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Titration of Intertrial Interval in the Matching-to-Sample Paradigm

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TITRATION OF INTERTRIAL INTERVAL

IN THE MATCHING-TO-SAMPLE PARADIGM

(TITLE)

BY

Gregory T. Hochstetter

THESIS

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TITRATION OF INTERTRIAL INTERVAL IN THE MATCHING-TO-SAMPLE PARADIGM

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Investigators have used many different values for the ITI in investigating the variables in matching-to-sample. Holt and Shafer (1973), showed that the ITI itself influences matching performance. In the present experiment the titration method was employed to determine the optimal or "preferred" ITI for pigeons. Three Ss began each session with an ITI of 0 sec. Three other Ss began each session with an ITI of 60 sec. During the session two consecutive correct responses reduced the ITI by 2 secs while a single error would increase the ITI by 2 secs. The results showed that the 60 sec ITI group worked down to the 0 sec ITI. However, performance at the 0 sec ITI then decreased. The 0 sec ITI group maintained the 0 sec ITI and performance improved in the second half of a session. The results were interpretated as suggesting that the titration method maintains observing behavior which accounts for high accuracy in matching-to-sample. Amsel's frustration hypothesis is also considered to account for the distribution of errors within a session.

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TABLE OF CONTENTS

LIST OF FIGURES

TITRATION OF INTERTRIAL INTERVAL IN THE MATCHING-TO-SAMPLE PARADIGM

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In matching-to-sample behavior, the subject is first presented with a standard stimulus. After responding to the standard stimulus a set of comparison stimuli are presented, from which the subject is required to select the stimulus that corresponds to the sample.

Weinstein (1941) was probably the first to use matching-to-sample under systematic experimental control. Two rhesus monkeys and two children were the subjects. Weinstein used two problems, a sample with two comparison stimuli and a sample with four comparison stimuli. Initially a simultaneous matching procedure was used with the sample and comparison stimuli present during the trial. Later, Weinstein employed a delayed matching procedure in which the sample was removed before the comparison stimuli were presented. Weinstein also tested for generalization of matching-from-sample behavior towards stimulus objects experienced for the first time. The performance of the monkeys and children were comparable. However, the children had faster acquisition and were able to generalize more broadly. Weinstein suggested that the children's matching performance was under the control of the concept of sameness while the monkeys engaged in discrimination behavior.

Nissen, Blum, and Blum (1948) considered three general ways in which the similarity or difference between sample and choice object may be effective in the matching problem. The first way is a conditioning situation. Reinforcing the sample reinforces response to the visual characteristics of the sample. Those characteristics are repeated in the matching choice-

object and are absent in the other choice-object. A correct response indicates that conditioning has occurred in that one trial.

The second interpretation is the "perception mechanism". This interpretation assumes that an immediate preception of likeness and/or of difference is possible and is the basis of solution. The third interpretation assumes that the subject can respond differentially to similarity and difference regardless of the particular visual characteristics of the stimuli. This interpretation is termed the "abstract generalization mechanism". It assumes that the basic association between a given stimulus and approach to that stimulus is learned in a single trial, early in training. The basic association is then effective in all subsequent trials.

Nissen, Blum, and Blum's data gave no clear indication as to which mechanism was operative. The authors suggested that possibly all three mechanisms were effective, separately or in combination.

Using pigeons as subjects, Skinner (1950) described matching-to-sample as reinforcing the discriminative responses of "striking-red-after-being-stimulated-by-red and striking-green-after-being-stimulated-by-green" while extinguishing the other two possibilities. The pigeon learns to respond to the sample stimulus. This response is reinforced by the illumination of the comparison stimuli. The response to the comparison stimulus follows immediately after the visual stimulation from the center key. Skinner considers the response to the sample as a requisite condition for the discrimination.

Ginsburg (1950) had pigeons learn three types of matching-to-sample problems. The first was matching, where the sample stimulus was identical to the correct choice stimulus. The second was nonmatching, where the sample was identical to the incorrect choice. The third was amatching, where

the sample stimulus and choice stimuli were different colors. Ginsburg
reported that nonmatching was learned significantly faster than both match-
ing and amatching. Matching and amatching did not differ significantly.
However, Skinner (1950) had found no difference in establishing matching
and nonmatching. Cumming and Berryman (Mostofsky, 1965) reported results
opposite that of Ginsburg. They found very slow acquisition of oddity and
rapid acquisition of matching. The two studies differ in the criterion of
learning used and possibly in the number of stimuli used.

Ginsburg further stated that since amatching was learned as readily as
matching it argued against a solution based on a purely perceptual basis.
He accounted for all three matching problems with the transverse patterning
mechanism of Spence. According to this idea the S reacts with either ap-
proach or avoidance to the combination of the trace of the sample and the
perception of the choice stimulus.

Since these investigations many variables in the matching-to-sample
paradigm have been investigated. The variables are: reinforcement, delay-
ed matching and short-term memory, time-out(TO), drug effects, observing
responses, generalization and transfer, stimulus change, conditioned rein-
forcers, extinction, and intertrial interval(TTI).

Ferster (1960) did a comprehensive investigation of intermittent rein-
forcement in matching-to-sample. He used a 1 sec time-out(TO), a 4 sec
reinforcement cycle and no intertrial interval(ITI). He reported that fix-
ed-ratio, fixed-interval, and variable-interval reinforcement produced the
typical performances normally obtained with these schedules. In examining
ratio reinforcement of matching behavior, Nevin, Cumming, and Berryman (1963)
started with a 3 sec TO and a 25 sec ITI. During the experiment the TO was
removed and the ITI was reduced to 1 sec. They reported a high incidence

of errors immediately after reinforcement on fixed-ratio schedules. Accuracy then increased as the ratio progressed. By contrast, accuracy was high throughout the ratio on a variable ratio schedule. Mintz, Mourer, and Weinberg, (1966) used an ITI of 350 msec after a correct match and a delay of 6 sec after an incorrect match. After the 2.6 sec reinforcement cycle the next trial began. A vertical array of lights was illuminated in relation to the successive steps of a FR 9 schedule of reinforcement. As a randomly introduced probe, the stimulus situation appropriate to having seven to the FR 9 steps already completed was occasionally introduced at the beginning of an FR cycle. Reinforcement followed the illumination of the two remaining lights by two correct matches. The number of errors in this probe condition were lower than the errors characteristic of the first two steps of the basic FR 9.

Boren and Gollub (1972) reinforced correct matches under fixed-interval, chained fixed-interval, and fixed-interval schedules that had exteroceptive stimulus changes correlated with time since the last reinforcer. Reinforcement consisted of 6 sec access to grain or a .5 sec magazine light. Incorrect responses were followed by a 5 sec TO and a correction procedure was used. For all four pigeons, accuracy decreased from the beginning of the interval to some point in the middle, and then became increasingly more accurate until the end of the interval.

The effects of the schedule of reinforcement in matching-to-sample are consistent with the effects found on other behaviors. Birds on FR schedules make more errors immediately after reinforcement. Performance then improves as the ratio continues. The steps in VR schedules have no effect on matching accuracy. Performance on FI schedules is similar to FR schedules.

Blough (1950) investigated delayed matching-to-sample. He found that matching behavior depended upon the length of the delay and upon the S's behavior during the delay interval. Pigeons matched a flickering or steady sample with a 5 sec ITI. Blough observed stereotyped superstitious behavior during the delay interval. Acquisition of delayed matching was analyzed by Berryman, Cumming, and Nevin (1963) using a 3 sec interval for TO and reinforcement and a 25 sec ITI. By the end of the experiment the order of performance level for all three pigeons was: simultaneous matching, zero delay, 1 sec, 2 sec, 4 sec, 10 sec, and 24 sec delay. Cumming, Berryman, and Cohen (1965) used six pigeons to study acquisition functions for zero-delay matching and simultaneous matching. They used a 3 sec interval for TO and reinforcement and a 25 sec ITI. They showed that zero-delay matching is a more difficult task for pigeons than simultaneous matching.

In studying the effect of satiation on delayed matching performance, Cumming, Berryman, and Nevin (1965) used a 3 sec interval for TO and reinforcement and a 25 sec ITI. Their results suggested that long delay matching was better under conditions of reduced drive. Smith (1967) compared a delayed discrimination and delayed matching problem in pigeons. He reported that performance was consistently poorer on the delayed matching problem. He also showed that accuracy of responding during delay procedures was a function of the length of delay interval. Smith used a 5 sec TO for incorrect matches but the next trial followed immediately after a correct match. Smith used a vertical and horizontal bar as stimuli and reported the same basic results as Blough (1950) who used a flickering or steady sample.

Roberts (1972) used the matching-to-sample procedure in establishing the effects of repetition and spacing on short-term memory in the pigeon.

He employed a 3 sec reinforcement interval, a 20 sec ITI and a nonmatching response terminated the trial. He reported that retention increased as a direct function of the frequency with which a sample stimulus was presented. Temporal spacing of repeated presentations of the sample lowered retention as compared to nonspaced presentations. The amount of spacing and repetition increased as the number of repetitions increased. Roberts further analyzed the data to determine the effect of color discriminability on delayed matching. He found that those colors that are close in their wavelengths yielded the highest levels of performance. Conditions which promoted a high level of retention led to the greatest differences in retention between color combinations of high and low discriminability. Zentall (1973) further investigated memory in the pigeon using matching-to-sample. He trained six pigeons on a wavelength matching task with a 5 sec delay between the offset of the sample and onset of the comparison stimuli. Zentall also used a 5 sec ITI but no TO or correction procedure. When he interpolated a novel wavelength or novel shape between the sample and comparison stimuli, he found that both disrupted matching performance. The novel wavelength was more disruptive than the novel shape. Zentall suggested that the interpolated stimulus presentation disrupted the memory trace for the sample stimulus.

When using pigeons in the delayed matching task accuracy decreases with increased delays. Matching at long delays is better under conditions of reduced drive. Accuracy is also improved if short delays are used with repetition of the sample stimulus. Matching accuracy is also reduced if a stimulus is presented during the delay interval.

Besides pigeons, monkeys have also been used extensively in delayed matching-to-sample tasks. Scheckel (1965) used a self-adjustment procedure

in which the range of delay intervals which could be presented to an S was 1-105 sec. However, the particular delays presented were a function of S's responses. During a given session the average limit of delay was 45 sec, with a range of 30-70 sec, for four rhesus monkeys.

The effects of retroactive and proactive interfering stimuli on performance of monkeys in a delayed matching task was demonstrated by Jarvik, Goldfarb, and Carley (1969). The results suggested that the apparent decay in memory that occurs over time in a delayed matching test may be due to the intrusion of interfering stimuli. Etkin and D'Amato (1969) varied sample set size, the number of stimuli used, with delay interval. Although accuracy decreased as the delay increased, the sample set size had no affect on performance. No evidence for short-term memory interference effects were found. A modified decay interpretation of the data was suggested.

Short-term memory in the stumptail macaque was investigated by Jarrard and Moise (1970). The importance of incompatiable responses during the delay intervals was evaluated under two conditions. The first condition was free movement. Physical restraint in a primate chair was the second condition. Matching accuracy at each delay interval indicated no significant differences between the two conditions.

