# STEREOTYPY OF A SPATIAL OPERANT IN PIGEONS
# AND THE LAW OF EFFECT

By

© GEORGE HILLER, B.A., M.A.

A Thesis
Submitted to the School of Graduate Studies
in Partial Fulfilment of the Requirements
for the Degree
Doctor of Philosophy

McMaster University
March, 1987

# STEREOTYPY OF A SPATIAL OPERANT AND THE LAW OF EFFECT

DOCTOR OF PHILOSOPHY (1987)
(Psychology)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: Stereotypy of a Spatial Operant in Pigeons and the Law of Effect

AUTHOR: George Hiller, B.A. (Harpur College)
M.A. (SUNY Binghamton)

SUPERVISOR: Dr. John R. Platt

NUMBER OF PAGES: xiii, 220

# ABSTRACT

The consequences of food reinforcement in pigeons were studied on a circular response continuum in which 72 possible keypeck responses were equated for effort. When every keypeck was rewarded equally, the pigeons did not come to peck in any particular location in the response continuum, contrary to expectations from the Law of Effect. Instead, they spread their keypecks over the entire continuum. Likewise, when a randomly-selected 20% of their keypecks were reinforced, the pigeons did not progressively concentrate their keypecks in any particular location. Successful shaping of keypecking to 12 evenly-spaced target locations showed that the pigeons could discriminate between different locations, and that they could be shaped to respond to each of the locations equally well.

When it was discovered that each pigeon was making shifts between keys from trial to trial which were consistent in direction and magnitude, these shifts were also examined for progressive stereotypy. None was found in this behavior either. Successful shaping of particular size and direction of shifts showed that this behavior could be controlled by reinforcement, although not as precisely as location of pecking.

Analysis of shifts following reinforced and nonreinforced trials in the random-reinforcement and location shaping conditions revealed a tendency for the pigeons to make consistent small shifts following reinforced trials, and more diffuse and much larger shifts following nonreinforced trials. Small consistent shifts were also generally found when every trial was reinforced, and large diffuse shifts when no trials were reinforced.

These findings were discussed in relation to reinforcement theory, and also to optimal foraging theory.

# ACKNOWLEDGEMENTS

I especially wish to thank John Platt (quite possibly the best advisor extant) for his advice, support, and guidance. I am also grateful to Herb Jenkins for his incisive commentary, which contributed greatly to whatever merit this thesis possesses; and Shep Siegal, who, by example, has shown me a way to view the world and science that I probably never would have encountered otherwise, to my enrichment. Next, I would like to thank Gary Weatherill, lab technician extraordinaire; and John Blythe, Itesh Sachdev, Dr. I. C. Jackson, Don Maxwell, and Ian Begg, whose interest and encouragement assisted me immeasureably. Finally, although my Mom is quite happy that this thesis is finished, I dedicate it to my children- Rachel and David- "the sunshine of my life".

## TABLE OF CONTENTS

# LIST OF TABLES

Table

Page

# LIST OF FIGURES

Figure Page

Figure

Figure Page

Figure

Page

# INTRODUCTION

My interest in spatial variability of operant responding was aroused by the finding of John Platt and his co-workers (Platt, 1980; Davis and Platt, 1983; Scott and Platt, 1985) that food-deprived rats, in a situation where movement of a manipulandum (a "joystick") in any direction will produce food, do not demonstrate a progressive tendency to respond in one direction. Instead, they distribute their responses in all the original directions, when given over 25 sessions with 50 reinforced trials per session. I had assumed that the first response direction that occurred and was reinforced would increase in probability of re-occurrence, in accordance with the Law of Effect (Thorndike, 1911). The probability of occurrence of responses in other directions would not be increased, although induction might strengthen responses close to the reinforced response (Keller and Schoenfeld, 1950). The animal should be slightly more likely to make the previously-reinforced response, or one close to it, than any of the other possible responses. This response would also be reinforced, producing a further increase in probability that it would occur in the future. As this process continued, responding would tend to become concentrated at one place- if not at the place where the first reinforcement was obtained, then surely at a place where a response was reinforced early in training.

As Keller and Schoenfeld (1950) put it:

> "Even assuming that the strengthening of one response will strengthen other, slightly different ones, how does it happen that a specific response with one set of properties does not, by virtue of more frequent reinforcement, come to be the only response emitted in a given experimental situation?"(p. 174)

## Chapter 1:

## BACKGROUND

A large part of learning theory is based upon principles derived from studies of food-reinforced behavior. At the least, food-reinforced behavior is the paradigm case for the study of instrumental responding. Therefore, an understanding of exactly what food reinforcement does is important for theories of learning. The terms response and reinforcement have been used with a number of different meanings in different contexts. In this thesis, "reinforcement" will mean the operation of presenting food to a mildly food-deprived animal. A "response" will mean any behavior on the part of the animal that can potentially produce reinforcement in a particular experimental situation.

Thorndike (1911), generalizing from studies of cats escaping from puzzle boxes and receiving pieces of fish, concluded that reinforcement "stamps in" whatever act immediately preceded reinforcement. To wit:

> "The Law of Effect is that: Of several responses made to the same situation, those which are accompanied or closely followed by satisfaction to the animal will, other things being equal, be more firmly connected with the situation, so that, when it recurs, they will be more likely to recur; those

> which are accompanied or closely followed by discomfort to the animal will, other things being equal, have their connections with that situation weakened, so that, when it recurs, they will be less likely to occur. The greater the satisfaction or discomfort, the greater the strengthening or weakening of the bond.
>
> The Law of Exercise is that: Any response to a situation will, other things being equal, be more strongly connected with the situation in proportion to the number of times it has been connected with that situation and to the average vigor and duration of the connections." (Thorndike, 1911, p. 244).

Skinner (1938) also incorporated the assumption that reinforcement increases the probability of a response which it follows into his system for explaining behavior. Generalizing from studies of rats pressing bars and receiving food pellets, he stated:

> "If the occurrence of an operant is followed by presentation of a reinforcing stimulus, the strength is increased." (Skinner, 1938, p.21)

Support for this position was provided by studies in which Skinner (1938) reinforced one single bar press and then recorded the number of nonreinforced bar presses that followed. He reported finding normal-appearing extinction curves following one reinforced response. This suggests that the probability of pressing the bar has been <u>increased</u> by a single reinforcement.

It seems obvious to anyone who has shaped a rat to press a bar or a pigeon to peck a key that <u>something</u> like the Law of Effect must be true. If a particular movement made by a rat is followed immediately by reinforcement, that movement is apparently strongly increased in probability of re-occurring. Often it is repeated in precise detail. Even if the most important factor in operant conditioning turns out to be the correlation between particular responses and reinforcement or nonreinforcement, the effect of a reinforcement still must be to increase (or at least maintain) the probability of occurrence of a response which it immediately follows. If this were not so, it is difficult to see how acquisition of operant responding could occur.

If whatever response immediately preceded reinforcement becomes more likely to occur because of having been reinforced, then it seems likely that one particular response or member of a response class will become dominant in a particular situation. Since the response is reinforced, it occurs more frequently; since it occurs more frequently, it is reinforced more frequently; and so on, as long as reinforcement continues.

Skinner (1948) assumed that a process such as the one described above was responsible for the stereotyped behavior displayed in his "superstition" experiment. In this experiment, pigeons were presented food periodically, independent of their behavior. Skinner stated:

> "The conditioning process is usually obvious. The bird happens to be executing some response as the hopper appears; as a result it tends to repeat this response. If the interval before the next

> presentation is not so great that extinction takes place, a second 'contingency' is probable. This strengthens the response still further and subsequent reinforcement becomes more probable. It is true that some responses go unreinforced and some reinforcements appear when ~~the~~ response has not just been made, but the net result is the development of a considerable state of strength." (Skinner, 1948, p. 168-9)

Herrnstein (1966) was also confident of the validity of the Law of Effect. Speaking of a one-key operant conditioning situation using pigeons, Herrnstein said:

> "If the duration, rate, and manner of execution of the response are potentially conditionable, then it is possible that they will be as much influenced by their temporal proximity to the reinforcement as are the location and force....Although differing from each other, each pigeon ought to be self-consistent in these properties of response. The stereotypy of an animal's responding which in the past has been used as evidence against the notion of reinforcement (Guthrie and Horton, 1946) is actually one of the direct implications of the concept....
>
> We may expect that with any of these non-criterial properties of behavior, a group of animals will show variation within a predictable range, but that each animal within the group will tend to become progressively more stereotyped with training." (Herrnstein, 1966, p. 38).

Referring to Skinner's (1948) superstition procedure, Herrnstein hypothesized:

> "If however, Skinner had used animals whose behavior was stereotyped to begin with, then his procedure would probably have served merely to emphasize the existing stereotype....One way to make a particular form of behavior dominant is to train the animal explicitly to engage in this behavior. Later, when reinforcers are presented independently of behavior, the dominant response will tend to be the one that is contiguous with the reinforcer." (Herrnstein, 1966, p. 35).

The implication here is that an aspect of a response (e.g.: duration, force, location) which has been shaped to some value should tend to remain at the shaped value when the organism is shifted to a non-differential schedule of reinforcement.

Staddon and Simmelhag (1971) replicated and extended Skinner's superstition experiment. Their careful observation and analysis of their pigeons' behavior showed that it was very unlikely that the behavior Skinner had observed was due to the Law of Effect. All of their birds developed the *same* responses, occurring toward the end of the interfood interval- orienting toward and pecking the wall containing the food magazine. As an alternative to the Law of Effect, Staddon and Simmelhag (1971) proposed that learning consists of "principles of variation" and "principles of reinforcement". The principles of variation produce a spectrum of behavior. The principles of reinforcement select behavior from this spectrum by means of eliminating behaviors that do not produce reinforcement rather than stamping in behaviors which immediately precede reinforcement. They stated:

> "Second, if reinforcement is considered as purely selective it *cannot* be invoked as an explanation of behavior when *no* imposed contingency exists between reinforcement and behavior (i.e., in the *absence* of selection). (Staddon and Simmelhag, 1971, p. 21. Italics in original.)

In this account, reinforcement is not seen as increasing the probability of a response it follows, but rather preserving that response from dropping out. No matter how many times a particular response variant were reinforced, it would never be stronger than the other response variants, as long as they were not emitted in the absence of reinforcement. Thus, progressive stereotypy of characteristics of the response (e.g., force, duration, location) should not occur unless only specific values of those characteristics are followed by reinforcement.

However, even within this system, Staddon and Simmelhag predicted a progressive decrease in response variability (i.e., an increase in response stereotypy) with repeated reinforcement, under certain conditions:

> "...if, as we have suggested, reinforcement has a purely selective effect: in these terms, training involves a progressive reduction in variability under the selective action of reinforcement (centripetal selection, see below), so that absence of reinforcement (extinction) represents a relaxation of selection- with an attendant rise in variability. ...the concept of centripetal selection...refers to the fact that selection under unchanging conditions, if, long continued, acts to weed out extremes, rather than systematically to shift population characteristics in any particular direction...." (Staddon and Simmelhag, 1971, p. 24).

If stereotyped behavior is found in the absence of (imposed) response-reinforcer contingencies, one can attempt to explain it on the basis of response bias. Baum (1974) wanted to account for deviations from matching in two-key concurrent-VI situations. He tried to do this with the concept of bias.

> "Bias means unaccounted for preference. It indicates that some independent variable affecting preference has not been measured." (Baum, 1974, p. 233.)

> "At least four sources of bias can be documented: (1) response bias, (2) discrepancy between scheduled and obtained reinforcement, (3) qualitatively different reinforcers, and (4) qualitatively different schedules." (Baum, 1974, p. 234.)

Response bias was assumed to include "handedness", color preferences, differences in adjustment of manipulanda so that one response is easier, and unknown factors, either uncontrollable or hypothetical. The other three sources of bias are all associated with differences in reinforcement for the alternative responses. Response bias could account for <u>progressive</u> stereotypy- for example, if the subjects gradually learn that some responses are easier than others and gradually learn to make those easier responses.

Although interest in the Law of Effect waned following the study by Staddon and Simmelhag (1971), it is, as Dennet (1978) pointed out, a question that will not go away. This is because the Law of Effect is the only non-question-begging theory of learning that has been proposed (Dennet, 1978). Dennet stated:

> "This rough idea, refined, is the Law of Effect, and my claim is that it is not just part of

> a possible explanation of behavior, but any possible adequate explanation of behavior." (Dennet, 1978, p. 72. Italics in original.)

Devenport (1983) believed that reinforcement produces response stereotypy, probably through neural circuits which use dopamine as a transmitter. He also maintained that a large proportion of the variability in learned behavior is not "error". Rather, it is something which is added to the learned response. The learned response is more accurate than the performance of that response. (Indeed, he called the learned response "stereotyped".) His evidence for this position was that response variability, measured in a number of ways, is greater in intact normal rats than it is in rats impaired by either brain lesions or alcohol.

Devenport stated:

> "...that animals (pigeons) which lack well developed frontal, septal and hippocampal formations are quite susceptible to reward-induced stereotypies....This finding is also consistent with the pigeon's tendency toward superstitious responding (e.g., Staddon and Simmelhag, 1971) (sic)....This is not to say that avians may not have developed other structures (e.g., the hyperstriatal complex) that may assist them in varying behaviors that are appropriate for their niche." (Devenport, 1983, pp. 114-115. Parentheses in original.)

Thus, according to Devenport, pigeons might be expected to show a higher degree of response stereotypy due to reinforcement than would rats. Indeed, most investigators who have conducted operant conditioning studies on pigeons would agree that pigeons appear to be excellent animals in which to study reinforcement-produced response stereotypy.

One strategy for investigating the possibility of response stereotypy caused by reinforcement would be to select a response which has a number of equivalent forms. Each of these equivalent responses would have the same cost, in terms of effort required by the animal. Each would be reinforced equally when it was performed. In other words, sources of response bias or reinforcer-produced bias, as enumerated by Baum (1974) would be eliminated insofar as this is possible. If the Law of Effect holds, a progressive tendency for one or a few of the responses to be emitted should be observed (Herrnstein, 1966). On the other hand, if reinforcement is purely selective (Staddon and Simmelhag, 1971), there should be no stereotypy of responses (as discussed above), since there is no imposed contingency between reinforcement and particular responses. Centripetal selection would not come into play since all of the responses would be equivalent. That is, none of the responses would be "extreme" responses that would be selected out. Care would have to be taken in selecting the dimension along which responses would vary. Responses varying in force, duration, or number would not be suitable, since the different forms would not be equivalent. A particularly good dimension along which to vary the responses would be a spatial one, since equivalent responses could be arranged. There are some studies extant which apparently meet the conditions given above.

Antonitis (1951) wished to determine the relationship between number of reinforced trials for an operant response, and variability of some quantifiable characteristic of that response. He also wished to determine the effect of extinction and subsequent reacquisition upon variability of the same characteristic of the response. He recorded the location of food-deprived rats' nose-poking in a 2.54-cm by 50-cm horizontal slot during operant level determination, continuous reinforcement (Fixed Ratio 1, or FR 1), extinction (EXT), reconditioning, reextinction, and rereconditioning of nose-pokes. Reinforcement was independent of the location of pokes. Response variability was defined as the mean distance of responses in a block of trials from the median response position in that block. Antonitis found that variability decreased over FR 1 trials, both between and within daily sessions; that variability increased in extinction; and that reconditioning following extinction produced variability lower than that found in a no-extinction control group. These findings apparently support the Law of Effect, since a FR 1 schedule, which reinforced nose-pokes irrespective of location, produced progressive stereotypy (i.e., decreased variability) of response location.

Herrnstein (1961a) attempted to determine the effect of intermittent reinforcement upon variability of an operant response, compared to the effect of FR 1. In a situation analogous to the one studied by Antonitis (1951), Herrnstein (1961a) trained three food-deprived pigeons to peck a 2.54-cm by 25.4-cm rubber strip for a grain reinforcer. The location of the peck was recorded within one of ten 2.54-cm by 2.54-cm squares, but reinforcement was not contingent upon response location. Under FR 1, the preferred location of the 10 possible locations received 40 to 52 per cent of all responses, but when the pigeons were shifted to a variable interval (VI) 3-min schedule, the preferred location received 78 to 99 per cent of all responses, showing decreased variability of response location. All three pigeons responded almost entirely to one end of the strip or the other. Herrnstein (1961a) concluded that response location becomes more stereotyped under intermittent reinforcement than under continuous reinforcement, although he did not attempt to explain why this occurred. The pigeons did, however, show some degree of locational stereotypy under both kinds of nondifferential schedules. Herrnstein only presented data averaged over the course of training, so that one cannot determine whether his pigeons displayed progressive stereotypy.

Ferraro and Branch (1968) intended to replicate and extend the finding of Herrnstein (1961a), that intermittent reinforcement produces less-variable behaviour on a spatial response dimension than does FR 1. After training four pigeons to peck an eight-key, 2.5-cm by 11-cm response strip, two of the pigeons were given 14 sessions on a VI 1 min schedule of reinforcement. All four pigeons were then given 14 sessions of FR 1, followed by 14 sessions of VI 1 min, and then 14 more sessions of FR 1. Reinforcement was not contingent upon response location. The measure of variability used was called "redundancy", which measures stereotypy of distributions of response locations, but the authors don't say how they calculated it. According to this measure, and by inspection of the response distributions, it can be seen that, contrary to the findings of Herrnstein (1961a), the VI schedule produced more variable responding than the FR 1 schedule. However, both FR 1 and VI schedules produced locational stereotypy. In this study, as in Herrnstein's, the pigeons tended to restrict their responding to one end or the other of the response strip. The authors remarked that analysis of responses immediately following reinforcement on the VI schedule showed a tendency for three of the four birds to repeat reinforced responses, but they did not give any data concerning this.

Eckerman and Lanson (1969) also wished to determine the effects of intermittent reinforcement upon variability of response location. They shaped three pigeons to peck a 20-key, 25.4-cm by 1.9-cm response strip. The pigeons were then given five sessions of FR 1, with 100 reinforcements per session; one EXT session of 100 pecks; one session of FR 1; one more of EXT; and one final session of FR 1. This is an analogous sequence of conditions to that used by Antonitis (1951). All three birds tended to respond around the middle of the response strip throughout the entire study. During acquisition, variability of response location, measured by the average deviation from the median location, decreased within and across sessions for two birds. Response variability for the other bird started low, increased, and then decreased, being essentially the same as for the other two birds over the last three sessions. Extinction increased variability. Reacquisition reduced variability to about the same levels as those produced at the end of acquisition. Reextinction increased variability, about the same amount as the first extinction session. Final reacquisition brought variability down again to levels found at the end of initial acquisition. These results are similar to those reported by Antonitis (1951) except that neither reacquisition session in the Eckerman and Lanson study showed lower variability than initial acquisition. The same three pigeons were then given five sessions of FR 1, two sessions of FI 15 sec, seven sessions of random-interval (RI) 150 sec, seven sessions of RI 75 sec, and seven sessions of RI 30. Two birds were then given FI 15 sec, and, finally, FR 1. Intermittent reinforcement increased variability of response location, compared to FR 1, for all three birds. Median response location shifted widely during the experiment, mostly during intermittent reinforcement. Two naive birds were then given six sessions of FR 1 followed by 14 sessions of VI 3 min (the conditions used by Herrnstein, (1961a)). Variability decreased over FR 1 sessions, increased sharply when the VI 3 min schedule was introduced, and stayed high over 14 sessions on the VI schedule. These results, like those of Ferraro and Branch (1968), do not replicate the findings of Herrnstein (1961a).

The studies cited above apparently support the Law of Effect, since repeated nondifferential reinforcement produced progressive stereotypy of response location.

However, there is a problem with all four of these studies. The response strips were all constructed such that the point of access to food was closest to or easiest to reach from one part of the strip (usually the center). Either a delay-of-reinforcement or least-effort analysis would predict that the most responding would occur at the part of the strip closest to the food magazine. This is because both the delay between making the response and collecting the reinforcer and the effort involved in responding and collecting the reinforcer would be the least when the animal responded there. Antonitis (1951) deliberately constructed his apparatus in this fashion:

> "In the determination of both the length and the position of the response slot... in the apparatus, account was taken of the fact that the difference limen for the discrimination of distance in the white rat is about 1/10.... The distance from the exit... to the center of the response slot (30.5 cm) was designed to be discriminably shorter than the distance from either extreme of the slot (39.4 cm). _As a result_, when the Ss were required during conditioning to run from the compartment... to the slot... and back to the compartment... to procure reinforcement, they developed tendencies to respond about the center of the response slot. _This then allowed observation of the scattering of responses around individual central tendencies_...." (p. 274, italics mine).

The other three investigators did not stress this point, but in all four studies, stereotypy of response location was encouraged, and was found. Indeed, in each of the four studies, all of the subjects stereotyped in the same place; in the center of the slot for Antonitis' rats (Antonitis, 1951), at the end of the strip for Herrnstein's pigeons (Herrnstein, 1961a), at the middle of the strip for Eckerman and Lanson's pigeons (Eckerman and Lanson, 1969), and at the ends of the strip for Ferraro and Branch's pigeons (Ferraro and Branch, 1968).

