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## Stimulus control of lever-holding responses by rats along a light intensity dimension.

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STIMULUS CONTROL OF LEVER-HOLDING RESPONSES BY RATS  
ALONG A LIGHT INTENSITY DIMENSION

A Thesis Presented

By

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In 1938 Skinner proclaimed the "main datum" in the study of operant behavior to be the rate of response, measured by the amount of time between successive responses and, often, recorded in the form of a cumulative response curve [p.58]. Rate in operant psychology began as a concept of responses occurring freely in time. The cumulative record allowed, to the limit of its "grain," an inspection of the moment to moment emissions of a response. Overall response rate (the average rate over an entire session) could be ascertained without excluding the local rates or patterns of responding (cf. Ferster and Skinner, 1957). While those concerned with the controlling factors in schedules of reinforcement have tended to concentrate on local response patterns, others concerned with the control of behaviors by antecedent stimulus conditions have found it useful to look at overall response rate under, most often, variable interval (VI) schedules of reinforcement (e.g. Donahoe, McCroskery, and Richardson, 1970; Herrnstein, 1970; Rachlin, 1973; Terrace, 1966).

An organism responding under a VI schedule of reinforcement receives a reinforcer for a response that occurs after a given interval of time since the last reinforcer (or start of the session). The intervals of time (usually at least six intervals) are unequal and occur in a random order, and the schedule is most often designated by the arithmetic mean of the intervals. The VI schedule generates a moderate, steady rate of responding. The stability of responding would seem to indicate that the overall or

average response rate is an appropriate summary statistic.

Under typical ranges of VI values (e.g. VI-15 seconds to VI-300 seconds), and given some minimum rate of response, the average response rate may vary with little change in reinforcement frequency during the session. Further, rate of response varies directly with reinforcement frequency.

Guttman and Kalish (1956) capitalized on another characteristic of the VI schedule--the responding of an organism previously reinforced on a VI schedule is very resistant to extinction. Pigeons were trained to peck a key for food on a VI schedule of reinforcement. The key was transilluminated by a monochromatic light. After training, various colors in a randomized sequence were repeatedly presented to the birds under extinction conditions. The resistance to extinction provided by a history of variable interval reinforcement enabled Guttman and Kalish to obtain sufficient data at each tested wavelength to construct a generalization gradient from a single subject. The dependent variable was rate of response plotted as a function of the test stimulus wavelength. The highest rate of response occurred at the training stimulus and progressively lesser rates were obtained in the presence of stimuli of progressively greater difference in wavelength from the training stimulus. The new test stimuli thus controlled an overall rate of response less than that controlled by the training stimulus.

Subsequent studies using elaborations of Guttman and Kalish's (1956) technique have focused on a myriad of variables involved in



stimulus control, such as the effects of prior differential training on various VI schedules (e.g. Hanson, 1959; Jenkins and Harrison, 1962), the effects of differential vs. nondifferential training on a stimulus dimension orthogonal to the tested stimulus dimension (e.g. Switalski, Lyons, and Thomas, 1966), and the investigation of inhibitory stimulus control (e.g. Hearst, 1968; Hearst, Besly, and Farthing, 1970). Generalization gradients have been found not only in the pigeon using a wavelength dimension, but also by using line angles (e.g. Weisman, 1969), brightness (e.g. Jenkins and Harrison, 1962), the tilt of the cage floor with line angles (Wilkie, 1973), and airflow (Van Houten and Rudolph, 1972). Similar generalization functions have commonly been found in other species such as the rat (e.g. Terman, 1970), monkey (e.g. McCoy and Lange, 1969), human, and goldfish (e.g. Ames and Yarczower, 1965; Yarczower and Switalski, 1969).

The studies of stimulus control have usually yielded interesting, orderly, and replicable results across a wide variety of species and stimuli, and the dependent variable has generally been overall rate of response at each test stimulus. Average rate is a summary statistic that enables order to be seen in a mass of data. Unfortunately, averaging and other forms of grouping data may also sacrifice information. Skinner (1976) has noted that averaging data on the behavior of a group of subjects may not allow conclusions about the behavior of any individual subject of the group. Similarly, the averaging of many local rates of response within the experimental



session of a single subject may not allow conclusions to be drawn about the subject's moment to moment patterns of responding. Skinner advocated using rate of response as the main datum of operant psychology, but this main datum was to be obtained from scrutinizing the cumulative record which preserves the momentary occurrences and sequences of the behavior that is being recorded (Skinner, 1938). Skinner (1976) has lamented the decrease in attention given to cumulative response curves; however, there may be several reasons that could justify this neglect. For example, the cumulative response curve may not provide sufficient fine grain resolution of the data. While this problem could be rectified by speeding up the paper drive, that would compound a second problem: the cumulative response curve provides a wealth of information--often too much information to be assessed without the aid of a summary measure, such as average rate. In addition, the use of average rate has yielded orderly, predictable results in an easily analyzable form. Nevertheless, average rate is not the only alternative to the cumulative record.

Other forms of summarizing data, which sacrifice less information than the mean rate, have been used. Blough (1963) presented a cathode ray tube display of the interresponse times (IRT) of the key peck response of pigeons in various experimental situations, including a stimulus generalization test. The progressive decrement in mean response rate, usually found as the test stimulus becomes more unlike the training stimulus, did not seem to be due to a general

shift of the mode of the distribution to longer IRTs as might be inferred from the decrease of the mean rate, a measure of central tendency of the IRT distribution. Rather, the distribution of IRTs remained relatively constant except for an increase in the long IRTs. It was as if the new test stimulus controlled the same patterns of behavior that were controlled by the training stimulus, but that those patterns of responses were emitted less often. The lack of control over key pecking by the test stimuli (or their control over other behaviors) was reflected by the long IRTs, and these long IRTs were primarily responsible for the decrements in mean rate of response.

A pigeon responding for food in the presence of stimulus key in an operant chamber may be said to be engaged in task oriented behaviors. The task behaviors may be under control of some aspects of the environment such as the key, food hopper, interoceptive stimuli from previous responses, etc. and may consist of such behaviors as key pecking, head movements around the key, orientation toward the food hopper area, etc. Non-task behaviors may be hard to differentiate from task behaviors since they might be related to the task or pattern of reinforcement (Anderson and Shettleworth, 1977). At the extreme, task and non-task behaviors must be related since an animal has both freely available concurrently, and thus if the "value" of one is altered, the proportion of time allocated to each will change (Donahoe, 1977; Killeen, 1972; Rachlin, 1971).

In Blough's (1963) study, the shorter IRTs could be considered

instances of task behaviors partitioned by the response of key pecking. If long IRTs consisted of non-task behaviors, then the decrement in overall rate of response at new test stimuli during generalization could be said to have been due to the mixing of task and non-task behaviors. Since a single instance of a long bout of non-task behaviors would only be marked at the onset of task behaviors (and then be marked only as a single, long IRT), such mixing would result in the frequency distributions of IRTs remaining relatively unchanged, although smaller.

Migler (1964) further investigated the nature of the response rate decrement in stimulus generalization. Rats were required to press one lever which turned on a compound discriminative stimulus. The discriminative stimulus consisted of a light illuminated over the second lever and a sound produced by a click frequency. The click frequency was either 2.5 clicks per second or 45.8 clicks per second. Reinforcement was contingent on pressing the second lever only after a specified interval had elapsed. The intervals were either zero seconds or six seconds, and the appropriate interval was signalled by the click frequency. Occasionally, one of six probe stimuli was presented instead of a training stimulus. The frequency distribution of the lever-to-lever response durations at each stimulus revealed two patterns of responding--IRTs were either short or clustered around the six second point. As the probe stimulus became closer to the training stimulus that occasioned a six second IRT, there were more occurrences of (approximate) six



second IRTs and fewer occurrences of short IRTs. These results suggested that the lowered overall rates of response commonly found to test stimuli in generalization testing could be due to the averaging of local response rates (similar to those controlled by the training stimulus) with periods of time consisting of no measured responding (Migler, 1964; cf. Migler and Millenson, 1969). This hypothesis is consistent with Blough's finding that the lowered mean rate in generalization testing after VI training was due to the increase in periods of not-responding, and that when the subject was responding, the IRT distribution resembled the distribution of responses emitted in the presence of the training stimulus (Blough, 1963).

It has been shown that the IRT may be considered an operant (e.g. Anger, 1956; Wilkie and Pear, 1971, 1972; Williams, 1968). An IRT distribution is thus a distribution of the occurrences of similar operants, and responding on a key under a VI schedule of reinforcement may be described not as a rate of "instantaneous" responses but as a frequency distribution of similar operants, each of which takes a certain amount of time to emit. This view helps make Migler's (1964) study, which involved trained interresponse times, compatible with Blough's (1963) study of "naturally occurring" interresponse times in generalization. The bulk of IRTs in Blough's study might be considered as those behaviors that were conditioned in the presence of the training stimulus, and the instances of very long IRTs might be considered to mark the termination of the subject's engaging in behaviors

other than those conditioned in the appetitive task. Thus a novel test stimulus would result in a mixing of the behaviors previously conditioned by delivery of food (the experimental appetitive task) and those other behaviors. As the test stimulus became farther from the training stimulus, fewer task behaviors and more non-task behaviors would be emitted. The IRT distribution would remain similar in shape except for the increase in long IRTs, but the commonly measured average rate of response would decrease.

This view of performance during generalization testing implies that the altered stimulus condition changes the subject's choice between task and non-task behavior. A decrement in average rate of response may imply that the altered stimulus conditions fundamentally alter the nature of the task oriented behavior which might be reflected in a change in the IRT distribution. Blough's data, supported by Migler (1964), implied that this was not the case.

Wildemann and Holland (1972) tested the hypothesis that performance during generalization consisted of mixtures of previously occurring responses. Rather than use the pattern of responding in time, they used a continuous spatial response dimension and a continuous stimulus dimension. A featureless grey response sensor was electrically divided into five 5.08 cm zones; one of five pure tone frequencies corresponded to each of the five zones in a progressively increasing order. Whenever a pigeon pecked the appropriate zone signalled by a tone, grain reinforcement was delivered. Three groups were trained on tone/zones 1&5, 2&4, and 1&3&5. During training, if

an error was made, it tended to be emitted to another training zone. During testing with the intermediate tones, the responses were not emitted to the zones that would have been appropriate to those tones, but were emitted to the nearest previously trained zone(s). For example, testing group 1-3-5 with tone 4 resulted in most responses being emitted to zones 3 and 5. Similarly, testing group 2-4 with tone 3 resulted in a bimodal distribution with about equal numbers of responses falling in the training zones 2 and 4. Thus Wildemann and Holland found no evidence that the task behaviors conditioned in training were altered during generalization testing. If the differential training with various tones coupled with consistent particular response locations had been sufficient to generate a "continuous response dimension," then testing group 2-4 with tone 3 would have resulted in many responses being emitted to zone 3.

Wildemann and Holland's (1972) data, however, suggest a form of "response continuum" when relative amount of mixing to a test stimulus is considered. When response positions 1&3&5 were conditioned, presentation of a stimulus intermediate to two of those response locations resulted primarily in a mixture of those adjacent locations, but little of the behavior from the distant location (see Wildemann and Holland, 1972, Figure 5, p.431). For example, if test tone 2 was presented, most of the responding occurred in zones 1 and 3 and little occurred in zone 5. These data suggest a response continuum that was segmented by differential reinforcement of the several response classes. Perhaps differential reinforcement of different forms of a single



response class on the continuous response dimension was a necessary condition for the response mixing. (This hypothesis is the opposite of Boakes' (1969) suggestion that differential reinforcement of different forms of responses from a single response class may result in intermediate stimuli controlling intermediate forms of the response, and not response mixing.) If only one tone/zone combination had been presented in training, the effect of the other stimuli may have been to increase response variability as the test stimulus frequency was more removed from the training stimulus frequency (cf. Cumming and Eckerman, 1965; Eckerman and Lanson, 1969). A strict mixing hypothesis would predict that the distribution of the peck locations would be the same, but that fewer overall pecks would be emitted, i.e. the bird's non-task behaviors would increase relative to the task behaviors which involve response surface pecking for food reinforcement.

An hypothesis of behavioral mixing has also been proposed by Weiss (1969, 1972b). Weiss has focused on rats' behavior controlled by compound stimuli consisting of the stimulus elements present during training. The different elements of the compound are proposed to control the rates of response that were emitted to the separate elements during training. If a tone controls one rate of response and a light controls a second rate, compounding light and tone will result in an intermediate rate. However, if no-light and no-tone control a low or zero rate of response, then the behaviors controlled in training by, for example, the light-alone are actually mixes or composites of the low rate controlled by the no-tone plus the rate

controlled by the light. In this condition light-alone is viewed as a composite of light + no-tone. Compounding light and tone results in a removal of the stimulus element of no-tone which controls the low rate of response, and therefore a rate above the rate controlled by the light + no-tone would be expected. Similarly, if the low rate was controlled by the light + tone (compound), then testing with no-light + no-tone should also result in the elevation of response rate above the rates controlled by the light + no-tone and no-light + tone. These results have been obtained (Weiss, 1969). Weiss (1972b) has also done a form of this experiment in which the stimuli control two different patterns of responding. An IRT analysis was performed and some mixing of the behaviors during compounding was seen.

The generality of the stimulus compounding studies to traditional stimulus control work might be restricted by the nature of the stimulus. Stimulus control studies done with pigeons often used continuous stimulus dimensions. Migler's (1964; also Migler and Millenson, 1969) continuous variation of click frequency might be considered a compound since higher rates of click could take on tonal qualities. It is conceivable that mixing of behaviors is the result of the compound nature of the stimulus and that the subject is controlled by the stimulus elements at separate times. This argument, however, is countered by the data obtained by Wildemann and Holland (1972). For a response that is free to vary on a spatial location dimension, intermediate stimuli on a continuous auditory

frequency dimension do control mixing of previously conditioned behaviors. Similar results, using a light intensity dimension, were obtained by Cumming and Eckerman (1965). It is an empirical question whether or not results from a behavior, free to vary on a spatial dimension, are comparable with results from behaviors free to vary on a temporal dimension.