Moise (1970) interpolated motor activity during delays in delayed matching-to-sample. He found significant performance deficits due to amount of interpolated activity but no effect as to the point of interpolation during the delay. D'Amato and O'Neill (1971) demonstrated that delayed matching was superior when the delay interval was spent in darkness rather than moderate illumination. In contrast to previous studies all subjects showed above chance matching at a 120 sec delay interval. Etkin (1972) also showed that capuchin monkeys performed significantly better after a

dark delay than after a lighted one. The relationship held for both spatial and nonspatial problems.

D'Amato and Worsham (1972) trained two capuchin monkeys in a delayed matching task with very brief, .075 to .45 sec sample durations. The performance of both Ss indicated that their capacity to match successfully at long retention intervals is not dependent on repeated viewing of the sample stimulus. The results could not be accounted for by enhanced attending to the sample stimulus but suggests that the animals have the capacity of "learning how to remember".

In investigating punishment of S^Δ responding in matching-to-sample with pigeons by time-out(TO), Ferster and Appel (1961) reported that the effect of TO depended upon the baseline schedule of positive reinforcement. Using a 4 sec reinforcement interval and no ITI they varied TO for .5 to 600 secs. Accuracy of matching was highest with TO durations of 10, 30, or 60 secs, but decreased at durations of either 1 sec or 120 sec. Using intermittent punishment, Zimmerman and Ferster (1963), reported that with intermediate TO durations accuracy increased as the frequency of TO increased. However, with an extremely short and an extremely long TO duration, accuracy was poor over the entire range of frequencies. Zimmerman and Baydan (1963) extended punishment of mismatching by TO to humans. The results from both humans and pigeons indicate that if punishment is to be used to lower the rate of, or eliminate particular responses, it should be applied continuously after the emission of those responses. Also, an optimal intensity of punishment should be chosen since punishment of too great an intensity will result in the suppression of overall behavior.

Berryman, Jarvik, and Nevin (1962) investigated the effects of pharmacological variables on matching-to-sample. They used pigeons on a 25 sec ITI with a 3 sec interval for reinforcement and TO. They reported

that pentobarbital produced considerable initial decrements in accuracy,
but relatively fast recovery to normal levels. Lysergic acid diethylanide
produced an initial period of inactivity which was followed by essentially
normal performance. Chlorpromazine effects showed such considerable var-
iability that the authors did not comment on its effects. The effects of
sodium pentobarbital on three types of matching-to-sample paradigms was
investigated by Berryman, Cumming, Nevin, and Jarvik (1964). They employ-
ed pigeons on a 3 sec interval for reinforcement and TO and a 25 sec ITI.
They showed decrements in accuracy with increasing dose levels on zero
delay matching-to-sample, simultaneous oddity, and variable delay matching-
to-sample. The oddity performance was less sensitive to the drug effects
than zero delay matching. In variable delay matching there was no clear
evidence for any relationship between the magnitude of the drug effect and
the length of the delay interval. Nevin and Leibold (1966) trained one
pigeon on matching and oddity with red and green key colors. They used a
10 sec ITI and a 3 sec interval for TO and reinforcement. Illumination
of a yellow light above the center key served as a cue for matching or
oddity. Injections of sodium pentobarbital and transfer to novel key col-
ors affected matching and oddity differently. This effect suggested that
stimulus control of two different kinds of performance had been established.
Accuracy tended to decrease with increasing doses of pentobarbital, but the
decrease in accuracy of matching was greater than for oddity.

Using rhesus monkeys, Melle (1971) studied alcohol effects on delayed
matching-to-sample. A titration procedure was employed in which delay dur-
ations changed as a function of performance accuracy. Accurate matching
was observed at delays beyond 3 min. Alcohol was then administered in as-
cending doses and alternated with control sessions. Although performance

accuracy decreased with increasing alcohol doses, short-term memory did not appear specifically impaired. Errors did not increase as a function of increasing delay intervals, rather, errors clustered between 1 and 30 sec delay. Also, the monkeys were able to perform accurately at longer delays despite high blood alcohol levels.

Combining drug effects with lesions, Glick and Jarvik (1970), administered D-amphetamine and scopolamine to four monkeys with dorsolateral frontal lesions and four unoperated monkeys performing a delayed matching task. They found that both D-amphetamine and scopolamine impaired the delayed and nondelayed matching of the unoperated control monkeys. Only scopolamine and not amphetamine impaired the matching performance of the frontal monkeys.

Ferster, Levitt, Zimmerman, and Brady (1961) used matching-to-sample as a baseline from which to evaluate the effects of hypnotic suggestion. Since frequency of emission of the behavior and the number of errors varied differentially as a result of different suggestions, the authors considered matching-to-sample was providing a baseline that was more sensitive to manipulation than the simple response often recorded in operant research.

Eckerman, Lansen, and Cumming (1968) demonstrated that matching-to-sample performance was improved when an explicit observing response was required to the sample stimulus. They used a 3 sec interval for reinforcement and TO and a 25 sec ITI. They also observed the development of an overt observing response by two of the three pigeons even when no observing response was required.

Cumming and Berryman (1961) reported the results of a test of the formation of a matching concept in pigeons. After training to match red, green, and blue stimuli with a 3 sec interval for reinforcement and TO and

a 25 sec ITI, a yellow light was substituted for the blue. The results showed no matching concept in the pigeons since matching accuracy was at chance levels under the yellow stimulus. Also, there was no evidence of a tendency of the Ss to respond exclusively to those stimuli to which they had been previously reinforced, or to avoid the novel yellow stimulus. Instead, the pigeons adopted a position preference when the standard stimulus was yellow. Using an adjustable comparison, Cohen (1969) investigated generalization during acquisition, extinction, and transfer of matching. Compared with the acquisition of simultaneous matching in the three key situation (Cumming and Berryman, 1961), the two key adjustable comparison procedure produced a more gradual increase in overall accuracy and the final levels of accuracy reached were considerably lower. Cohen used a 15 sec ITI and a 3 sec interval of reinforcement and TO. The generalization gradients showed that all pigeons reached a high level of accuracy in the presence of at least one standard and some pigeons did so in the presence of as many as many as four of the six standards. Extinction had no systematic effect upon overall accuracy or the individual generalization gradients.

Kamil and Sacks (1972) trained pigeons on a matching-to-sample procedure with only three of the four possible stimulus configurations present. They used a 3 sec interval for reinforcement, a 10 sec TO and no ITI. When the birds were exposed to all four configurations as a transfer test a high degree of negative transfer was seen. During the transfer test, responding after one sample was apparently based on position, while responding after the other sample was based on color. These results were discussed according to the coding hypothesis. The hypothesis states the choice response on individual trials is under the control of specific mediating stimuli associated with each sample. That during matching ac-

quisition with pigeons, each mediating response becomes established as a discriminative stimulus, exerting control over choice responses made in its presence. These responses are independent of all other mediating stimuli associated with other sample stimuli.

Evidence has been presented that shows that monkeys differ from pigeons when tested for transfer of matching. Wright, French, and Riley (1968) trained monkeys to respond on the basis of stimulus identity. They then showed immediate efficient generalization from identity to similarity responding. Jackson and Pegram (1970) required monkeys to transfer from color matching to form matching. Although only 2 of the 10 subjects performed above chance during the first day of transfer, most of the remaining animals performed above chance during the second day. The monkeys did not revert to a position preference during transfer. Upon retesting color matching after 14 days of form matching, the monkeys showed very high savings.

The effects of stimulus change on matching-to-sample performance was investigated by Stubbs and Thomas (1966). Pigeons were given 4 sec grain access on a FR 25 schedule with a .5 sec magazine light presentation after each correct match. A 30 sec TO interval followed a mismatch and the ITI was not reported. Stimulus change was effected by illuminating the red house lights which were unilluminated during the training sessions. Each S received several stimulus change probes during three different sessions. For both Ss on all three probe sessions matching performance was disrupted by the conditions of stimulus change. Long pauses and low response rates occurred and accuracy was impaired. With the reinstatement of training conditions, the prestimulus change performance immediately returned.

Clark and Sherman (1970) trained two pigeons on a two key sequential match-to-sample task. Grain reinforcement was available on a FI 8 min schedule and orange illumination of the response keys preceded grain delivery by .5 sec. Since presentation of the sample was under the control of the S the ITI was varied by the S's behavior. The .5 sec orange keylight flash was sometimes presented contingent upon mismatch responses on a VI 1 min schedule. Compared to baseline the rate of mismatch responses increased and the accuracy of matching performance decreased. The effectiveness of the orange flash to reinforce mismatch responses was markedly reduced when it no longer preceded grain delivery. The results were consistent with those of conditioned reinforcers employing a simple response and extended the findings to the more complex behavior of matching-to-sample.

Two pigeons were trained to high levels of matching accuracy by Cumming, Berryman, Cohen, and Lansen (1967). They then put the birds on extinction to determine whether the response alone loses strength or if both the response and the stimulus control over the response are weakened. They reported that although extinction produced large decrements in the strength of the key peck response it had little or no effect upon the accuracy of matching. One of the birds was on a 24 sec ITI during extinction and the other bird underwent extinction on a 4 sec ITI and a later extinction session at 25 sec ITI. However, the authors did not comment on the relation of ITI length to accuracy.

The function of the intertrial interval in matching-to-sample was investigated by Holt and Shafer (1973). They used a 3 sec interval for reinforcement and a 2 sec TO. Twelve pigeons were trained with either a 0, 5, 15, 25, or 60 sec ITI. Eight of the 12 pigeons were given an ITI change of either: 0 to 60, 0 to 5, 5 to 0, 60 to 0, 15 to 25, 5 to 15, 60 to 5, 5 to 1, 1 to 5, 1 to 25, and 25 to 1 sec. The zero sec ITI subjects failed to

match beyond chance levels, while other ITI values resulted in matching acquisition. Changes from 0 sec to other ITI values increased accuracy and changes to 0 sec decreased matching performance. Changes to ITI values other than 0 sec resulted in little change in matching accuracy once stable performance had been attained. They also reported that only the 25 and 60 sec ITIs resulted in consistently high terminal performance and rapid acquisition. However, once stable correct matching had been acquired, an ITI as low as 1 sec was sufficient to maintain accurate performance.

Cotton and Lewis (1957) studied the effect of the intertrial interval on the acquisition and extinction of a running response. They reported no indication that running time during acquisition depended on the ITI. There were interaction effects between acquisition and extinction interval during extinction. There was no significant effects of ITI during a spontaneous recovery trail. Jernstedt (1971) investigated the joint effects of pattern of reinforcement, ITI, and amount of reinforcement in the running speed of rats. He reported that groups running at a 20 min ITI were faster than groups running at a 20 sec ITI early in acquisition. However, there was no difference in speeds after the first few days. The massed trials produced greater resistance to extinction than spaced trials, but only later in extinction. A test of the relationship between ITI and the development of differential response to alternating partial-reinforcement schedules was performed by Katz, Woods, and Carrithers (1966). Three groups of rats ran a runway for 30 days with ITIs of $\frac{1}{4}$, 2 or 20 min. Starting-, running-. and goal-time measures indicated the marked superiority of the $\frac{1}{4}$ min group in developing the differential response. Katz (1959) hypothesized that the stimulus aftereffects of reinforcement and nonreinforcement served as a differential cue function in single-alternation intermittent rein-

forcement schedules. He tested the hypothesis by comparing massed practice (35 sec ITI) with spaced practice (30 min ITI). Katz predicted that only the massed subjects would form the discrimination. However, the results indicated that although massing of training facilitates the formation of the discrimination, spacing does not eliminate the possibility of discrimination formation.