The studies cited above found progressive stereotypy of response location when the opportunity was given to respond at a number of locations, and reinforcement was presented for any response, independent of location of the response. They also generally found a greater degree of stereotypy on FR 1 than on intermittent schedules, and the lowest degree of stereotypy in extinction. However, all of these studies had apparatus asymmetries which could produce response biases (Baum, 1974) favoring particular locations. As Davis and Platt (1983) pointed out:

> "Only if such biasing factors are minimized and various response values are shown to be functionally equivalent operants can 'superstitious stereotyping' of response values reasonably be taken as evidence for the efficacy of temporal contiguity." (of response and reinforcer) (p. 6. Parenthetical addendum mine).

One way to construct a spatial response dimension with equivalent responses would be to use a centrally-located food magazine and a circular response strip, with all of the possible responses equidistant from the magazine. This situation not only equates all of the responses for distance from the feeder, but also eliminates potential response bias to the edges or the center of a response strip.

# Chapter 2:

# EXPERIMENT I

## INTRODUCTION

As pointed out by Herrnstein (1966), stereotypy of responding, even under nondifferential reinforcement, is a direct consequence of the Law of Effect. Whether pigeons would show progressive stereotypy of response location in a circular response continuum, where every response has equal cost and equal benefit, and where every attempt has been made to eliminate apparatus-produced response bias, has not been investigated and is one of the questions this thesis was intended to answer. In addition, it was necessary to determine whether pigeons would shape equally well to any arbitrarily selected location in this situation, in order to be sure that the response alternatives *were* equivalent.

Another objective of this thesis was to compare locational variability in FR 1 with locational variability under an intermittent reinforcement schedule. Both types of schedules reinforce response locations nondifferentially, differing only in the presence or absence of nonreinforced trials. For example, if FR 1 did not produce locational stereotypy, but intermittent reinforcement did, it might be concluded that the mere presence of nonreinforced trials in a reinforcement schedule is sufficient to produce stereotypy of location.

The suggestion by Ferraro and Branch (1968), that pigeons on an intermittent schedule of reinforcement tended to repeat reinforced responses, prompted a systematic analysis of where pigeons respond following both reinforced and nonreinforced trials.

If stereotypy of response location did occur, another objective was to attempt to determine what cues were controlling the pigeons' behavior.

## METHOD

### Subjects

Six White King pigeons, approximately 1 1/2 years old, of undetermined sex, and experimentally naive, were maintained at approximately 80% ad libitum weight on Purina Pigeon Checkers and tap water. They were individually housed, and kept on a 15-hour light, 9-hour dark schedule. Each pigeon was run daily, except as noted below, at the same hour of the afternoon ± 1 hr.

### Apparatus

The experimental chamber was cylindrical, 103 cm in diameter and 35 cm high, constructed of sheet metal, and painted a medium grey. The bottom of the response strip was located 24 cm from the floor, and the top, 28.5 cm. This strip ran entirely around the wall of the chamber. It was composed of 72 translucent white acrylic response keys, each subtending 5° of the complete circle. Each key was 4 ~~cm~~ wide, and the keys were separated from each other by black acrylic blocks, .5 cm wide, 1.2 cm deep, and 4.5 cm high, with rounded ends and edges. These acrylic separators were placed between the keys in order to prevent the pigeons from pecking two keys at once, which was a fairly common response in the pilot birds, and one which was uninterpretable to the computer. A transducer circuit employing a Hall-Effect transistor located behind each key and a small ceramic magnet on the back of each key sensed any movement of the key of at least 2 mm, with a necessary force of .2 N, and registered it as a response on that key. The keys were illuminated simultaneously and evenly with an average luminance of 16 foot-lamberts, by means of a string of sixteen 12-v incandescent lamps. The lamps were located 3 cm behind the keys, and were reflected from a cylindrical, white, light-tight surface surrounding the keys. The measured luminance of each key was actually between 15 and 17 foot-lamberts, and did not vary systematically with key position. The floor was composed of .64-cm hardware cloth, with a 2.54-cm high, 7.62-cm diameter, cylindrical food magazine located in the center. The magazine had a 2.54-cm hole, with rounded edges, centered in its top. An inner sleeve containing Purina Pigeon Checkers raised or lowered at appropriate times to provide the pigeons with access to food when reinforcement was programmed. The distance from the food magazine to the different keys varied by an average of 1.1%. The chamber was covered by either a translucent white acrylic or a transparent acrylic top with a houselight of 5 w located approximately .5 m above the top.

Presentation of stimuli, programming of schedule contingencies, and response recording were accomplished by a Digital Equipment Corporation LSI 11/1 computer, in conjunction with a Data Translation DT 2762 analogue-to-digital converter, a Data Systems Design 210 dual-disk drive, and an electro-mechanical interface of in-house manufacture.

When the clear top was on the chamber, the pigeon's behavior was observed, and occasionally taped, via a video camera in one upper corner of the experimental room and a monitor and tape deck in the control room. White noise was continuously presented through a speaker located in the ceiling of the experimental room.

Procedure

8

Since the pilot animals had shown no tendency to autoshape (see Chapter 4), eight pigeons (B51, B52, B55, B58, B59, B60, B62, and B63) were shaped by successive approximations to peck the keys, with all the keys lit. This was not easily accomplished. Pigeon B51 showed repeated periods of not eating from the magazine, and was discarded after seven shaping sessions of approximately one hour each since it was not even approaching the keys. Pigeon B60 was also discarded for similar reasons. The remaining pigeons; B52, B55, B58, B59, B62, and B63; took 1, 2, 5, 3, 6, and 3 one-hour sessions, respectively, to shape to peck the lit keys.

Shaping was conducted with the FR 1 program loaded, so that once the pigeons started pecking the keys, they were immediately given a session of 50 FR 1 trials while the experimenter observed them through the clear top. The keylights were kept on continuously during this session, since the pilot subjects had shown startle responses and had frozen when the keylights went out upon pecking.

The 6 pigeons were then given 42 daily sessions consisting of 50 trials of FR 1, with 3 days off between Sessions 28 and 29, due to failure of the disk drive. In this condition, every response, irrespective of location, produced reinforcement and simultaneously extinguished the keylights. Reinforcement in all cases consisted of a 4-sec magazine presentation. Sessions 1-35 were conducted with the translucent top, and 36-42 with the clear top in order to observe the pigeons, which were seemingly not eating during the beginning of a session. From the start of FR 1, and throughout the experiment, a discrete-trials procedure was in effect, such that illumination of the keys, and hence the opportunity to respond, was contingent upon the pigeon breaking a beam of light across the mouth of the feeder at the beginning of each trial. There was no imposed intertrial interval; that is, a trial could be initiated as soon as the reinforcement presentation from the previous trial was finished. Following FR 1, the 6 pigeons were given 14 daily sessions of 250 trials on a random-ratio 5 (RR 5) schedule, which reinforced approximately 20% of the responses at "random", irrespective of response location. These sessions were all conducted with the clear top on the chamber.

Following RR 5,the pigeons were given 28 daily sessions of 250 trials each on a symmetrical targeted percentile (TP) schedule (Davis and Platt, 1983; Platt, 1973) upon which, on the average, the closest 20% of each pigeon's responses to an arbitrarily selected target location were reinforced. Actually, the symmetrical TP schedule consisted of two simple percentile schedules. If the keypeck was in the hemicircle clockwise of the target, it was compared to the distribution of responses held in memory which had been made in that hemicircle. If it was closer to the target than 80% of those responses, it was reinforced. Keypecks in the hemicircle counterclockwise of the target were compared to the distribution of responses held in memory which had been made in that hemicircle. If it was closer to the target than 80% of those responses, it was reinforced. The target direction was chosen to be between two keys, in order to facilitate calculations. Reinforcement or nonreinforcement of ties was determined by a random number routine which reinforced a random 20% of ties. The memory referred to contained the last 24 responses made by the particular pigeon, irrespective of location.

Six targets were chosen, evenly spaced 60° apart, with B52, B55, B58, B59, B62, and B63 being assigned targets of 120°, 300°, 0°, 180°, 210°, and 60° respectively. The pigeons were given 28 daily sessions on the initial target (Target 1). Next, the target for each pigeon was shifted 90° counterclockwise (Target 2) and the pigeons were given 20 daily sessions with 250 trials per session and the same percentile parameters. The targets were all shifted 90° counterclockwise again (Target 3) for 30 sessions, again with the same percentile parameters. All percentile sessions to this point had been conducted with the clear top, and the first 20 sessions in this phase (Target 3) were also. For the last 10 sessions (Target 3'), however, the transparent top was replaced by the translucent top, which was used for the remainder of the experiment. Target 4 consisted of a clockwise shift of 90°, for 50 daily sessions of 250 trials with the same percentile parameters. During Target 4 sessions, the chamber was rotated 90° clockwise for the 19th session, the white noise speaker was displaced 180° for the 24th session, the chamber and the top were rotated 90° counterclockwise for the 27th session, and the top was rotated 90° counterclockwise on the 33rd day, for all of the pigeons. During Sessions 34-50, the two target keys (with the actual target in the middle) for each pigeon were distinctively marked. This was done by affixing a strip of quarter-inch black vinyl tape from the upper adjacent corner to the lower non-adjacent corner of each of the two target keys, forming an inverted "V" upon them. These manipulations were conducted in an attempt to determine what stimuli were controlling shaped responding. The target for each pigeon was again shifted 90° clockwise, to Target 5, for 9 daily sessions of 250 trials, with the same percentile parameters. The two new target keys were marked during this phase, with the same tape strips that had been used during Target 4. Finally, all the pigeons were given 9 daily sessions of 250 trials with Target 6, 90° clockwise from Target 5. For the first 2 sessions of Target 6, the two target keys were marked with the tape strips. For the third session, the tape was removed, and Sessions 3 through 9 of Target 6 were conducted with unmarked keys. The same percentile parameters were in effect during this phase.

The response record for B58, Session 27, was lost via disk-drive failure. Pigeon B62 was fed accidentally and was not run in Sessions 36-38. The record for B63, Session 21 of FR 1, was discarded because one of the Hall-Effect transistors began to oscillate, causing false responses to Key 56 and frequent program termination during the session. For Pigeon B62, the records for four daily sessions of RR 5 were unreadable for detailed analyses, although daily mean data were available. The same was true for the record for one daily session of RR 5 for B63. Toward the end of Target 4, and throughout Target 5 and Target 6, the disk-drive began to fail intermittently. This meant that there were 9 separate days out of 52 that the pigeons could not be run, and finally the study was terminated so that effective repairs could be made.

## Descriptive Statistics

Each response was treated as a unit vector, originating at the center of the chamber and terminating at the center of the key that was pecked, in accordance with the circular statistics described by Batschelet (1981). That is, for analytical purposes, a constant arbitrary zero point was chosen, permitting the definition of each response in polar coordinates, $(\alpha^{o}, 1)$.

The mean vector m, which points to the center of mass of a circular distribution, was calculated for the keypecks in each session. The mean vector is found by summing the unit vectors for a session to form the resultant vector, and dividing by the number of unit vectors. In the present set of studies, it was routinely calculated trigonometrically.

The direction of the mean vector, $\alpha$, is the maximum-likelihood estimate of the population mean angle, given a "circular normal" or von Mises distribution. Its length, r, is the maximum-likelihood estimate of concentration around the mean direction. This mean vector will be referred to as the Place measure. Thus, the mean direction of the Place vector, $\alpha_p$, reflects any tendency to respond in a particular place or direction; while $r_p$ reflects the strength of that tendency. As

Batschelet says:

> "A mean angle of a sample taken from a unimodal distribution indicates a preferred direction, but it does not contain any information as to what extent the sample values are clustered around the mean. As in linear statistics the following is also true in circular statistics: A measure of dispersion is as important as a measure of location." (Batschelet, 1981, p.31. Italics in original).

Inferential Statistics

In order to investigate the variability *per se* of the Place measure, the direction of each daily mean vector was disregarded, leaving only *r*. This was converted to *s*, the mean angular deviation, according to the formula advocated by Batschelet (1981). This formula is:

$$s^{o} = 180^{o} / \mathrm{pi} \; ( 2 ( 1 - r))^{1/2}.$$

The angular variance, and its square root, the mean angular deviation, are linear variables rather than circular variables. This can be seen from the fact that they can be calculated from *r*, ignoring the direction associated with *r* (Schou, 1975). Thus, linear statistics are appropriate for testing differences between mean angular deviations.

Having converted the mean vector into a linear variable (*s*) reflecting only variability around each particular daily mean direction, analyses of variance were performed upon *s*, with Sessions as a within-subjects variable.

This procedure was followed because there is presently no statistical test analogous to the analysis of variance available for circular data, which could determine whether there was an effect due to Sessions (i.e., progressive stereotypy). The only method that Batschelet (1981) gives to compare two measures on the same subjects is the confidence ellipse (pp. 201-205). This method could be used for the summary data for all of FR 1 presented in Figure 1, but it would <u>not</u> test anything about progressive stereotypy.

One other measure which was used in analysis of TP and RR 5 was the target component, <u>v</u>, which is simply the projection of the mean vector <u>m</u> upon a previously-determined target direction. The target component can range from -1 to +1. It is calculated by the formula:

$$v = r \cos (a - a_o)$$

where a is the angle of the mean vector and $a_o$ is the target angle. This measure is widely used in homing experiments with pigeons, where it is called the "homeward component". It has also been used in cases where the target direction is unknown (e.g., Herrnkind and McLean, 1971), but this is a poor procedure since the hypothesized target direction <u>must</u> be chosen in advance (Batschelet, 1981).

## RESULTS: PLACE

### Fixed Ratio 1

The first question to answer is whether there is some source of response bias in the experimental situation despite all efforts to eliminate such a bias. If, for example, the keys in one area of the box were easier to operate, or were closer to the feeder, a response stereotypy could be formed, apparently based upon the effects of reinforcement. In order to check for this sort of bias, a mean vector was calculated for all of the responses in FR 1 for each pigeon. The mean vectors for Place (location of pecking) for each of the six pigeons, as well as the grand mean vector for Place for all six pigeons, summed over all 42 sessions of FR 1, are presented in Figure 1. The grand mean vector for all 12,130 trials of FR 1 was (209°, .039), showing no overall tendency on the part of the pigeons as a group to peck in any particular place or direction.

In order to check for more specific Place biases, as well as to determine the form of the distribution, the number of pecks on each key for all six pigeons was pooled for all 42 days of FR 1. The data are shown in terms of per cent pecks per key in Figure 2, along with the grand mean vector, which summarizes this circular distribution.

Figure 1. Mean vectors for Place averaged over all 42 daily sessions of FR 1 for each of 6 pigeons, and the grand mean vector (represented by the dot) averaged over all 6 pigeons in Experiment 1.

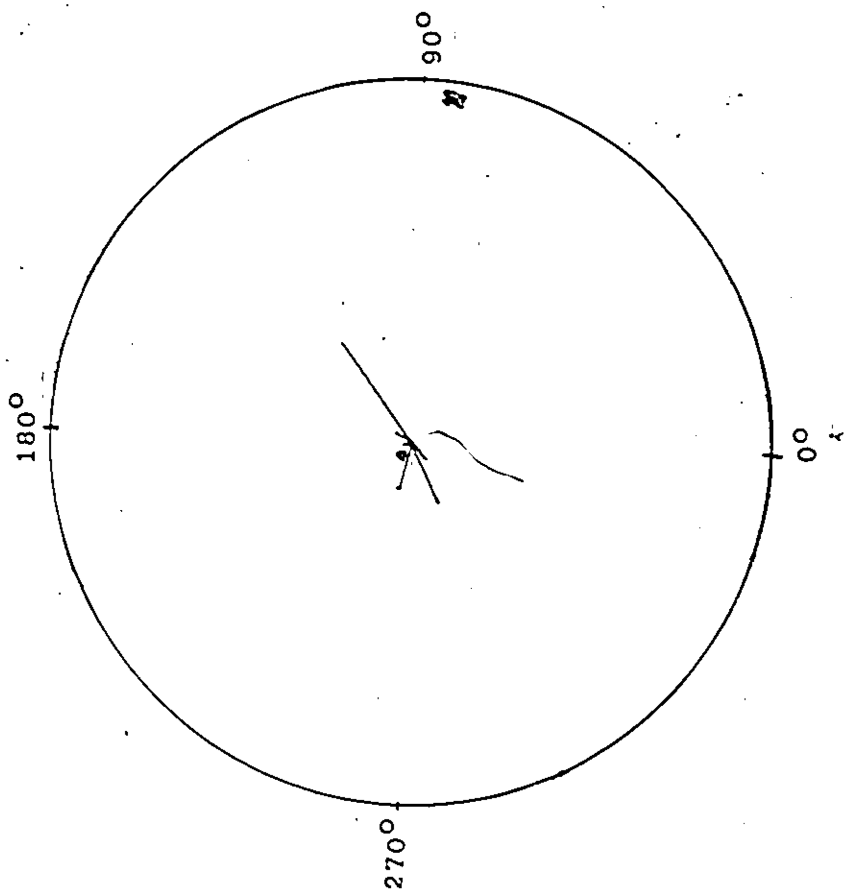
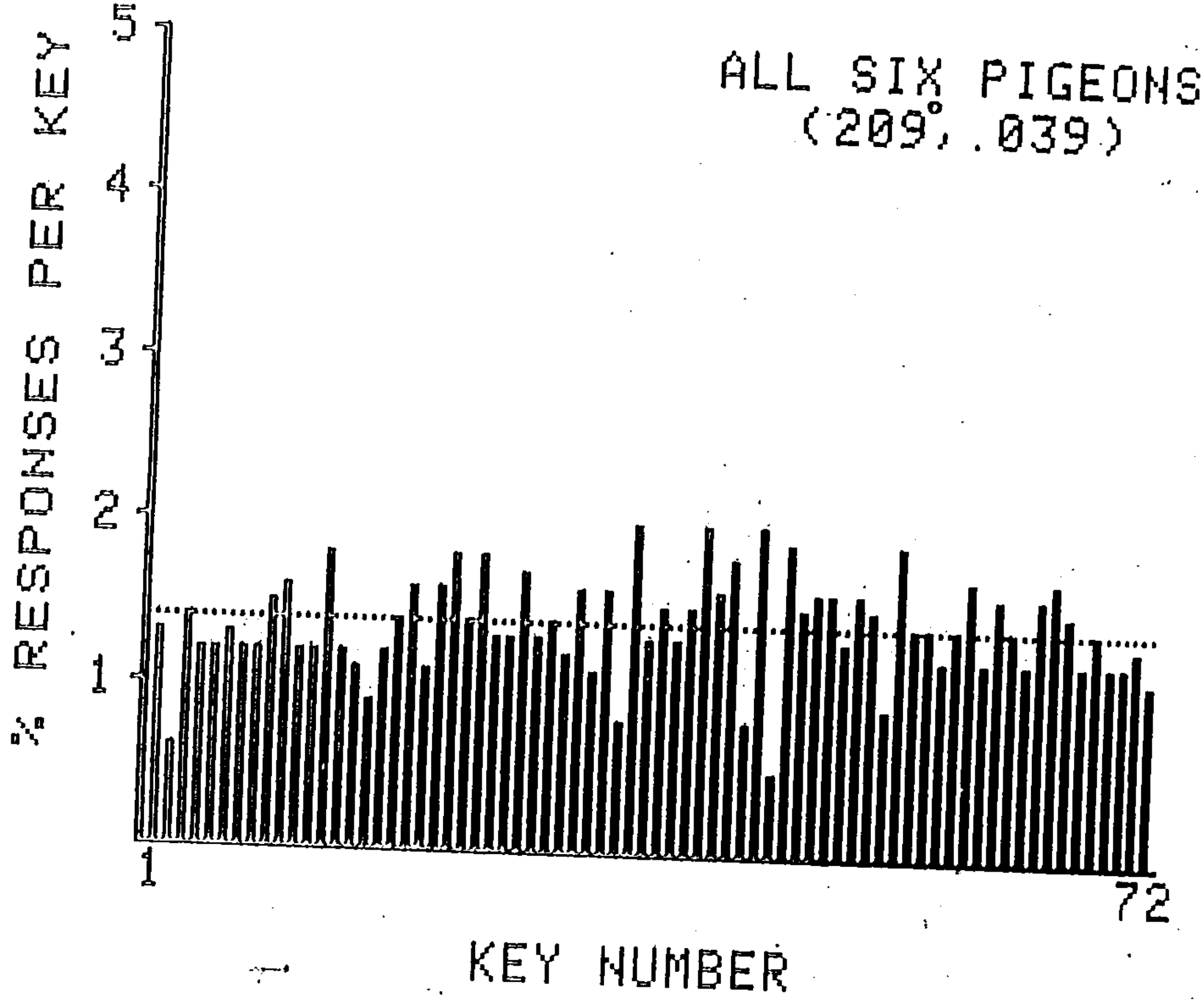

90°
180°
0°
270°

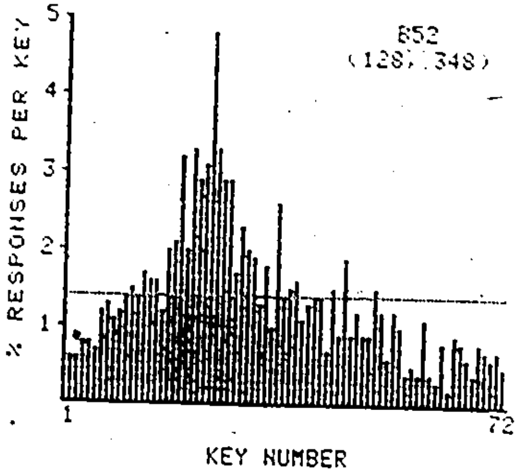
Figure 2. Per cent pecks per key, averaged over all 42 sessions of FR 1 and all 6 pigeons in Experiment 1.