Average rate of response may be a good estimator of the overall performance of a subject to novel stimulus situations after VI training with a single response topography. However, studies such as Blough (1963), Migler (1964), and Wildemann and Holland (1972) indicate that a more in-depth analysis of the separate behaviors occurring in generalization would be beneficial for further understanding and prediction of behaviors emitted in the presence of novel stimuli. Generalized performance after VI training with an "instantaneous" operant such as the key peck or the lever press may yield restricted behavioral results when compared with operants that require spatial accuracy or some longer duration to emit. This does not imply that the variables operating in these (seemingly) more complex situations are absent from the more traditional generalization testing situation; however, those variables may be more difficult to unequivocally discern in the traditional test.

Unfortunately the traditional generalization test situations which might use IRT analyses are presented with certain limitations. Migler and Millenson (1969) note:

IRT analyses suggest that a mixing of different response



topographies may be responsible for generalization "gradients", but IRTs alone provide little information concerning the composition of any behaviors being mixed. In the usual generalization study, only one response class is systematically measured. Any other competing behaviors that might be contributing to a composite response rate must be inferred from the absence of the measured response or, more generally, from multi-modal distributions of IRTs (Migler, 1964). [ p.81 ]

Contingencies of reinforcement which produce relatively discrete or "multi-modal" IRT distributions controlled by different stimuli do allow inferences to be made concerning the degree of control a test stimulus has over the previously conditioned response patterns and how these response patterns might interact in the test situation. Limitations in this system of measurement remain. The contingencies of reinforcement programmed by the experimenter may be considered to be concurrent with other "naturally" occurring reinforcement contingencies (Herrnstein, 1970). A subject will engage both in behaviors reinforced through the experimentally controlled contingencies (task behaviors) and in other behaviors (non-task behaviors). The times between measured responses in the IRT analysis may occasionally consist of a combination of the task behaviors and non-task behaviors. For example, if an IRT of 2 seconds is conditioned in the presence of one stimulus and an IRT of 6 seconds is conditioned in the presence of a second stimulus, some IRTs of 6 seconds may result from the

combination of an occurrence of the 2 second behaviors and a 4 second non-task behavior. The longer IRTs may be even more ambiguous as to the combinations of task behaviors and non-task behaviors. With well-defined IRT distributions this problem probably would be restricted to slightly increasing the variability of the distributions of the task behaviors. However, in traditional generalization experiments, the task behaviors were not "labelled" by distinctive IRT distributions. The mixing of task behaviors and non-task behaviors assumed to be occurring in the work of Blough (1963) could only be inferred from an arbitrarily selected, minimum-length "long" IRT. A stronger case could be made for the generality of the IRT analysis studies to traditional problems in stimulus control if the non-task behaviors could also be recorded. The frequency distributions of non-task behaviors would thus seem important, if not essential, for a complete analysis of behaviors occurring during a generalization test.

In summary, Blough's (1963) study suggested that behavioral mixing was occurring during a generalization test to the chromatic test stimuli on the wavelength dimension; however, this was inferred from the similarity of the distribution of the bulk of the IRTs and the increase in a few long IRTs. Although few in number, such long IRTs would amount to a considerable proportion of time and would be primarily responsible for the reduced rates. A method of labelling task vs. non-task behaviors would be desirable, as would a scheme for accounting for the large amount of time spent in low frequency but

long-duration behaviors. A modification of an IRT technique, which requires an organism to space its (recorded) responses in time, would be to require the subject to engage in a behavior between responses and allow the spacing of responses for a specific interval of time. A simple method of accomplishing such a goal would be to have reinforcement contingent upon a rat pressing a lever down and only releasing the lever after a certain interval of time had elapsed. Although the traditional generalization test involves measuring "instantaneous" responses, such as the pigeon's key peck or the rat's lever press, these operants necessitate some minimum amount of time (Baum and Rachlin, 1969). Thus the contingencies involved in the bar duration response are not qualitatively different from the contingencies involved in the more commonly used responses. The behavioral changes that occur in the presence of novel stimuli should be similar whether or not the minimum duration necessary for the operant is defined by the construction of the apparatus or by explicitly imposed contingencies. The bar duration makes the task behaviors more explicit and measurable, and thus allows a further assessment of the changes in task behaviors and non-task behaviors occurring during generalization.

Wildemann and Holland (1972) used a different method of response labelling and obtained mixing of previously conditioned behaviors while using a continuous stimulus dimension--tone frequency. The conditioned response was a key peck to a particular location on a continuous spatial dimension. Two or more locations were conditioned.



Response mixing could have been due to the nature of the response requirement. Differential responding on a spatial dimension may differ from differential responding on a temporal dimension.

Secondly, two or more similar task related behaviors were conditioned. Explicit conditioning of two similar forms of a response may be necessary for response mixing. If only one form of response were conditioned to one stimulus and non-task behaviors were controlled by another stimulus, would mixing of the task and non-task behaviors have occurred?

Migler (1964) has differentially reinforced rats' lever to lever response times. Although this involved differential reinforcement of forms of response varying on a temporal dimension, Boakes (1969) was concerned that the response requirement was either a short lever to lever interval or a six second minimum interval. Boakes suggested that mixing might have been less likely if the response requirements both necessitated some minimum duration. Another consideration of Migler's results concerned the stimulus dimension. The short click frequency might have been functionally an orthogonal stimulus to the longer click frequency. Perhaps the use of a continuous stimulus dimension and a temporal response requirement would not result in behavioral mixing when stimuli intermediate to the training stimuli are presented, but would result in some intermediate duration of response.

The present study used a light intensity stimulus dimension. Different forms of behavior were controlled by each of two intensities.

Condition I served to insure that rats, trained under the more traditional methods of differential reinforcement, would produce monotonically changing gradients of response rate during generalization testing. This condition was essentially a test of the apparatus and stimulus parameters.

In Conditions II and III the response requirement involved a temporal aspect. It was necessary to hold a lever down for a certain interval of time. This bar duration involved both a minimum and maximum time such that the length of the reinforced time slot was one half the duration of the minimum time (i.e.  $t_{\max} = t_{\min} + \frac{1}{2}t_{\min}$ ).

Condition II served to determine whether response mixing would occur when only one form of response was conditioned. In the presence of one stimulus, a given bar duration was required for reinforcement; in the presence of the other stimulus there were no programmed consequences of responding (extinction). If the animal mixed task and non-task behaviors as indicated in Blough's (1963) study, then the responses emitted to the stimuli intermediate to the training stimulus values should be similar to those emitted in the presence of the stimulus condition correlated with reinforcement, but there should be fewer responses. On the other hand, intermediate stimuli might result in the animal pressing the lever for more variable amounts of time or for durations that were not emitted during the training stimuli. In this case generalized responding would be altered in form as well as frequency, as seems to happen somewhat to the duration of responses during extinction

conditions (Margulies, 1961; Millenson, Hurwitz, and Nixon, 1961; Millenson and Hurwitz, 1961; Schaefer and Steinhorst, 1959).

Such a result would be inconsistent with a strict mixing hypothesis which specifies that previously controlled behaviors will be emitted regardless of whether or not those behaviors are from the same response class or on the same response dimension.

Finally in Condition III, two forms of response duration were conditioned. In one stimulus condition a "long" duration was required and in the other stimulus condition a "short" duration was required. The time slots required for reinforcement did not overlap. Of interest in this condition was whether forms of a response class that varied on a temporal dimension would mix in a fashion similar to the response class used by Wildemann and Holland (1972) which varied on a spatial location dimension. The temporal response dimension differs from a spatial location dimension in a possibly important aspect. In order to emit the "longer" duration response, the animal must have held the lever down for the time required to make the "short" duration response. The use of two different durations also differs from Migler's (1964) procedure of conditioning a minimum (long) lever to lever IRT in one stimulus and a maximum (short) lever to lever IRT in another stimulus, since the "short" in Condition III required a minimum amount of time to emit. As in Condition II, the question remains: will mixing of the conditioned behaviors occur at intermediate stimulus conditions or will the animal emit some novel form of behavior such as



an intermediate duration?

Thus the purpose of the present study was to determine whether the response mixing hypothesis might be a plausible explanation for the progressive decrease in rates of response found to generalization test stimuli which are progressively distant from the training stimulus. While the data of Blough (1963) indicated that mixing was a distinct possibility, and other studies have shown that mixing of previously trained behaviors does occur under various conditions of stimuli and forms of conditioned responses, the previous studies raised some questions concerning the nature of the stimulus and form of conditioned response. These questions remain to be answered in order for the hypothesis of behavioral mixing to be accepted as a plausible explanation for performance in a generalization test. And more generally, the questions should be answered to determine the generality of the principle of behavioral mixing.

#### Method

##### Subjects

Twenty five Sprague-Dawley rats were maintained at 80% of their free feeding weights. Twelve (R3 through R14) previously served in a one-trial conditioned suppression experiment in which the conditioned stimulus was a tone, the unconditioned stimulus was a brief shock, and the response measured was licking a drinking tube. R2 had served in a pilot study in the present apparatus and had been exposed to various VI schedules, extinction, and reconditioning for the two duration criteria used in the current study. The remainder of the

subjects were experimentally naive. No subject other than R2 had any previous history which involved lever pressing or light discriminations. R5, R9, and R14 died prior to generalization testing.

### Apparatus

The experimental chamber housed a Lehigh Valley Electronics retractable lever, mounted on the left side of the cage 3.8 cm above the grid floor. The lever protracted 2.2 cm into the cage and was 4.8 cm long. The lever required 0.3 to 0.4 N to actuate a microswitch and thus be recorded as a lever depression. On the right side of the cage was a food cup into which the 45 mg Noyes pellet reinforcers were delivered. Directly above the lever (6.3 cm when the lever was not depressed) was a 15 VDC (#1893) lamp covered by a milk-white jewel (the stimulus lamp). The cage was set in a wood enclosure lined with flat white acoustic tile. White noise and ventilation fans provided 85 to 90 db masking noise.

Control equipment was housed in adjacent rooms. The stimulus dimension that was varied during generalization testing was the intensity of the light over the lever. Since all that was required was a continuous stimulus dimension, the light intensity was varied by placing rheostats in series with the lamp, thereby varying the DC voltage across the lamp. Intensity values, measured at the stimulus lamp jewel by a Techtronix digital photometer, were approximately 10, 27, 60, 135, and 300 Nits and are subsequently labelled stimulus 1 through 5 respectively (dim to bright). The placement of the particular rheostat in series with the lamp was accomplished by

energizing one of five relays by the control equipment. The control equipment was a ModComp II digital computer interfaced with electromechanical equipment, and this equipment was located in rooms adjacent to the one housing the experimental chambers. Data recording was done primarily with the computer which was capable of recording on magnetic tape the moment to moment events in the sessions of each subject. Four experimental chambers could be operated simultaneously by the computer.

### Procedure

General. In order to insure that their behavior was under the control of the light, all subjects acquired a discrimination on the light intensity dimension (Jenkins and Harrison, 1962). The two training stimuli were either S1 and S5, or S2 and S4. The response requirement associated with a training stimulus was counterbalanced. Table 1 summarizes the three experimental conditions. (R14 died prior to initial training. During the discrimination phase, several of the animals became sick. R5 and R9 died at this time. R2, a pilot subject, was substituted for R9. R13 died after most of the discrimination test data had been acquired. Prior to becoming ill, R13 had undergone 19 out of the 24 generalization test sessions.)

In Condition I, there was no time requirement for the lever response to be considered a criterion response. In Condition II, a lever-hold was a criterion response only if it was between 4 and 6



seconds in duration. In the presence of one training stimulus (S+), the criterion response produced a reinforcer on a VI schedule (usually a VI-20 second) while in the presence of the other stimulus (S-), extinction conditions were in effect. In Condition III, there were two criterion response requirements. In one stimulus condition the criterion was 4 to 6 seconds ( $S+_{\text{long}}$ ) and in the other stimulus condition it was 1 to  $1\frac{1}{2}$  seconds ( $S+_{\text{short}}$ ). For R2 these values, however, were 5 to  $7\frac{1}{2}$  and 2 to 3 seconds. Separate VI schedules were in effect during the two stimulus conditions.

The variable interval schedules used consisted of three repetitions of six intervals produced by the distribution of Fleshler and Hoffman (1962). The 18 intervals were chosen such that short (smallest two intervals), medium (middle two intervals), and long (longest two intervals) were followed by short, medium, and long intervals equally often. The VI schedules for different stimulus conditions were independent, and, when a stimulus changed, the time remaining before a reinforcer was available was unchanged when that stimulus was again presented. For a criterion response to be reinforced, the initiation of the response must have occurred after the interval had elapsed (timed out).

In discrimination training, stimuli were presented for 60 one minute periods. During the initial discrimination phase, the two training stimuli occurred in strict, one minute alternation or in a pattern of three minutes of the stimulus presented at the start of training (S+ of Conditions I and II, the  $S+_{\text{I}}$  of Condition III), followed

by one minute of the "newer" training stimulus. The "one in four" pattern was used to reduce excessive disruption of the distribution of criterion responses in some subjects. Later in discrimination training, the stimuli were presented for one minute in a quasi-random order such that no stimulus occurred more than three successive times. If introduction of new patterns of stimuli had an overly disruptive effect on the occurrence of criterion responses, an earlier pattern of stimulus presentations was reinstated.

Prior to generalization testing, probe tests with the training stimuli were inserted into the sequence of stimuli. No reinforcer was ever delivered during a probe stimulus and the VI schedule intervals did not change. Six probes (three of each training stimulus value) were inserted during this phase to reduce effects of the decrease in reinforcement density during generalization testing. The one minute probes were inserted into the quasi-random sequence with certain restrictions. First, they occurred between minute numbers 15 and 48 of the one hour sessions. Their placement was an effort to reduce effects of "warmup" and changes in behavior that might occur toward the end of the session. Second, they were inserted into a location that was preceded by a stimulus that had been present for only a single minute. This was to reduce any changes in behavior that might have occurred when a given stimulus had been present for a long period of time. Third, a probe did not follow another probe by less than 5 minutes. Finally, all probes in a session were preceded by either one or the other training stimulus.



