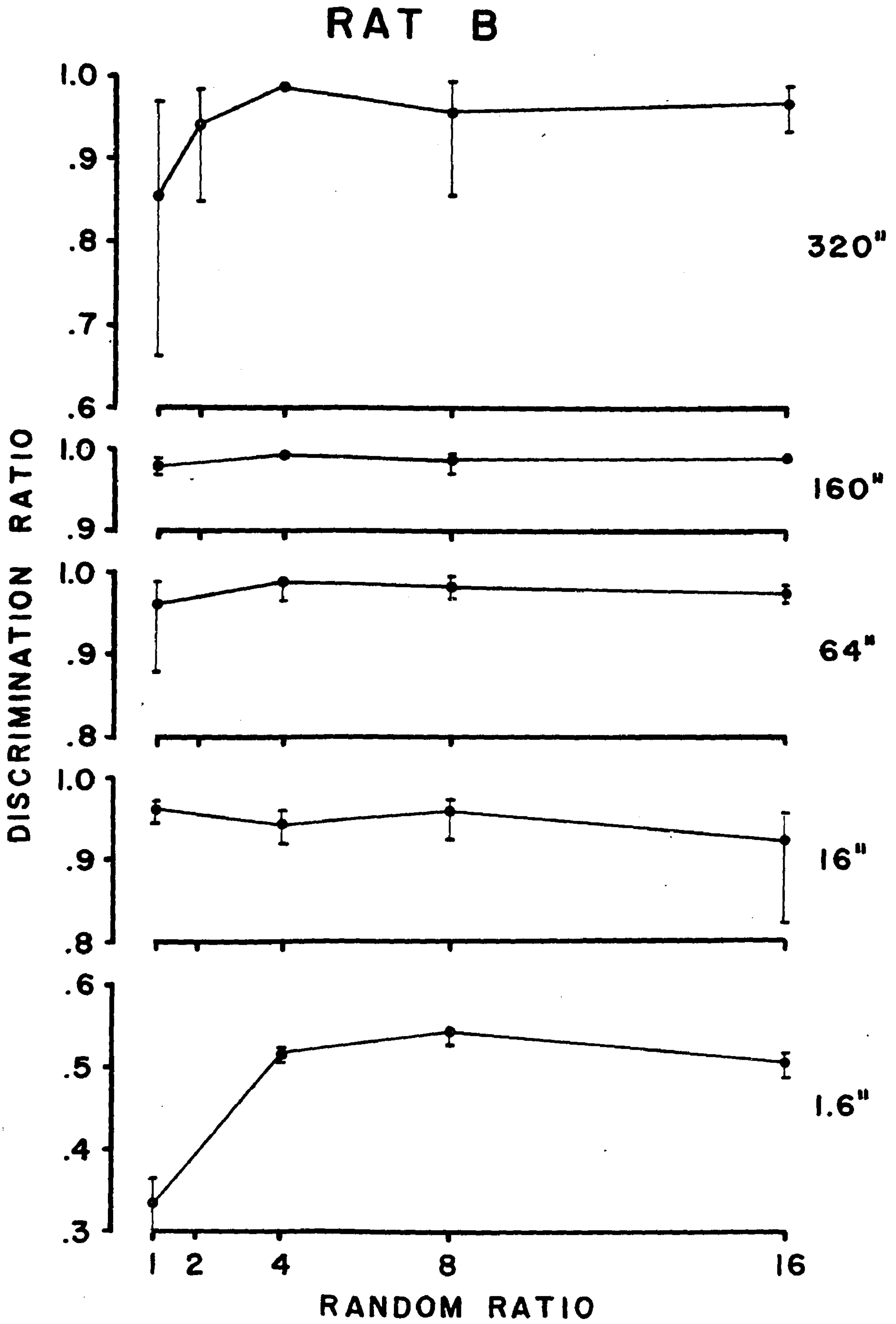

RAT B
DISCRIMINATION RATIO
1.0
.9
.8
.7
.6
320"
160"
64"
16"
1.6"
.5
.4
.3
1
2
4
8
16
RANDOM RATIO

Figure 42.