Jerome, Moody, Conner, and Gremler (1958) investigated the effect of the ITI on the number of responses made in work periods of various lengths. In general the results indicated that the optimal ITI was directly related to the duration of work. Consistent with the assumption that reactive inhibition dissipates during the ITI, response latencies were found to decrease as the ITI increased.

Four ITI intervals were used by Spence and Norris (1950) in determining the function of the ITI in eyelid conditioning. They found that the amount of conditioning increased with increase in the magnitude of the ITI. Prokasy, Grant, and Myers (1958) investigated the effects of UCS intensity and ITI upon acquisition and extinction of conditioned eyelid responses. Generally, as UCS intensity increased and as ITI lengthened, the frequency of CRs also increased. The longest ITI was associated with superior conditioning and greater resistance to extinction.

The effects of the ITI and first trial reward was studied by Deets, Harlow, and Bloomquist (1970) for acquisition of an object-discrimination learning set in monkeys. They reported that ITI duration had no effect upon performance during the initial stages of object-discrimination learning set training. Performance differences associated with ITI differences became apparent during the later stages of training when trial two performance decreased with increased ITI duration.

D'Amico and Viney (1972) studied the effects of response force and ITI on extinction in children. They used two force requirements and two ITIs, 5 and 20 sec. They reported no significant effects associated with ITI in acquisition or extinction and none of the possible interactions were significant.

The role of the ITI in matching-to-sample seems most related to the function of ITI in classical conditioning as seen in the eyelid conditioning experiments (Spence & Norris, 1950; Prokasy, Grant & Myers, 1958). The effect of ITI in matching-to-sample and object-discrimination learning set do not seem related. The function of the ITI in runways seems opposite that of matching.

To establish stable stimulus parameters or preferred stimulus values a self-adjustment procedure based on the Békésy audiometer has been employed (Oldfield, 1949; Blough, 1955; Lindsley, 1957; Blough, 1958). In the Békésy method the subject's responses govern the stimulus intensity. However, the stimulus intensity also controls the subject's responses. In the original Békésy procedure (Békésy, 1947) the intensity of a tone increases continuously as long as a signal button is pressed and decreases automatically when the button is released. The subject controlling the button thus is able to let the intensity of the tone fluctuate just above and below threshold.

The Békésy procedure is similar to the "Up and down" method which was developed and used in testing the sensitivity of explosives to shock (Dixon & Massey, 1957). In this technique some initial height is chosen with a succession of heights above it and a succession below. If the first specimen explodes at the initial level the second specimen will be tested one step below the initial level, otherwise the second specimen will be

tested one step above the initial level. In general, any specimen will be tested at the level immediately below or immediately above the level of the previous test. The primary advantage of this method is that it automatically concentrates testing near the mean and increases the accuracy with which the mean can be estimated.

In psychophysics this method is called the staircase method (Corn-sweet, 1962). Usually only two response categories are used, such as, "Yes" or "No". The technique begins as in the usual method of limits but changes direction each time the observer changes his response. For example, during an ascending series in a Reiz Limen experiment, when the observer changes from saying "No" to "Yes", the experimenter will decrease the stimulus value for the next stimulus. The experimenter continues in a descending series until the observer says "No", whereupon he will start ascending again.

Although the staircase method resembles Békésy's method, the methods differ in that the stimulus is varied continuously in the Békésy procedure while the stimulus steps in the staircase method are discrete. Since the stimulus is varied continuously in the Békésy method it is often referred to as "tracking". The tracking method has been adapted to animal psychophysics. Blough (1955, 1958) first trained pigeons to peck one key when a target was visible and another when it was too dim, and thereafter they tracked their own dark-adaptaion curves. The tracking method has been employed by other investigators to determine visual and auditory thresholds in other species, such as: the starling (Adler & Dalland, 1959), the rat (Gourevitch, Hack, & Hawkins, 1960), the cat (Elliott, Frazier, & Riach, 1962), and the monkey (Symmes, 1962).

Lindsley (1957) used a method similar to tracking to study the depth of sleep. Subjects wore a helmet which delivered an aversive tone. Slow operation of a switch on the S's hand kept the tone at a moderate intensity. Rapid operation of the switch reduced the tone to zero intensity and the S could avoid the tone by continued responding. Lindsley considered the method sensitive and widely applicable to the study of sleep behavior.

A technique similar to Lindsley's was used by Weiss and Laties (1958) to study fractional escape and avoidance. They used a constant current shock stimulator whose output was increased or decreased in discrete steps. Every 20 secs a timer increased the shock level one increment. However, each time a rat pressed a lever in the chamber, the stimulator output was reduced one step. Weiss and Laties labeled this program a "titration schedule". From the titration method they had a continuous record of the rat's tolerance to electric shock. Rachlin (1972) let rats and pigeons adjust the intensity of electric shock by the rate of response. Trial titration schedules were used to determine aversive thresholds in cats by Fields and Glusman (1967).

Evans (1963) used a titration schedule to measure performance decrement as a function of continuing heavy muscular exertion. A treadmill was constantly accelerated unless the subject depressed a switch which would decelerate the treadmill at a constant rate. Evans reported that the method was sensitive to ongoing performance changes and yielded fairly consistent results from session to session.

The titration method was used in a spatial dimension in a discrimination problem in monkeys bv Schrier, Stellnitz, and Green (1963). Separation of discriminanda from manipulanda was increased from zero inches as rapidly as each S's progress permitted. After two correct responses at a

given separation, the separation was increased by a small amount. After each error the separation was decreased. The authors reported that training time was considerably less than times previously reported.

Wunderlich (1971) used titration and double responding as techniques to promote learning of a color discrimination problem in retardates. The results indicated that the techniques of double responding and titration facilitated learning by retardates under conditions of a spatial separation between stimulus and response. Titration of delayed matching-to-sample in children was studied by Ferrare and Francis (1971). Two consecutive correct matches increased the delay by 2 sec; an incorrect match decreased the delay by 2 sec. The average delay achieved was directly related to age with only the older Ss performing correctly at delays greater than 40 sec.

Cumming and Berryman (Mostofsky, 1965) reported titrating delayed matching-to-sample in pigeons. Two successive correct matches resulted in an increment to the delay interval on the next trial of approximately $\frac{1}{2}$ sec. Each error shortened the delay period on the succeeding trial also by approximately $\frac{1}{2}$ sec. While the bird was doing well the delay progressively lengthened until he reached an interval that would permit him to be correct on two-thirds of the trials. The delay interval tends to remain at such a level since he is at that point decreasing the delay as frequently as he is increasing it. They showed a $\underline{S}$ that began an experimental session at a delay of $\frac{1}{2}$ sec and progressively lengthened the interval until the delay remained at around 10 sec by the end of the session. That delay interval was consistent with the animal's performance under a variable-delay procedure. The results suggested that delayed matching performance did not require the presence of simultaneous matching trials, and

that it was unaffected by the absence of delays other than those at which the bird can successfully work.

The review of the matching-to-sample literature has shown a number of variables that have been investigated. The most pertinent was the intertrial interval. Investigators have used many different ITIs. The most common ITI is the 25 sec ITI, with other authors using a 5 sec, 10 sec, 15 sec, or no ITI. The ITI has also been confounded by varied TOs, intermittent reinforcement, and use of corrective procedures such that the actual intertrial interval varies among presentations.

It has been reported (Holt and Shafer, 1973) that due to procedural differences involving different ITIs, many studies are not directly comparable. In order to make inter-experimental comparisons it seems necessary to determine the function of the ITI in matching-to-sample behavior. The titration method is a very sensitive measure and also generates a continuous record of performance. By using the titration method in delayed matching-to-sample, Scheckel (1965) and Nelle (1971) showed that the range of successful delayed matching exceeded the delays reported in the literature for monkeys. Schrier, Stollnitz, and Green (1963) reported that titration reduced training time for monkeys. Wunderlich (1971) showed how titration facilated learning in retardates. Omming and Berryman (Mostofsky, 1965) reported that with the titration method, delayed matching performance for the pigeon is unaffected by the absence of delays that the bird is not exposed to.

Therefore, it is hypothesized that the titration method is able to generate an optimal intertrial interval at which pigeons accurately perform the matching-to-sample task.

Method

Subjects

Six white Carneaux pigeons, approximately 5 years old, were maintained within 15 grams of eighty percent ad lib weight. The Ss were divided into two groups of three pigeons each.

Apparatus

The pigeon test chamber was self constructed and contained in isolation. The response chamber itself was 45.72 cm long, 30.48 cm wide, and 43.18 cm high. On the far wall of the chamber pecking keys were mounted behind 3.175 cm diameter circles that were 5.08 cm apart from edge to edge. The distance from the chamber floor to the keys was 27.305 cm. The response keys were transilluminated by three visual IEE light projecting display cells. The feeding aperture to which the grain magazine delivered reinforcement was 13.335 cm above the chamber floor. Two six watt, 120 volt houselights were mounted above the response keys at the top of the chamber. All programed stimuli and response consequences were controlled by relay circuitry.

Procedure

Preliminary Training. All Ss were magazined trained to approach the feeding aperture at the sound of the grain magazine. The pecking response was differentiated to an FR 5 on the center key which was randomly illuminated with one of three hues: red, green, or amber. Response to the illuminated key was reinforced by a 3 sec grain magazine presentation. After the pecking response was established to the center key, pecks were successively approximated to randomly presented comparison keys. Preliminary training was terminated when the Ss pecked the illuminated keys with short latencies regardless of hue.

Matching procedure. At the start of a trial a hue was presented on the center key. A single peck to the center key produced a comparison hue on each of the two side keys. A peck to the key of the hue that corresponded to the sample or center key resulted in reinforcement. A correct match also terminated the sample and comparison stimuli. An incorrect match, a peck to the response key illuminated by a hue other than the hue of the sample key, resulted in a 3 sec time-out. During TO the sample and comparison stimuli were terminated and the houselight was turned off. After the TO, the incorrect match was followed by a correction procedure. During the correction procedure the same sample and comparison stimuli were presented until a correct match was emitted. Following the TO or reinforcement interval there was a 5 sec intertrial interval. During the ITI, all stimuli lights were dark, the houselight remained lit, and the response keys were ineffective. The Ss followed this procedure until they were matching at chance accuracy. Chance accuracy was considered as fifty percent correct matches on the first presentation of a trial.

Titration Procedure. After the Ss were matching at fifty percent accuracy, the value of the ITI was under subject control. Whenever an S made two consecutive correct responses the ITI was reduced one interval, which was 2 secs. However, a single incorrect response increased the ITI by one interval. One group of birds began with an ITI of zero secs. The other group of birds began with an ITI of 60 secs. The possible range of ITIs was 0 to 98 secs.

The sequence of presentation of the 12 stimulus conditions was arranged according to a randomized block design which was repeated 12 times in each session. Thus a session consisted of 144 correct responses.

All Ss underwent the experimental procedure until all of the birds had reached a criterion of 90% accuracy for three consecutive days.