In generalization testing, similar rules for probe insertion applied, but only five probe stimuli were inserted. The sequence of insertion of the five probe stimuli was balanced. The two training stimuli were inserted into position 2 and position 4. S3 always occurred in position 3. The remaining two probe stimuli occurred first and last such that the stimulus more dissimilar to the training stimulus probe in position 2 occupied position 1. Thus animals trained with stimuli 2 and 4 had probe sequences 1,4,3,2,5 and 5,2,3,4,1; while animals trained with stimuli 1 and 5 had probe sequences 2,5,3,1,4 and 4,1,3,5,2. These orders were balanced in this way to help reduce effects of responding arising solely from the position of the probe during the session, and placement of training stimulus probes in positions 2 and 4 helped maximally separate "new" probe stimuli from each other. Each sequence of probes followed a single one minute period of one training stimulus or the other.

Training. In Condition I, subjects were shaped by successive approximations to press the lever in the S+ condition. All releases of the lever were reinforced for several sessions. The schedule of reinforcement was then changed to VI-5 seconds, to VI-10 seconds, and finally to VI-20 seconds over a period of several days. Table 2 shows the number of days of training for each subject at each training condition. The generalization testing for R13 was terminated after 19 days due to a fatal illness.

Table 2 also shows the sequence of training for Conditions II and



III. All subjects were trained in the presence of the stimulus which was to signal the longer duration requirement (S+ for Condition II, S+<sub>1</sub> for Condition III). The rats were shaped to press the lever by successive approximations. Between approximately 50 and 100 reinforced responses with no duration requirement, a  $\frac{1}{2}$  second minimum duration requirement was introduced. The minimum requirement was gradually raised to the terminal 4 second (5 second for R2) requirement. Although the upper limit of 6 seconds ( $7\frac{1}{2}$  seconds for R2) was in effect, this contingency was rarely encountered during this phase. For most subjects, the duration requirement was increased by  $\frac{1}{2}$  second per day. These daily sessions entailed from 200 to 300 reinforced responses. The subjects received continuous reinforcement for the final criterion duration response prior to the introduction of the second training stimulus and its associated response requirement. When a new pattern of training stimuli was introduced, and if the percentage of criterion responses steadily declined across days or abruptly declined, a previous pattern of stimulus presentation was reintroduced.

When the proportion of time engaging in criterion responding seemed to indicate that discriminative performance was not markedly improving, a VI schedule was introduced, and the values of the VI schedules were slightly increased every few days. The usual increase was between 2 and 5 seconds. In Condition III, the VI values were adjusted for some animals so that the proportion of reinforcers in each stimulus condition was between 45 and 55 percent. For R31

through R34, and most subjects of Condition II, the VI values were 20 seconds. The VI value of 20 seconds was selected since it resulted in little disruption of the duration performance when introduced in slow, progressive steps from VI-0 seconds, and the long interval of VI-20 was approximately 45 seconds. Thus for a sixth of the intervals, the subjects were exposed to a period of non-reinforcement nearly as long as would be experienced during the generalization test probes.

When performance on the terminal VI values (measured by the proportion of time spent engaging in criterion responding) showed no trend over days, generalization testing was begun. Generalization testing lasted 24 days, thus providing 24 minutes of probe testing at each stimulus value. Half of that time consisted of probes following one training stimulus or the other.

### Results

Condition I. Figures 1 and 2 show the relative generalization gradients from the subjects with no duration requirement. The total number of responses on which the curves are based are also shown. Each stimulus was presented for a total of 24 minutes, except for R13 who was exposed to each for 19 minutes. The gradients formed by the unconnected filled circles are curves based on the responding to probes which followed the dimmer training stimulus (S1 or S2). The open circles represent curves based on probes which followed the brighter of the training stimuli (S4 or S5).

All subjects, with the exception of R41, showed clear

evidence of control by the stimulus dimension. The curves showed a higher number of responses were emitted to the S+, irrespective of whether that stimulus was the brighter or dimmer of the discriminative stimuli. The number of responses decreased monotonically as the test stimulus became more like the S-. The subjects shown in Figure 2 were trained with S2/S4 and thus were tested with stimuli "outside the range" of the training stimuli. When the test stimulus was on the side of the S+ distal to the S-, R43 emitted more responses to the test stimulus than were emitted to the S+. For R12 and R13 this also occurred overall, but the effect was "context specific." The peak of the gradient was only displaced during the test probe which followed the S+. When the distal stimulus followed the S-, responding was less than it was when the S+ (probe) followed the S-. R44, however, showed no evidence of a peak shift to the brighter S5. Although judging by the relative number of responses to the test stimuli, R41 was not under stimulus control, the pattern of responding was seen to systematically differ between the S+ and S- when the data was assembled in a format appropriate to Conditions II and III (Figure 5).

Data format for Conditions II and III. When a response requires little time to emit, or if two responses take equal times to emit, then the use of rate may be an appropriate measure; however, when responses take various amounts of time, then rate may be inappropriate (Baum and Rachlin, 1969). In Conditions II and III, the response requirement involved holding a lever down for a period



of time, and thus a measure besides rate was adopted.

Consider an ideal rat in a box with a lever. When this rat presses the lever, he does so for either 1 second (response A) or 4 seconds (response B). In a 1 hour session, one might find that the animal emitted 900 A responses and 225 B responses. The relative frequency of A would be:

$$900 / (900+225) = 0.80$$

and the relative frequency of B would be:

$$225 / (1125) = 0.20 \quad .$$

If preference for a behavior were measured by the amount of that behavior emitted, then it could be said that this ideal rat preferred A. However, using relative frequency to determine "amount" of behavior neglects the time it takes to emit that behavior. The relative amount of time allocated to each behavior during the session does not neglect this factor. Further, determining the relative amount of time allocated to behaviors also provides a measure of how much time is allocated to behaviors other than A and B. The relative time allocation in this example would be:

$$\text{Behavior (A): } 900 \text{ R} * 1 \text{ sec} / 1 \text{ hr} = 0.25$$

$$\text{Behavior (B): } 225 \text{ R} * 4 \text{ sec} / 1 \text{ hr} = 0.25$$

$$\text{Behavior } (\bar{A} \text{ and } \bar{B}): 1 - (0.25 + 0.25) = 0.50 \quad .$$

The animal has allocated as much time to A as he did to B. It can also be seen that engaging in non-task behaviors ( $\bar{A}$  and  $\bar{B}$ ) occupies as much of the animal's time as task oriented behaviors (A or B).

The extension of this measure to the relative frequency

distribution of both lever-holding durations and durations of IRTs provides the relative amount of time allocated to the various durations specified by the bin widths. Since the times between responses may be related to the task behaviors of holding the lever down, the time allocated to various length IRTs may be included in the relative time allocation distribution, rather than lumping them all together as "non-task" behaviors.

Figures 3 through 10 depict the relative time allocation for the lever-holding behaviors (BAR) and interresponse time behaviors (IRT) of the subjects in Conditions II and III. Both the BAR and IRT behaviors were segmented into  $\frac{1}{2}$  second bins and an overflow bin (o.f.  $>$  9 seconds). The IRTs also included an overlap (o.l.) category which indicated the proportion of time spent engaging in "interresponse behaviors" that overlapped a stimulus change, either at the beginning or end of a probe stimulus period. The proportion of time spent engaging in a BAR behavior when the stimulus changed was usually less than 5% of the BAR behaviors and was not depicted. Percentages by points in parentheses indicate off-scale overflow or overlap points. The total area under each BAR/IRT pair of curves is equivalent to the 24 minutes of exposure to that stimulus. As in Figures 1 and 2, the open circles indicate points obtained from probes following one minute of the brighter training stimulus (S4 or S5) while the dark circles indicate points obtained from probes following the dimmer training stimulus (S1 or S2). The range of reinforced durations is shown on the abscissa.

Condition II. These subjects were reinforced for holding the lever down for 4 to 6 seconds in the presence of one stimulus and, in the presence of another stimulus, were under extinction conditions. Figures 3,4,5,and 6 show that all subjects were controlled by these contingencies. In the presence of the S+, the proportion of time spent holding the lever was greatest for those durations which were reinforced.

In the presence of the S-, little lever-holding behavior was emitted. Figure 3 shows that R21 was an exception. In the S-, R21 engaged in lever-holding behaviors that generally lasted less than  $1\frac{1}{2}$  seconds, and usually less than 4 seconds would elapse between these responses.

Figure 5 includes R41, the subject from Condition I which involved no duration requirement. Even with no contingency for any duration, the S+ controlled primarily a 1 to  $2\frac{1}{2}$  second lever-hold and a similar duration interresponse time. The S- controlled a much shorter duration lever-hold and IRT. The duration of lever responses for the other subjects in Condition I were generally less than  $\frac{1}{2}$  second.

For all subjects of Condition II, the mode of the distributions at the S+ was between 4 and 5 seconds. Generally, as the stimulus conditions departed from the S+ value, the mode stayed within the 4 to 6 second range. The shape of the distributions remained similar, but, at stimulus values intermediate between the S+ and S-, the amount of time spent engaging in S+ controlled behaviors decreased.



The intermediate stimuli controlled some lever-holding behavior similar to those controlled by the S+ as well as controlling behavior patterns (not lever-holding) similar to those controlled by the S-. Generally the intermediate stimulus values did not result in a wider ranged distribution of BAR responses, although the S- condition did occasion some durations greater than 6 seconds. These long duration behaviors may have been related to the training conditions. When the S- was introduced, the 4 to 6 second lever-holding response was on extinction in the presence of that stimulus. Under extinction conditions, the lever holding behavior tended to become more variable and many behaviors shorter and longer than the 4 to 6 second criterion were emitted.

Figures 3 through 6 show the relative amounts of times allocated to various length IRTs. With no contingencies of reinforcement placed on IRTs, the distributions tended to be more idiosyncratic for the individual subject. Nevertheless, the IRT duration for the subjects at the S+ was very regular and usually had a mode of 2 seconds or less (including R41 of Condition I). R6, the one exception, tended to pause for 5 to 8 seconds between responses. Informal observations of the subjects during training revealed that most subjects would tend to release the lever and press the lever again very soon (producing a short IRT) or move to the food cup and back to the lever (producing a slightly longer but still rapid IRT). If a reinforcer was delivered when the lever was released, the move toward the food cup would result in the subject's

having his nose in the cup as the pellet landed. Thus much of the time allocated to IRT behaviors could be considered task oriented behaviors. Figures 3 through 6 show that at stimulus values intermediate to the S+ and S-, these behaviors decreased along with the 4 to 6 second BAR responses, further indicating that they were controlled by the S+. In general these IRT distributions did not become progressively longer as the stimulus became more like the S-. The long IRTs, represented by the overflow (>9 seconds) and overlap bins, did progressively increase as the stimulus became more like the S-.

Figures 5 and 6 also show the pattern of responding which occurred outside the range of S+ and S- for subjects of Condition II. Regardless of the stimulus which preceded the probe (context effect), the amount of responding controlled by the test stimulus that was on the side of the S- farther away from the S+ was less than that controlled by the S-. Further, the amount of criterion responding that was controlled by the test stimulus that was on the side of the S+ farther away from the S- exceeded the amount of criterion responding emitted to the S+ for subjects R23 and R6. For R24, however, the S+ (s4) controlled approximately equal amounts of criterion responding.

In general there was very little effect of context--the value of the preceding training stimulus--on the responding to a probe stimulus. When there was an effect of context on the probe stimulus responses, it tended to be of two sorts. One was that the distribution

obtained in one context was displaced to the left of the distribution obtained in the other context. When the stimulus intensity difference between the preceding training stimulus and the probe stimulus was in the same direction as the intensity difference between the S- and S+, then that probe distribution was to the left of the other. The concrete example of the most pronounced instance of this "left shift" is seen on Figure 3 for subject R3 at the S2 probe. The distributions formed by closed circles are from probes which follow the dimmer training stimulus. (In the case of Figures 3 and 5 this is the S+.) Thus for subject R3 at S2, the open circles represent the distribution from the S2 probes which followed the brighter S-. The S2 probe was a bright-dim transition which was the same direction as the S- to S+ (bright to dim) transition. The S2 probes represented by the closed circles involved a context which was the opposite. Those probes were S2 preceded by S+ (S1), a transition in the direction of the S-. A similar but smaller "left shift" may be seen in Figure 3 for R21 at both S+ (S1) and S2, and for R23 at S1 and S+ (S2). For subjects shown on Figures 4 and 6, the S+ and S- were reversed and thus a "left shift" appeared as the distribution of closed circles occurring to the left of the open circles. This occurred for R4 at S4 and S+ (S5), for R6 at S3, and slightly for R24 at S5. The only occurrence of a "right shift" was a slight displacement of distributions for R6 at S5 which was outside the range of S+ and S-.

The second slight effect of context was to elevate the BAR



distribution when the training stimulus-probe stimulus intensity transition was in the same direction as the transition from S- to S+. This occurred more often and could be more easily seen in the vicinity of the S-. For subjects of Figures 3 and 5, this is seen as the elevation of open circles over closed circles, and for subjects of Figures 4 and 6, the effect is seen as an elevation of closed circles over open circles. The only major exceptions to this trend occurred for R3 at the S+ (S1), and R24 at the S+ (S4).

Condition III. For the subjects in this condition, the training stimuli were both S+, but the responses required for reinforcement differed in duration. Figures 7, 8, 9, and 10 show that all subjects were under control of the training stimuli. The results paralleled those of Condition II in that as the stimuli were varied, the animal emitted a mixture of the behaviors that were emitted to the training stimuli, and that the amount of mixing was a function of the relation between the test stimulus and the training stimuli. The amount of time allocated to the longer duration behavior was greatest in the vicinity of the  $S+_{1}$  and decreased monotonically as the  $S+_{s}$  was approached. Similarly, the amount of time allocated to the shorter duration behavior was greatest in the vicinity of the  $S+_{s}$  and decreased as the  $S+_{1}$  was approached. In no case did an intermediate stimulus result in any increase in intermediate response durations. This general result occurred in all subjects despite individual differences in the characteristics of responding. R7, R31, and R33 tended to emit few "errors"--responses in the

presence of one training stimulus appropriate to the other training stimulus. However, the subjects did tend to emit many responses that were slightly outside the criterion, i.e. they were "inaccurate." R32 and R34 also emitted few "errors," but less time was spent in responding outside the criteria. R2, R8, and R10, on the other hand, tended to emit many "errors." Nevertheless, the mixing of the behaviors at intermediate stimuli always occurred. In addition, R2, which had previously been exposed to various VI schedules and extinction conditions for his short (2 to 3 second) and long (5 to  $7\frac{1}{2}$  second) behaviors, had distributions at the  $S+_s$  and  $S+_l$  which overlapped. This overlap did not mitigate the effect. Finally, there were differences between subjects in the overall amount of responding controlled by the training stimuli.