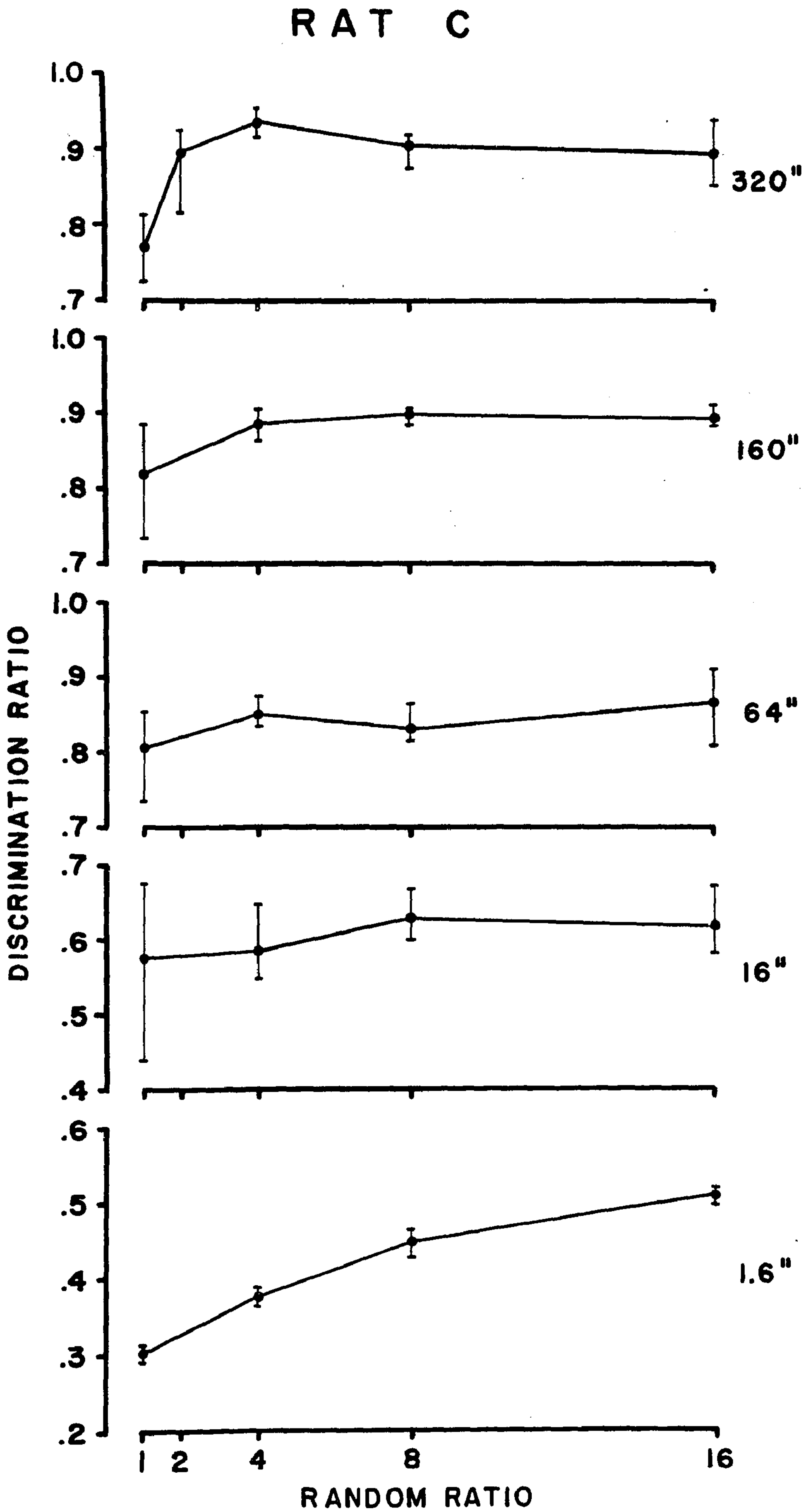

RAT C
1.0
.9
.8
.7
320"
160"
64"
.6
.5
.4
16"
.3
.2
1.6"
DISCRIMINATION RATIO
1 2 4 8 16
RANDOM RATIO

Figure 43.