Results

All Ss acquired a high level of matching accuracy with low variability. Figure 1 shows the matching accuracy of the Ss that began each session with a 0 sec ITI. Figure 2 shows the matching accuracy of the 60 sec ITI Ss. The 0 sec ITI group reached the criterion of three consecutive days of at least 90% accuracy before the 60 sec ITI group. In the 0 sec ITI group, S 83 reached criterion in 6 sessions, S 14 in 7 session, and S 55 in 21 sessions. For the 60 sec ITI group, S 31 and S 90 reached criterion in 12 sessions with S 53 reaching it after 22 sessions.

Figure 3 shows the modal ITI for each session for the 0 sec ITI group. Bird 14 maintained a modal ITI of 0 secs after the second session. S 83 maintained a modal ITI of 0 secs after the third session. However, S 55 did not achieve a constant modal ITI of 0 secs until after session eleven. Figure 4 shows the modal ITI for each session for the 60 sec ITI group. Bird 53 achieved a modal ITI of 0 secs on session 5 but did not hold the modal 0 sec ITI until after session 14. S 31 reached a modal ITI of 0 secs in four sessions and maintained it after session 9. S 90 reached a modal ITI of 0 secs and maintained it after the sixth session.

Figures 5 through 10 show continuous records of the ITI changes through a single session for each subject.

The relationship between the number of errors made in the first and second halves of each of the last eight sessions is shown in figure 11. There is a tendency for the Ss starting each session at the 0 sec ITI to make more errors in the first half than in the second half. The Ss starting each session at the 60 sec ITI made fewer errors in the first half than in the second half of a session. A median test of the number of errors, first and second half, for each group was significant. ($x^2 = 17.96$, p .001)
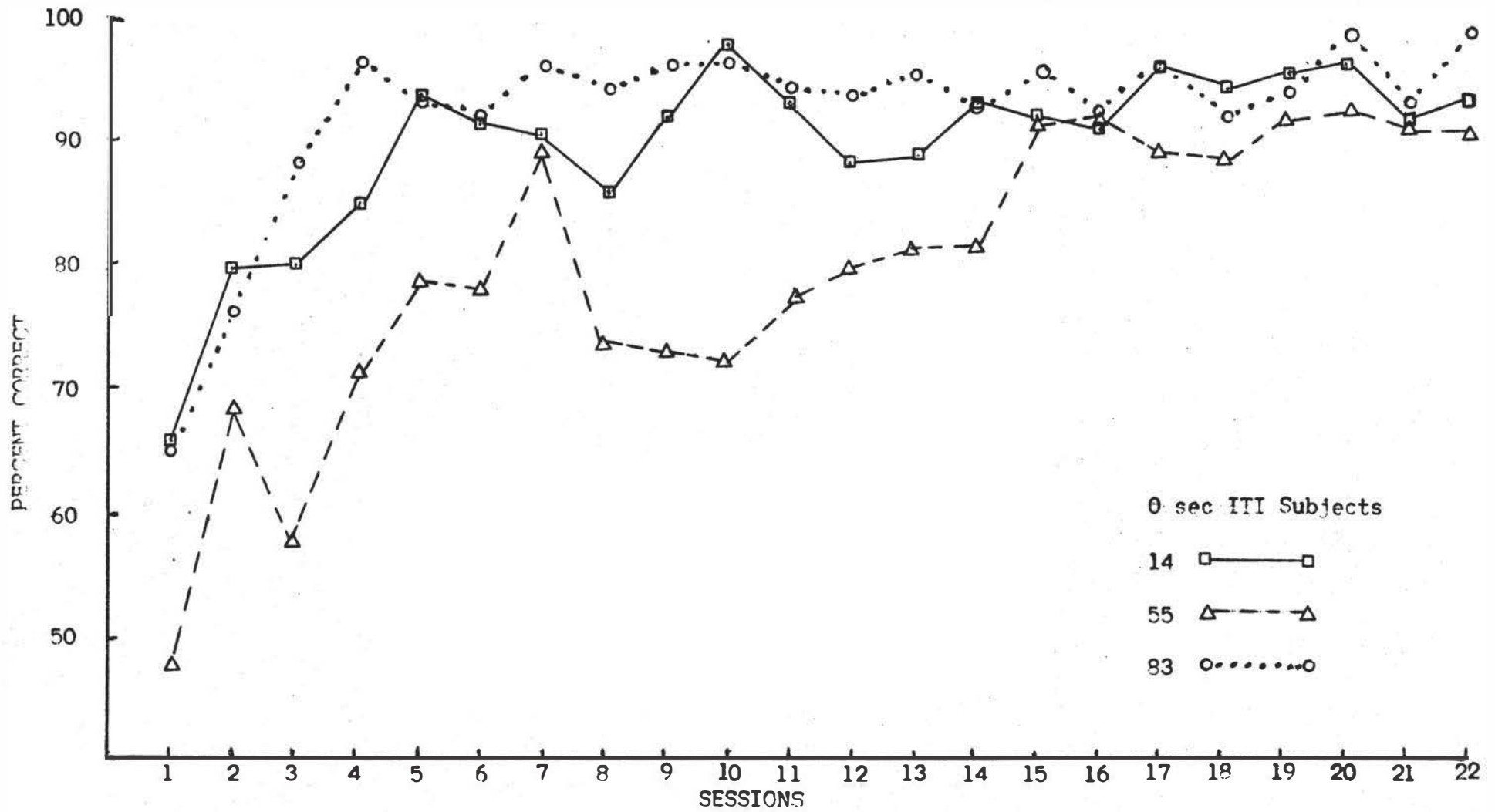
FIGURE 1. Percent correct matching for Ss 14, 55, & 83, the 0 sec ITI group.
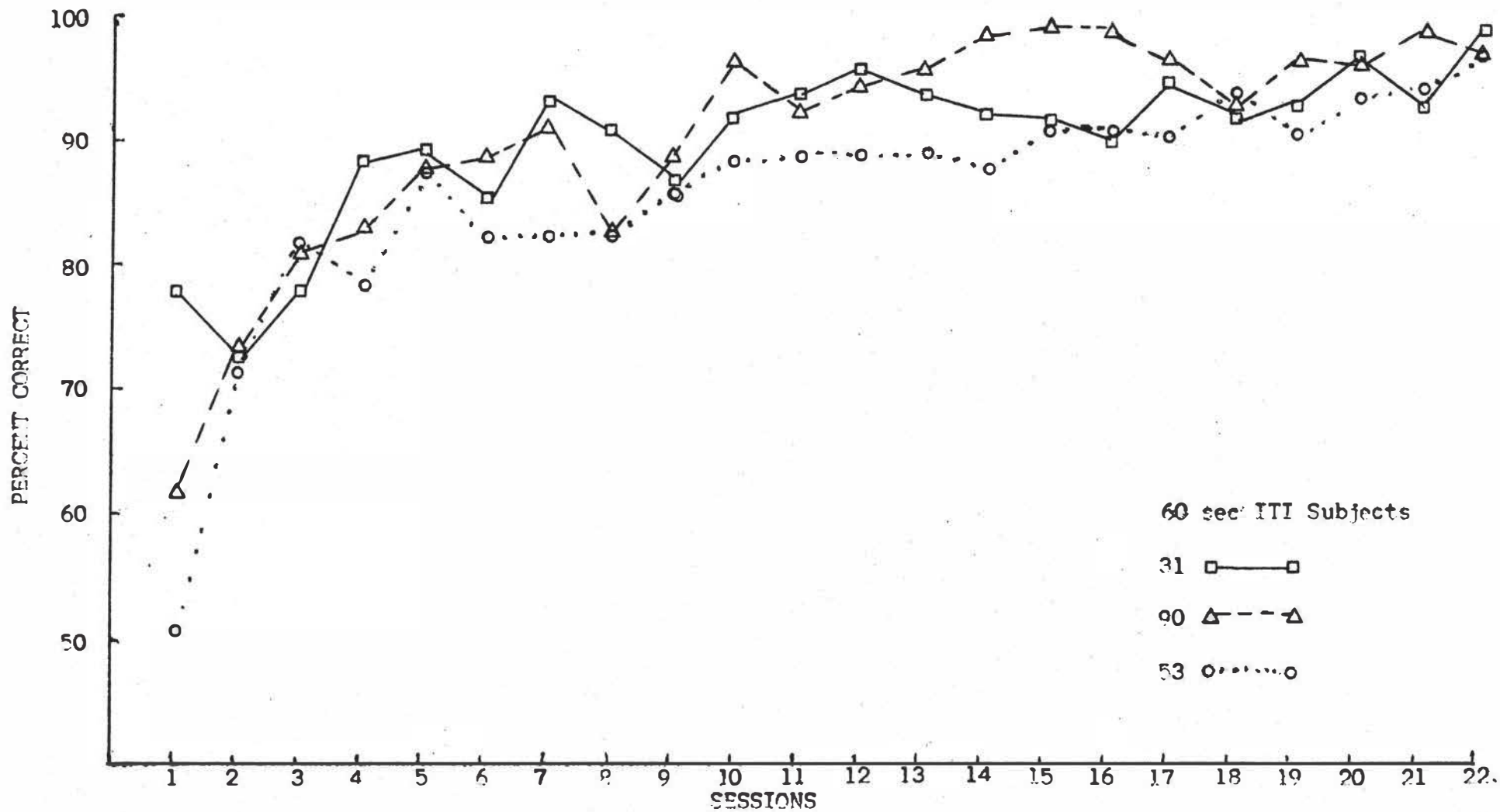
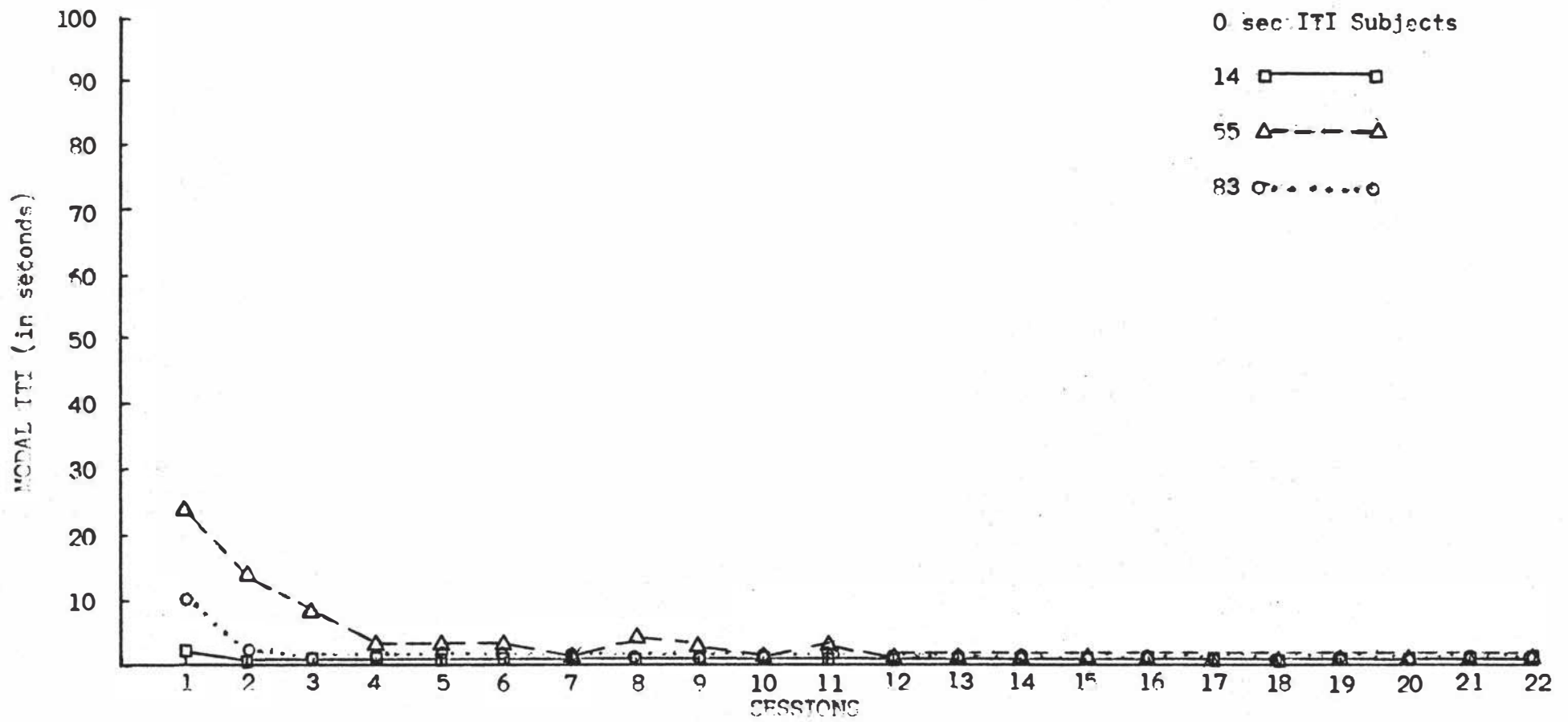FIGURE 2. Percent correct matching for Ss 31, 90, & 53, the 60 sec ITI group.