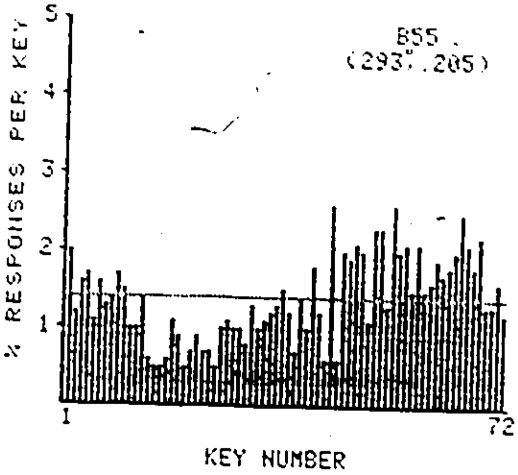

ALL SIX PIGEONS
(209°, .039)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER

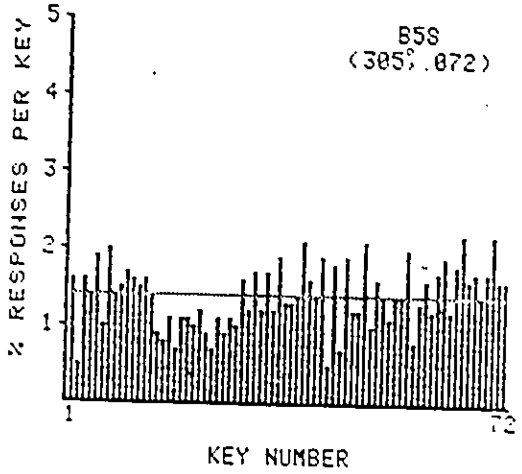
Inspection of Figure 2 suggests that responding may have been depressed on some keys, notably Keys #2, #34, #43, #45, and #53. In four of these cases (Keys #34, #43, #45, and #53), the number of pecks on the keys next to the low key is conspicuously high. Observation of the pigeons suggested that, in most cases, if a pigeon pecked at a key and the key did not operate, it would make additional pecks to the key. If the key still did not operate, the pigeon would peck another key, usually a key next to the one pecked originally. Despite these deviations of number of pecks observed from those expected, there was no systematic directional bias evident, as confirmed by the extremely low grand mean vector length.

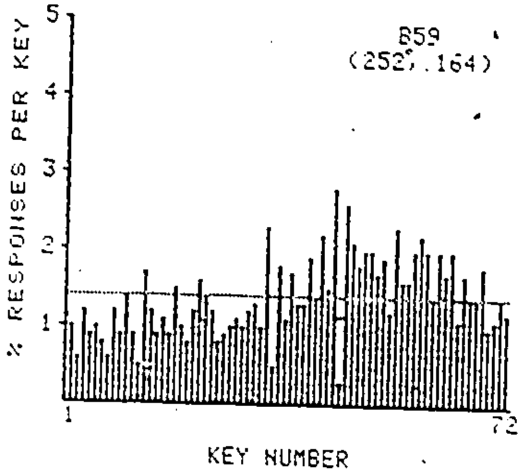
Although the pigeons as a group did not respond in any particular place or direction, it was possible that one or more of the individual pigeons did so. Distributions of number of pecks to each key, summed over all FR 1, are given for each pigeon in Figure 3, along with the mean vectors which summarize the distributions. Two of these distributions, those for B62 and B63, have mean vectors lower than .1, and appear to be reasonably rectangular. The next three distributions of pecks per key, for B58, B59, and B55, have mean vector lengths of .07, .16, and .21 respectively. None of these

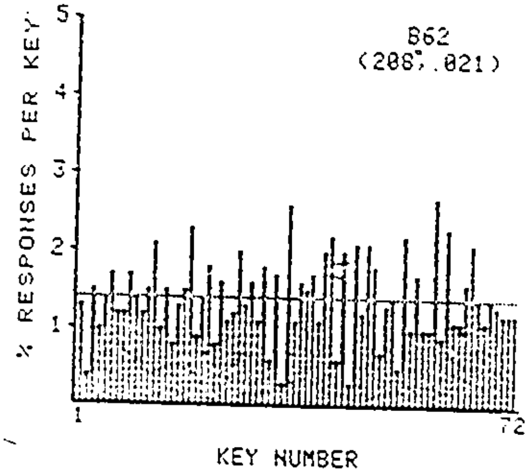
Figure 3. Per cent pecks per key averaged over all 42 sessions of FR 1 for each of 6 pigeons in Experiment 1.

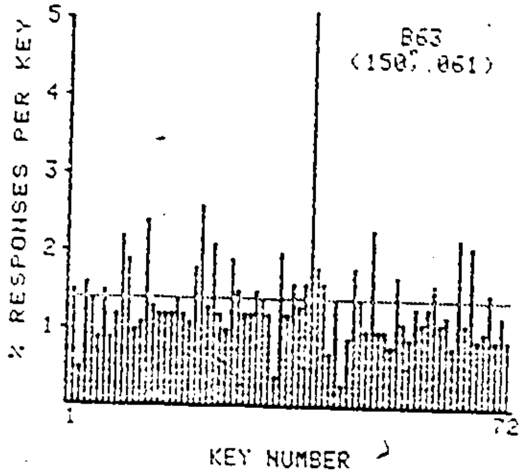

B52
(128°, .348)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B55
(293°, .205)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B58
(305°, .072)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B59
(252°, .164)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER

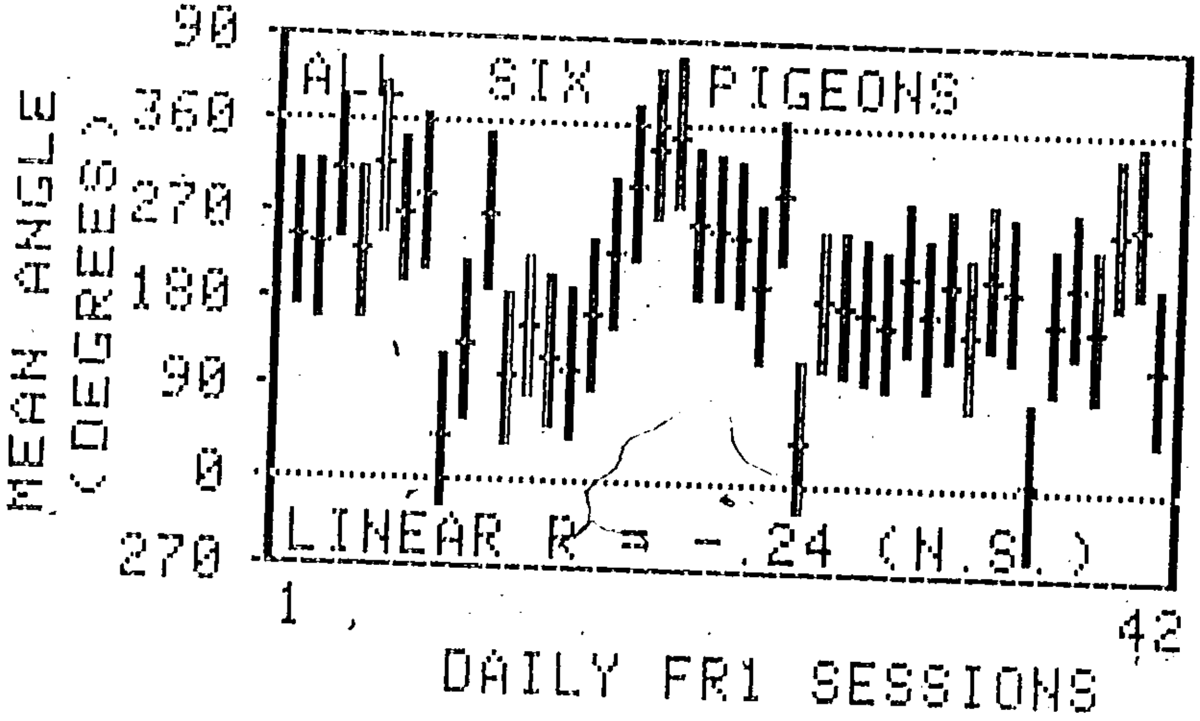

B62
(208°, .021)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B63
(150°, .061)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER

distributions shows a particularly high concentration, but the shape of the distribution appears to be similar for all three pigeons, and the mean angle is similar for all three. The distribution with the highest concentration, that for B52, (128°, .348), has a clearly defined central tendency, with a regularly-descending slope to either side. That is, it has the appearance of a unimodal distribution; for example, an induction or a generalization gradient.

These measures show whether there was any overall tendency to peck in a particular place or direction, and how strong that tendency was, but they do <u>not</u> show whether that tendency increased over sessions of reinforced trials, as would be predicted by the Law of Effect. The first step in this analysis is to ascertain whether there was any general tendency for the pigeons as a group to show regular changes in preferred place of pecking over days. The daily group mean Place vector is plotted in terms of mean angle, $\alpha$, ± the mean angular deviation, $\underline{s}$ (Batschelet, 1981, p.34), in Figure 4. The mean angles show no consistent trend, and the mean angular deviations for each day are very close to the maximum obtainable. The Pearson product-moment correlation between daily group mean angle and sessions is -.24, which is not significantly different from chance.

Figure 4. Group mean vectors for Place for each of 42 daily sessions of FR 1 averaged over all 6 pigeons in Experiment 1. The data are plotted in terms of the mean angle ± the mean angular deviation.



ALL SIX PIGEONS
LINEAR R = -.24 (N.S.)
MEAN ANGLE (DEGREES)
90
360
270
180
90
0
270
1
42
DAILY FR1 SESSIONS

Possibly, however, even though the group of pigeons is not displaying a concentration of responding at a given place over days, individual pigeons are doing so, at different places on different days. This is where one might expect to find idiosyncratic progressive stereotypy of location of pecking. The daily mean Place vectors for each pigeon, in terms of mean angle and *s*, are shown as a function of daily sessions of FR 1 in Figure 5. Pigeons B58, B62, and B63 all had large values of *s*, and little consistency in mean angle over daily sessions. Pigeon B59 also had a high daily *s*, but each daily mean angle seemed to be related to that of the day before, with a string of mean angles around 300° for days 17-28 and 38-42. Pigeon B55 also showed a high *s*, but its daily mean angles appeared to be related, being around 330° for days 1-25, and around 250° for days 26-42. Pigeon B52 had the lowest values for *s*, and except for the first seven days, the mean angle oscillated around 130°, with each daily mean vector very similar to the one before.

Although it appears from Figure 5 that variability (*s*) does not change much over days, it is difficult to be sure. Figure 6 shows *s* over Sessions during FR 1 for each pigeon. The mean value of *s* decreased slightly over daily sessions for B55. The mean value of

Figure 5. Mean vectors for Place for each of 42 daily sessions of FR 1 for each of 6 pigeons in Experiment 1. The data are plotted in terms of the mean angle ± the mean angular deviation.

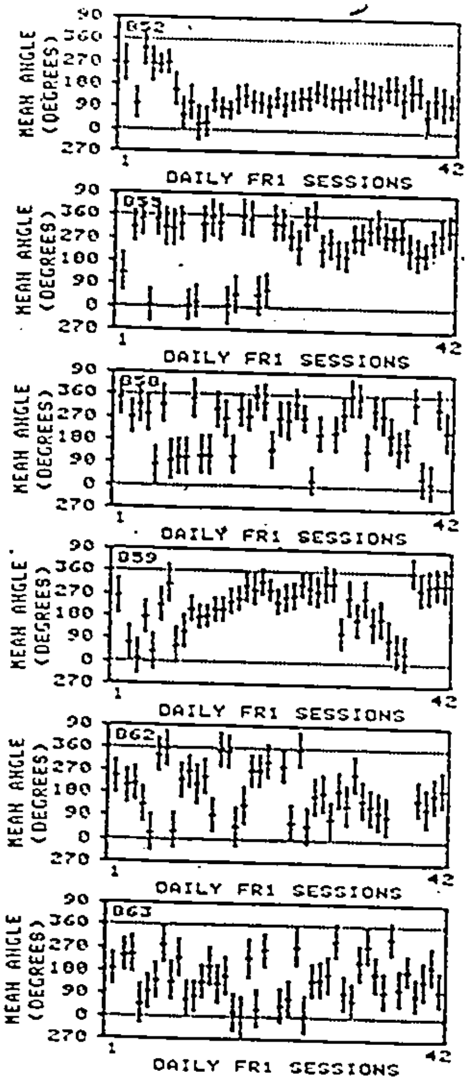
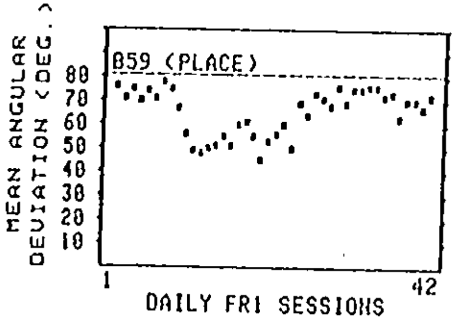
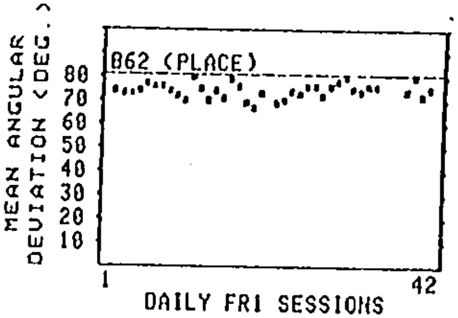
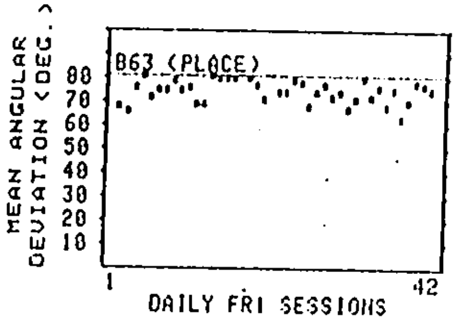
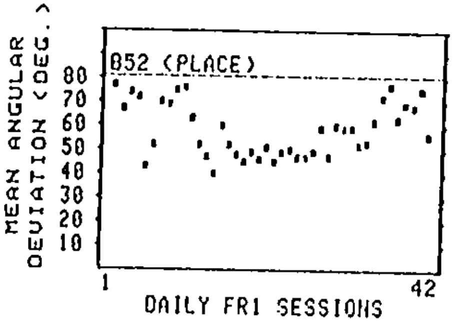

B52
B53
B58
B59
B62
B63
MEAN ANGLE (DEGREES)
90
360
270
180
90
0
270
1
42
DAILY FR1 SESSIONS

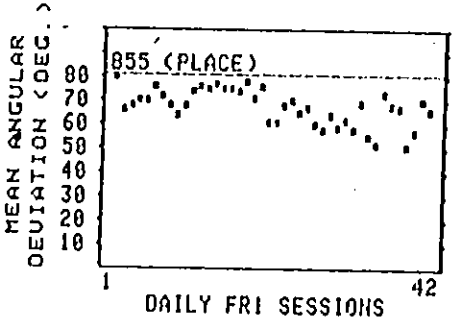
Figure 6. Mean angular deviations for Place for each of 42 daily sessions of FR 1 for each of 6 pigeons in Experiment 1.

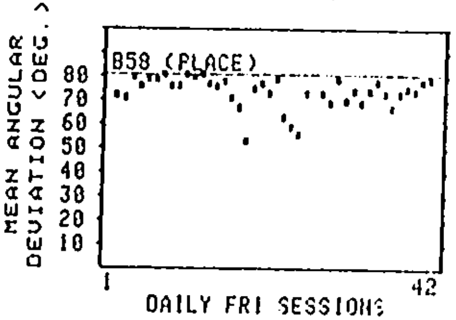

B59 (PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
42
DAILY FRI SESSIONS


B62 (PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
42
DAILY FRI SESSIONS


B63 (PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
42
DAILY FRI SESSIONS


B52 (PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
42
DAILY FRI SESSIONS


B55 (PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
42
DAILY FRI SESSIONS


B58 (PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
42
DAILY FRI SESSIONS

*s* decreased slightly over daily sessions for B55. The mean value of *s* decreased for B52 and B59, but then increased again to about the value at which it started. The oth[illegible] three pigeons displayed consistently high values of *s*. Analysis of variance on the mean angular deviations for all six pigeons showed no significant effect of Sessions.

Random Ratio 5

As in FR 1, pecks on each key were summed over all six pigeons and over all 14 days (20,000 trials) of RR 5. This yielded the distribution shown in Figure 7, which had a mean vector of (12°, .155), possibly indicating a slight tendency for the pigeons as a group to peck in a particular direction.

Figure 8 presents distributions of pecks per key and mean vectors calculated for all of RR 5 for each pigeon. The three pigeons which had mean vector lengths for FR 1 shorter than .1 (B58, B62, and B63) also had mean vectors shorter than .1 for RR 5; while the three pigeons which had mean vector lengths longer than .1 for FR 1 (B52, B55, and B59) also had mean vector lengths longer than .1 for RR 5. Pigeon B52 showed a decrease in mean vector length for RR 5 compared to FR I, while B55 and B59 showed increases.

Comparison of variability on RR 5 to variability

Figure 7. Per cent pecks per key averaged over all 14 daily sessions of RR 5 and all 6 pigeons in Experiment 1.

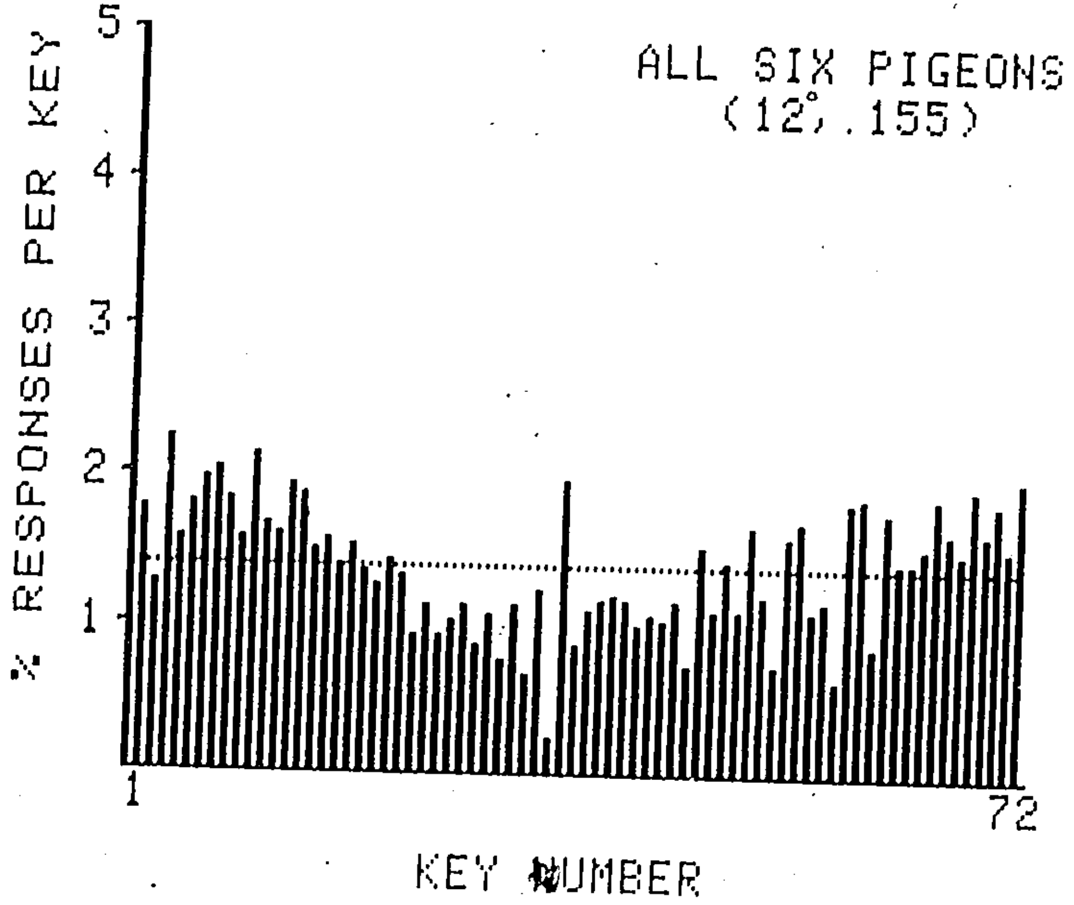
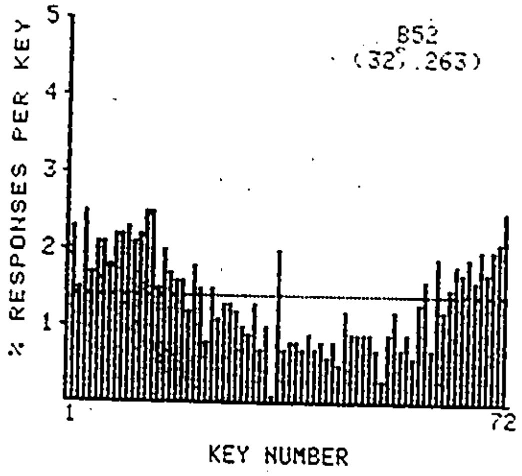
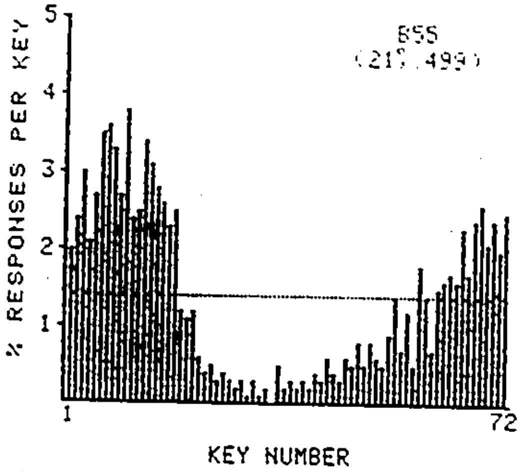
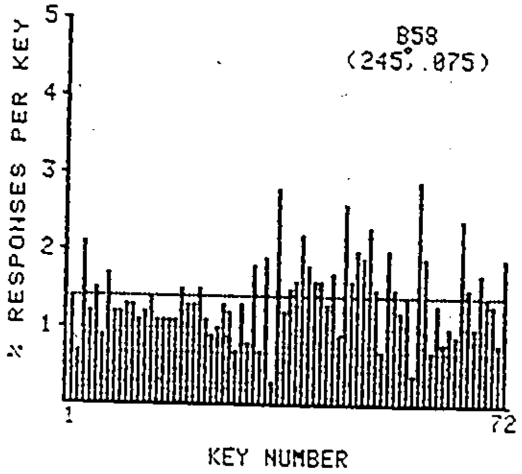
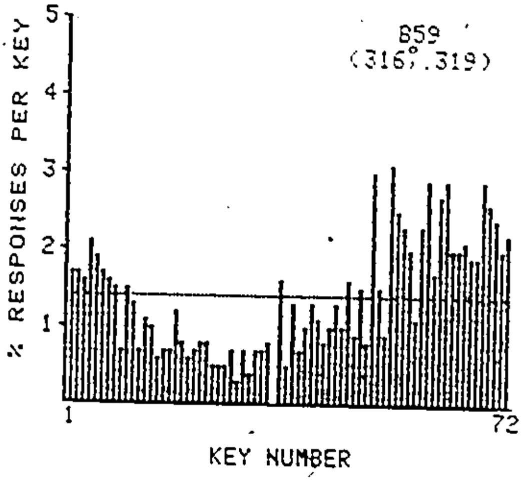