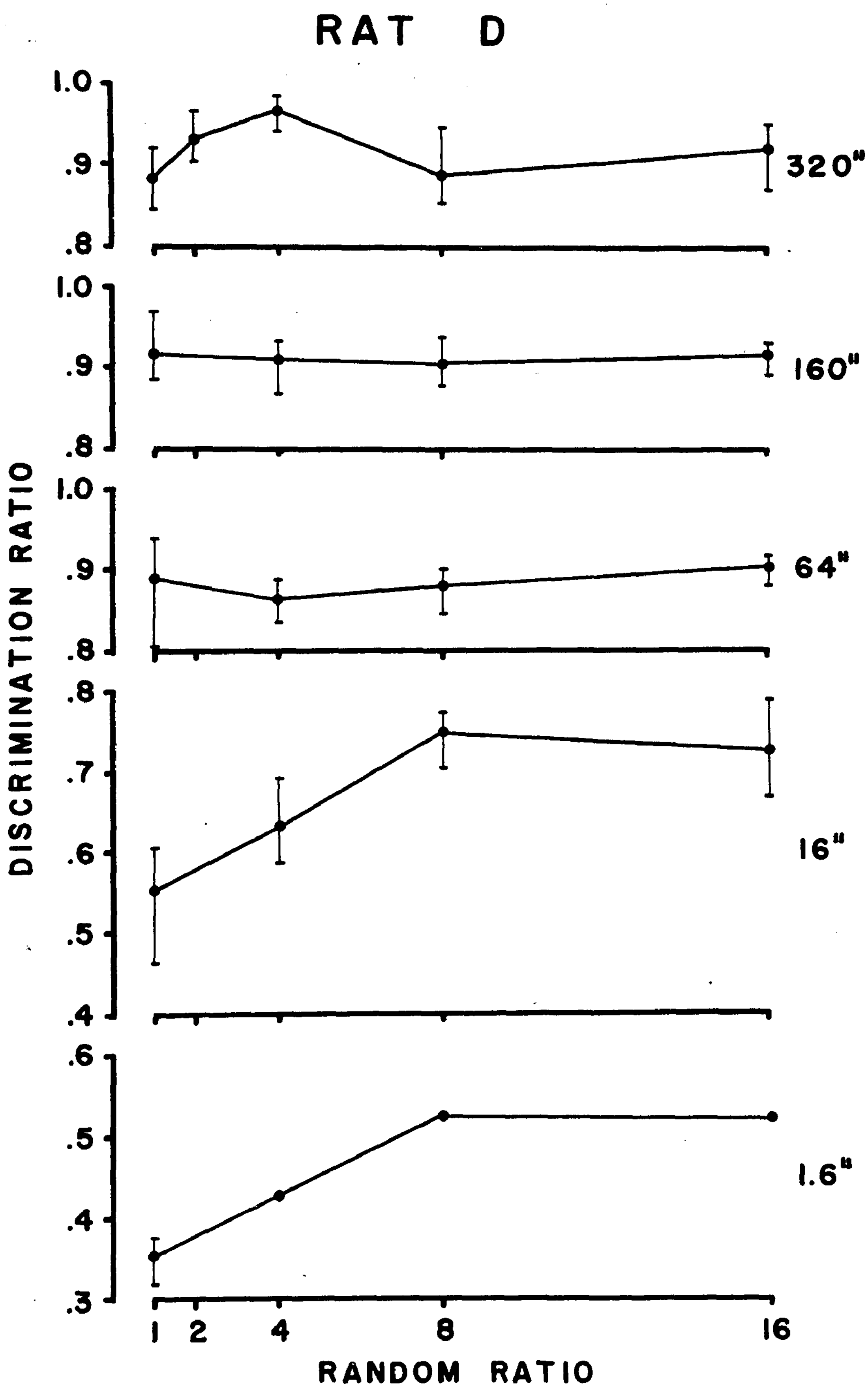