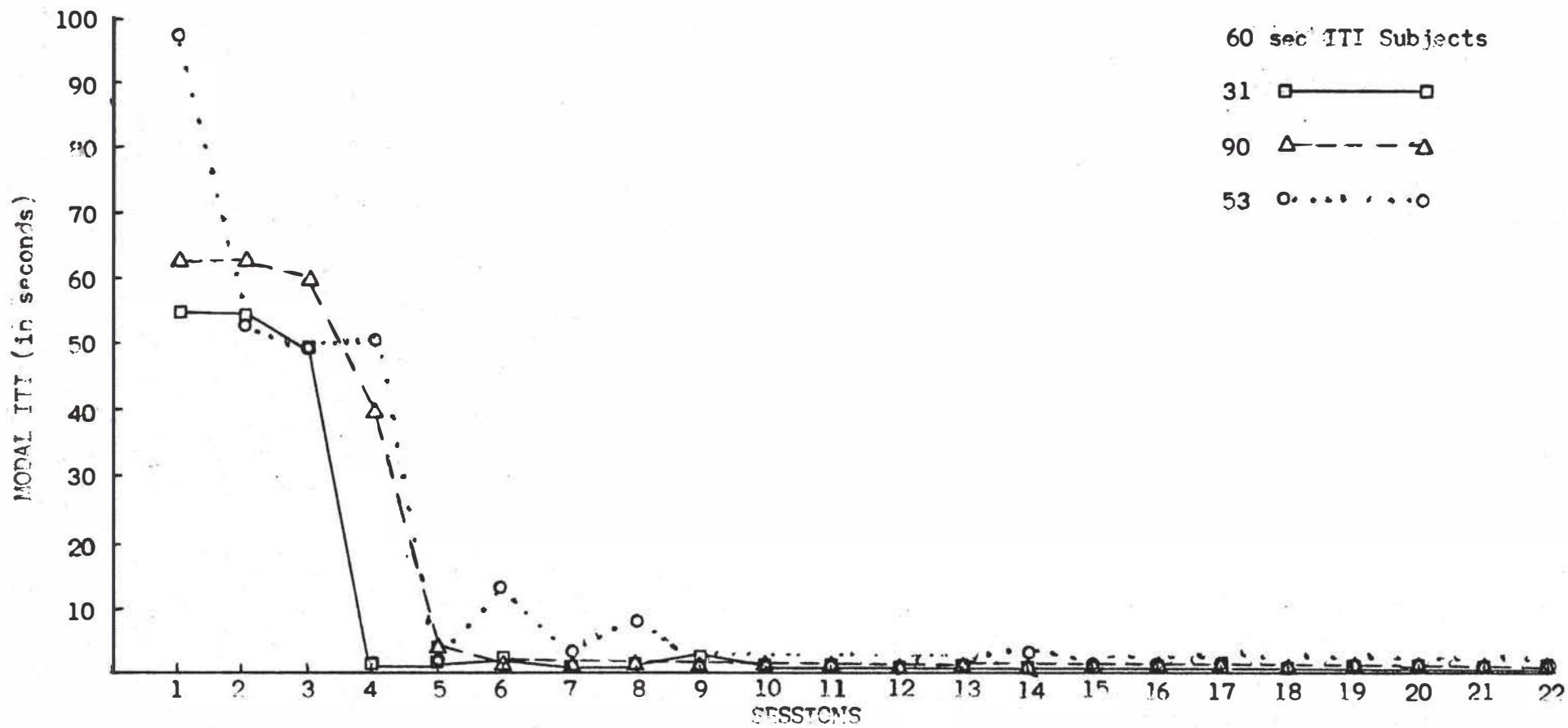FIGURE 3. Modal ITI in seconds over sessions for Ss 14, 55, & 83, the 0 sec ITI group.

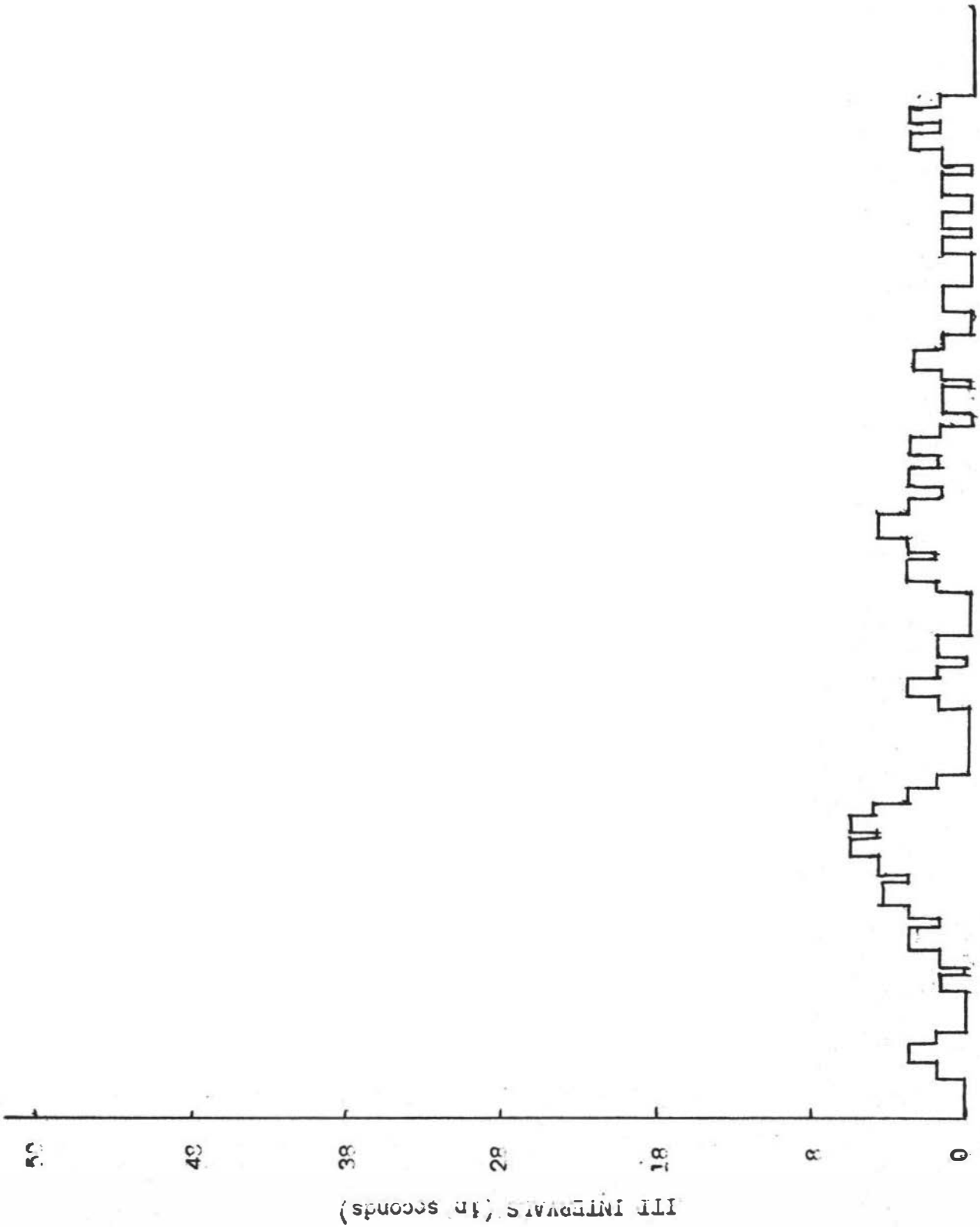FIGURE 4. Modal ITI in seconds over sessions for Ss 31, 90, & 53, the 60 sec ITI group.