ALL SIX PIGEONS
(12°, .155)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER

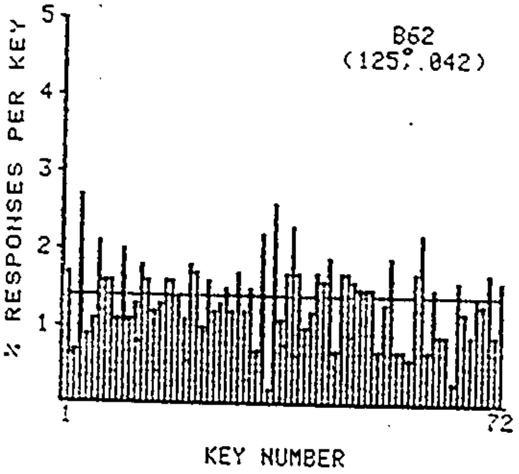
Figure 8. Per cent pecks per key averaged over all 14 daily sessions of RR 5 for each of 6 pigeons in Experiment 1.

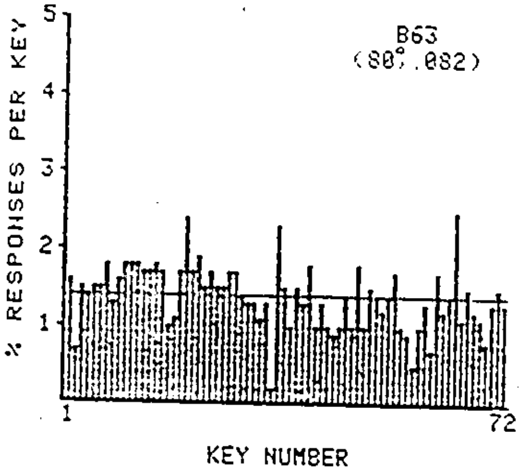

B52
(32°,.263)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B55
(21°,.499)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B58
(245°,.075)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B59
(316°,.319)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B62
(125°,.042)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B63
(80°,.082)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER

on FR 1 is complicated by the different number of trials in a daily session for the two schedules (250 and 50, respectively). The expected value of $r$ (mean vector length) is a function of sample size. Mean vector length is consistently overestimated for any size sample, and the degree of bias is greater the smaller the sample (Batschelet, 1981). Therefore, if one wishes to make a comparison between second-order statistics, one based on 250 observations, and the other based on 50, a correction should be made for bias. Given the "true" distribution of $r$, the bias due to sample size can be estimated and factored out, but the true distribution of $r$ is unknown in the present case.

Comparison of variability of peck location following reinforced trials and following nonreinforced trials is likewise complicated by the different number of trials following reinforcement (approximately 50) and following nonreinforcement (approximately 200) per session. The correction given by Batschelet (1981) is not appropriate for $r<.2$, and depends in addition upon the true concentration of the distribution under consideration (which is unknown, and must be estimated from the data). Therefore, the bias was in effect estimated from the data by calculating a mean vector for all trials on which reinforcement was presented, and another mean vector for trials on which reinforcement was not presented. Presumably, these mean vectors should represent two random samples of all trials from a given pigeon for a given session, differing only in that the numbers of trials are equivalent to the corresponding condition *following* reinforcement and nonreinforcement. These data are presented in Table 1. Pigeons B58, B62, and B63, which displayed no apparent overall concentration of responding in RR 5, showed a very consistent pattern. The value of *r* was approximately .2 on reinforced trials, and approximately .125 on nonreinforced trials. The difference in the two values of *r* were in the expected direction, although they were slightly higher than would be expected by chance. Following reinforced trials, *r* was still about .2; and following nonreinforced trials, it was between .12 and .16 - quite close to, and probably not distinct from, the baseline value. The other three pigeons, which showed a detectable overall mean vector for Place in RR 5, all had a higher average *r* following nonreinforced trials than they did following reinforced trials. Pigeon B52 showed a very slightly higher average *r* following nonreinforced trials than following reinforced trials, but also (by chance) had a higher *r* on nonreinforced than on reinforced trials. Pigeons B55 and B59, however, had, as expected, a slightly higher

### Table 1

### Lengths of Mean Vectors for Place for Each Pigeon Averaged Over All 14 Days of RR5, On and Following Reinforced Trials and Nonreinforced Trials

| PIGEON | ON: |  | FOLLOWING: |  |
|---|---|---|---|---|
|  | Nonreinf. Trials | Reinf. Trials | Nonreinf. Trials | Reinf. Trials |
| B52 | .390 | .358 | .393 | .380 |
| B55 | .720 | .750 | .794 | .552 |
| B58 | .129 | .194 | .162 | .226 |
| B59 | .448 | .503 | .490 | .358 |
| B62* | .106 | .199 | .121 | .192 |
| B63** | .140 | .199 | .151 | .203 |

* Number of daily sessions = 10.
** Number of daily sessions = 13

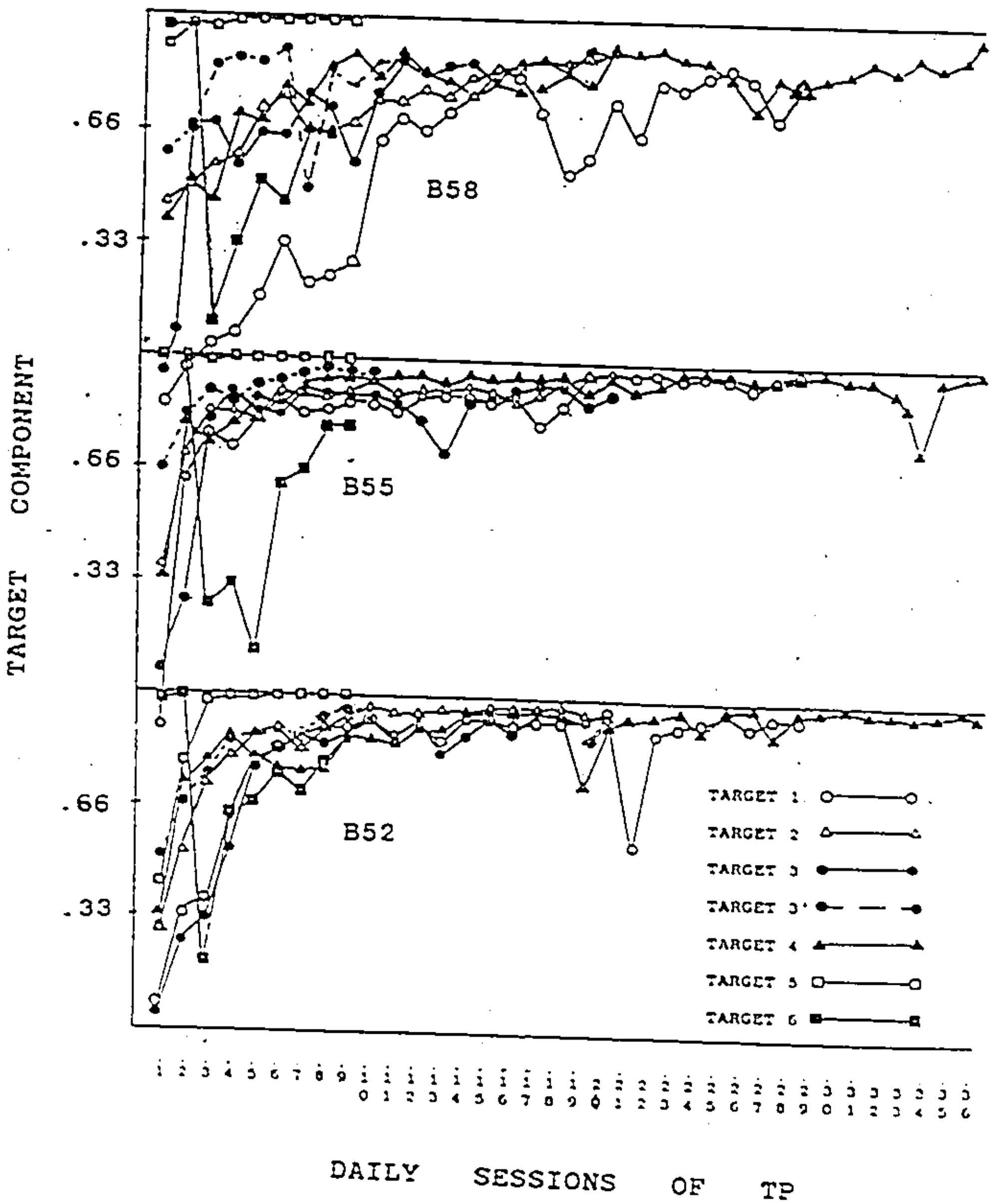
average r on reinforced trials than on nonreinforced trials; but had a substantially higher r following nonreinforced trials than following reinforced trials. That is, for a given session, B55 and B59 tended to peck consistently in a particular place following nonreinforcement, and to peck more diffusely following reinforcement. An important point to note is that the pigeons' behavior was not homogeneous- i.e., three of the pigeons behaved in a particular way, while the rest behaved in a quite different manner. A group mean vector would tend to conceal this difference.

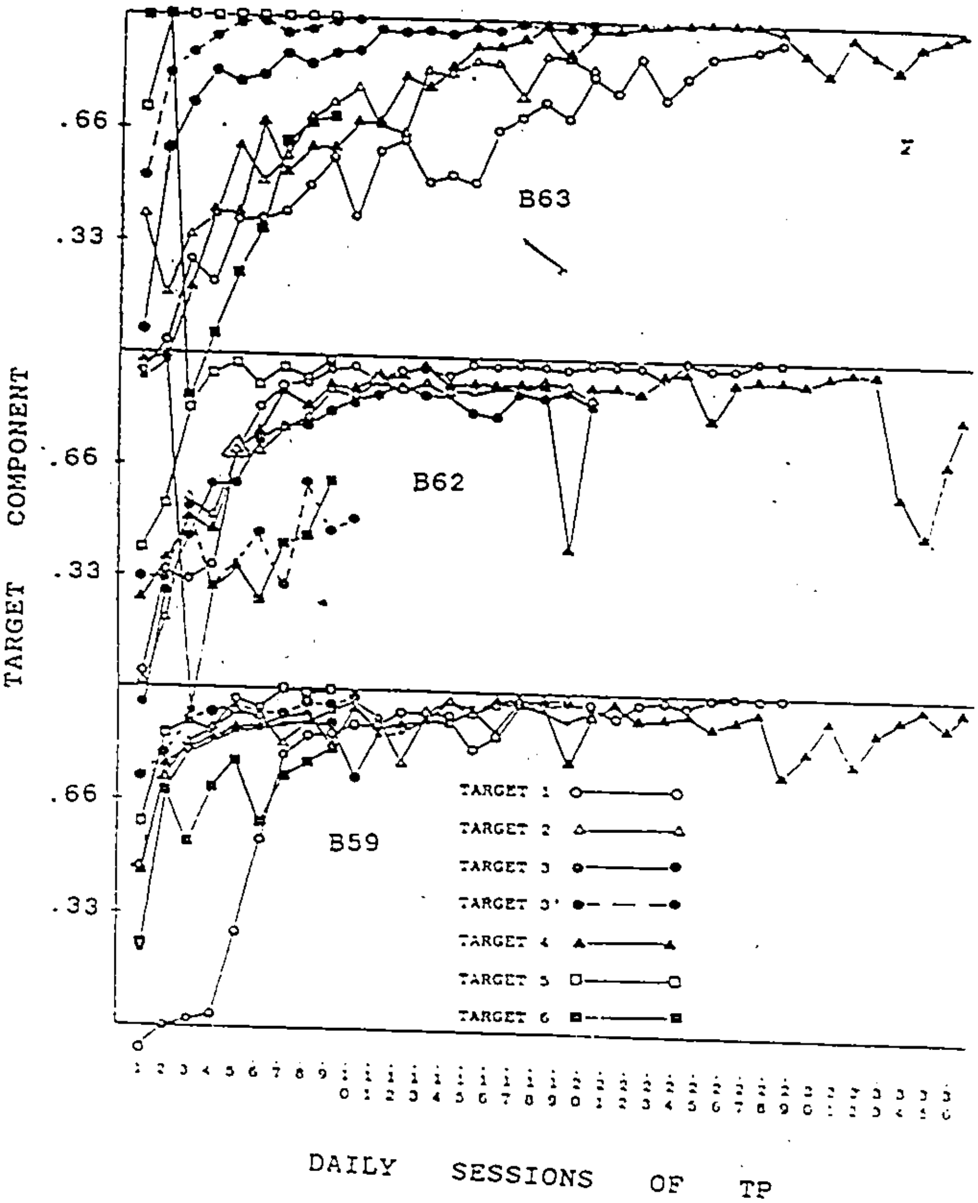
Targeted Percentile

The data for shaping to Target 1 through Target 6 are presented in Figure 9 in terms of target component, with Targets 1 through 6 used successively for each pigeon as the "homeward direction". These data indicate that pecking to each target was acquired smoothly; in an incremental fashion typical of learning curves; and with little evidence of "learning-how-to-learn" over successive targets (except possibly in the case of B63).

The percentile shaping data were also analyzed in terms of daily mean vectors for trials following reinforced trials and for trials following nonreinforced trials, as had been done for RR 5. In order to aid in comprehending the large amount of data, they were

Figure 9. Daily target component for Targets 1 through 6 in TP shaping of Place for each of 6 pigeons in Experiment 1.


.66
.33
B58
.66
.33
B55
.66
.33
B52
TARGET 1
TARGET 2
TARGET 3
TARGET 3'
TARGET 4
TARGET 5
TARGET 6
TARGET COMPONENT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
DAILY SESSIONS OF TP


.66
.33
B63
.66
.33
B62
.66
.33
B59
TARGET COMPONENT
TARGET 1
TARGET 2
TARGET 3
TARGET 3'
TARGET 4
TARGET 5
TARGET 6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
DAILY SESSIONS OF TP

considered in terms of the angle of the daily mean vector and the mean angular deviation separately. The angle of the daily mean vector was taken to represent "accuracy" of pecking, while the mean angular deviation, s, was assumed to represent "variability" around the mean angle. The data for accuracy are presented in Figure 10, plotted in terms of the angles of the daily mean vectors for each pigeon. The data for variability are presented in Figure 11, plotted in terms of the mean angular deviation of the daily mean vectors for each pigeon, corrected for bias due to number of trials. The largest correction was 4°. The majority were 1-2°. The data show that successive targets were <u>not</u> acquired in the same fashion, although the overall measure (target component) would suggest that they were. These data will therefore be described in detail.

For Target 1, the daily mean angle for trials following reinforced trials is within 90° of the target on the first day, and essentially "perfect" after a few days. The daily mean angle following nonreinforced trials takes longer to become accurate (2-6 days), but is also essentially "perfect" from then on. The increases in daily target component following the first few days of TP were therefore due to a decrease in the variability around the target direction, rather than a gradual discovery of

Figure 10. Mean angle for trials following reinforced trials and for trials following nonreinforced trials, for each daily session on Targets 1 through 6 in TP shaping of Place for each of 6 pigeons in Experiment 1.