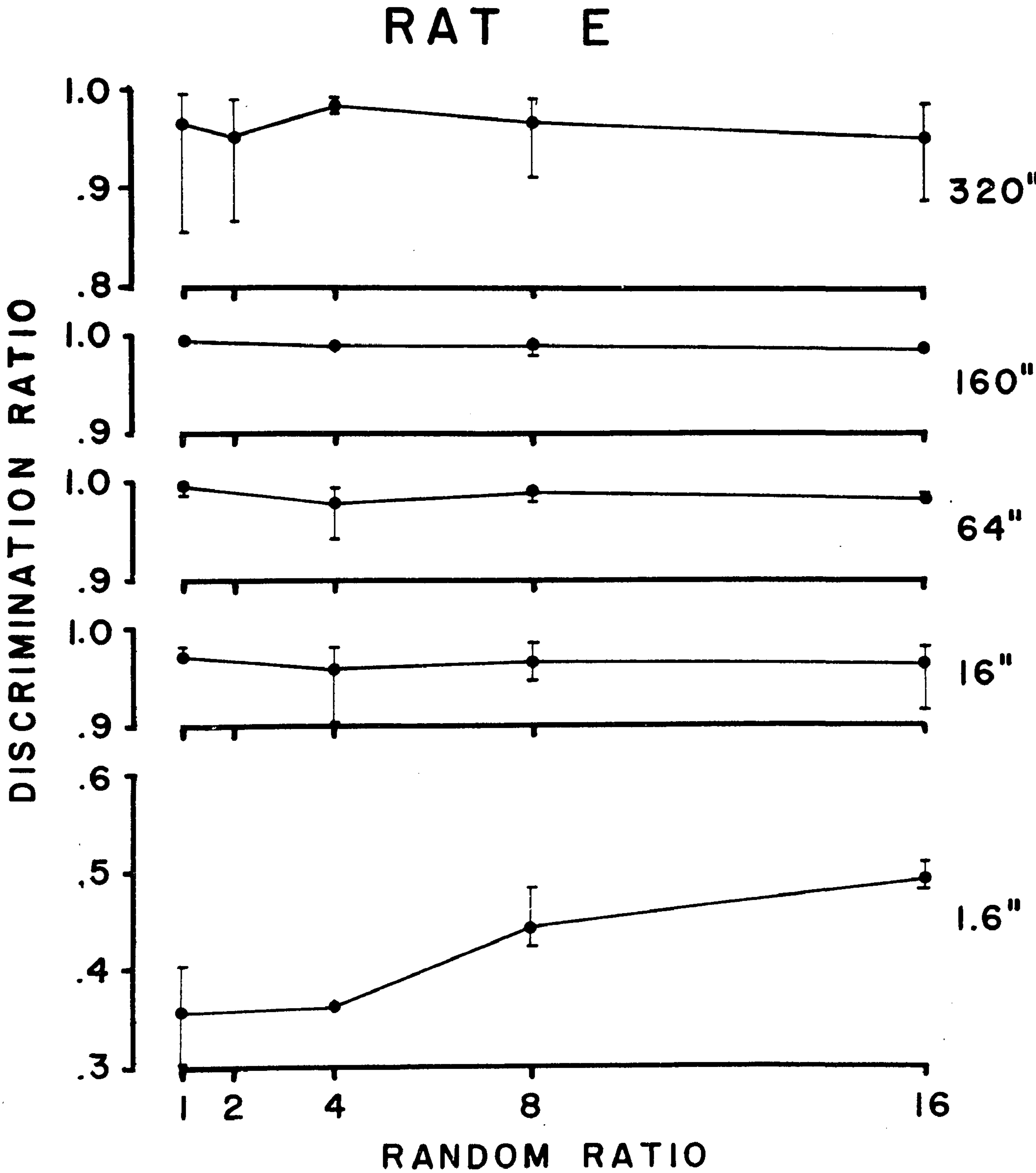