For most subjects, the amount of reinforcement in the presence of each training stimulus was kept between 45 and 55 percent. For R31 and R33 this was not the case. R31 (Figure 7) received 40 to 45 percent of his reinforcers in a session for the longer duration response. R33 (Figure 9), a very "inaccurate" subject received very few and a variable amount of reinforcers (7 to 25 percent) for the long duration response.

As with Condition II, the IRTs were more idiosyncratic. Further, the distribution of IRTs indicated that much of the time allocated to not-BAR behaviors were task related behaviors. For most subjects in both training conditions, there seemed to be the short (2 seconds or less) IRTs that were found in Condition II.

This was not true for R8 and R34 which tended to have longer IRTs. In general, one of the stimulus conditions also controlled longer IRTs. At  $S+_s$  for R33 and R34, for example, a secondary mode formed at  $5\frac{1}{2}$  to 9 seconds and 2 to  $4\frac{1}{2}$  seconds respectively. In other subjects such as the  $S+_s$  of R7, R31, and R2, the increase in longer duration IRTs was associated with the short duration requirement. Since R8 was an "inaccurate" subject, it was difficult to determine whether this trend was present. Since the total time per reinforcer was kept approximately equal for both stimulus conditions, and since there were more short duration behaviors possible (and also more emitted) than long duration behaviors in a given time interval, there was always a greater number of short duration behaviors per reinforcer than long duration behaviors, even though there was more actual bar-holding time per reinforcer for the long duration behavior.

The effects of presenting probe stimuli outside the range of the training stimuli were also similar to that of Condition II. Figures 9 and 10 show that the test stimuli outside the range of the training stimuli generally resulted in an increased proportion of the behaviors controlled by and appropriate to the adjacent training stimulus. Only R10 at S5 had less long BAR behavior at S5 than at the  $S+_1$ . In addition, Figures 9 and 10 show that all subjects spent a decreased proportion of time engaged in "errors" to the distant training stimulus than was spent in "errors" in the adjacent training stimulus.



When the effects of context were present, they were also similar to those found in Condition II. If a transition from a training stimulus to an intermediate probe stimulus resulted in more responding to that probe appropriate to the other training stimulus, then the probes depicted by closed circles should have an increased number of short behaviors for subjects on Figures 7 and 9. The open circles of Figures 7 and 9 should show an increased number of long behaviors. This was evident at S3 for R7 and R2, and slightly for R31. Subjects depicted on Figures 8 and 10 and the training stimuli reversed so the trend should have been reversed--closed circles elevated for long behaviors and open circles elevated for short behaviors. At S3, all subjects slightly showed this trend. The "left shift" of the distribution of long behaviors only occurred for subjects R31 at S3 and R32 at S4.

In general, regardless of the context or individual differences, the data show that the amount of time spent engaging in a behavior monotonically decreased as the stimulus conditions approached that stimulus condition in which that behavior was not appropriate. This occurred in Condition II in which no other behavior could obtain food reinforcement and in Condition III in which a second behavior was appropriate for food reinforcement. Behaviors that did not occur during the training conditions did not appear when test stimuli were introduced. There also seemed to be no effect of the dimmer intensity training stimulus signalling one form of behavior or another.

## Discussion

Condition I. The monotonically decreasing gradients shown in Figures 1 and 2 indicated that the apparatus and stimuli used in this study resulted in typical postdiscrimination gradients (cf. Hanson, 1959). All subjects come under dimensional control by light intensity. Although R41 seemed to show a lack of control by the stimulus dimension when only the number of responses were considered, the form those responses took differed across stimuli (Figure 5). In the S-, R41 spent much time engaged in short duration BAR and IRT responses. Since S- always changed into S+, it was possible that these responses were maintained by adventitious occurrences of the S+. The pattern of responding in S- differed from the pattern controlled by S+ and reinforcement. The S+ pattern was probably also a result of adventitious reinforcement. Since there was a great deal of overlap between the distributions of responses controlled by the S+ and the S-, it could not be determined whether the data from this animal at intermediate stimuli supported the response mixing hypothesis or supported a position that would predict intermediate forms of behaviors. Nevertheless, it is important to note that a conclusion of lack of stimulus control should not be based on only one measure of behavior. Such a conclusion should always be made with caution.

Figure 2 shows that the parameters of light intensities (and perhaps location of the lamp in the cage) were sufficient to produce a peak shift (Hanson, 1959) in three of the four subjects.

For R12 and R13, however, the peak shift only occurred when the probe stimulus (S1 or S5) followed the adjacent S+. This effect of context may have been due to the nature of training in which the S+ and S- always followed each other. Although finding a peak shift was not a necessary condition for the purpose of the study, its presence in the Condition I subjects was an interesting adjunct and suggested that a related change in behavior might be found in Conditions II and III when stimuli outside the range of S+ were tested.

In general Condition I served to show that the typical, monotonically changing gradient following discrimination training would be obtained for the apparatus and light intensities used. In addition, it did not seem to matter whether the S+ was the dimmer or the brighter of the training stimuli.

Condition II. The data on Figures 3 through 6 show that response mixing occurred when only one form of the response was explicitly conditioned. The behaviors that were controlled by intermediate stimuli were mixtures of the behaviors controlled by the training stimuli, even though these behaviors were from different response classes. Further, explicit reinforcement for the two controlled forms of behavior was not necessary for response mixing to occur. As the stimulus conditions changed, the durations of the BAR responses remained the same, but the total proportion of time allocated to that response decreased as the stimulus conditions diverged from the S+ and moved towards the S-.

The IRT data were also consistent with Blough (1963) and thus



not only supports the response mixing hypothesis but also its generality. Although there were no contingencies on the IRT behaviors, many of those behaviors might be considered to be task behaviors. As in Blough's data, the non-task behaviors would be reflected in the long IRTs which occur in the overflow and overlap bins. The proportion of time allocated to the shorter IRTs was decreased as the probe stimulus value approached the S-, but in general the duration of those IRTs remained relatively constant.

Figures 3 and 4 show the behavior of the animals trained at stimuli 1 and 5. In the three intermediate stimulus conditions, the amount of BAR behavior steadily decreased. If the behavior change had been abrupt (as it tends to be for R4), it might have indicated that the stimuli were, for some reason, functionally not on the same dimension. These data indicated that the light intensities used comprised a continuous stimulus dimension. The click frequency dimension used with rats by Migler (1964) might have functionally served as a pair of orthogonal stimuli. On the other hand, Wildemann and Holland (1972) used a continuous tone dimension with pigeons; however, they also used differentially reinforced responses from a continuous response dimension. The present data have shown that behavioral mixing does occur when both a continuous stimulus dimension and only a single form of reinforced response are present in training. Since these are the conditions commonly found in studies of stimulus control, such as Blough (1963), it seems appropriate to extend the generality of the principle of response

mixing to those situations. (Using the term "principle" is not to necessarily imply that mixing is a function of phylogenetic factors. Commonly occurring events during development may also play a role in the later occurrences of behavioral mixing.)

Condition III. Although Wildemann and Holland (1972) used a continuous response dimension, the dimension was spatial and not temporal. In Migler's (1964) study, the responses controlled by the stimuli involved a very short or a very long time interval. These responses might be considered different response classes (Boakes, 1969). Response mixing, therefore, might only occur in a temporal dimension if the controlled responses are from different response classes, such as an extremely short vs. long duration or, as in Condition II, and in Blough's (1963) study, where one stimulus controlled some temporal pattern of responding and the other stimulus controlled other, unspecified behaviors. Boakes (1969) suggested that differential reinforcement of different forms of a response from a single response class might be the conditions which result in intermediate forms of the response to intermediate stimuli. In addition, two responses varying on a temporal dimension have a peculiarity--the duration of the longer response includes the duration of the shorter response. The informal observation of the subjects failed to reveal any obvious differences in the way the subjects pressed the lever in the two stimulus conditions. Thus it would not have been surprising, in accordance with Boakes' (1969) suggestion, to find that a stimulus intermediate

to the  $S+_s$  and  $S+_1$  controlled an intermediate duration. That this did not occur further bolsters the generality of the principle of behavioral mixing.

The individual differences between subjects also tend to support the generality of mixing. The results were not confined to animals which emitted a substantial number of "errors" during the training stimuli. In addition, the mixing results were also found when there was overlap between the distributions controlled by the training stimuli.

In general, the principle of behavioral mixing seems to apply to all situations thus far tested. It remains to be seen what conditions might be necessary for a response dimension to become aligned to a stimulus dimension such that an intermediate stimulus will result in an intermediate, and perhaps never before emitted, response.

Behavioral mixing has implications for the concepts of stimulus generalization and response generalization (induction). Keller and Schoenfeld (1950) specify that responses may vary in three ways--topography, force, and duration. When a response is reinforced, the probability of that response is increased as well as responses with similar, but not identical, topographies, forces, and durations. The concomitant increase in the other response variants gives rise to the notion of response class, and the phenomenon is named (but not explained by the term) response generalization or induction. If the response variants produce a similar result on the environment, they may be termed members of the same operant. If the response



variants do not produce similar environmental results, then differential reinforcement may be occurring.

Stimulus generalization describes the condition in which a response, controlled by some aspect(s) of one environment, will tend to occur in a slightly different environment. When a response is conditioned in some environment and then that environment is changed, does some aspect of the response necessarily change also? The present results show that the pattern of responding remains unchanged in an altered environment. What changes is the proportion of time allocated to behaviors controlled by the original environment and to behaviors controlled by another environment.

To the extent that the topography, force, or duration of a response is independent from some aspect of the environment, then to that extent when the environment is changed, the response, if it is emitted, will be unchanged. An example of conditions of non-independence under which behavioral mixing might not occur would involve a duration response similar to the one used in this study. If the stimulus were a 1 per second flashing light in training and if then the rate of flash were varied, the response duration might vary accordingly.

This hypothetical result may be reconciled with a response mixing position if the aspects of the response (topography, force, and duration) are treated as (producing) stimulus conditions for the organism (Donahoe, Schulte, and Moulton, 1968). If the number

of light flashes were the sole controlling stimulus, then changing the rate of flashing might alter the duration of the response. However, if the flashing light only controlled the allocation of time to the task, and the duration of the particular response produced internal stimuli controlled the termination of the response (the release of the lever), then a variation of the flashing light would only have the effect of altering the allocation of time to the task.

The behavior of the rats in the present study may be viewed as being controlled by a compound stimulus. One dimension was exteroceptive--the light intensity. The other stimulus may be assumed to be constantly changing internal cues arising from holding the lever down. As the compound stimulus conditions more closely approximate previous situations in which the release of the lever was previously reinforced, the probability of release increases. For the subjects trained with two durations, if an animal exceeded the short duration, the next occurrence of a stimulus situation that would occasion a bar-release would be when the duration of the response was appropriately "long," even if the exteroceptive stimulus was appropriate to the emission of a short duration response. It's the animal's "best bet."

This analysis may be neutral with respect to whether or not the long-response/short-response "decision" is made at the onset of the response or at the time the lever is released. Donahoe, Schulte, and Moulton (1968) have shown that the behavior of rats

responding on a fixed ratio schedule are primarily controlled by internal cues. Similarly, in the present study once the lever was depressed and the animal under internal cues, the light intensities might have little effect over the behavior. Nevertheless, the essential aspect of the analysis is that the organism is under internal stimulus control as well as external control.

If this analysis is correct, then results inconsistent with response mixing would arise from a situation in which the response produced stimuli do not control the response and that only the exteroceptive stimulus has control over the response. As in the hypothetical study mentioned above, this might be done by de-correlating the response produced cues with reinforcement. If a 1 per second flashing light was the stimulus condition and a lever-hold of 4 to 6 seconds was required for reinforcement, the response might come to be controlled by the interoceptive stimuli (Donahoe, Schulte, and Moulton, 1968). If the light was varied in frequency but reinforcement only available when 4 to 6 flashes had occurred, then the response duration might come to "follow" the stimulus dimension since the response produced cues would be less relevant.

Intermediate response forms to intermediate stimuli may be emitted if the exteroceptive stimulus dimension could be "aligned" with the internal stimulus dimension. This would seem to require that the subject respond to a complex relationship between two, normally orthogonal stimulus dimensions. For example, with light intensity (L) and response duration (D), the subject would not



only have to acquire the conditional discrimination of  $D_1$  being appropriate to  $L_1$  and  $D_2$  appropriate to  $L_2$ , but that  $L_1 > L_2$  and  $D_1 < D_2$ , i.e. "brighter is faster, dimmer slower." In this situation a different inequality between  $L_1$  and  $L_{\text{test}}$  might result in a different inequality for the duration, and thus a  $D_{\text{test}}$  could be emitted. Perhaps this is what Boakes (1969) was considering. It is possible that it is necessary to train several response durations that are ordinally consistent with light intensity in order for such a situation to develop.

On the other hand, perhaps some characteristic of the nature of interoceptive cues might make it difficult to "align" that stimulus dimension with an external stimulus dimension. In order to investigate conditions under which behavioral mixing did not occur, it might be advantageous to explicitly state the stimulus dimensions that are being varied. For example, in a pigeon chamber, a line, constantly changing in angular orientation, might be superimposed on a chromatic stimulus projected on a response key. A peck might only be reinforced if it was emitted when the line was at a particular angle. The particular reinforced angle would depend on the color of the key. With such a preparation, it might be feasible to determine how many color/angle combinations might be necessary to train before a new color would result in a new angle, consistent with the color, being selected. Perhaps other training methods might be necessary to "align" the stimulus dimensions.