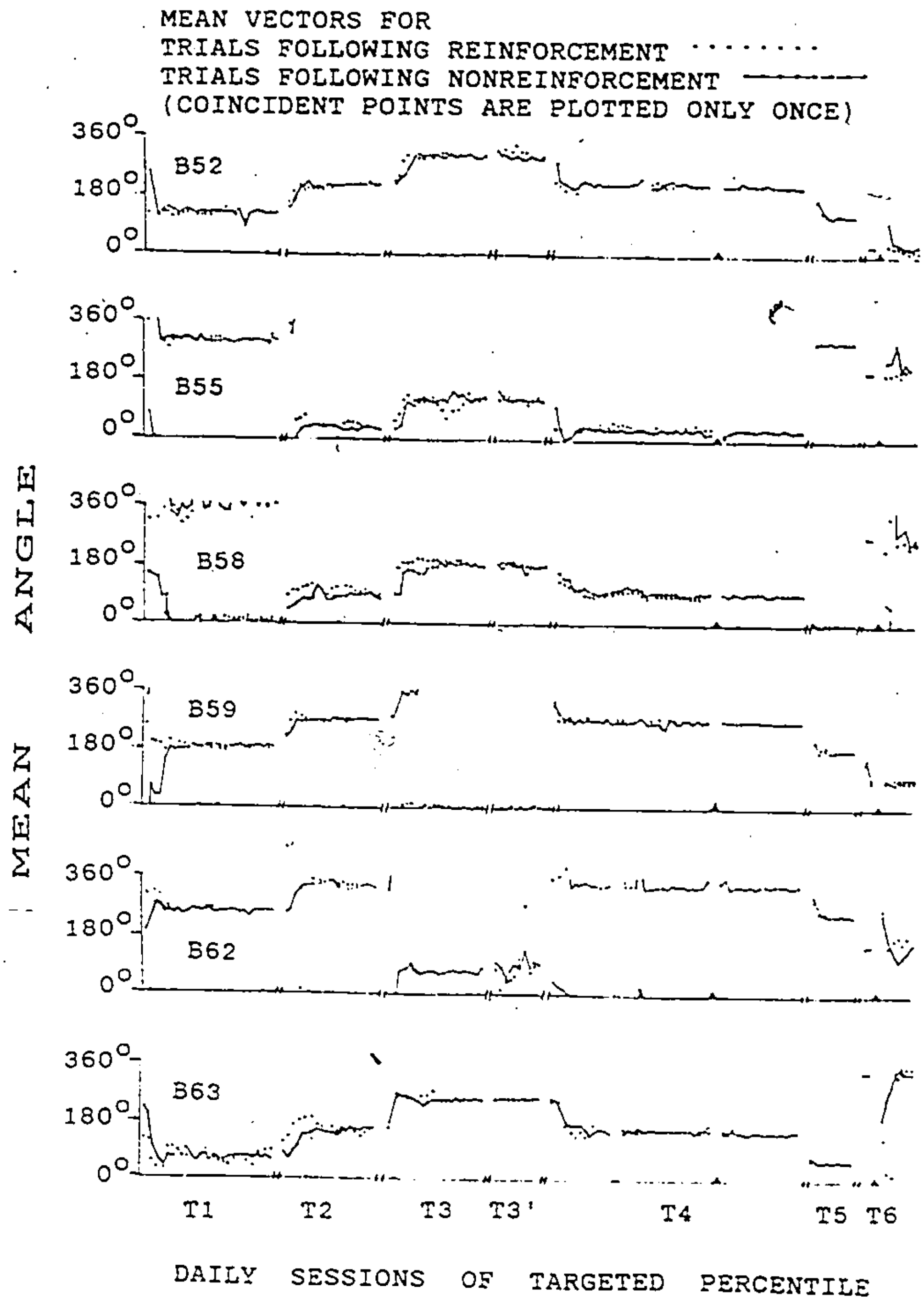
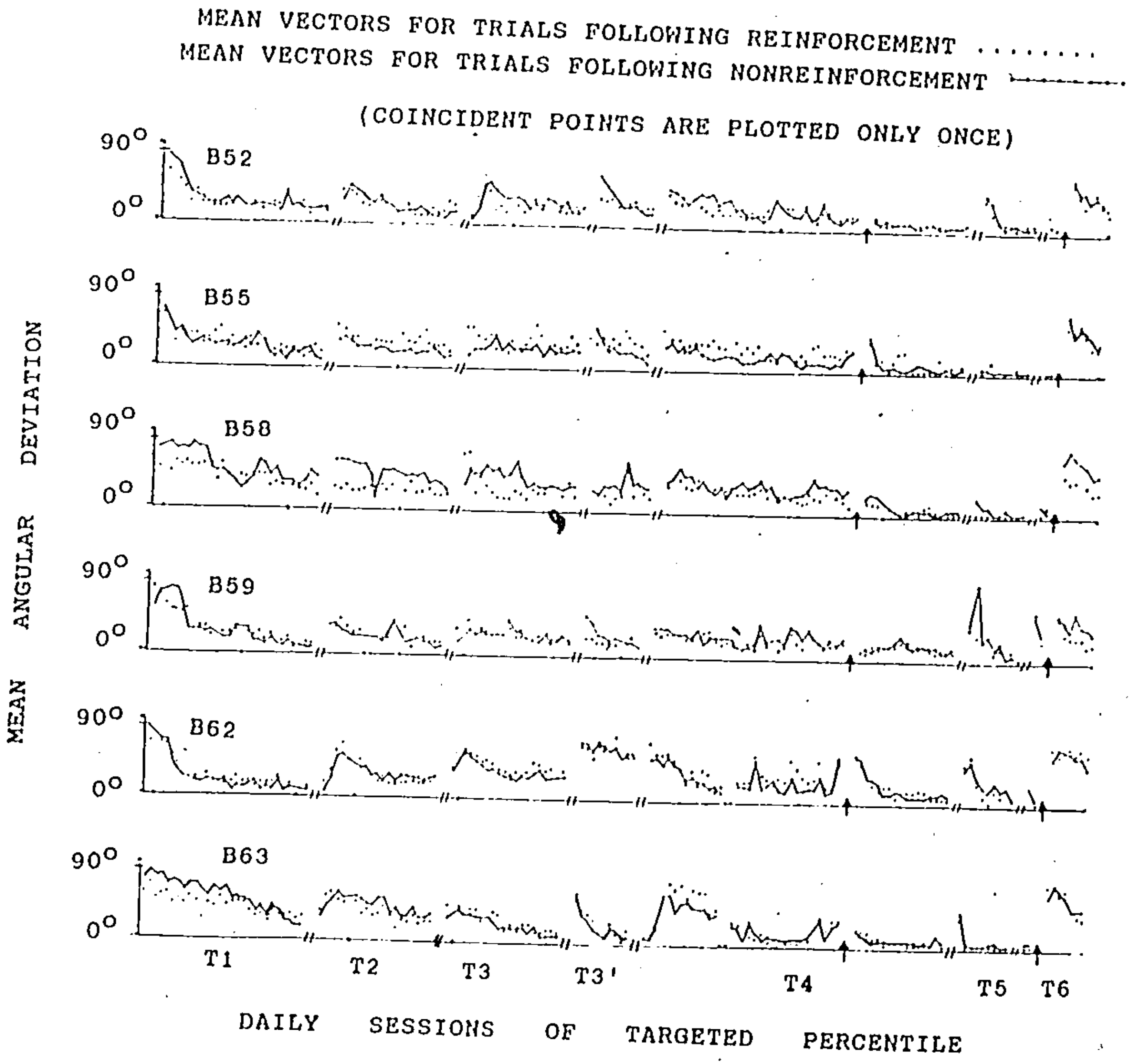

MEAN VECTORS FOR
TRIALS FOLLOWING REINFORCEMENT ········
TRIALS FOLLOWING NONREINFORCEMENT ————
(COINCIDENT POINTS ARE PLOTTED ONLY ONCE)
MEAN ANGLE
360°
180°
0°
B52
B55
B58
B59
B62
B63
T1
T2
T3
T3'
T4
T5
T6
DAILY SESSIONS OF TARGETED PERCENTILE

Figure 11. Mean angular deviation for trials following reinforced trials and for trials following nonreinforced trials, for each daily session on Targets 1 through 6 in TP shaping of Place for each of 6 pigeons in Experiment 1.


MEAN VECTORS FOR TRIALS FOLLOWING REINFORCEMENT ........
MEAN VECTORS FOR TRIALS FOLLOWING NONREINFORCEMENT
(COINCIDENT POINTS ARE PLOTTED ONLY ONCE)
MEAN ANGULAR DEVIATION
90°
0°
B52
B55
B58
B59
B62
B63
T1
T2
T3
T3'
T4
T5
T6
DAILY SESSIONS OF TARGETED PERCENTILE

the target direction. The daily mean angular deviation, s, decreased over sessions, both on trials following reinforcement and on trials following nonreinforcement. The mean angular deviation following nonreinforced trials was higher than that following reinforced trials for the first few days of Target 1, for all 6 pigeons. The variability of trials following reinforcement and trials following nonreinforcement was essentially indistinguishable after this initial period. Variability for both kinds of trials decreased for the entire 28 days on Target 1. The only exception was B63, which continued to show lower variance following reinforced than following nonreinforced trials for the first 24 days, then had lower variance following nonreinforced trials for the last 4 days. Pigeon B58 also generally had lower variance following reinforced trials than following nonreinforced trials throughout Target 1, but was not as consistent as B63.

The shift 90° counterclockwise to Target 2 produced two differences in the angles of the daily mean vectors of trials following reinforced trials, compared to those following nonreinforced trials. The shift to the new target was faster following reinforced trials, and there was an "overshoot" past the new target, followed by a return to the target direction over a period of days.

For B58 and B63, the return to the target direction following the overshoot took about two weeks. In other words, these two pigeons consistently responded at one place following reinforced trials and at another place following nonreinforced trials for at least the first 11 daily sessions of Target 2. Variability around Target 2 was generally lower following reinforced than following nonreinforced trials for B58 and B63, but just as clearly lower following nonreinforced trials for B55.

The next shift, 90° counterclockwise to Target 3, produced faster shaping of direction than had occurred to Target 1 or Target 2, and an overshoot in direction following reinforced trials, although it was attenuated compared to the overshoot the pigeons had shown when shifted to Target 2.

Replacement of the transparent top by the translucent top, with no change in target direction, was considered to be Target 3'. This change apparently forced the pigeons to relearn the target. For every pigeon, the daily target component dropped from .8 - .9 on the last day of Target 3 down to .33 - .75 on the first day of Target 3'. However, this manipulation had essentially <u>no effect</u> on direction of pecking following either reinforced or nonreinforced trials, except in the case of B62. This pigeon displayed more variability in mean direction from day to day following both reinforced and nonreinforced trials (but still within 30° or less from the target direction) after the translucent top was installed. There were immediate, large effects upon variability around the target, as measured by s. Pigeons B55 and B59 showed large increases in variability following nonreinforced trials. Pigeons B52, B62, and B63 showed large increases in variability following both reinforced and nonreinforced trials, but the effect was larger following nonreinforced trials. Variability around the target direction decreased over sessions on Target 3', following both reinforced and nonreinforced trials. As usual, variability was generally lower following nonreinforced trials for B55. Pigeon B58 showed an atypical decrease in s, at least on trials following nonreinforced trials, for two days following installation of the translucent top.

A 90° clockwise shift to Target 4 produced faster shaping to the target direction following reinforced trials than following nonreinforced trials. Shifting to Target 4 also produced an overshoot of direction on trials following reinforced trials, which was slight, but evident in all of the pigeons (see particularly B58). The rotations of the chamber, top, and white-noise speaker carried out during Target 4 had minimal effects. The only pigeon that showed a change in mean direction due to these manipulations was B62. (Pigeon B62 was also the only pigeon which showed disruption of the mean direction when the translucent top was installed.) Placing strips of black tape on the two target keys caused a slight initial disruption of mean angle, followed by extremely accurate direction of responding, together with a decrease in s down to 8-10°.

A further 90° clockwise rotation, to Target 5, with the target keys marked from the start with strips of black tape, produced essentially perfect directional responding from the first day for three of the pigeons-B55, B58, and B63. Variability around the mean direction was very low for these pigeons, and took at most two days to reach its asymptotic level. The other three pigeons took two to three daily sessions to achieve accurate directional responding. Variability around the mean direction decreased gradually for these three pigeons, reaching 10° or less by the end of Target 5.

The last target, Target 6, shifted 90° clockwise, was marked with the tape strips for two days, then left unmarked for the last seven days. Mean angle of response was essentially perfect on the first two days for five of the pigeons. Variability around the mean angle was also quite low for these five pigeons, particularly on the second day. Pigeon B59 displayed a less rapid shift, with a mean angle 50° off on the first day, but within a few degrees of the target on the second day. Variability around the mean angle was more than 50° on the first day, and 20-30° on the second day for B59.

When the tape was removed from the target keys for the last seven days of Target 6, the correct mean angle was maintained following both reinforced and nonreinforced trials by only one pigeon, B59. Pigeons B52 and B55 maintained the correct mean angle following reinforced trials, but the mean angle following nonreinforced trials was displaced toward the previous target, Target 5. The mean angle following both reinforced and nonreinforced trials was displaced for the other three pigeons- B58, B62, and B63. For B62, the mean angle following both reinforced and nonreinforced trials on the first post-tape day was very close to the previous target; Target 5. For pigeons B58 and B63, however, the mean angle was not displaced close to Target 5, but rather to the vicinity of Target 4, which was 180° from Target 6. Each of these two pigeons then shaped to the target angle from opposite directions following reinforced and following nonreinforced trials. Variability increased immediately upon removal of the tape, to levels which had not occurred since Target 1, and decreased gradually over days for all pigeons (except for trials following reinforcement for B62, which stayed high). Variability following reinforced trials was clearly lower than that following nonreinforced trials for B58 and B59, while B52, B55, and B63 showed no evident differences in variability following reinforced and nonreinforced trials.

## DISCUSSION: PLACE

Three out of the six pigeons in this experiment appeared to show some stereotypy of response location in both FR 1 and RR 5, as shown by daily mean vector length and consistency of mean vector direction over days. These three pigeons also took the least number of sessions to shape to peck the keys. The development of this stereotypy was gradual, it persisted for some number of sessions, and then it dissipated, sometimes to occur again at some other place in the chamber.

Stereotypy was consistently much higher on the TP schedules than on FR 1 or RR 5, showing that differential reinforcement controlled location of responding in this situation. Also, the similarity of acquisition rates and asymptotic response levels for the 12 different target directions suggests that they were all "functionally equivalent operants".

When the transparent cover was replaced by the translucent cover, performance on TP, measured by target component, reverted almost to baseline. The differentiation apparently had to be reacquired. This might suggest that the pigeons were orienting themselves by means of room cues seen through the top, and had to re-orient themselves by other cues when the room cues were removed. However, closer analysis showed that installing the translucent top had little if any effect upon the angle of the mean vector, which remained very close to the target angle. Installing the translucent top instead increased the variability around the target angle, particularly following nonreinforced trials. Since the mean angle did not change, it is unlikely that the increase in variability was simply due to a decrease in available cues. This increase in variability would make sense if viewed as a response strategy adopted when a radical change of stimulus conditions is encountered. I feel that this interpretation would be overgeneralizing from these data. The increase in variability is, however, consistent with the system proposed by Staddon and Simmelhag (1971). These investigators predict that any change in the experimental conditions will produce a shift away from centripetal selection and hence to increased variability.

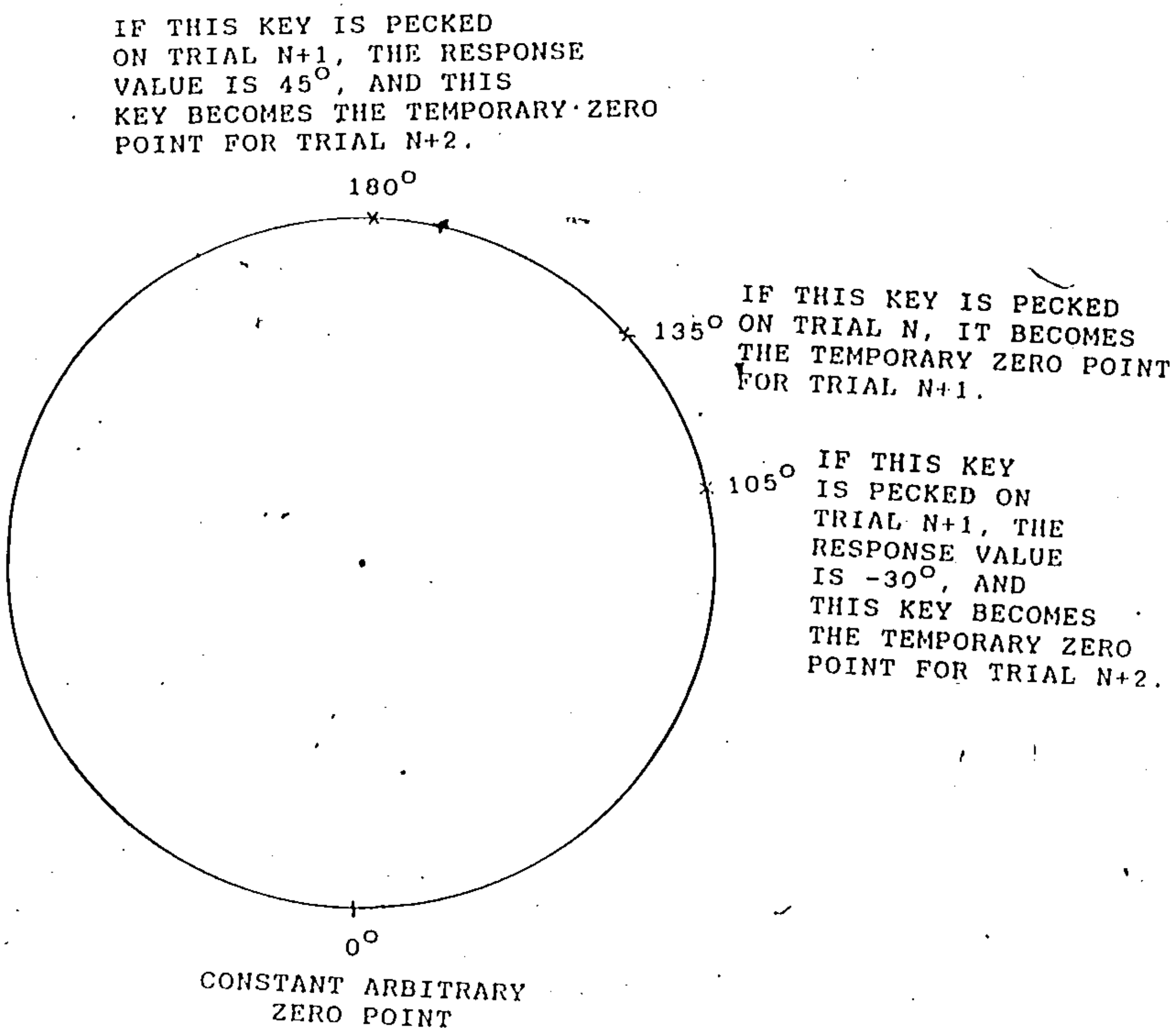
When the target keys were marked with tape, the pigeons produced mean vector lengths in excess of .99, since pecking was mainly restricted to the two target keys. All of the pecks were not made on the target keys, however, and those that were not formed an apparent spatial generalization gradient around the target keys. When the tape strips were removed, performance reverted to baseline and the differentiation had to be reacquired. Both accuracy and variability were affected, following both reinforced and nonreinforced trials. This implies that the pigeons had been attending almost exclusively to the tape, and had to find new cues for location when the tape was removed. When the translucent top was in place, rotation of the top alone carried responding along in the direction of rotation for two of the pigeons, indicating that these pigeons were using cues associated with the top to differentiate responding to place. Rotation of the entire apparatus and shifting the white noise source had no discernable effect upon location of responding. This suggests that the white noise and other uncontrolled stimuli were not effective cues for location.

The results of FR 1 do not support the Law of Effect, in that a <u>progressive</u> stereotypy of response location (Place) was not found. If FR 1 had not been conducted for 42 days, but rather had been halted after 10 or 20 days, one or more of the pigeons might have appeared to display a progressive stereotypy. On the other hand, some degree of transient Place stereotypy was found. In all cases, targeted percentile shaping produced a high degree of Place stereotypy, with steep unimodal distributions of pecks per key centered around the targets.

The level of Place stereotypy under conditions of nondifferential reinforcement was disappointingly low in this experiment. However, it was noted that successive pecks appeared to be related, in that each pigeon seemed to move in a consistent direction at a consistent angle from trial to trial. Therefore, a second measure, the deviation of each peck from the peck before it, was also analyzed (Figure 12). This measure was named Response by analogy with the analysis of Place and Response learning in studies with rats in t-mazes. (It was debated for a number of years whether rats learned to turn left or turn right in a t-maze (Response), or to turn toward landmarks either in the maze or in the surrounding room (Place) (e.g., Restle, 1957).)

In this experiment, it was observed that the pigeons, once they had pecked a key and the food magazine had been raised, would proceed on a bee-line to the

Figure 12. Comparison of the Place and the Response measure.


IF THIS KEY IS PECKED ON TRIAL N+1, THE RESPONSE VALUE IS 45°, AND THIS KEY BECOMES THE TEMPORARY ZERO POINT FOR TRIAL N+2.
180°
135°
IF THIS KEY IS PECKED ON TRIAL N, IT BECOMES THE TEMPORARY ZERO POINT FOR TRIAL N+1.
105°
IF THIS KEY IS PECKED ON TRIAL N+1, THE RESPONSE VALUE IS -30°, AND THIS KEY BECOMES THE TEMPORARY ZERO POINT FOR TRIAL N+2.
0°
CONSTANT ARBITRARY ZERO POINT

feeder. They would therefore be oriented with their beaks 180° from the key they had last pecked. It was considered quite possible that the pigeons were stereotyping their turns from the food cup to orient to and approach the keys for their next peck. If the pigeons were doing this, at any angle other than 0°, it would tend to spread their pecks around the response strip. This behavior could interfere with potential Place stereotypy.

The questions asked were whether the Response measure showed appreciable stereotypy; and if it did, whether this stereotypy increased as a function of number of sessions of FR 1 and RR 5, as the Law of Effect would predict if Response were affected by reinforcement.

## RESULTS: RESPONSE

### Fixed Ratio 1

The basic measure used in analyzing Response was obtained by using the location of the pigeon's peck on trial n as the zero point for trial n+1, rather than the fixed arbitrary zero point used to analyze Place (see Figure 12). This measure, like Place, is a circular variable. It has a possible range from -180° to

+180°. The expected value of r (given random responding) is 0.0, since the probability of any given key being used on any given trial is assumed to be the same for all of the keys (namely, .01388...).

The Place and Response measures are statistically independent (in the long run, given random sampling). In order to make sure that they were independent as I calculated them, I constructed 600 data files of 250 trials of RR 5 data, using a random selection of direction and "reinforcement" or "nonreinforcement", and a unit vector for each trial. I then analyzed them for Place and Response, following reinforced and following nonreinforced trials. The mean r for Place was .062 following nonreinforced trials, and .126 following reinforced trials. The mean r for Response was .063 following nonreinforced trials, and .120 following reinforced trials. These data agree with the expectations from the Rayleigh Test (Batschelet, 1981, Table H). This shows that Place and Response, following reinforced and following nonreinforced trials, are independent as calculated in these studies. However, Place and Response may be related if the pigeons do not sample directions or locations at random. A strong tendency to peck in one area of the spatial continuum will not only produce a high mean vector for Place, but also a high mean vector for

Response, around $0^{\circ}$. A tendency to peck diffusely, in all areas of the continuum, will produce a low mean vector for Place, but not necessarily any particular mean vector for Response. Conversely, a strong tendency to make turns of $0^{\circ}$ will produce a high mean vector for Response and probably, but not necessarily, a high mean vector for Place. A strong tendency to make turns at any angle other than $0^{\circ}$ will produce a high mean vector for Response and a low mean vector for Place, as noted above. A tendency to turn at a number of different angles will produce a low mean vector for Response, and probably, but not necessarily, a low mean vector for Place.

The analysis of Response will parallel that for Place. Thus, the first step in analyzing Response is to determine whether the pigeons, as a group, had a tendency to turn in any particular direction from their last keypeck. Figure 13 shows the mean vectors for Response summed over all of FR 1 for each pigeon, and for all of the pigeons (as a group mean vector). These overall mean vectors are substantially longer than the corresponding vectors for Place.