FIGURE 5. Continuous record of ITI changes for S 55 during session ten.
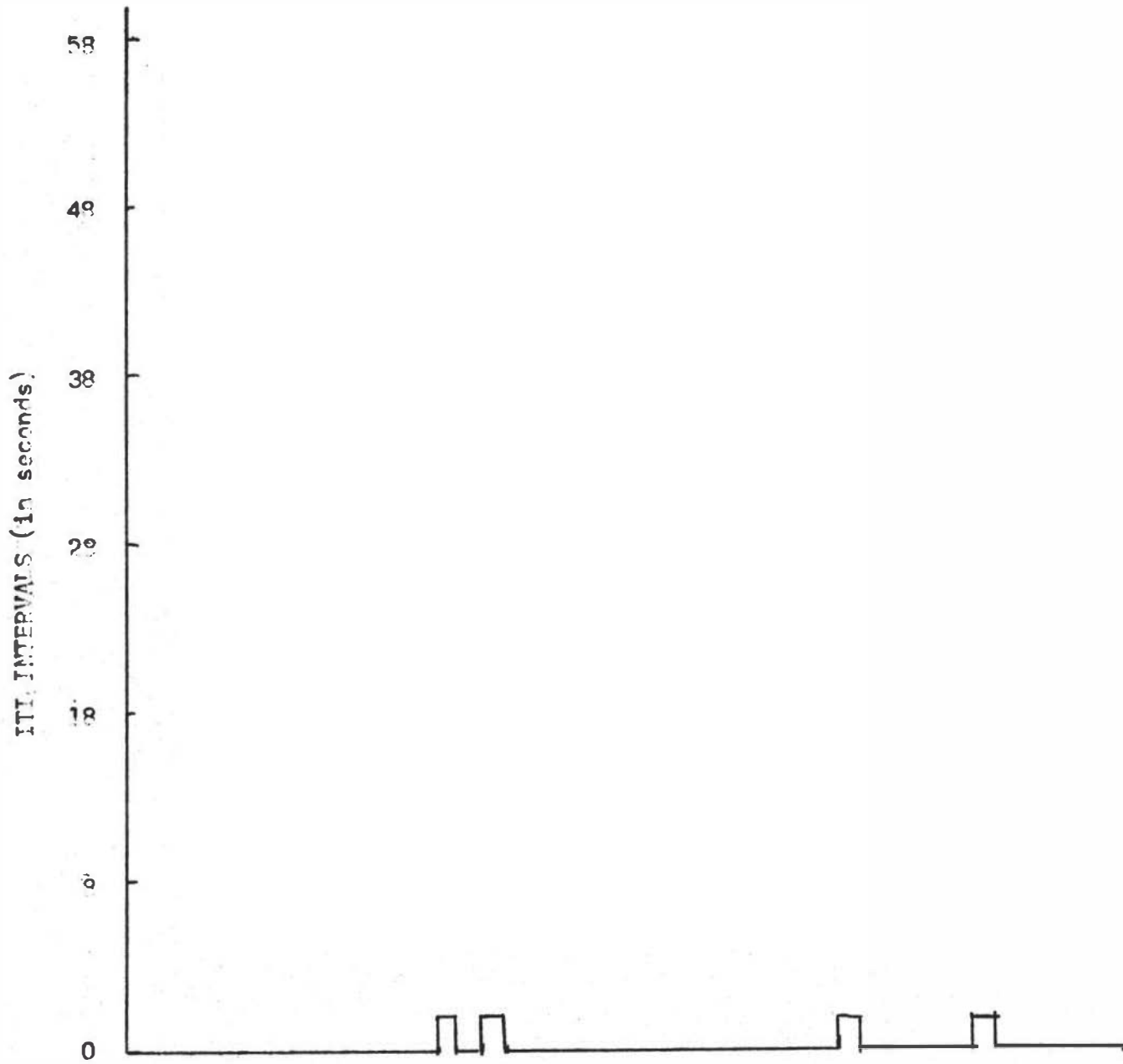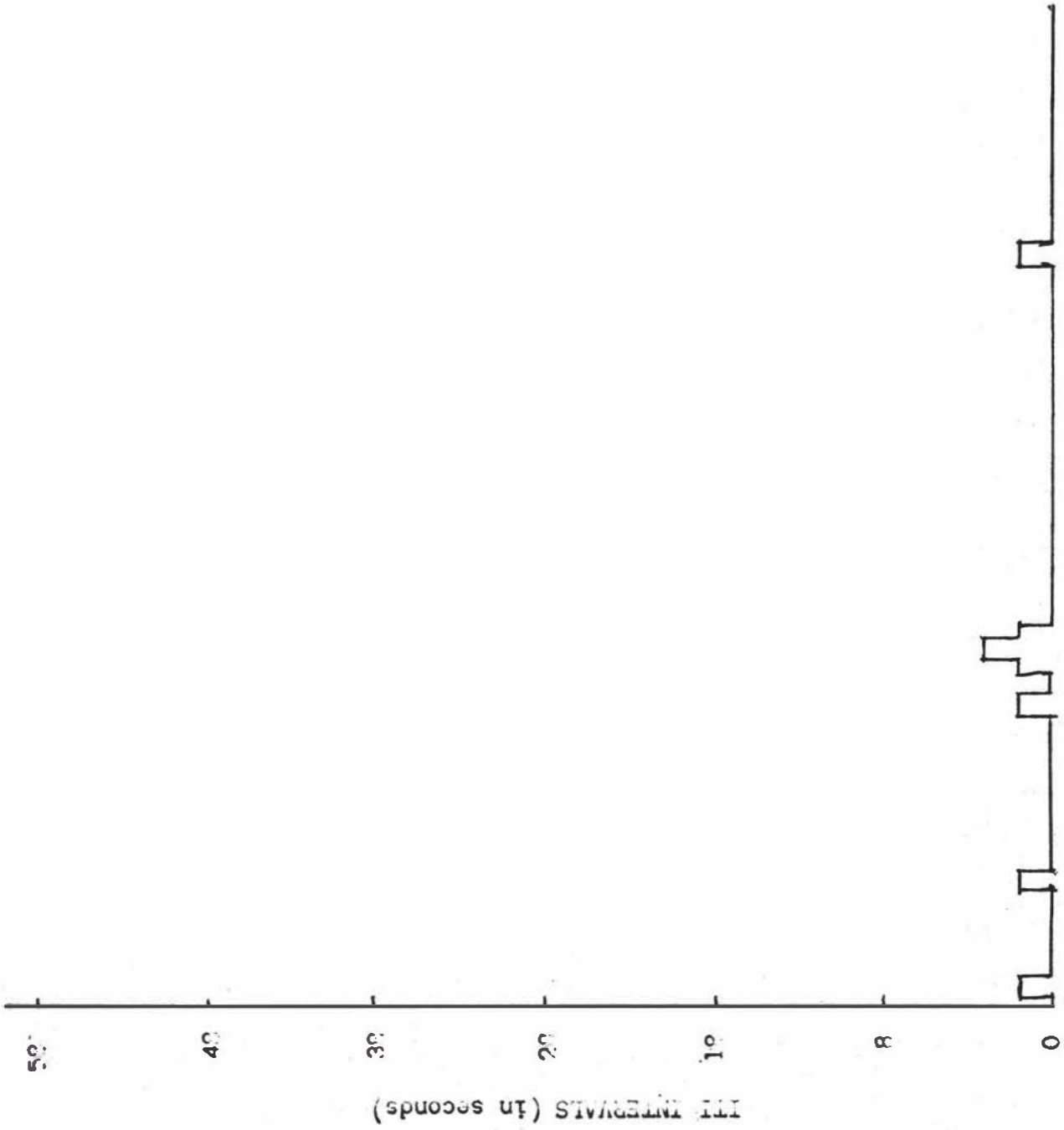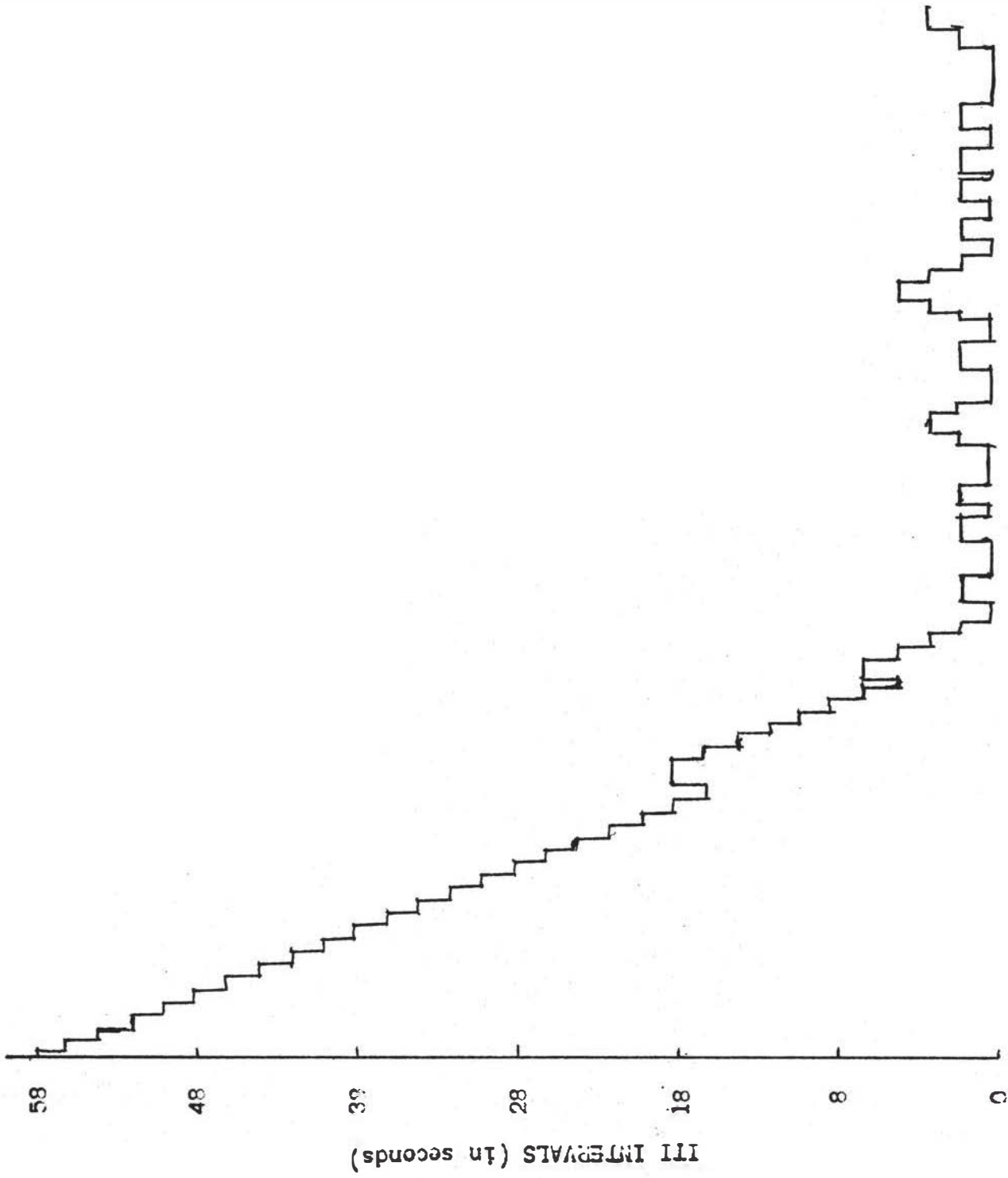
FIGURE 6. Continuous record of ITI changes for S 14 during session ten.

FIGURE 7. Continuous record of ITI changes for S 83 during session ten.