In the present study, the method of differentially reinforcing responses in the presence of two stimuli was used to insure that the subjects' behaviors would be controlled by the light intensity dimension (Jenkins and Harrison, 1962). Although the stimulus periods varied in length (from 1 to 3 minutes), a change in stimulus during training was always followed by the other training stimulus. Thus if the dim training stimulus was S- and the bright S+, then a stimulus shift from dim to brighter would occasion the S+ behaviors, irrespective of the actual intensity of the brighter test stimulus. Conversely, if that intermediate test stimulus occurred following the brighter S+, then the test stimulus would occasion S- controlled behaviors. The data tended to show such context effects, although the effects were generally not large (however, see S3 for subject R2 on Figure 9). One or a combination of several factors could have been responsible for this effect.

Temporal factors could have produced the "context" effects. Using this procedure and disregarding the stimulus value, the longer an animal had been responding appropriate to one stimulus, the more probable was the appropriateness of the other behavior. However, the procedure was designed to minimize the temporal factors by having varied training stimulus durations and by inserting probe stimuli after a single minute of the preceding training stimulus.

Secondly, an animal could learn not only that behaviors A are appropriate to dim and behaviors B are appropriate to bright, but

that behaviors A are appropriate after a bright to dim shift and that behaviors B are appropriate after a dim to bright stimulus shift.

Finally, the stimulus light was the only illumination in the box. Thus after being in a given stimulus condition, the subject's eyes would have been adapted to that level of illumination. Thus a shift in illumination would result in the difference in the stimulus value initially being accentuated. For example, the intermediate S3 would be functionally brighter if it followed the dim S1 than if it followed the bright S5.

The context effects were primarily responsible for altering the height of the distribution. On occasion, when the stimulus shift was in the direction of a richer schedule of reinforcement, the distribution was displaced to the left of the distribution obtained when the shift to that stimulus was in the direction of the leaner schedule of reinforcement. For example, the lever-holding behavior of R3 at S2 was generally shorter when S2 followed the brighter S- (S5), as shown by the open circles. When S2 followed the dimmer S+ (S1), the behaviors were longer (closed circles). The antecedents of this shift in the duration are not clear, although the shift might be related to results found in pilot work done with the lever-holding response. When the schedule of reinforcement for a given duration response was changed from a rich schedule to a leaner schedule, the durations tended to become longer. When the schedule was shifted to a richer VI schedule of reinforcement, the



distribution shifted to the left (responding became shorter). Similarly, when the stimulus shift to S2 was toward the S+, the durations of R3 tended to be shorter than when the shift was toward the S-. The general conclusion may be that, given similar stimulus situations and given the subject depresses the lever, the higher the probability of a reinforcer, the more the animal will tend to shorten the response duration, i.e., to "err" on the "short side."

The subjects trained with stimuli 2 and 4 were tested with stimuli outside the range of the training stimuli. In Condition I, this resulted in "peak shifts" (Hanson, 1959) in three of the four subjects. Several subjects in Conditions II and III also showed an increase in amount of responding to the stimuli outside the range of the training stimuli. Consistent with the principle of behavioral mixing, the increase in behavior was not produced by a change in the form of responding, but by an alteration in the subjects' choice of task vs. non-task (or, in Condition III, task vs. task vs. non-task) behaviors. Thus some Condition II subjects (R6, R24) showed an increase in the amount of S- (S2) controlled behaviors when S1 was presented. Condition III subjects would tend to both increase the amount of behavior appropriate to the adjacent S+ and decrease the amount of behavior appropriate to the distant S+. However, it was not necessary for "errors" to be emitted in the S+ condition for the behavior to increase. R33 emitted very few "long" responses in the S+<sub>s</sub> (S4)

condition and yet the proportion of time spent engaged in "short" behaviors increased in S5 over the S4 proportion. Nevertheless, the subjects were still mixing behaviors. In Condition III, there were two task behaviors as well as non-task behaviors to which the animal could allocate his time.

The results of the present study and others have indicated that response mixing is a robust phenomenon and that the proper question is no longer, "Does mixing of previously controlled behaviors result in the progressive decrement in rate of responding during generalization testing, or do the altered stimulus conditions result in an altered form of responding that is responsible for the lowered rates?" The questions facing those interested in response mixing now concern the boundary conditions of the phenomenon, what conditioning history might preclude response mixing in altered environments, and how do internal and external stimuli interact to control the behavior.

One of the goals of a science of behavior is the prediction of behavior (Holland and Skinner, 1961). In the more "natural" situation of a complex environment in which there are a multitude of possible responses and many simultaneously operating contingencies of reinforcement, there are few responses which might be considered "instantaneous" (Baum and Rachlin, 1969). Most behaviors do require a certain amount of time to emit and are often composed of various component responses which occur in a somewhat restricted order, often referred to as a behavioral chain (Holland and Skinner, 1961;

Keller and Schoenfeld, 1950). Thus it would seem simplistic to say that an altered environment lowers the probability of response. These results have shown that the altered environment changes the allocation of time to task and non-task, or between different tasks and non-task behaviors. In other words, what is changed when the environment is changed is the animal's choice between response alternatives.



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Table 1

The response criteria, stimuli, and subject numbers  
for the three experimental conditions.

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Condition	Required response duration (sec.)	Stimulus conditions (S+/S- or S <sub>1</sub> <sup>+</sup> /S <sub>s</sub> <sup>+</sup> )			
		S1/S5	S5/S1	S2/S4	S4/S2
I	0-infinite/Extinction	R11	R12	---	R13
I	0-infinite/Extinction	R41	R42	R43	R44
II	4 - 6 / Extinction	R3	R4	---	R6
II	4 - 6 / Extinction	R21	R22	R23	R24
III	4 - 6 / 1 - 1½	R7	R8	R2*	R10
III	4 - 6 / 1 - 1½	R31	R32	R33	R34

\* R2 was substituted for R9 who died. R2 was a pilot animal which had extensive conditioning history of various VI schedules imposed on the duration requirements of 5-7½ seconds and 2-3 seconds in the presence of S2/S4. The response requirement was kept at 5-7½/2-3 seconds.

Table 2

Number of days at the various training conditions for all subjects.

Subject (Condition)	# days	Stimulus sequence	Reinforcement conditions (S+/S- or S+ <sub>1</sub> /S+ <sub>s</sub> )
R11,R12,R13 (I)	4	all S+	CRF/---
	5	all S+	VI-10/---
	14	all S+	VI-20/---
	30	alternating	VI-20/EXT
	14	quasi-random	VI-20/EXT
	24	generalization	VI-20/EXT
R41,R42,	2	all S+	CRF/---
R43,R44 (I)	1	all S+	VI-5/---
	2	all S+	VI-10/---
	3	all S+	VI-20/EXT
	26	quasi-random	VI-20/EXT
	24	generalization	VI-20/EXT
R3 (II)	15	all S+	shape duration/---
	16	all S+	CRF/---
	14	alternating	CRF/EXT
	20	alternating	leaning/EXT
	19	quasi-random	leaning/EXT
	14	quasi-random	VI-20/EXT

Table 2 (continued)

Subject (Condition)	# days	Stimulus sequence	Reinforcement conditions (S+/S- or S+ <sub>1</sub> /S+ <sub>s</sub> )
	24	generalization	VI-20/EXT
R4 (II)	13	all S+	shape duration/---
	16	all S+	CRF/---
	15	alternating	CRF/EXT
	20	alternating	leaning/EXT
	19	quasi-random	leaning/EXT
	11	quasi-random	VI-20/EXT
	--	(sick)	
	7	quasi-random	leaning/EXT
	23	quasi-random	VI-15/EXT
	24	generalization	VI-15/EXT
R6 (II)	15	all S+	shape duration/---
	16	all S+	CRF/---
	15	alternating	CRF/EXT
	20	alternating	leaning/EXT
	18	quasi-random	leaning/EXT
	12	quasi-random	VI-20/EXT
	--	(sick)	
	12	quasi-random	leaning/EXT



Table 2 (continued)

Subject (Condition)	# days	Stimulus sequence	Reinforcement conditions (S+/S- or S+ <sub>1</sub> /S+ <sub>s</sub> )
	9	quasi-random	VI-20/EXT
	24	generalization	VI-20/EXT
R21 (II)	8	all S+	shape duration/---
	7	all S+	CRF/---
	14	1 of 4 S-	CRF/EXT
	21	quasi-random	CRF/EXT
	51	quasi-random	leaning/EXT
	12	quasi-random	VI-20/EXT
	24	generalization	VI-20/EXT
R22 (II)	10	all S+	shape duration/---
	6	all S+	CRF/---
	3	1 of 4 S-	CRF/EXT
	5	quasi-random	CRF/EXT
	23	quasi-random	leaning/EXT
	12	quasi-random	VI-20/EXT
	24	generalization	VI-20/EXT
R23 (II)	8	all S+	shape duration/---
	5	all S+	CRF/---
	9	1 of 4 S-	CRF/EXT

Table 2 (continued)

Subject (Condition)	# days	Stimulus sequence	Reinforcement conditions (S+/S- or S+ <sub>1</sub> /S+ <sub>s</sub> )
	3	all S+	CRF/---
	4	1 of 4 S-	CRF/EXT
	3	quasi-random	CRF/EXT
	6	1 of 4 S-	CRF/EXT
	9	all S+	CRF/---
	22	1 of 4 S-	CRF/EXT
	6	quasi-random	CRF/EXT
	24	quasi-random	leaning/EXT
	12	quasi-random	VI-20/EXT
	24	generalization	VI-20/EXT
R24 (II)	5	all S+	shape duration/---
	7	all S+	CRF/---
	16	1 of 4 S-	CRF/EXT
	20	quasi-random	CRF/EXT
	45	quasi-random	leaning/EXT
	12	quasi-random	VI-20/EXT
	24	generalization	VI-20/EXT
R7 (III)	13	all S+ <sub>1</sub>	shape duration/---
	16	all S+ <sub>1</sub>	CRF/---

Table 2 (continued)

Subject (Condition)	# days	Stimulus sequence	Reinforcement conditions (S+/S- or S+ <sub>1</sub> /S+ <sub>s</sub> )
	17	alternating	CRF/CRF
	18	alternating	leaning/leaning
	31	quasi-random	leaning/leaning
	--	(sick)	
	10	quasi-random	leaning/leaning
	18	quasi-random	VI-20/VI-21
	24	generalization	VI-20/VI-21
R8 (III)	13	all S+ <sub>1</sub>	shape duration/---
	16	all S+ <sub>1</sub>	CRF/---
	17	alternating	CRF/CRF
	18	alternating	leaning/leaning
	37	quasi-random	leaning/leaning
	--	(sick)	
	21	quasi-random	leaning/leaning
	12	quasi-random	VI-20/VI-15
	24	generalization	VI-20/VI-15
R2 (III)	--	(prior history)	
	19	alternating	CRF/CRF
	4	alternating	leaning/leaning



Table 2 (continued)

Subject (Condition)	# days	Stimulus sequence	Reinforcement conditions (S+/S- or S+ <sub>1</sub> /S+ <sub>s</sub> )
	20	quasi-random	leaning/leaning
	11	quasi-random	VI-20/VI-20
	24	generalization	VI-20/VI-20
R10 (III)	13	all S+ <sub>1</sub>	shape duration/---
	16	all S+ <sub>1</sub>	CRF/---
	31	alternating	CRF/CRF
	4	alternating	leaning/leaning
	30	quasi-random	leaning/leaning
	13	quasi-random	VI-20/VI-22
	24	generalization	VI-20/VI-22
R31 (III)	8	all S+ <sub>1</sub>	shape duration/---
	5	all S+ <sub>1</sub>	CRF/---
	9	quasi-random	CRF/CRF
	9	1 of 4 S+ <sub>s</sub>	CRF/CRF
	11	quasi-random	CRF/CRF
	24	quasi-random	leaning/leaning
	20	quasi-random	VI-20/VI-20
	24	generalization	VI-20/VI-20
R32 (III)	8	all S+ <sub>1</sub>	shape duration/---

Table 2 (continued)

Subject (Condition)	# days	Stimulus sequence	Reinforcement conditions (S+/S- or S+ <sub>1</sub> /S+ <sub>s</sub> )
	5	all S+ <sub>1</sub>	CRF/---
	9	quasi-random	CRF/CRF
	9	1 of 4 S+ <sub>s</sub>	CRF/CRF
	11	quasi-random	CRF/CRF
	33	quasi-random	leaning/leaning
	18	quasi-random	VI-20/VI-20
	24	generalization	VI-20/VI-20
R33 (III)	6	all S+ <sub>1</sub>	shape duration/---
	7	all S+ <sub>1</sub>	CRF/---
	9	quasi-random	CRF/CRF
	9	1 of 4 S+ <sub>s</sub>	CRF/CRF
	15	quasi-random	CRF/CRF
	5	1 of 4 S+ <sub>s</sub>	CRF/CRF
	2	quasi-random	CRF/CRF
	3	all S+ <sub>1</sub>	CRF/---
	6	1 of 4 S+ <sub>s</sub>	CRF/CRF
	28	quasi-random	leaning/leaning
	14	quasi-random	VI-20/VI-20
	24	generalization	VI-20/VI-20

Table 2 (continued)

Subject (Condition)	# days	Stimulus sequence	Reinforcement conditions (S+/S- or S+ <sub>1</sub> /S+ <sub>s</sub> )
R34 (III)	8	all S+ <sub>1</sub>	shape duration/---
	5	all S+ <sub>1</sub>	CRF/---
	9	quasi-random	CRF/CRF
	9	1 of 4 S+ <sub>s</sub>	CRF/CRF
	1	quasi-random	CRF/CRF
	2	1 of 4 S+ <sub>s</sub>	CRF/CRF
	2	all S+ <sub>1</sub>	CRF/---
	2	1 of 4 S+ <sub>s</sub>	CRF/CRF
	4	quasi-random	CRF/CRF
	24	quasi-random	leaning/leaning
	19	quasi-random	VI-20/VI-20
	24	generalization	VI-20/VI-20