Figure 14 shows the overall distribution of per cent Responses per $5^{\circ}$ interval, summed over pigeons and over sessions. Apparently, there was some tendency for the pigeons to make similar turns from the food

Figure 13. Mean vectors for Response averaged over all 42 daily sessions of FR 1 for each of 6 pigeons, and the grand mean vector (represented by the dot) averaged over all 6 pigeons in Experiment 1.

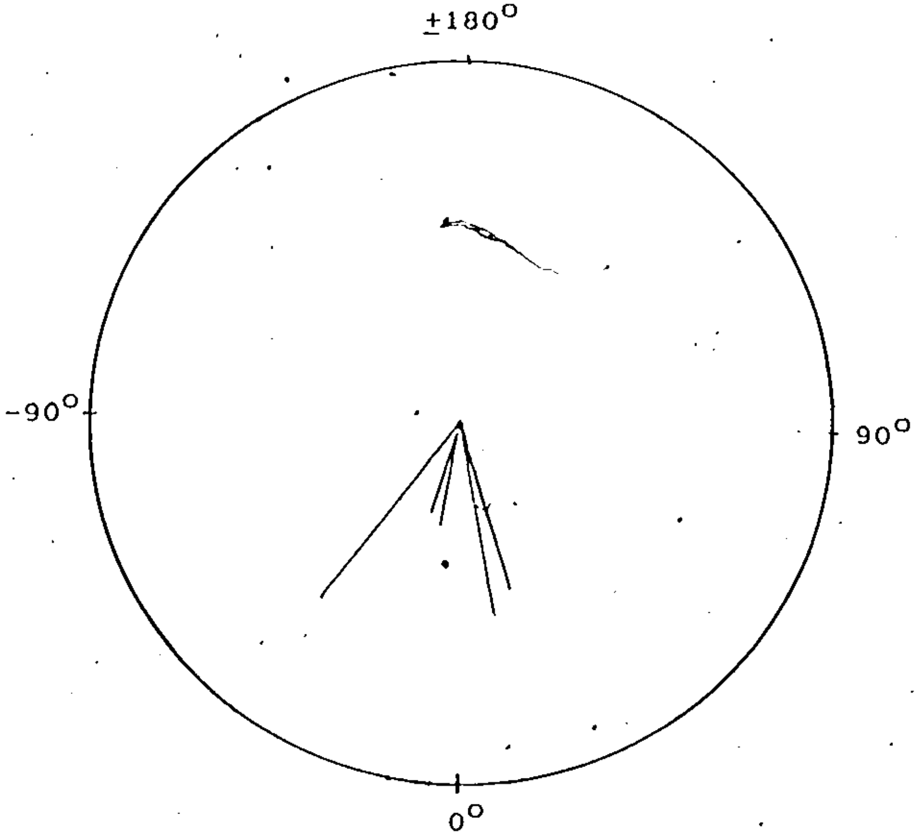
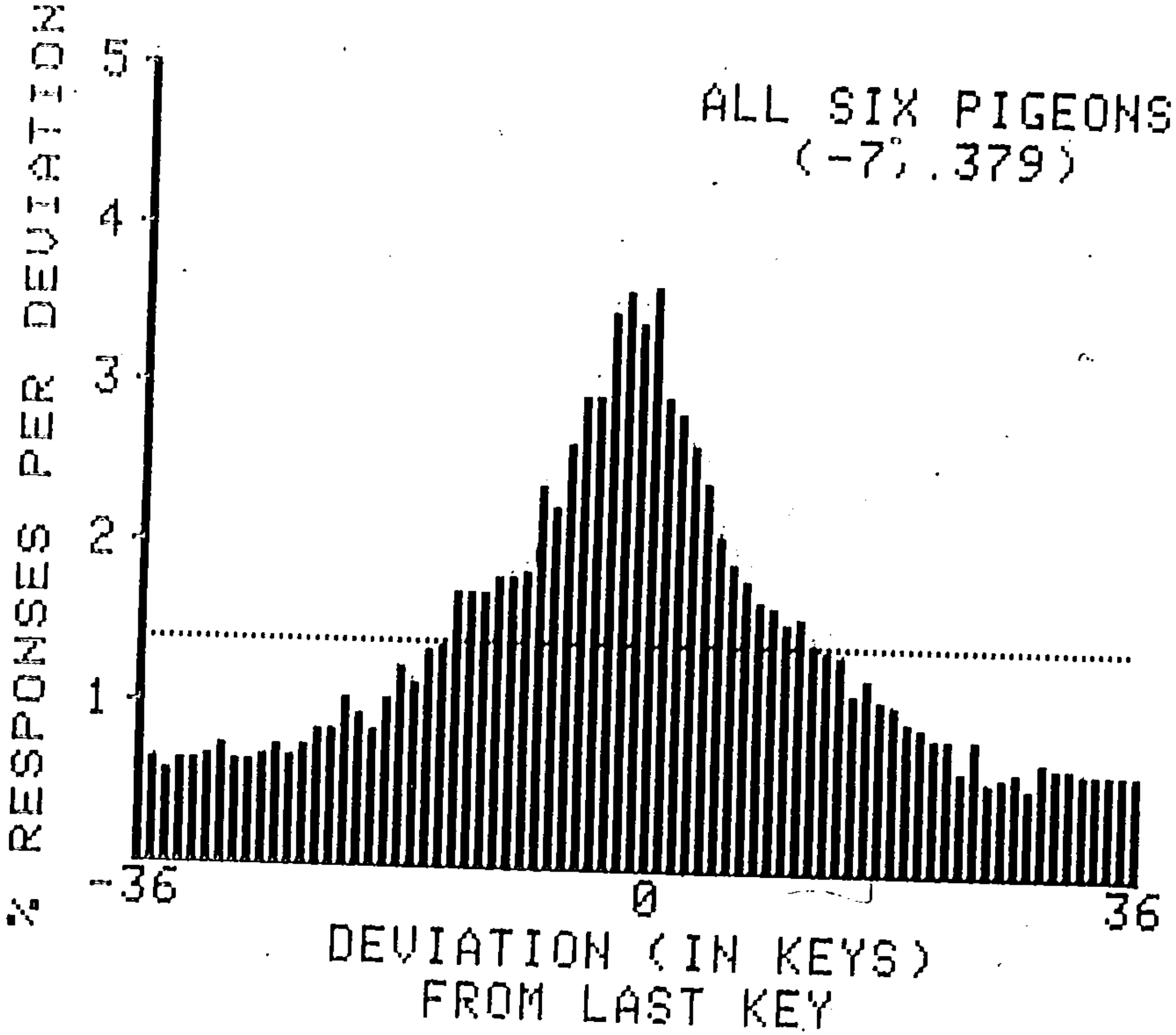

±180°
-90°
90°
0°

Figure 14. Per cent Responses per $5^{o}$ interval, averaged over all 42 daily sessions of FR 1 and all 6 pigeons in Experiment 1.

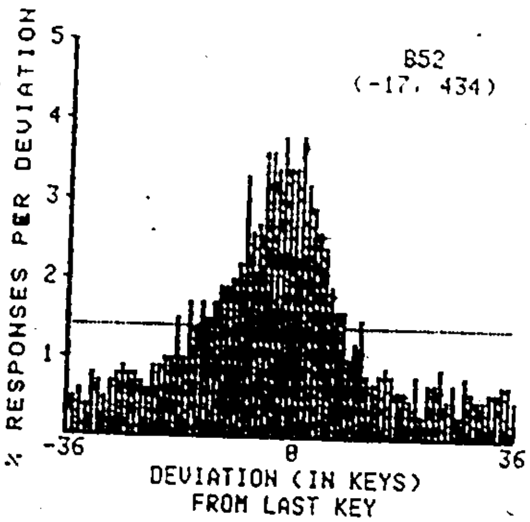

ALL SIX PIGEONS
(-7°, .379)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

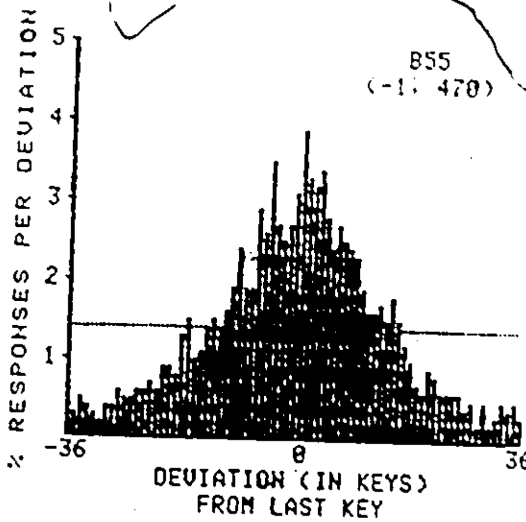
magazine, since the mean vector is (-7°, .379).

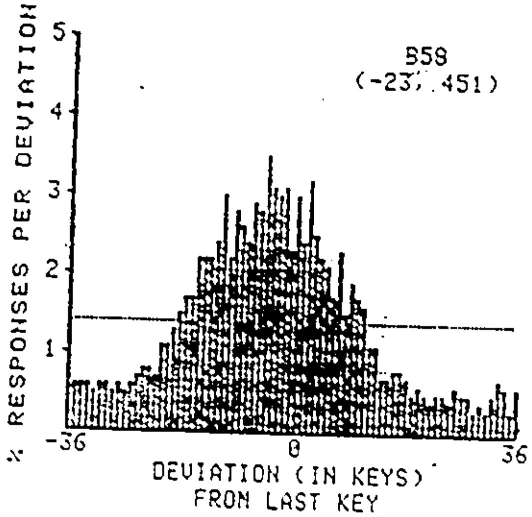
Since there was a tendency for the pigeons as a group to make turns of similar size and direction, the next question was whether all the pigeons had a weak tendency to turn in the same direction, or whether each had a somewhat stronger tendency to turn in a different but still similar direction. Figure 15 presents the Response data for each pigeon, summed over all 42 sessions of FR 1. For every pigeon, the mean vector was longer for Response than it was for Place. For all of the pigeons, even those with relatively short Response mean vectors, the cumulated responses form a distinct distribution with a mean close to, but <u>not</u> equal to, 0°. The only exception was B59. This pigeon had a bimodal distribution, with a sharp peak clockwise at approximately -10°, and a much smaller peak counterclockwise at approximately 60°.

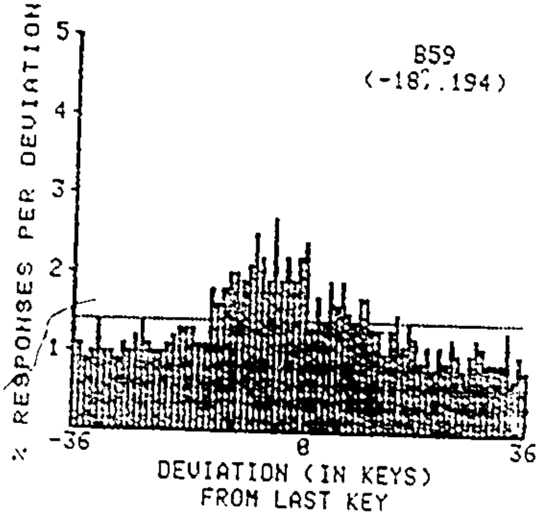
These measures show that there was not only an overall tendency for the pigeons as a group to make similar turns, but that each pigeon had a tendency to make a given size turn, summed over all of FR 1. They do not show, however, whether there were progressive changes in Response over sessions. The first step, as in the analysis of Place, was to assess any group changes in Response as a function of sessions. These data are

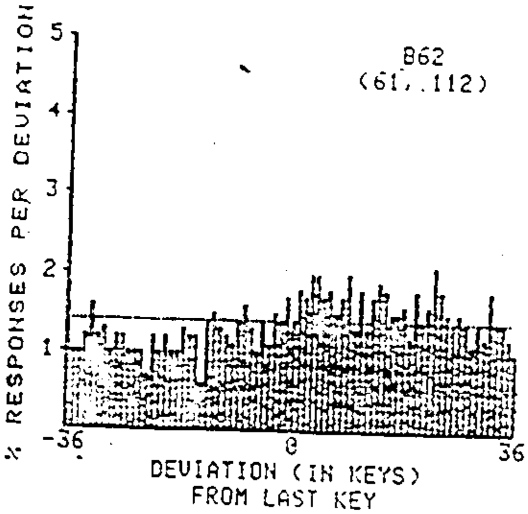
Figure 15. Per cent Responses per 5° interval averaged over all 42 daily sessions of FR 1 for each of 6 pigeons in Experiment 1.

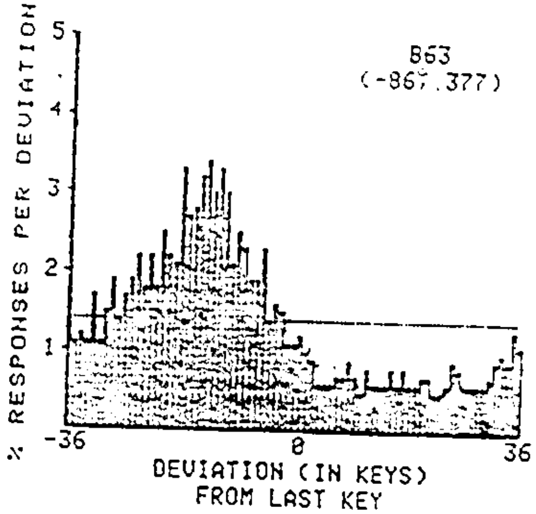

B52
(-17, 434)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY


B55
(-1, 470)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY


B58
(-23, .451)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY


B59
(-18, .194)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

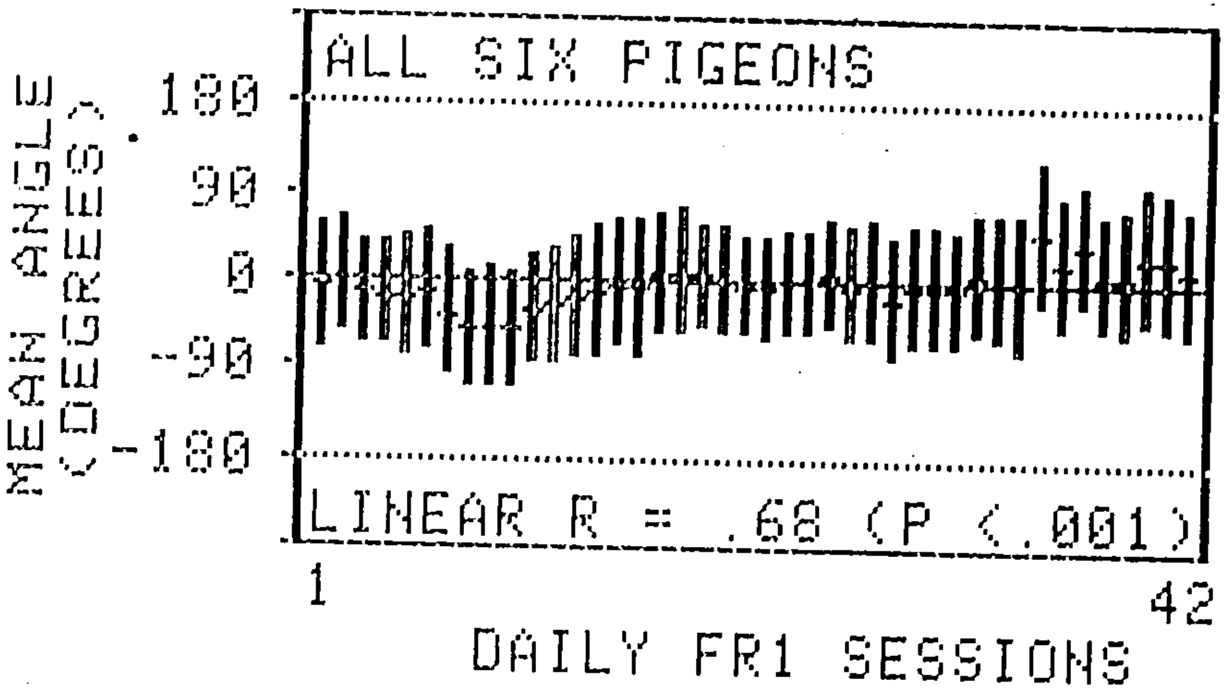

B62
(61, .112)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY


B63
(-86, .377)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

presented in Figure 16, plotted in terms of mean angle and *s*. They show that there was, indeed, a tendency for the pigeons as a group to make similar turns for any given session, and that these daily group mean vectors varied in an orderly fashion over sessions. Variability did not change greatly as a function of days, starting at around 70°, dropping to around 65° between sessions 15-35, and finishing again at around 70°. The mean angle, however, showed a progressive change over sessions. Since all of the mean angles were close to 0°, a linear correlation was calculated between daily mean angle and days (Batschelet, 1981). A Pearson product-moment correlation of .68 was found between the daily group mean Response angle and sessions. The probability of a relationship of this magnitude occurring by chance is less than .001. The best-fitting straight line through the daily mean angles had a slope of 1.17, and an intercept of -30°, showing that the mean angle was clockwise at the beginning of FR 1 and steadily became more counterclockwise over sessions.

Thus, each pigeon had a tendency to make a particular idiosyncratic Response. The individual Response tendencies, although not the same, were similar. Therefore, the pigeons as a group had some tendency to make a particular Response. The interesting question,

Figure 16. Group mean vectors for Response for each of 42 daily sessions of FR 1 averaged over all 6 pigeons in Experiment 1. The data are plotted in terms of the mean angle ± the mean angular deviation.


ALL SIX PIGEONS
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
LINEAR R = .68 (P <.001)
1
42
DAILY FR1 SESSIONS

however, is whether each individual pigeon not only had a preferred Response, but whether that Response showed progressive stereotypy over daily sessions. The daily mean vector for Response for each pigeon is shown as a function of daily sessions of FR 1 in Figure 17, in terms of mean angle and the mean angular deviation, s. These data show that s was lower for Response than it was for Place, for every pigeon, for almost every day; and that although the mean angle drifted or oscillated, the mean angles were very similar from day to day.

Although it appears from Figure 17 that s did not change much over sessions, it is difficult to be sure about this. Figure 18 shows s alone as a function of sessions for each pigeon. Comparison of Figure 18 with Figure 6 emphasizes the lower variability of the Response measure compared to the Place measure. There is no evidence of a decrease in variability over sessions, however. Indeed, for pigeons B52 and B58, there was an obvious increase in variability over sessions.

## Random Reinforcement 5

Mean Response vectors were summed across all six pigeons for all 14 sessions of RR 5. These data, for 19,916 trials of RR 5, are shown in Figure 19. The grand mean vector for Response was approximately (-22°, .289), showing a tendency for the pigeons as a group to

Figure 17. Mean vectors for Response for each of 42 daily sessions of FR 1 for each of 6 pigeons in Experiment 1. The data are plotted in terms of the mean angle ± the mean angular deviation.

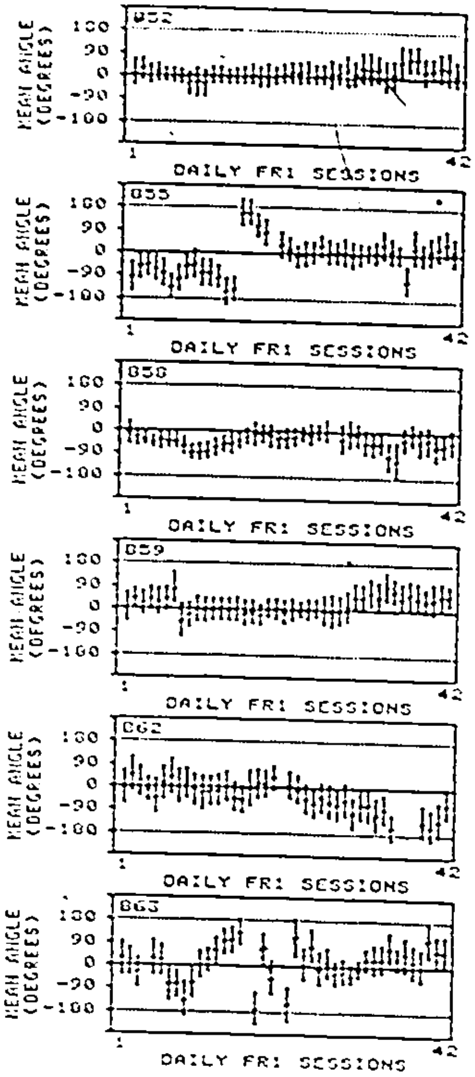
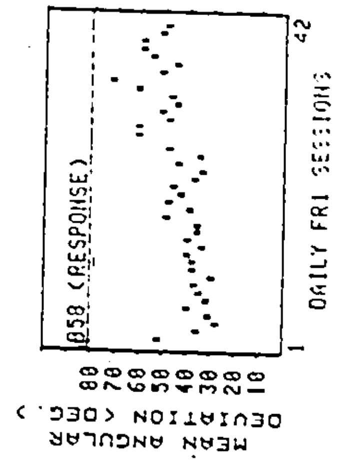
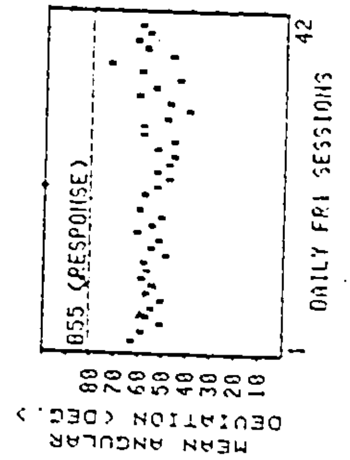

B52
MEAN ANGLE (DEGREES)
100
90
0
-90
-100
1
42
DAILY FRI SESSIONS
B55
MEAN ANGLE (DEGREES)
100
90
0
-90
-100
1
42
DAILY FRI SESSIONS
B58
MEAN ANGLE (DEGREES)
100
90
0
-90
-100
1
42
DAILY FRI SESSIONS
B59
MEAN ANGLE (DEGREES)
100
90
0
-90
-100
1
42
DAILY FRI SESSIONS
B62
MEAN ANGLE (DEGREES)
100
90
0
-90
-100
1
42
DAILY FRI SESSIONS
B63
MEAN ANGLE (DEGREES)
100
90
0
-90
-100
1
42
DAILY FRI SESSIONS

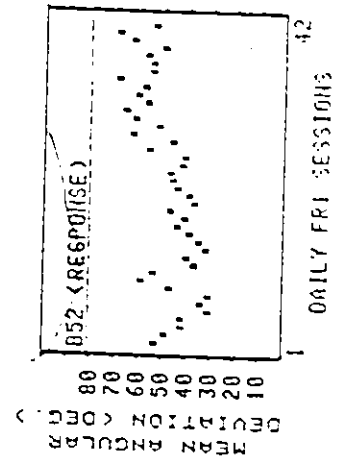
Figure 18. Mean angular deviations for Response for each of 42 daily sessions of FR 1 for each of 6 pigeons in Experiment 1.