RAT D
DISCRIMINATION RATIO
320"
160"
64"
16"
1.6"
1.0
.9
.8
.7
.6
.5
.4
.3
1
2
4
8
16
RANDOM RATIO

Figure 44.



RAT E
DISCRIMINATION RATIO
1.0
.9
.8
1.0
.9
1.0
.9
1.0
.9
.6
.5
.4
.3
320"
160"
64"
16"
1.6"
1
2
4
8
16
RANDOM RATIO

Figure 45.

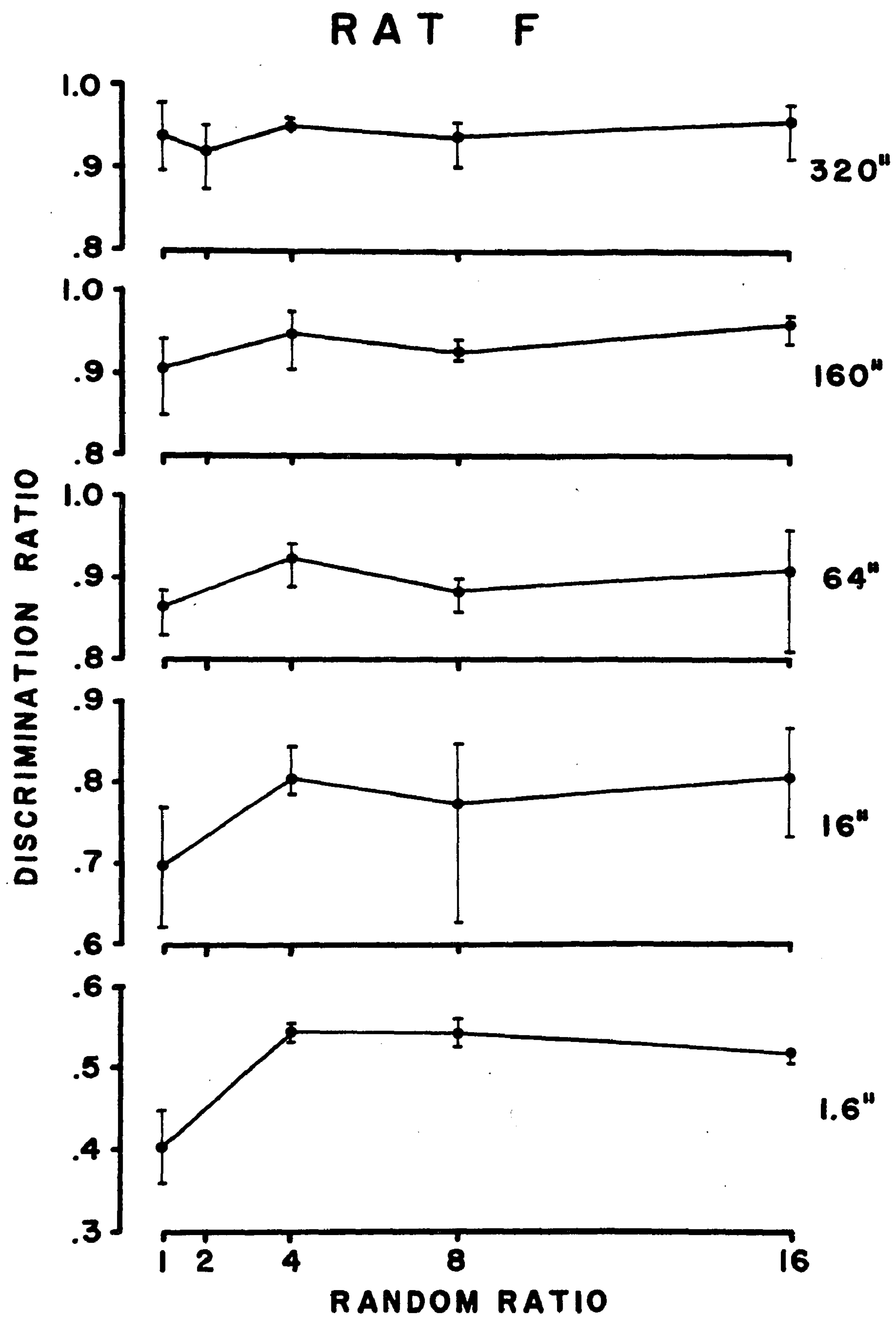

RAT F
1.0
.9
.8
320"
1.0
.9
.8
160"
1.0
.9
.8
64"
.9
.8
.7
.6
16"
.6
.5
.4
.3
1.6"
DISCRIMINATION RATIO
1
2
4
8
16
RANDOM RATIO

Figure 46.

Appendix: Table 3.