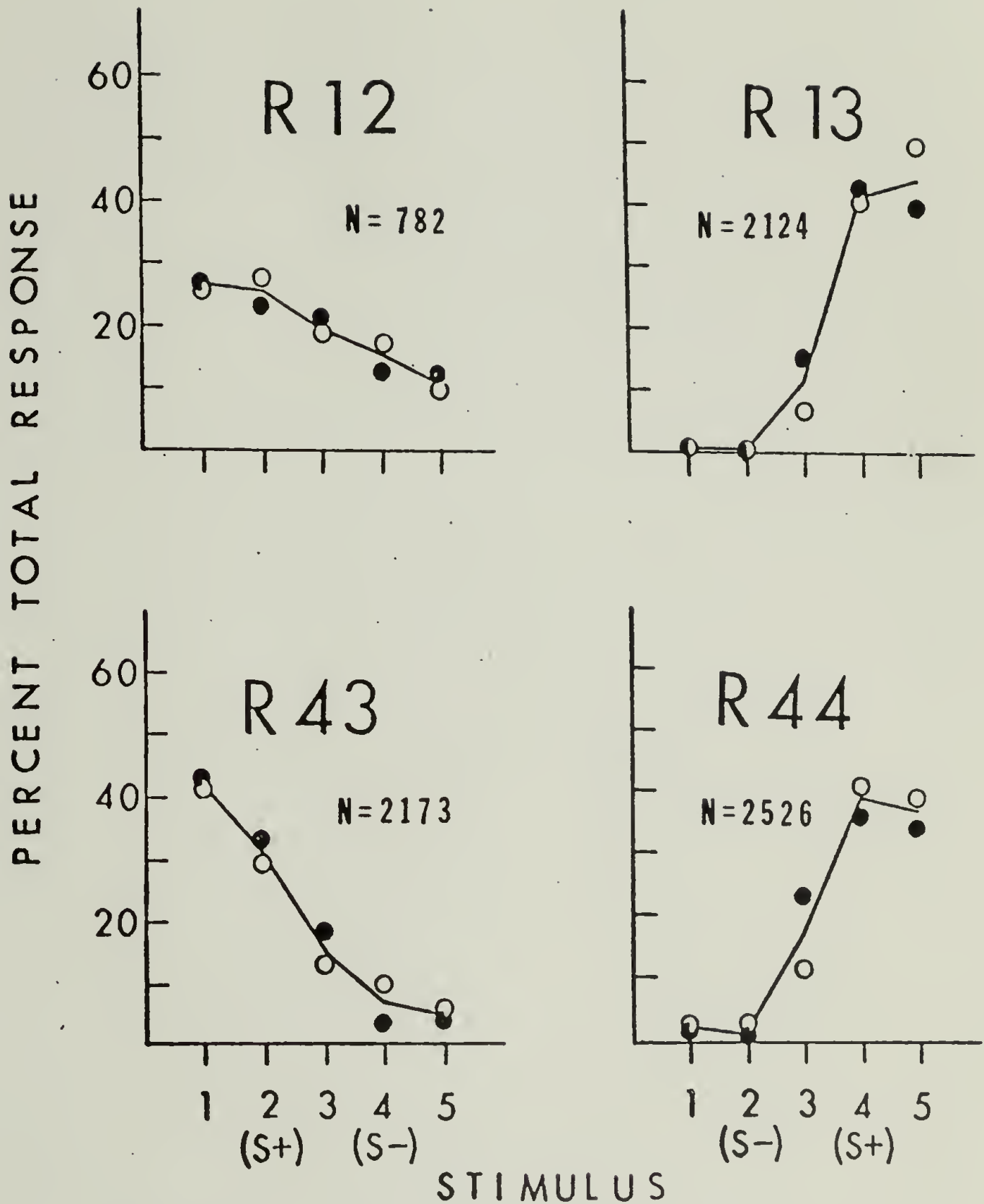


Figure 2. Relative generalization gradients for Condition I. Dark circles form gradients based on probes following S2; open circles are gradients based on probes following S4. "N" is the number of responses on which the total gradient is based.

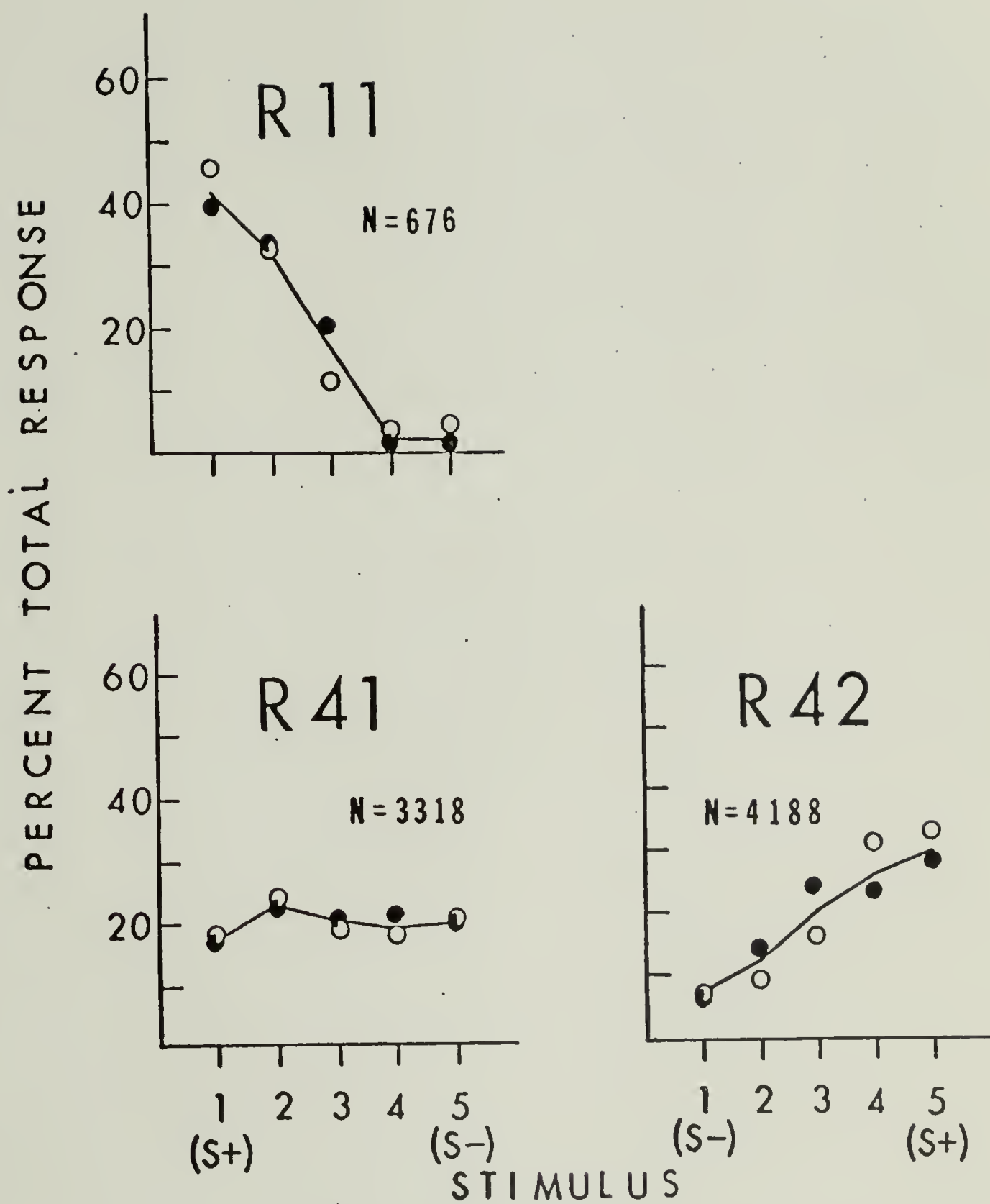


Figure 1. Relative generalization gradients for Condition I. Dark circles form gradients based on probes following S1; open circles form gradients based on probes following S5. "N" is the number of responses on which the total gradient is based.

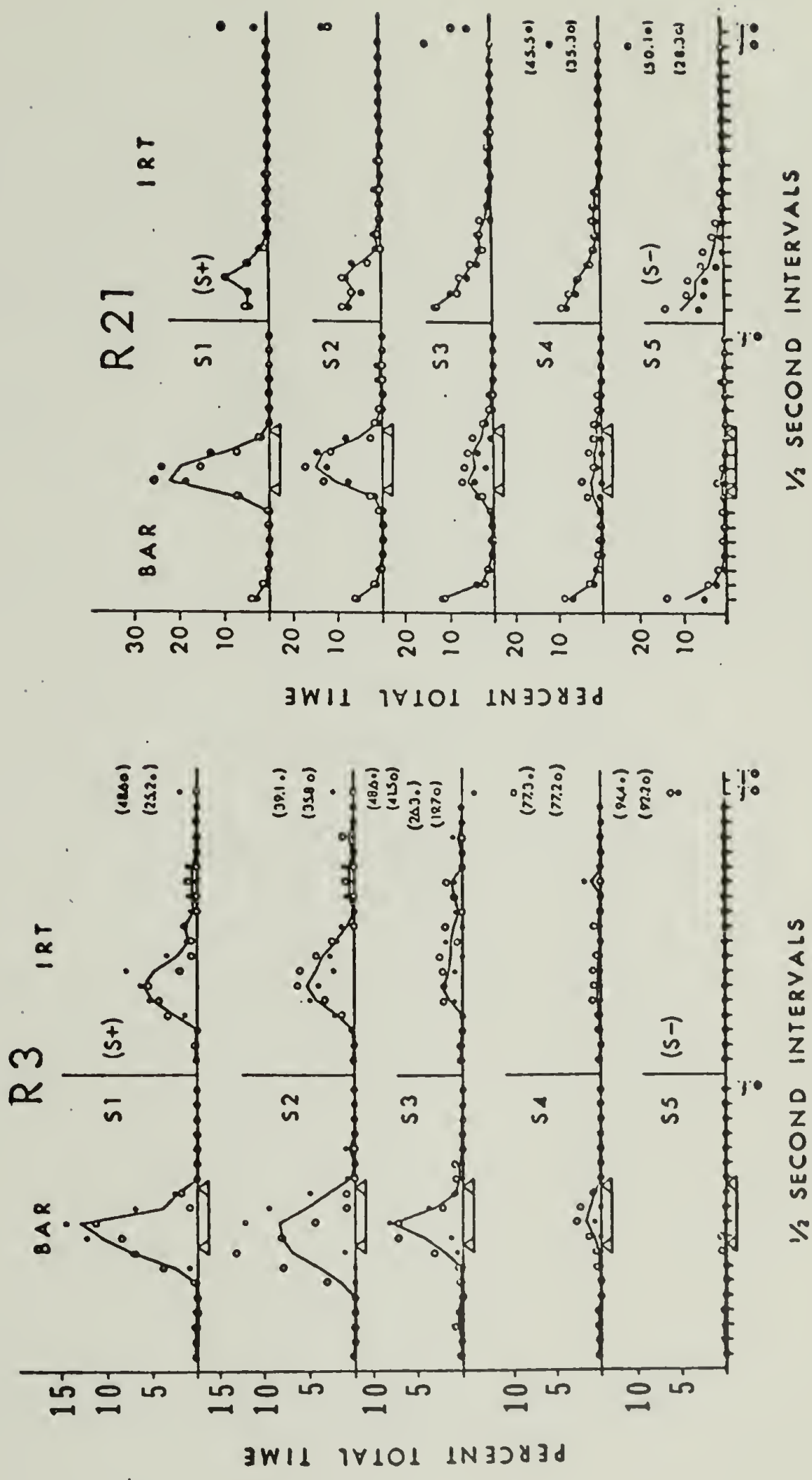


Figure 3. Relative time allocation distributions for Condition II. Complete explanation of symbols is included in the text.



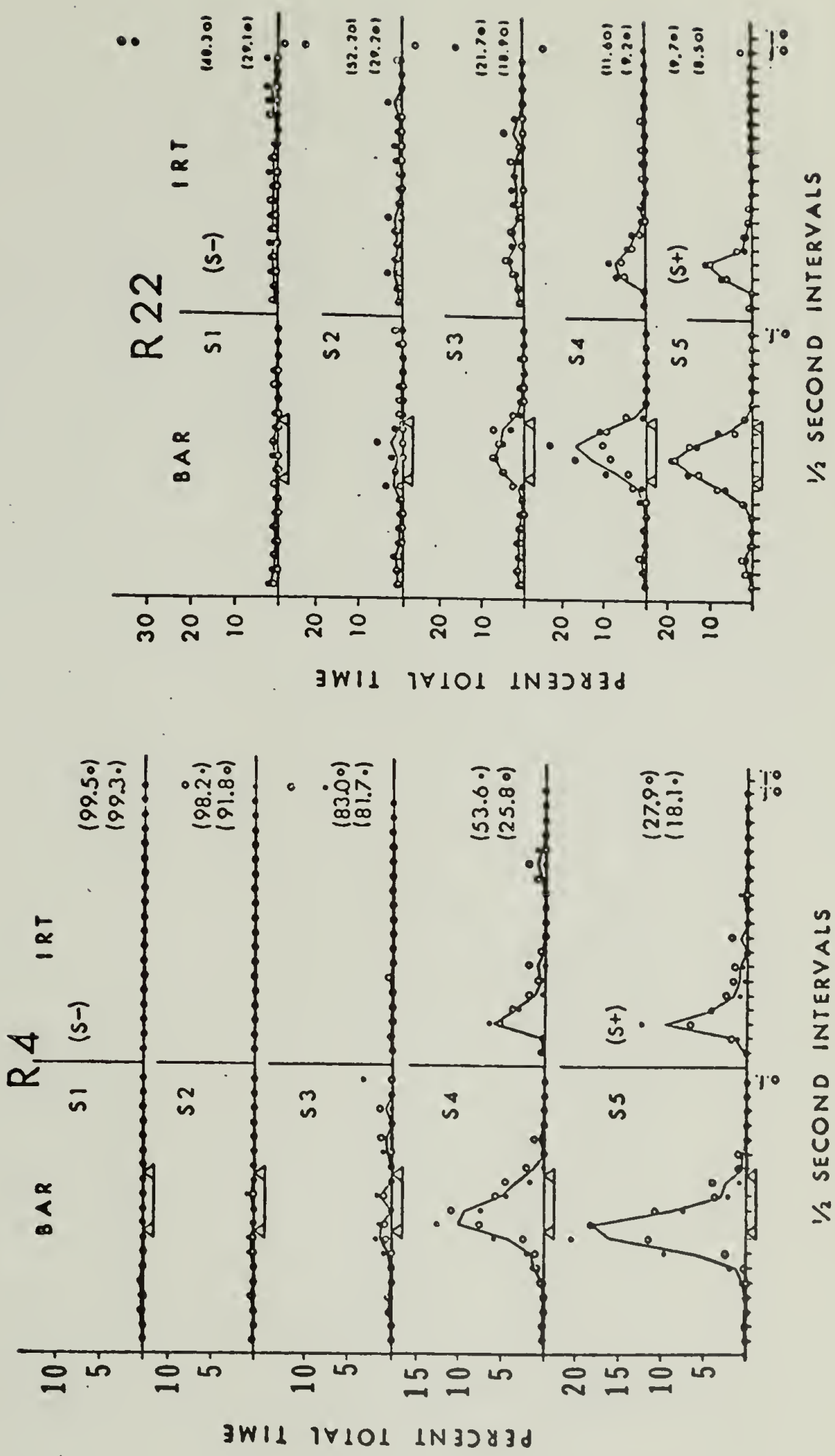


Figure 4. Relative time allocation distributions for Condition II. Complete explanation of symbols is included in the text.