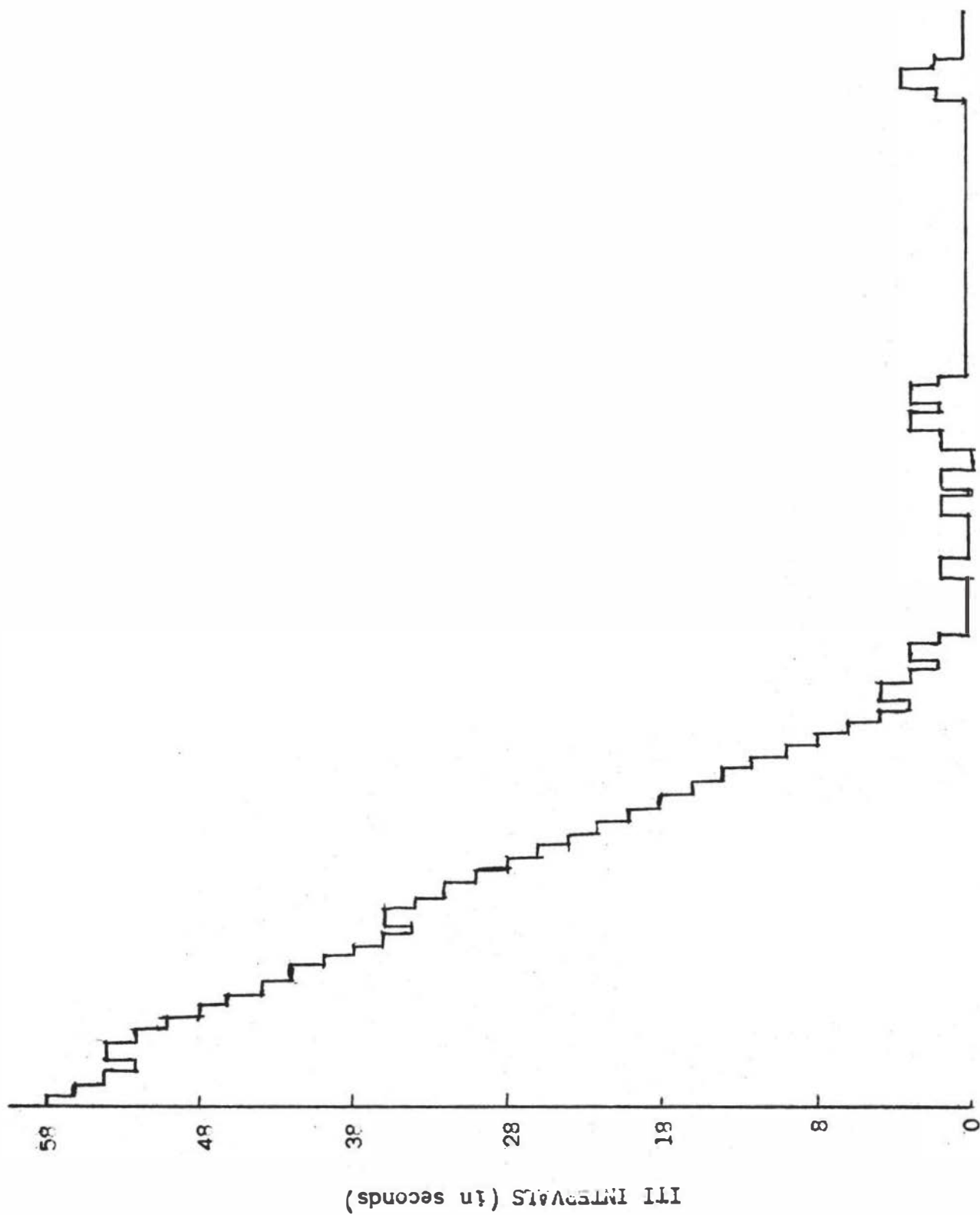FIGURE 8. Continuous record of ITI changes for S 53 during session ten.

ITI INTERVALS (in seconds)

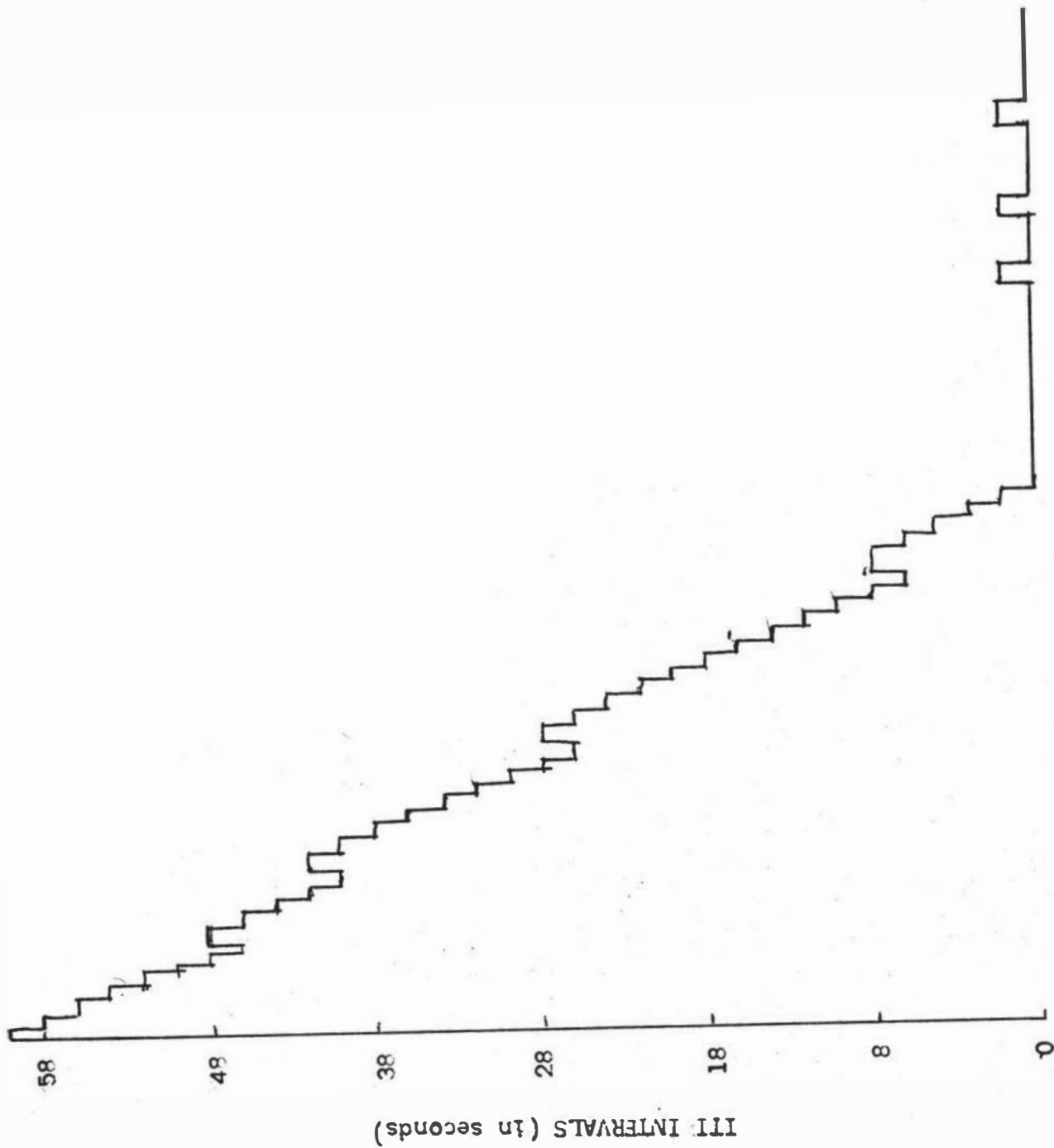FIGURE 9. Continuous record of ITI changes for S 31 during session ten.

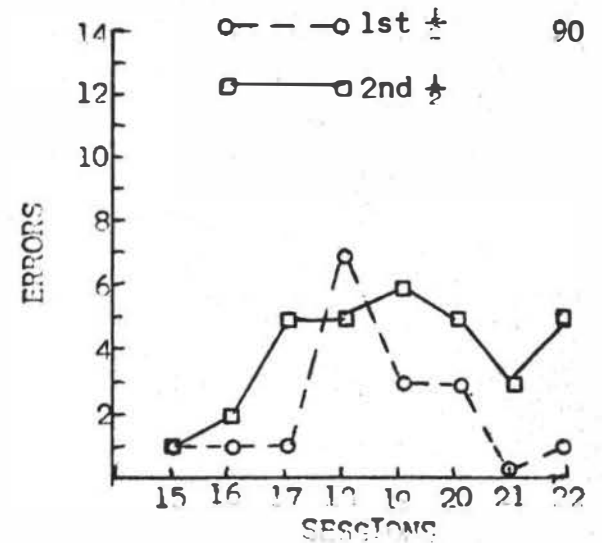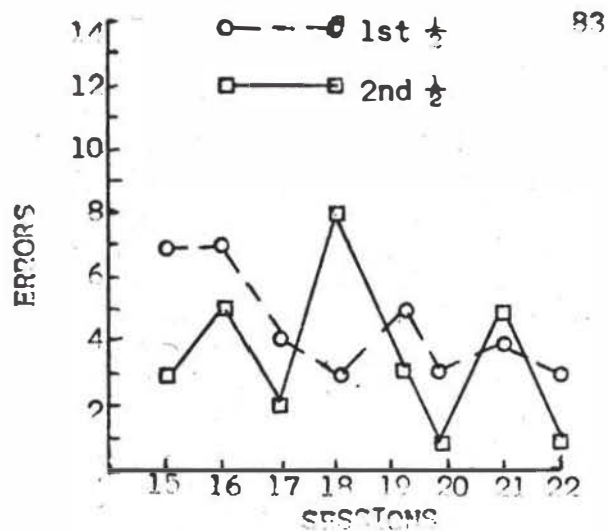FIGURE 10. Continuous record of ITI changes for S 90 during session ten.
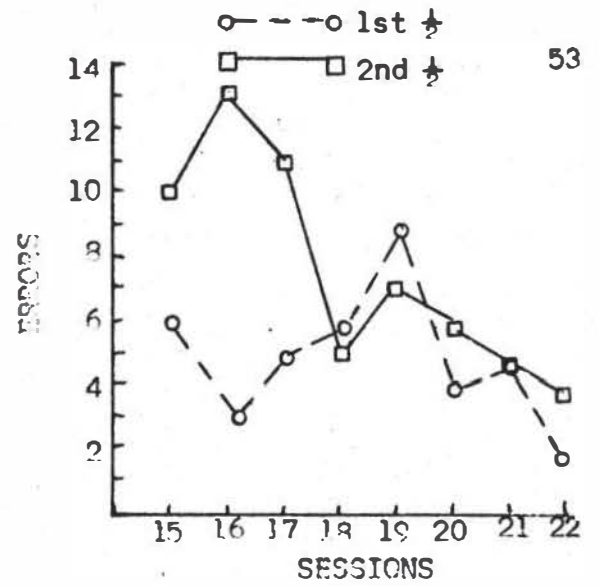
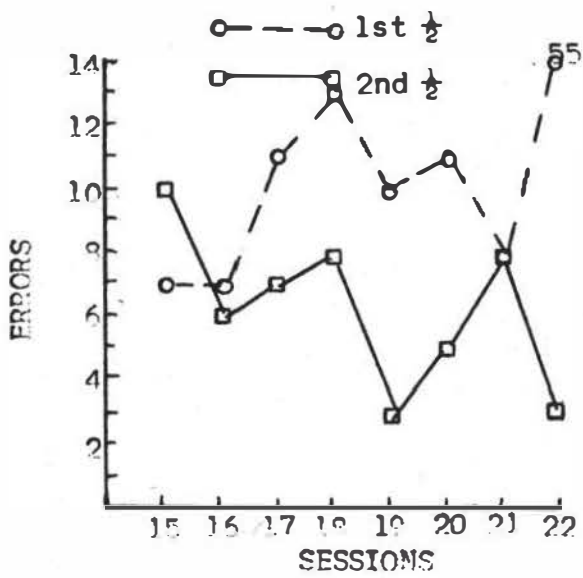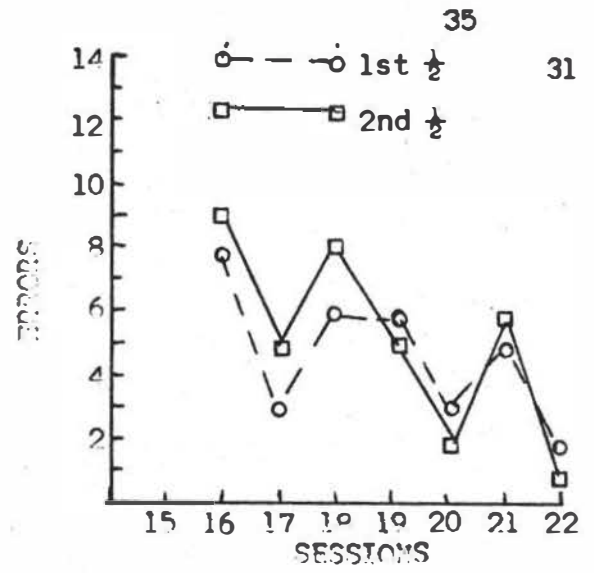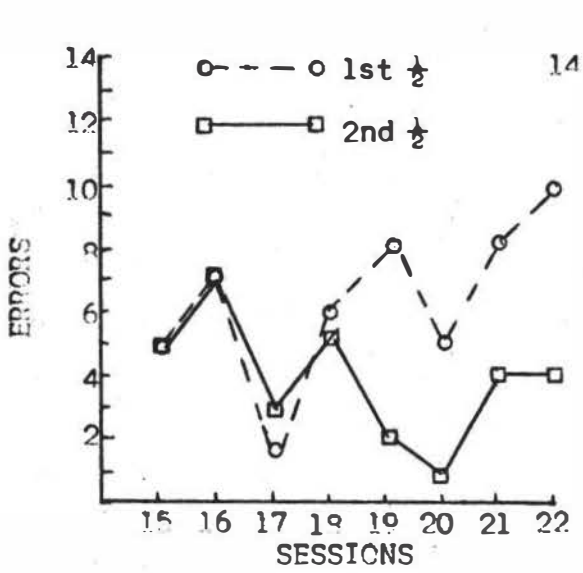FIGURE 11. Relationship of errors during first half of session(dashed line) with errors made in second half of session(solid line). The 0 sec ITI group is shown on the left. The 60 sec ITI group is shown on the right.