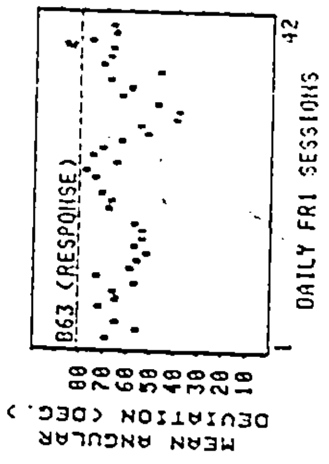
B58 (RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
DAILY FRI SESSIONS
1
42



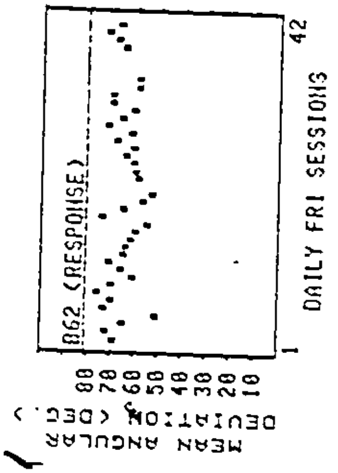
B55 (RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
DAILY FRI SESSIONS
1
42



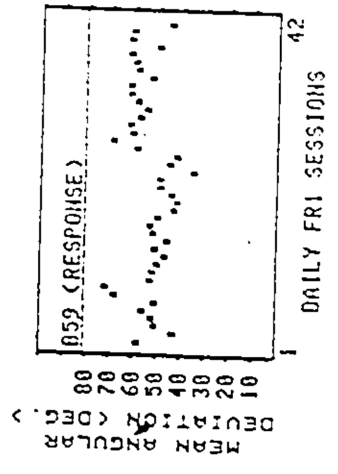
B52 (RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
DAILY FRI SESSIONS
1
42



B63 (RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
DAILY FRI SESSIONS
1
42

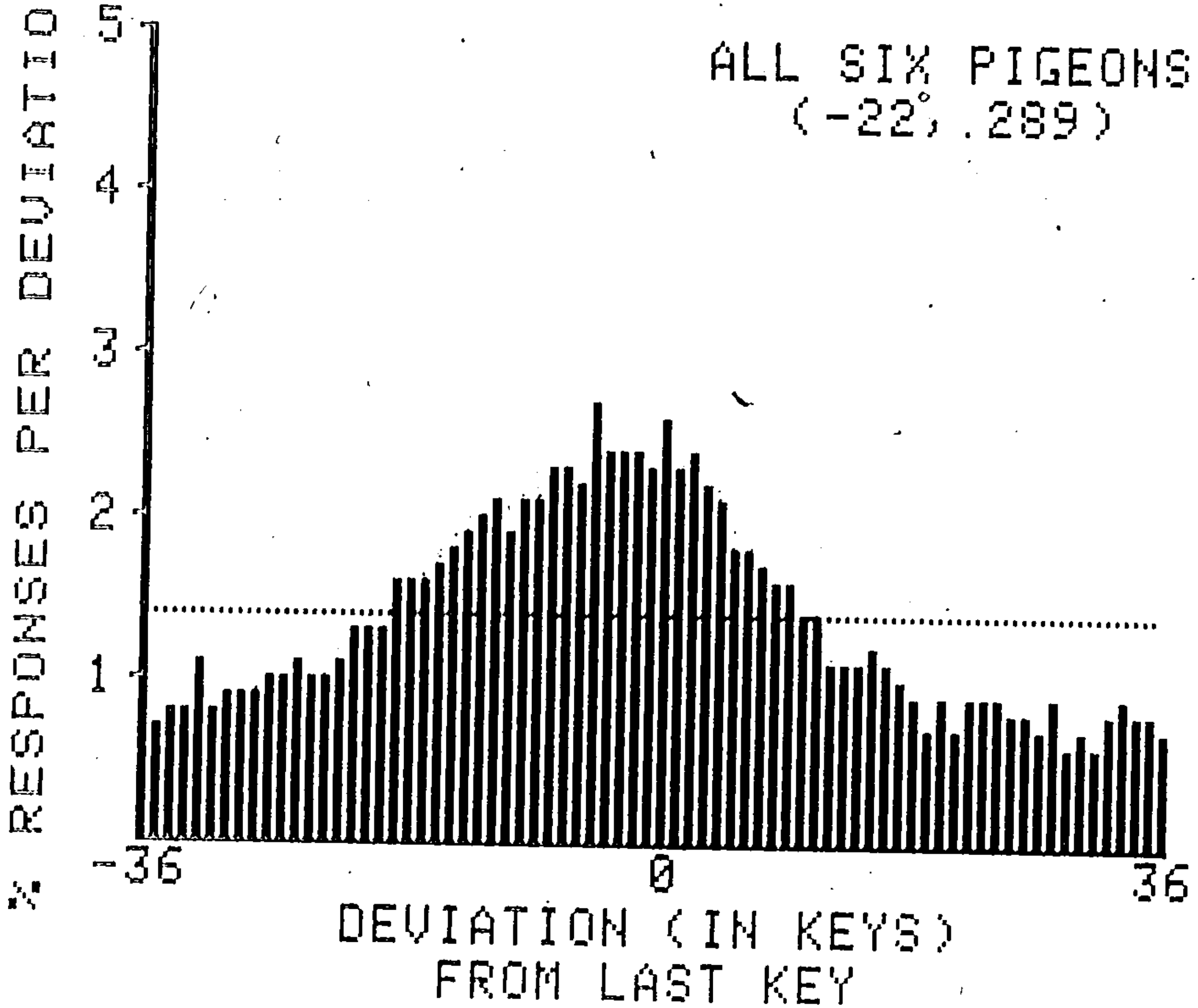


B62 (RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
DAILY FRI SESSIONS
1
42



B59 (RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
DAILY FRI SESSIONS
1
42

Figure 19. Per cent Responses per $5^{\circ}$ interval averaged over all 14 daily sessions of RR 5 and all 6 pigeons in Experiment 1.

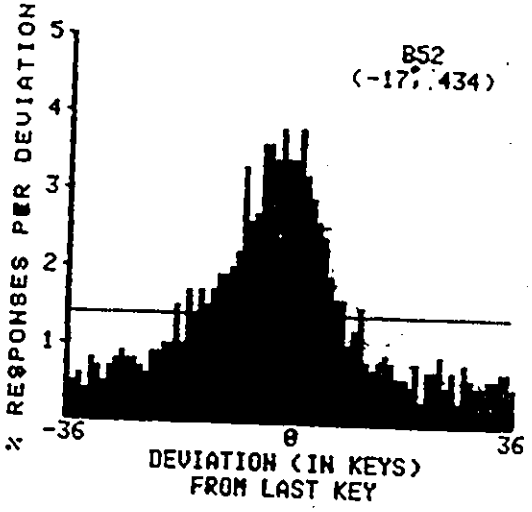

ALL SIX PIGEONS
(-22°, .289)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

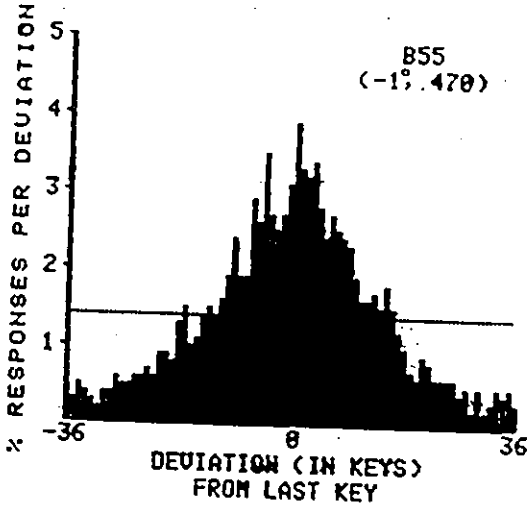
turn in a particular direction in RR 5, but with slightly more variability and farther from 0° than in FR 1.

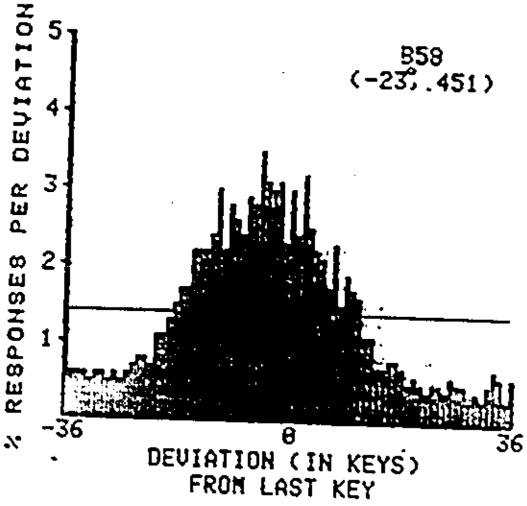
Distributions for Response summed over all of RR 5 are presented for each pigeon in Figure 20. Two pigeons, B55 and B63, displayed a higher mean vector length for Response in RR 5 than in FR 1; while the other four pigeons, B52, B55, B59, and B62, displayed a lower mean vector length in RR 5 than in FR 1.

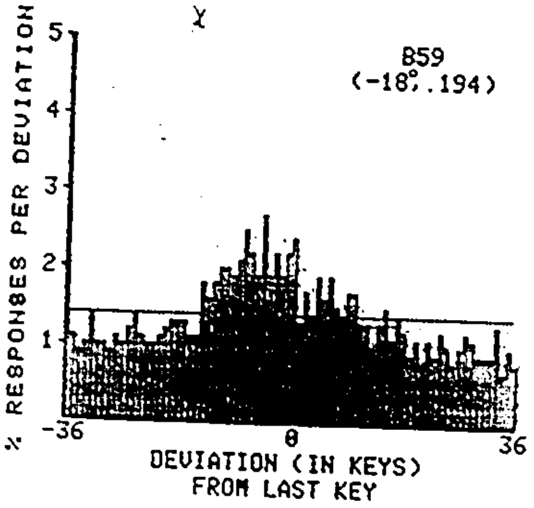
Comparison of Response (summed over all of RR 5) following reinforced and nonreinforced trials is complicated by the different number of reinforced and nonreinforced trials in a session. Therefore, these data are compared, in Table 2, to Response <u>on</u> reinforced and nonreinforced trials. The mean vectors <u>on</u> reinforced and nonreinforced trials are quite similar in both length and angle, showing a maximum difference in length of .06, and in angle of 16°. The mean vectors for trials <u>following</u> reinforced trials were generally considerably longer than those following nonreinforced trials, with the exception of pigeons B55 and B63, which had slightly longer mean vectors following nonreinforced trials. Pigeons B55 and B63 were also the only two birds that had an increase in overall mean vector length for Place in RR 5 compared to FR 1. The mean vectors for trials following reinforced trials were also closer to

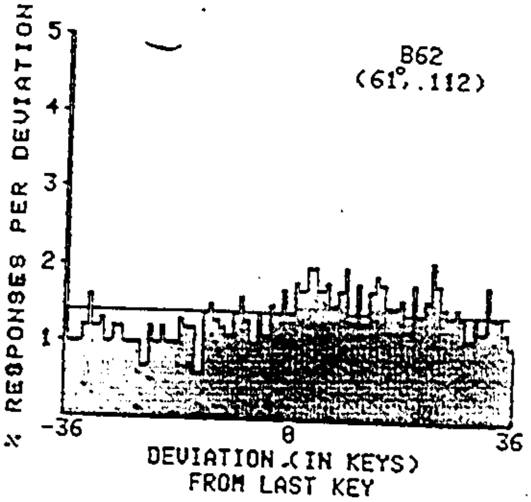
Figure 20. Per cent Responses per $5^{\circ}$ interval averaged over all 14 daily sessions of RR 5 for each of 6 pigeons in Experiment 1.

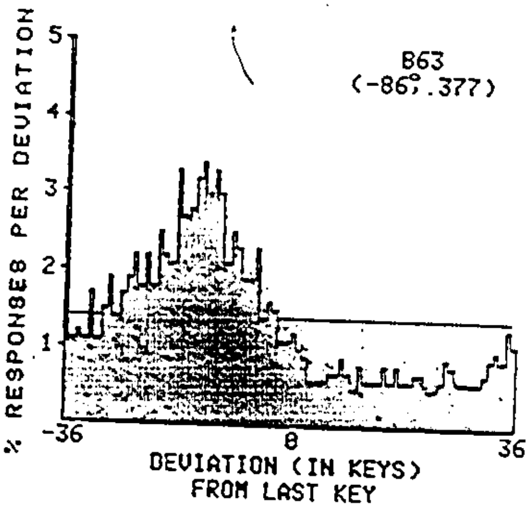

B52
(-17°, .434)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY


B55
(-1°, .470)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY


B58
(-23°, .451)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY


B59
(-18°, .194)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY


B62
(61°, .112)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY


B63
(-86°, .377)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

## Table 2

### Lengths of Mean Vectors for Response for Each Pigeon Averaged Over All 14 Days of RR5, On and Following Reinforced Trials and Nonreinforced Trials

| PIGEON | ON: | | FOLLOWING: | |
|---|---|---|---|---|
| | Nonreinf. Trials | Reinf. Trials | Nonreinf. Trials | Reinf. Trials |
| B52 | .449 | .476 | .428 | .620 |
| B55 | .475 | .464 | .497 | .491 |
| B58 | .476 | .481 | .468 | .693 |
| B59 | .243 | .280 | .252 | .505 |
| B62* | .106 | .184 | .078 | .440 |
| B63** | .449 | .474 | .502 | .428 |

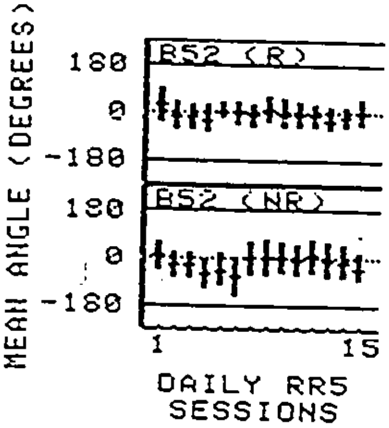
* Number of daily sessions = 10.
** Number of daily sessions = 13

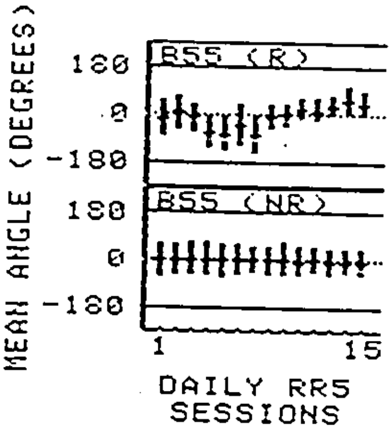
$0^{\circ}$ than those following nonreinforced trials, again with two minor exceptions- B55 and B58.

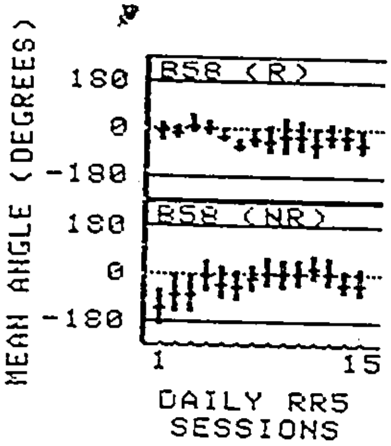
The Response data given above show a tendency for the pigeons to make more consistent turns, nearer to $0^{\circ}$, following reinforced trials than following nonreinforced trials in RR 5. They do not, however, reflect any changes in response tendency occurring across the 14 sessions. Figure 21 shows daily mean vectors for each pigeon for trials following reinforcement and for trials following nonreinforcement during RR 5. There are few generalizable trends in these data. Variability of the daily mean vector was generally lower following reinforced trials than following nonreinforced trials, throughout RR 5. In most cases, at the beginning of RR 5 the angle of the daily mean vector for trials following nonreinforced trials was greater than $90^{\circ}$, and variability was high. The mean vectors for trials following reinforced trials did not appear to change in any consistent way, nor did those for trials following nonreinforced trials (except at the beginning of RR 5).

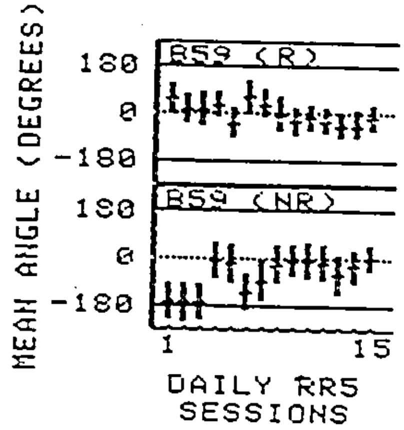
It was suspected that tendencies to peck in a particular Place in RR 5 might have been affected by Response patterns. For example, contrast between reinforced and nonreinforced trials occurring in the same session might cause the pigeons to make smaller turns

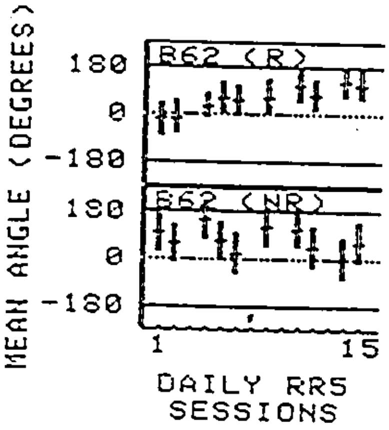
Figure 21. Mean vectors for Response on trials following reinforced trials and on trials following nonreinforced trials, for each daily session of RR 5 for each of 6 pigeons in Experiment 1.