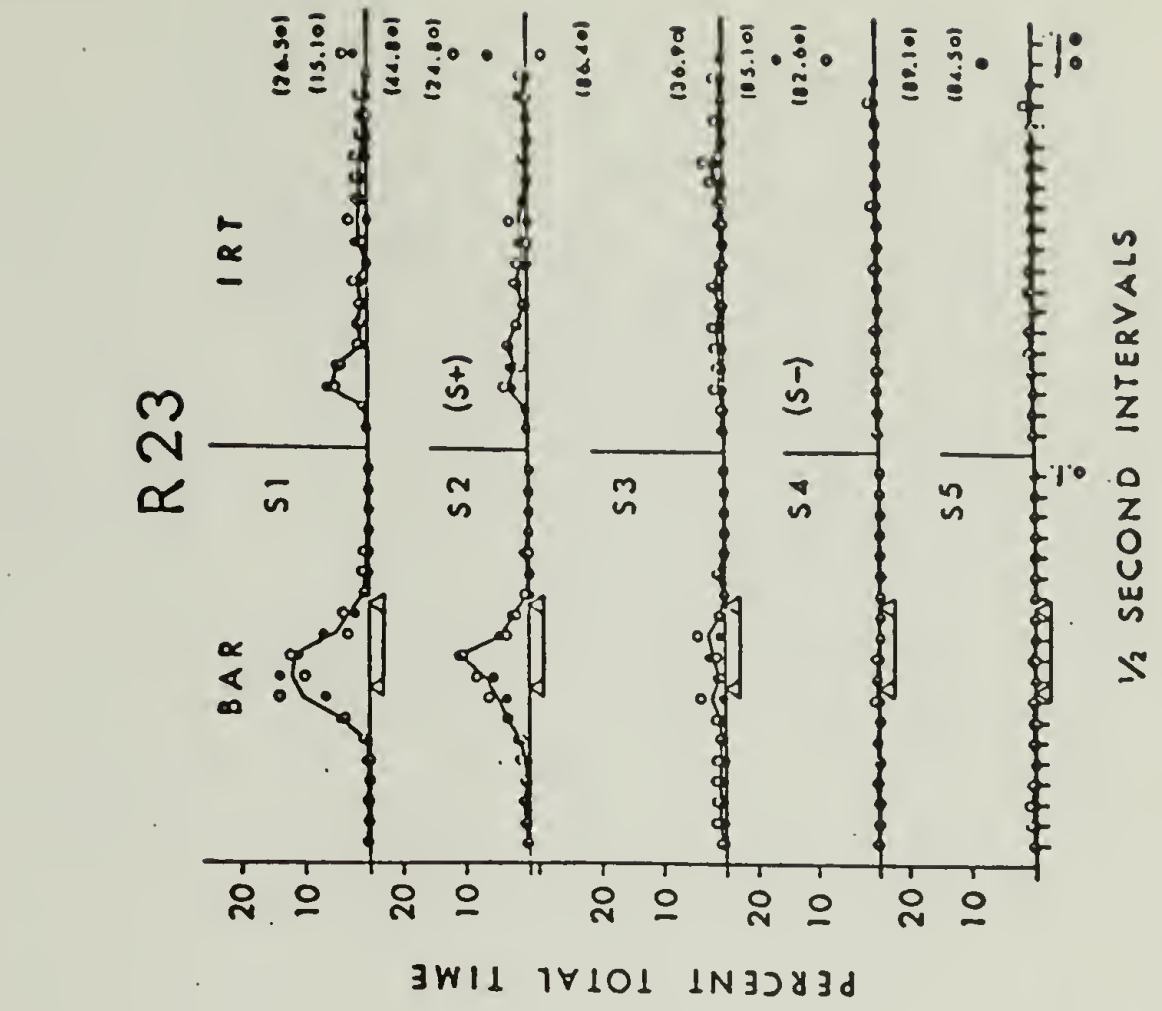
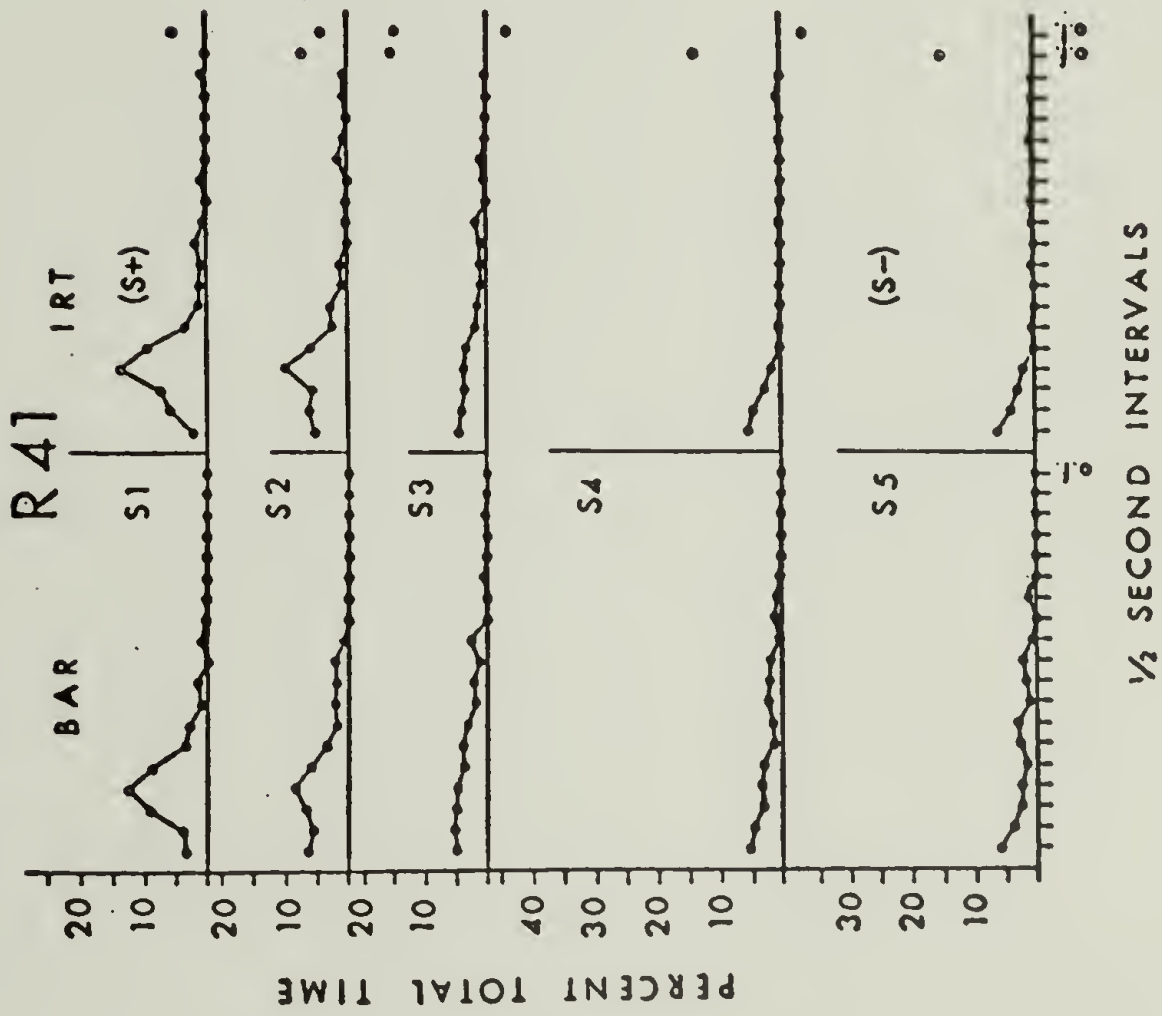


Figure 5. Relative time allocation distributions. R41 is from Condition I and R23 is from Condition II. Complete explanation of symbols is included in the text.

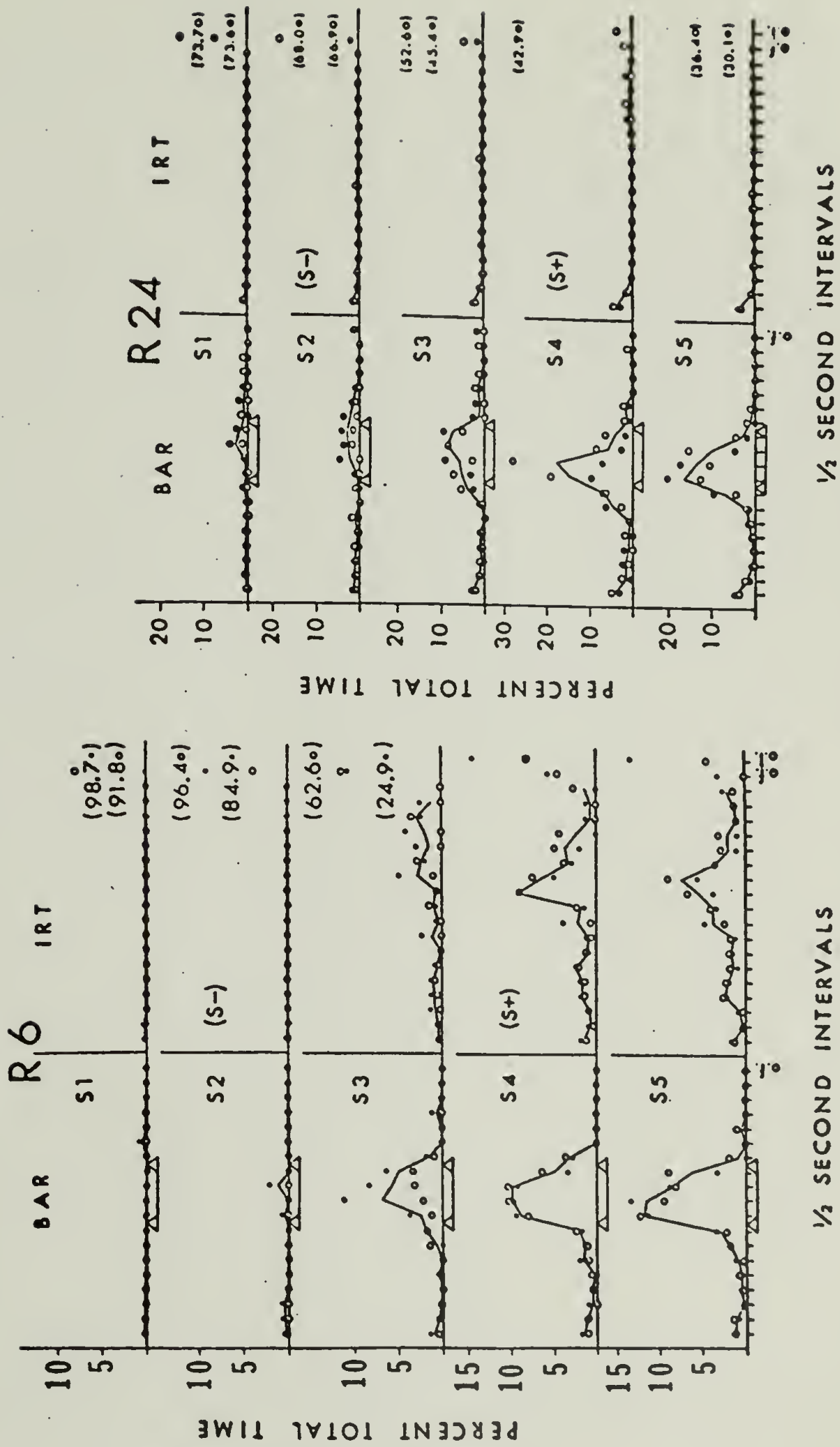


Figure 6. Relative time allocation distributions for Condition II. Complete explanation of symbols is included in the text.