Average absolute deviations for median responses per session plotted in Figures 1-6.

Figure 1, Rat A.

Component	RR1		RR4		RR8		RR16	
Duration	S+	S-	S+	S-	S+	S-	S+	S-
1.6 sec	61.6	128.4	216.0	340.4	158.0	218.8	353.6	457.6
16 sec	74.8	96.0	251.4	221.2	293.6	105.8	351.2	275.8
64 sec	91.2	55.6	103.8	26.4	189.2	140.2	129.0	177.2
160 sec	108.6	16.4	197.4	69.4	147.2	65.6	319.0	73.2
320 sec	77.6	48.2	261.4	67.0	300.8	91.0	181.8	138.2

Figure 2, Rat B.

Component	RR1		RR4		RR8		RR16	
Duration	S+	S-	S+	S-	S+	S-	S+	S-
1.6 sec	222.8	643.0	267.0	274.6	365.2	290.0	521.0	670.0
16 sec	38.0	6.6	148.2	24.6	266.6	28.2	183.2	239.0
64 sec	84.6	15.0	116.6	14.8	228.6	36.8	127.4	36.0
160 sec	43.4	3.4	68.6	8.0	150.2	31.0	135.2	14.4
320 sec	55.6	112.4	124.8	4.2	110.0	151.4	272.6	117.6

Table 3 (continued).

Figure 3, Rat C.

Component	RR1		RR4		RR8		RR16	
Duration	S+	S-	S+	S-	S+	S-	S+	S-
1.6 sec	84.2	175.8	386.8	696.4	639.0	706.6	331.8	375.2
16 sec	63.2	136.6	328.4	212.4	378.8	280.0	348.2	262.2
64 sec	128.4	77.4	222.6	38.2	282.0	90.8	209.6	143.2
160 sec	63.8	26.8	225.8	42.2	438.0	26.8	259.4	73.4
320 sec	23.4	19.8	356.8	25.6	812.8	133.2	579.4	127.8

Figure 4, Rat D.

Component	RR1		RR4		RR8		RR16	
Duration	S+	S-	S+	S-	S+	S-	S+	S-
1.6 sec	144.6	115.6	191.4	316.2	689.4	668.2	524.6	474.4
16 sec	120.6	114.8	152.6	192.4	324.2	182.6	186.6	224.4
64 sec	126.8	84.6	79.2	74.2	377.8	83.2	401.0	61.0
160 sec	181.8	39.4	129.2	63.2	204.0	91.0	214.6	68.0
320 sec	43.4	37.8	271.4	51.4	194.2	138.4	247.2	117.6

Table 3 (continued).

Figure 5, Rat E.

Component Duration	RR1		RR4		RR8		RR16	
	S+	S-	S+	S-	S+	S-	S+	S-
1.6 sec	76.0	337.8	344.0	529.0	595.4	886.8	272.6	254.8
16 sec	110.0	4.8	92.0	59.4	212.6	59.6	185.4	47.8
64 sec	186.4	4.2	261.8	64.2	343.8	28.2	824.0	15.8
160 sec	203.8	0.6	615.0	25.0	535.5	32.4	1066.6	12.8
320 sec	245.4	38.0	102.0	12.6	398.8	88.6	528.6	118.0

Figure 6, Rat F.

Component Duration	RR1		RR4		RR8		RR16	
	S+	S-	S+	S-	S+	S-	S+	S-
1.6 sec	195.0	422.6	165.8	167.2	299.2	246.2	181.4	225.6
16 sec	178.2	90.2	90.6	90.4	139.4	316.0	355.6	216.8
64 sec	279.8	62.6	119.2	50.8	131.0	35.8	216.6	176.0
160 sec	50.0	31.2	239.2	59.8	96.4	27.8	89.4	32.4
320 sec	44.6	27.6	116.8	17.0	193.8	53.6	223.2	72.2

REFERENCES

Amsel, A. Frustrative reward in partial reinforcement and discrimination learning: some recent history and a theoretical extension. Psychological Review, 1962, 69, 309-328.

Bersh, P. J. The influence of two variables upon the establishment of a secondary reinforcer for operant responses. Journal of Experimental Psychology, 1951, 41, 62-73.