A Wilcoxon Matched-Pairs Signed-Ranks test was performed between the first and second half errors within each group. There was a significant difference for the 60 sec ITI group (T = 1, p <.05) and for the 0 sec ITI group (T = 0, p <.01). To test the difference in first half errors between the two groups the Mann-Whitney U test for small samples was used. There was a significant difference between the groups for first half errors (U = 1, p =.000). The 0 sec ITI group had more errors than the 60 sec group for the first half. The 60 sec ITI group had more errors than the 0 sec ITI group in the second half. However, the difference was not significant (U = 1, p = .164).

Figure 12 shows a ratio of the errors made in the first half of a session divided by the errors made in the second half. A ratio greater than one for the Ss in the upper figure means that there were more errors in the first half of a session than in the second half. This upper figure is of the Ss that began each session with a 0 sec ITI. The middle figure is of the Ss that began each session with a 60 sec ITI. A ratio less than one shows fewer errors in the first half of the session than in the second half of the session. The lower figure shows the ratio of errors averaged over the 3 Ss of each group. The ratio for the group that began each session with the 0 sec ITI is greater than one on sessions 15 through 22. The ratio of errors for the 60 sec ITI group is less than one on seven of the eight sessions.

A Mann-Whitney U test was calculated between the total number of errors for each group for all twenty-two sessions. The test showed no significant difference between the groups (z = 1.04). A Wald-Wolfowitz Runs test was performed to test for a difference in any way: central tendency, variability,
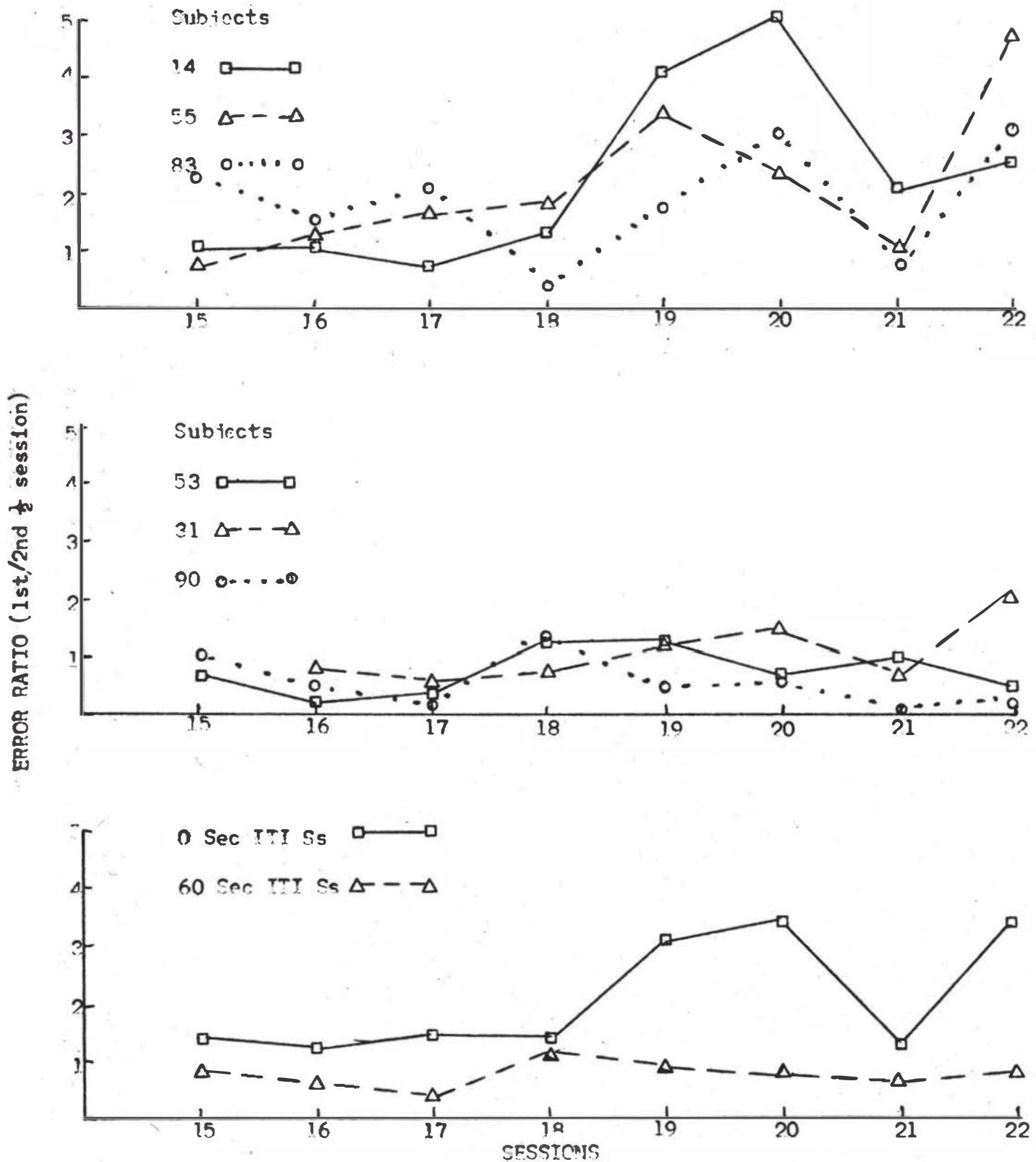
FIGURE 12. The upper figure shows the ratio of errors for the Ss that began each session with an 0 sec ITI. The middle figure shows the ratio of errors for the Ss that began each session with a 60 sec ITI. The bottom figure represents the mean ratio of errors for each group.

skewness, kurtosis, or whatever. The runs test was also not significant ($z = 0$). However, a Mann-Whitney U test calculated on the last eleven sessions did show a significant difference between the two groups in number of errors ($U = 29.5$, $p < .05$). The 0 sec ITI group showed more errors than the 60 sec ITI group.

Discussion

The titration method was employed in this experiment so that an optimal ITI for pigeons matching-to-sample could be found. The results show that all the birds "preferred" the 0 sec ITI. The Ss that began each session with a 60 sec ITI worked towards the 0 sec ITI. The Ss that began with the 0 sec ITI maintained it.

These results seem contrary to that of Holt and Shafer (1973). They reported that Ss on a 0 sec ITI failed to match beyond chance levels. However, in the present experiment using a titration method Ss on a 0 sec ITI acquired and maintained high matching accuracy. The results do tend to agree with those of Holt and Shafer in that the 0 sec ITI group made more errors than the 60 sec ITI group. However, this difference was only significant over the last half of the sessions, and not during the early trials of acquisition which are usually the most sensitive to experimental manipulations.

Holt and Shafer related the function of the ITI to the role of observing responses. Eckerman, Lanson, and Cumming (1968) showed that observing responses increased matching accuracy. Also, Ferster (1960), found that continuous reinforcement resulted in lower accuracy than fixed-ratio schedules. Under conditions of high reinforcement frequency the pigeon is oriented toward the grain magazine instead of the stimuli. Holt and Shafer considered that a 0 sec ITI or continuous reinforcement which increased reinforcement density, decreased observing responses and hence, matching accuracy.

In the present experiment the 0 sec ITI and continuous reinforcement maintained a high level of accuracy. This suggests that perhaps the titration method maintains observing behavior.

Matching accuracy may have been maintained because of the aversive quality of the titration method. A mismatch not only produced a TO interval and no reinforcement but also a postponement of the next trial. The delay of the opportunity to work for positive reinforcement may be aversive in itself. The increased ITI due to the titration may be similar to increasing the TO duration. Zimmerman and Ferster (1963) found that by increasing the TO duration matching errors decreased. To investigate the aversive aspects of titration it is suggested that the titration method be used in matching-to-sample without a correction procedure or TO intervals.

A noteworthy finding of this experiment is the difference in errors made during the first and second halves of the session between the 0 sec and 60 sec ITI groups. The 60 sec ITI group showed fewer errors in the first half than in the second half of the session. The findings of Holt and Shafer (1973) can be applied to this finding. In the first half of the session the Ss are on ITIs greater than zero. As Holt and Shafer show these higher ITIs maintain high accuracy. However, during the second half of the session the Ss are generally on a 0 sec ITI and performance decreases, as shown by Holt and Shafer.

The 0 sec ITI group showed more errors in the first half of the session than in the second half of the session. This result cannot be explained by the Holt and Shafer experiment. The explanation of the distribution of errors may be that the errors dropped out through a session. or perhaps the birds habituated to the short ITI.

From a motivational viewpoint, Amsel's frustration hypothesis may account for the distribution of errors. Birds on a 60 sec ITI develop a high level of fractional anticipatory frustration. As they work down to-

ward a 0 sec ITI the amount of this frustration is reduced since a mis-
match does not delay the possibility of reinforcement as long as it did
on the longer ITIs. This loss of anticipatory frustration reduces the gen-
eral drive level and reduces matching accuracy.

However, the birds on the 0 sec ITI develop fractional anticipatory
frustration over the trials within a session. Any departure from the 0
sec ITI is frustrating and builds up the fractional anticipatory frus-
tration. The growth of anticipatory frustration increases the general
drive level and maintains matching accuracy.

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