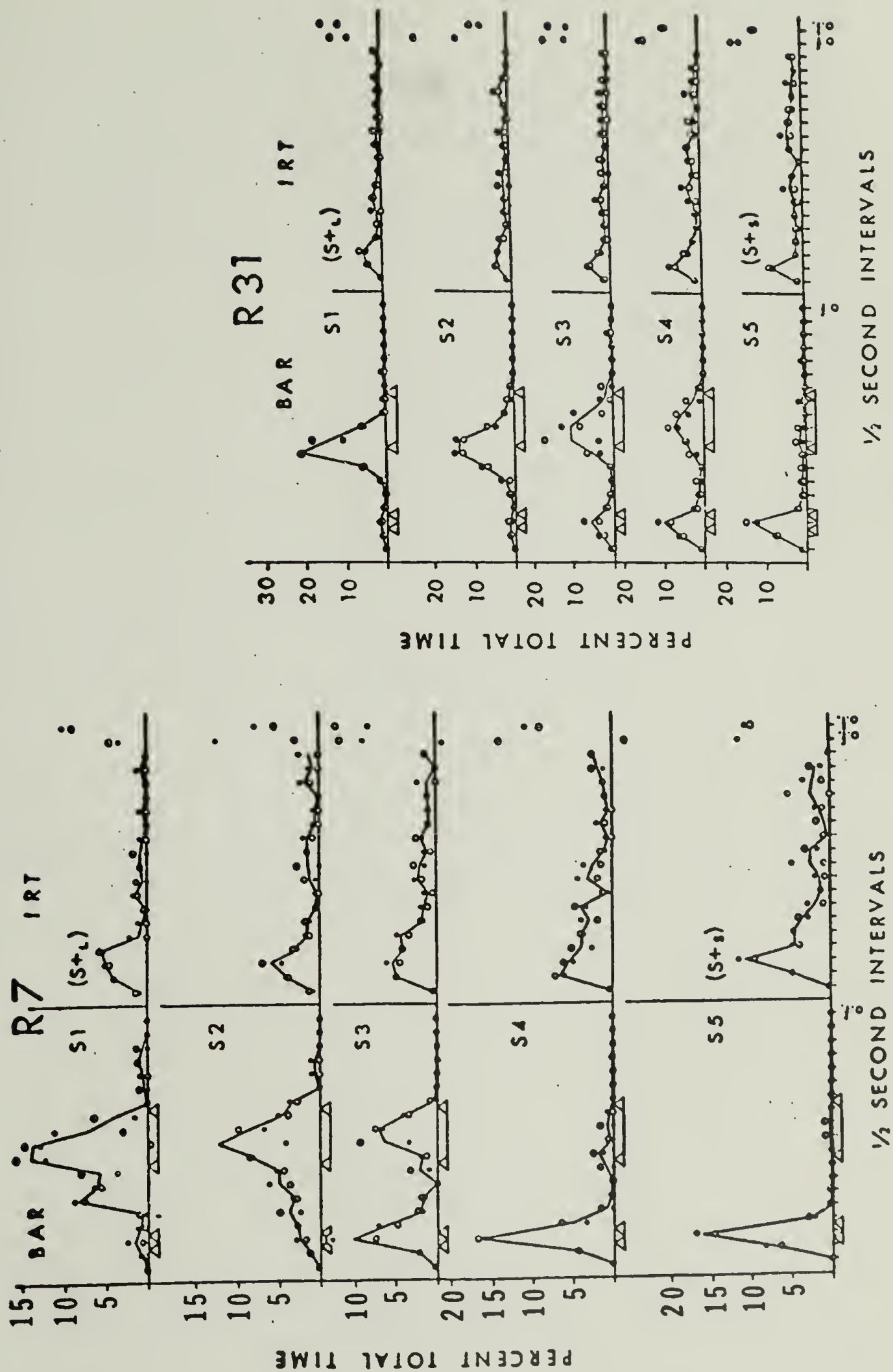


Figure 7. Relative time allocation distributions for Condition III. Complete.

explanation of symbols is included in the text.

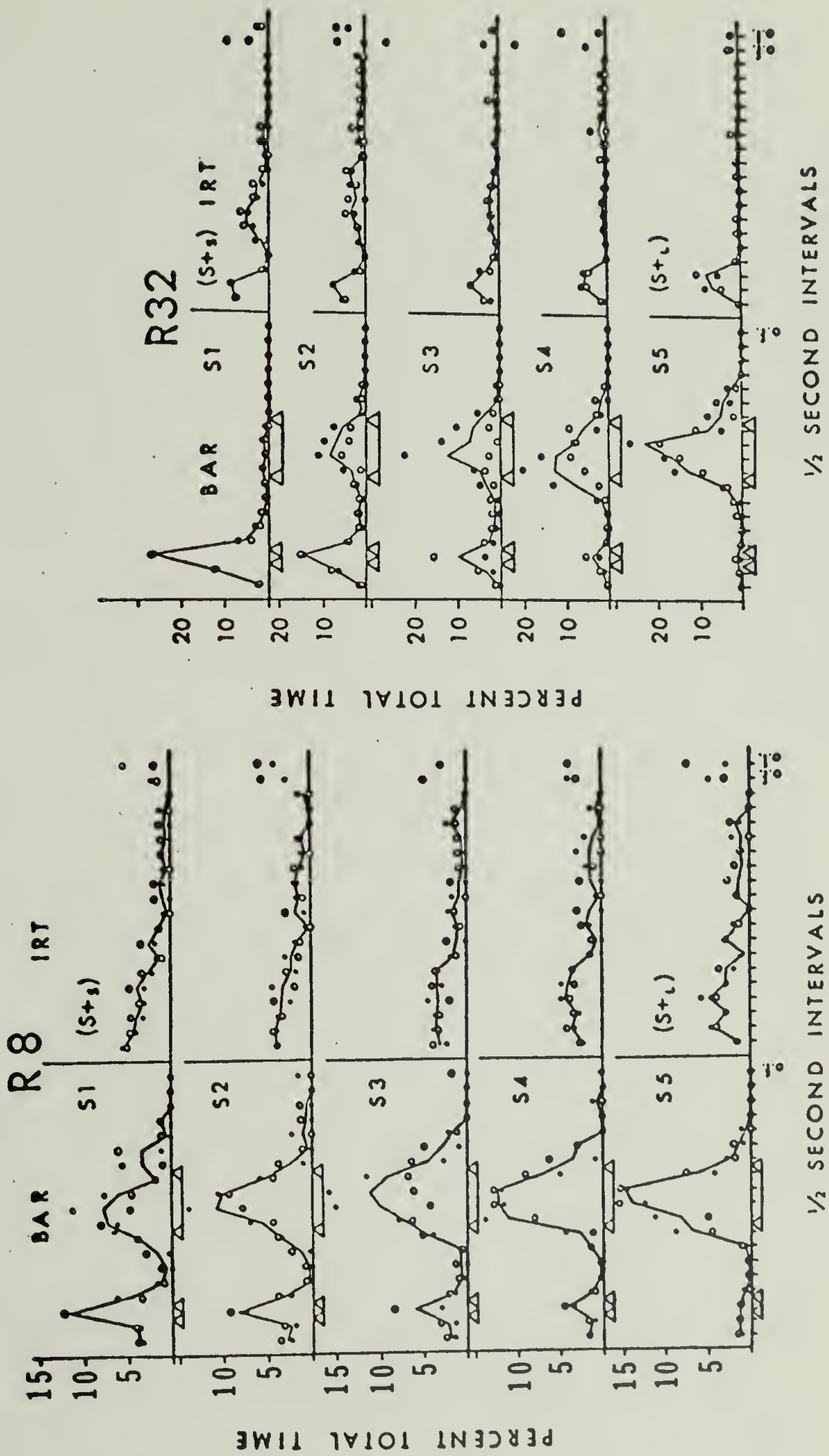


Figure 8. Relative time allocation distributions for Condition III. Complete explanation of symbols is included in the text.

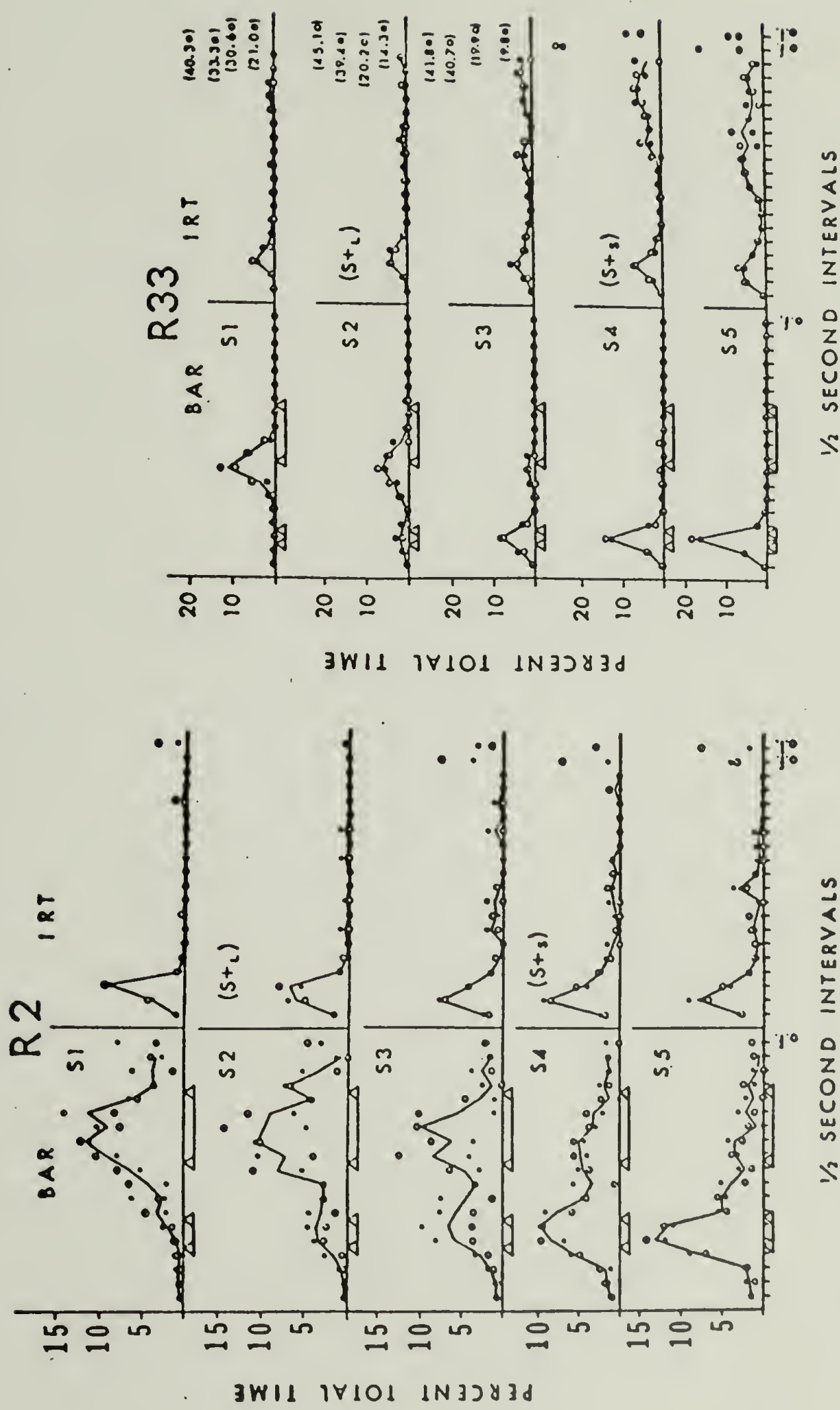


Figure 9. Relative time allocation distributions for Condition III. Complete explanation of symbols is included in the text.



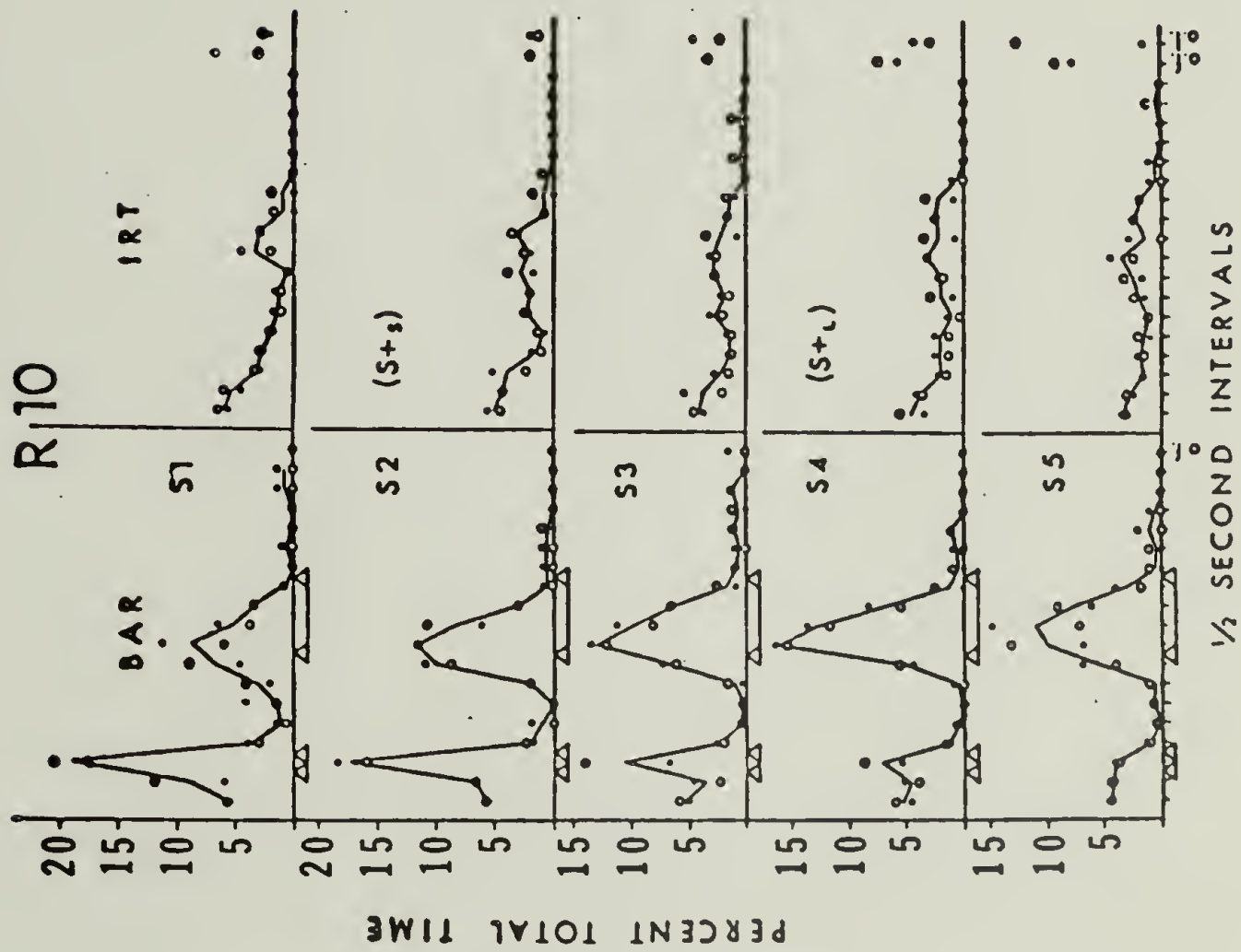


Figure 10. Relative time allocation distributions for Condition III. Complete explanation of symbols is included in the text.