Bloomfield, T. M. Behavioural contrast and the peak shift. In R. M. Gilbert & N. S. Sutherland (Eds.), Animal Discrimination Learning. London: Academic Press, 1969.

Boneau, C. A., & Axelrod, S. Work decrement and reminiscence in pigeon operant responding. Journal of Experimental Psychology, 1962, 64, 352-354.

Branch, M. N. Observing responses in pigeons: effects of schedule component duration and schedule value. Journal of the Experimental Analysis of Behavior, 1973, 20, 417-428.

Brandauer, C. M. The effects of uniform probabilities of reinforcement upon the response rate of the pigeon. Unpublished doctoral dissertation, Columbia University, 1958. Ann Arbor, Mich.: University Microfilms, No. 59-1478.

Catania, A. C., & Gill, C. A. Inhibition and behavioral contrast. *Psychonomic Science*, 1964, *1*, 257-258.

Cumming, W. W., & Schoenfeld, W. N. Some data on behavior reversibility in a steady state experiment. *Journal of the Experimental Analysis of Behavior*, 1959, *2*, 87-90.

Cumming, W. W., & Schoenfeld, W. N. *A comparison of behavior in the components of a two-ply multiple* t^D-t^Δ schedule. Unpublished manuscript, 1962.

Cumming, W. W., & Schoenfeld, W. N. Effects of varying cycle length in a tau reinforcement schedule. *Journal of the Experimental Analysis of Behavior*, 1963, *6*, 623-626.

Dinsmoor, J. A. A quantitative comparison of the discriminative and reinforcing functions of a stimulus. *Journal of Experimental Psychology*, 1950, *40*, 458-472.

Dinsmoor, J. A. The effect of periodic reinforcement of bar-pressing in the presence of a discriminative stimulus. *Journal of Comparative and Physiological Psychology*, 1951, *44*, 354-361.

Farmer, J., & Schoenfeld, W. N. Response rates under varying probability of reinforcement. *Psychonomic Science*, 1967, *7*, 173-174.

Ferster, C. B., & Skinner, B. F. *Schedules of Reinforcement*. Englewood Cliffs, N. J.: Prentice-Hall, 1957.

Freeman, B. J. Behavioral contrast: reinforcement frequency or response suppression? Psychological Bulletin, 1971, 75, 347-356.

Frick, F. C. An analysis of an operant discrimination. The Journal of Psychology, 1948, 26, 93-123.

Goff, W. R. Measurement of absolute olfactory sensitivity in rats. American Journal of Psychology, 1961, 74, 384-393.

Hearst, E., Besley, S., & Farthing, G. W. Inhibition and the stimulus control of operant behavior. Journal of the Experimental Analysis of Behavior, 1970, 14, 373-409.

Herrnstein, R. J. On the law of effect. Journal of the Experimental Analysis of Behavior, 1970, 13, 243-266.

Herrnstein, R. J., & Brady, J. V. Interaction among components of a multiple schedule. Journal of the Experimental Analysis of Behavior, 1958, 1, 293-300.

Hoffman, H. S. Stimulus generalization versus discrimination failure in conditioned suppression. In R. M. Gilbert & N. S. Sutherland (Eds.), Animal Discrimination Learning. London: Academic Press, 1969.

Kelleher, R. T., & Gollub, L. R. A review of positive conditioned reinforcement. Journal of the Experimental Analysis of Behavior, 1962, 5, 543-597.

Keller, F. S., & Schoenfeld, W. N. Principles of Psychology. New York: Appleton-Century-Crofts, 1950.

Killeen, P. A yoked-chamber comparison of concurrent and multiple schedules. _Journal of the Experimental Analysis of Behavior_, 1972, _18_, 13-22.

Lander, D. G., & Irwin, R. J. Multiple schedules: effects of the distribution of reinforcements between components on the distribution of responses between components. _Journal of the Experimental Analysis of Behavior_, 1968, _11_, 517-524.

Lange, H. de. Experiments on flicker and some calculations on an electrical analogue of the foveal systems. _Physica_, 1952, _18_, 935-950.

Merigan, W. H., Miller, J. S., & Gollub, L. R. Short-component multiple schedules: effects of relative reinforcement duration. _Journal of the Experimental Analysis of Behavior_, 1975, _24_, 183-189.

Pavlov, I. P. _Conditioned Reflexes_ (G. V. Anrep, trans.). London: Oxford U. Press, 1927.

Pierrel, R. A generalization gradient for auditory intensity in the rat. _Journal of the Experimental Analysis of Behavior_, 1958, _1_, 303-313.

Raslaer, T. G., Pierrel-Sorrentino, R., & Brissey, C. Concurrent assessment of schedule and intensity control across successive discriminations. _Journal of the Experimental Analysis of Behavior_, 1975, _23_, 247-254.

Reynolds, G. S. An analysis of interactions in a multiple schedule. *Journal of the Experimental Analysis of Behavior*, 1961a, *4*, 107-117.

Reynolds, G. S. Relativity of response rate and reinforcement frequency in a multiple schedule. *Journal of the Experimental Analysis of Behavior*, 1961b, *4*, 179-184.

Reynolds, G. S. Some limitations on behavioral contrast and induction during successive discrimination. *Journal of the Experimental Analysis of Behavior*, 1963, *6*, 131-139.

Schaub, R. E. Response-cue contingency and cue effectiveness. In D. P. Hendry (Ed.), *Conditioned Reinforcement*. Homewood, Ill: Dorsey Press, 1969.

Schoenfeld, W. N., Antonitis, J. J., & Bersh, P. J. A preliminary study of training conditions necessary for secondary reinforcement. *Journal of Experimental Psychology*, 1950, *40*, 40-45.

Schoenfeld, W. N., & Cole, B. K. *Stimulus Schedules: The t-τ Systems*. New York: Harper & Row, 1972.

Schoenfeld, W. N., & Cumming, W. W. Studies in a temporal classification of reinforcement schedules: summary and projection. *Proceedings of the National Academy of Sciences*, 1960, *46*, 753-758.

Shimp, C. P., & Wheatley, K. L. Matching to relative reinforcement frequency in multiple schedules with a short component duration. *Journal of the Experi-*

mental Analysis of Behavior, 1971, *15*, 205-210.

Sidley, N. A., & Schoenfeld, W. N. Behavior stability and response rate as functions of reinforcement probability on "random ratio" schedules. *Journal of the Experimental Analysis of Behavior*, 1964, *7*, 281-283.

Silberberg, A., & Schrot, J. A yoked-chamber comparison of concurrent and multiple schedules: the relationship between component duration and responding. *Journal of the Experimental Analysis of Behavior*, 1974, *22*, 21-30.

Skinner, B. F. The rate of establishment of a discrimination. *Journal of General Psychology*, 1933, *9*, 302-350.

Skinner, B. F. *The Behavior of Organisms*. New York: Appleton-Century-Crofts, 1938.

Snapper, A. G. *Properties of behavior under response independent temporally defined reinforcement schedules*. Unpublished doctoral dissertation, Columbia University, 1962. Ann Arbor, Mich.: University Microfilms, No. 62-5196.

Terrace, H. S. Stimulus control. In W. K. Honig (Ed.), *Operant Behavior: Areas of Research and Application*. New York: Appleton-Century-Crofts, 1966.

Terrace, H. S. Discrimination learning, the peak shift, and behavioral contrast. *Journal of the Experimen-*

tal *Analysis of Behavior*, 1968, *11*, 727-741.

Todorov, J. C. Component duration and relative response rates in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1972, *17*, 45-49.

Vickery, C. C. *Some effects of cycle length and probability of reinforcement on responding maintained by T schedules of reinforcement*. Unpublished doctoral dissertation, City University of New York, 1971. Ann Arbor, Mich.: University Microfilms, No. 72-1013.

Weissman, A. Impairment of performance when a discriminative stimulus is correlated with a reinforcement contingency. *Journal of the Experimental Analysis of Behavior*, 1961, *4*, 365-369.

Wike, E. L. *Secondary Reinforcement: Selected Experiments*. New York: Harper & Row, 1966.

Yarczower, M. Behavioral contrast and inhibitive stimulus control. *Psychonomic Science*, 1970, *18*, 1-3.