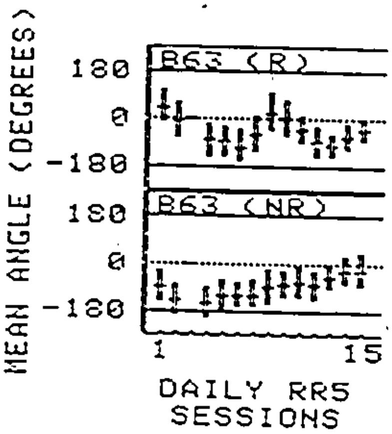

MEAN ANGLE (DEGREES)
B52 (R)
180
0
-180
B52 (NR)
180
0
-180
1
15
DAILY RR5
SESSIONS


MEAN ANGLE (DEGREES)
B55 (R)
180
0
-180
B55 (NR)
180
0
-180
1
15
DAILY RR5
SESSIONS


MEAN ANGLE (DEGREES)
B58 (R)
180
0
-180
B58 (NR)
180
0
-180
1
15
DAILY RR5
SESSIONS


MEAN ANGLE (DEGREES)
B59 (R)
180
0
-180
B59 (NR)
180
0
-180
1
15
DAILY RR5
SESSIONS


MEAN ANGLE (DEGREES)
B62 (R)
180
0
-180
B62 (NR)
180
0
-180
1
15
DAILY RR5
SESSIONS

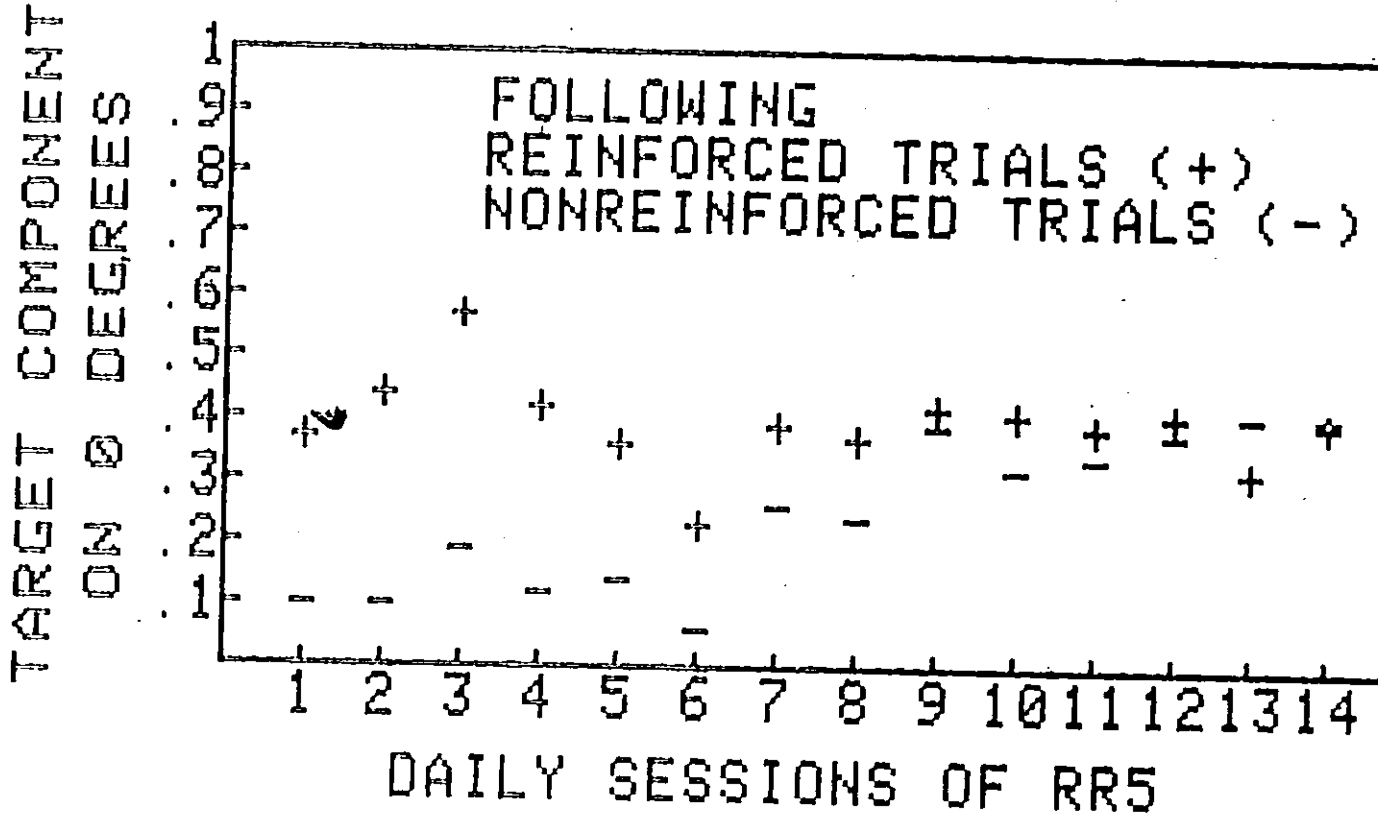

MEAN ANGLE (DEGREES)
B63 (R)
180
0
-180
B63 (NR)
180
0
-180
1
15
DAILY RR5
SESSIONS

following reinforced trials than they had during FR 1. This could lengthen the Place mean vector. Because of this suspicion, the target component for Response on $0^\circ$ was calculated for each daily Response vector, following reinforcement and following nonreinforcement, and the results averaged over pigeons. (A Response of $0^\circ$ means that a key has been repeated.) These data are presented in Figure 22. They show that the target component on $0^\circ$ of trials following reinforced trials is high at the start of RR 5 and remains high, with little if any change, over the 14 days of RR 5. The target component on $0^\circ$ for trials following nonreinforced trials, on the other hand, is initially quite low, and steadily increases over days to the same level as trials following reinforced trials.

### Targeted Percentile

Calculation of the Response measure in TP following reinforced trials is redundant. Once the schedule is consistently reinforcing only responses close to the target, the mean Place at which the pigeon pecks following reinforced trials will be the target direction plus the mean Response following reinforced trials. Therefore, once the pigeon is responding consistently around the target direction, Place and Response contain the same information. Indeed, separate analyses of Place

Figure 22. Mean target component on 0° for Response on trials following reinforced trials and on trials following nonreinforced trials for each daily session of RR 5 averaged over all 6 pigeons in Experiment 1.


TARGET COMPONENT
ON 0 DEGREES
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
FOLLOWING
REINFORCED TRIALS (+)
NONREINFORCED TRIALS (-)
1 2 3 4 5 6 7 8 9 10 11 12 13 14
DAILY SESSIONS OF RR5

and Response only make sense in situations in which no particular area or direction is reinforced, for example, in FR 1 or RR 5.

## DISCUSSION: RESPONSE

All six pigeons had a higher mean vector for Response than for Place in FR 1. In addition, the mean vectors for Response showed gradual changes from day to day throughout FR 1, unlike the mean vectors for Place. Thus, the pigeons' behavior in FR 1 could be explained in a more parsimonious fashion by hypothesizing that they were controlled by means of internal cues (Response) rather than external cues (Place). Although the stereotypy of Response was fairly high throughout FR 1, there were no progressive increases in stereotypy.

There was a progressive change in Response stereotypy following nonreinforced trials in RR 5, which took the form of an increasing tendency over days to shift toward a Response of 0° following nonreinforcement. It was thought at first that perhaps the RR 5 schedule was affecting Response, which in turn was causing an increase in apparent Place stereotypy. Closer analysis of Place suggested very strongly, however, that Place was being affected by an interaction between least effort, frustration, or some similar mechanism and the RR 5 schedule, and that this Place stereotypy was causing the apparent Response stereotypy. That is, three of the pigeons (B52, B55, and B59) seemed to show avoidance gradients around Key #34 (see Figure 7). For all of the pigeons, key #34 was used much less than any other key during RR 5, indicating that it might have been much more difficult to operate than the other keys. The pattern of results found in RR 5 could be explained by hypothesizing that three of the pigeons formed a progressive avoidance of key #34, and possibly the keys around it.

Analysis of Response vectors following reinforced and nonreinforced trials appeared to be a powerful technique for assessing the effects of reinforcement and nonreinforcement. Early in both RR 5 and TP, there was a strong tendency to respond near 0° following reinforcement, and to respond more diffusely at angles greater than ±90° following nonreinforcement.

Response stereotypy may have had a retarding effect upon Place shaping in TP. Whether or not there was competition between Response and Place in Place shaping, there certainly was a tendency to turn in one direction following reinforced trials and in another direction following nonreinforced trials. It is also possible that Response stereotypy caused or at least contributed to the overshooting of the target, commonly found following reinforced trials each time the pigeons were shifted to a new target direction.

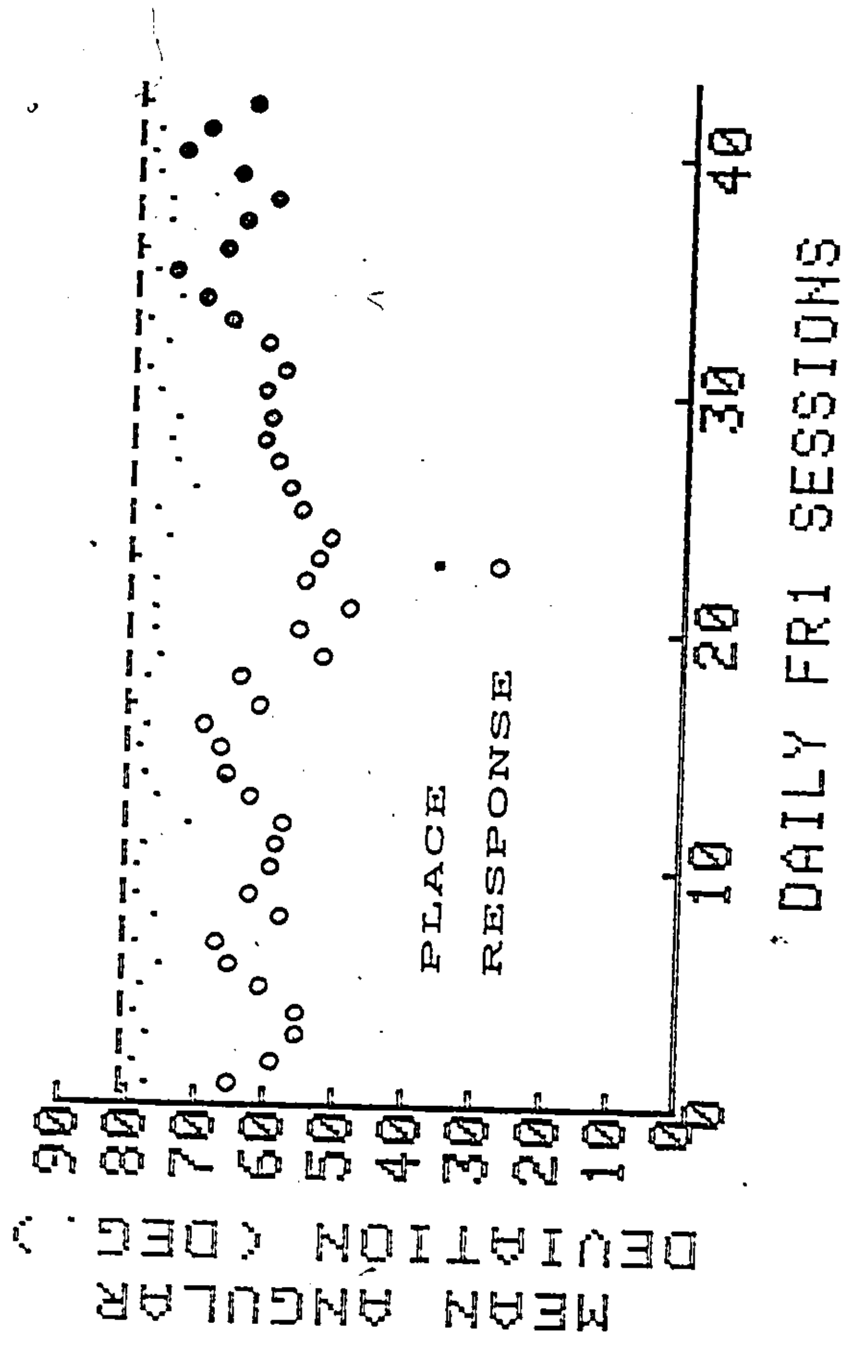
## RESULTS: COMPARISON OF PLACE AND RESPONSE

Analysis of variance was conducted on $\underline{s}$ (mean angular deviation) calculated from daily mean vector lengths for FR 1, with Measures (Place vs Response) and Sessions as within-subjects variables. Response was significantly less variable than Place, $\underline{F}(1, 5) = 20.98$, $\underline{p} < .01$, and Sessions was marginally significant, $\underline{F}(41, 205) = 1.48$, $\underline{p} < .05$). However, inspection of Figure 23 shows that the mean angular deviations neither increased nor decreased consistently over daily sessions. Rather, both Place and Response showed a slight U-shaped curve, decreasing and then increasing in variability between approximately days 10-30. This may reflect either a moderate transient Place stereotypy or a moderate transient Response stereotypy (at $0^{\circ}$) for three of the six pigeons.

## DISCUSSION: COMPARISON OF PLACE AND RESPONSE

When every keypeck was reinforced, the pigeons in

Figure 23. Mean angular deviations for Place and for Response for each of 42 daily sessions of FR 1 averaged over all 6 pigeons in Experiment 1.


MEAN ANGULAR DEVIATION (DEG.)
0
10
20
30
40
50
60
70
80
90
10
20
30
40
DAILY FR1 SESSIONS
PLACE
RESPONSE

this study appeared to orient themselves by referring to internal cues (Response) rather than by orienting in a particular direction or to a particular location (Place). Three of the pigeons developed transient Place stereotypies in FR 1, but these continued for some number of days, and then disappeared. Stereotypy of Response, however, occurred in all of the pigeons, at least to a moderate degree, and remained throughout FR 1.

The overshoot past the target in TP shaping may have at least in part been due to the properties of the symmetrical targeted percentile schedule. When responding is mostly on one side ~~of~~ the target, (as would be so at the start of a 90° target shift), the probability of a response on the other side of the target being reinforced is increased. Calculation of the mean vector for trials upon which reinforcement occurred showed that the schedule was indeed reinforcing a direction or location just on the other side of the new target from the old target. However, the overshoot of the daily mean vectors for trials upon which reinforcement occurred was much smaller than the overshoot for trials following reinforcement, so that the pigeons were not merely matching their response rate to the reinforcement rate for particular keys. Thus, overshooting a target direction when shifted from another target direction does not appear to be an artifact of the reinforcement schedule.

Overshooting could be accounted for if, while being shaped to peck at a particular Place, the pigeons were also being shaped to make a particular Response. Notterman and Mintz (1965) have presented data suggesting that rats learning a force differentiation may also learn particular <u>shifts</u> in force exerted from trial to trial. They refer to this as incidental directional reinforcement. For example, when shifting from Target 1 to Target 2, the pigeons began with a strong Place tendency (to respond around Target 1) and a concomitant Response tendency (to respond around 0°). When the pigeons were reinforced for pecks which were between Target 1 and Target 2, they were also, on the average, being reinforced for Responses (shifts) in the direction of Target 2. Indeed, if only the Place of reinforcement mattered to the pigeons, it would seem that they would tend to fixate upon the new Place where they got reinforcement immediately following institution of the shift, and move to the new target slowly (if at all). Reinforcement of movement toward the new target (Response) would seem to be useful in shaping a new target (Place).

## DISCUSSION: OVERALL

The three pigeons that showed some Place stereotypy in FR 1 also showed Place stereotypy in RR 5. In RR 5, these three pigeons did not tend to respond in the same location, but they all did avoid the same location. If the pigeons avoided some location in RR 5, they could have also done this in FR 1. Thus, the weak transient Place stereotypy seen in FR 1 might have been due to either processes subsumable under least effort, or to frustration, engendered by a difficult key (or keys). In RR 5, the avoidance of key #34 generalized to surrounding keys. On the other hand, the pigeons did not avoid the keys around non-preferred keys in FR 1.

Thus, another experiment was deemed necessary, since the evidence from Experiment 1 concerning the Law of Effect was equivocal.

## Chapter 3:

## EXPERIMENT TWO

### INTRODUCTION

Three of the six pigeons in Experiment 1 displayed <u>some</u> apparent stereotypy of response location or Place, under conditions where response location was not related to reinforcement. However, the results of RR 5 suggested that perhaps the pigeons might have been avoiding some of the keys. Therefore, the keys were modified by adding stops behind them, in order to limit their excursion and maintain their calibration. Experiment 2 was intended to determine whether Place stereotypy would still occur in this situation. If it did occur, the experiment was designed to discover what cues supported this Place stereotypy, and whether the degree of stereotypy could be controlled by the particular cues that were presented. Since changing local cues associated with the keys and changing the cues associated with the top of the apparatus both had some effect upon Place performance during Experiment 1, these were the cues manipulated. In addition, a pilot study with four pigeons indicated that Place shaping on a TP schedule was enhanced by distinctively marking every key. It was hypothesized that degree of Place stereotypy would be a positive function of the richness of cues in the situation.

Experiment 2 was also designed to determine whether, in an unbiassed situation, successive phases of extinction and reconditioning would produce an increase in Place stereotypy, as found by Antonitis (1951), or in Response stereotypy, or neither.

Another purpose was to determine whether Response stereotypy is a learnable behavior, or simply a relatively fixed "response bias" (Baum, 1974), by attempting to shape Response using targeted percentile reinforcement. If Response turned out to be shapeable, shaping of Place and Response could be compared, using the same percentile parameters for both. Even if Response were affected by differential reinforcement, the Response stereotypy found under nondifferential reinforcement might still be a response bias, but one that could be overcome.

If Response stereotypy were simply a bias, following Response shaping with a nondifferential reinforcement schedule should produce a relatively rapid return to the pre-shaping Response stereotypy. For example, one pigeon might have a shorter right leg, or it might be "right-handed" (Baum, 1974). Either condition could cause a counter-clockwise turn bias in the present experimental situation. Differential reinforcement might counteract this tendency, and produce predominantly left turns when leaving the food magazine. If the pressure of differential reinforcement were removed, however, the response bias would be expected to reassert itself, since the conditions that produced it would still exist. On the other hand, if Response were under the control of reinforcement, nondifferential reinforcement following shaping should maintain the shaped Response value (Herrnstein, 1966). Comparison of maintenance of Place and Response shaping when shifted to a nondifferential schedule would also be of interest.

## METHOD

### Subjects

Twelve White King pigeons, approximately 3 years old, of undetermined sex, and experimentally naive, were maintained at approximately 80% ad libitum weight by daily feedings of Purina Pigeon Checkers and tap water. They were individually housed, and kept on a 15-hr light, 9-hr dark schedule. Each pigeon was run daily, at the same hour of the afternoon or evening ± 2 hr.

### Experimental Groups

As soon as each pigeon was magazine trained, it was assigned to one of three groups, which differed in the stimuli presented to them. The four pigeons in the plain group (Group P) were run with no added cues. This stimulus condition was a systematic replication of Experiment 1. The four pigeons in the letter group (Group L) were run with 72 different letters and numbers (see Appendix I) affixed to the keys. (Letters of the alphabet have been shown to be discriminable by pigeons (Blough, 1982)). The correspondence between particular symbols and particular keys was the same for the entire experiment. Group L was expected to show a higher degree of Place stereotypy than Group P, due to the distinctive local cues. The four pigeons in the top group (Group T) were run with an opaque top with an ovoid cutout near the center placed over the regular top. Group T was also expected to display a higher degree of Place stereotypy than Group P, due to the presence of a distinctive global or configurational cue. The four pigeons in Group T were all shaped after the eight pigeons in Groups P and L had begun FR 1. The final letter in each pigeon's code refers to the stimulus group to which that pigeon was assigned. For example, B2T was run in group T.

### Apparatus

The apparatus was the same as that used in Experiment 1, with some modifications. The houselight was moved to 2 m above the center of the top, increased to

60W, and the reflector behind the bulb was removed. This was done to eliminate possible directional cues provided by the houselight casting an asymmetrical pattern of brightness on the top of the experimental chamber. Stops were added behind the keys to limit their excursion and to prevent them from drifting out of calibration. The translucent top was used throughout Experiment 2.

A set of 72 letters and numbers and reversed letters and numbers was prepared, using Geotype 119-48CN transfers. These symbols were approximately 1 cm square, and were black on a transparent background. They had transparent adhesive backs, so that they could be affixed to the proper keys when the pigeons in Group L were run. These symbols are given in Appendix I.

An opaque black top was constructed, which fit over the translucent top. It was constructed of black bristol board, with an ovoid approximately 30 cm by 60 cm cut out near the center. The small end of the cutout overlapped the edge of the chamber above key #45. This top was used when running the pigeons in Group T.

Procedure

Four pigeons (B4P, B5L, B6L, and B7) were given daily sessions of 50 autoshaping trials, with a CS consisting of an 8-sec illumination of Key #10 only, and a US consisting of a 4-sec magazine presentation. The intertrial interval averaged 1 min. Pigeon B7 made 12 keypecks on day 10 of this procedure, and was given its first session of FR 1 the next day. Pigeon B7, the only one to autoshape, was run under the same conditions as Group P, but the data for this pigeon were analyzed separately (see Chapter 4). The other three pigeons had not responded after 14 daily sessions of autoshaping, so they were handshaped, and given 10 trials of FR 1 on key #10 in one session. Nine other pigeons: B2T, B8P, B9L, B10L, B11P, B12P, B13T, B14T, and B15T: were given daily sessions of 50 autoshaping trials for one to three sessions, until they ate on most of the trials. They were then handshaped to peck Key #10 and given ten FR 1 trials, all with only Key #10 lit. None of these pigeons made any keypecks while on the autoshaping schedule.

Beginning the day after 10 successful FR 1 trials were completed, each pigeon was given 50 daily sessions of 50 trials each on a FR 1 schedule, upon which every response (regardless of location) produced a 4-sec magazine presentation and simultaneously extinguished the keylights. From the start of FR 1, and throughout the experiment, a discrete-trials procedure was in effect such that illumination of the keys, which signalled the opportunity to respond, was contingent upon the pigeon pecking into the feeder to begin each trial. As in

Experiment 1, there was no added intertrial interval: trials were subject-paced.

Each pigeon was then given two daily sessions of 50 extinction (EXT) trials, in which a peck to any key extinguished the keylights but had no other effect. Extinction sessions were terminated after 1 hr if the pigeon had not completed 50 trials. Following EXT each pigeon was given 10 more daily sessions of FR 1 (FR 1'), 2 more daily sessions of EXT (EXT'), and 10 more daily sessions of FR 1 (FR 1'').

After the last FR 1'' session, each pigeon was given 30 daily sessions of 250 trials on a symmetrical targeted percentile (TP) shaping schedule (Davis and Platt, 1983). Two of the pigeons in each of Groups P, L, and T were presented with schedules which reinforced, on the average, the 20% of their keypecks closest to a particular direction or Place. The pigeons shaped to a particular Place were B4P, B12P, B5L, B9L, B2T, and B14T. The target direction was chosen to be approximately 90° from each pigeon's mean angle for Place on the last day of FR 1''. The other two pigeons in each group were presented with schedules which reinforced, on the average, the 20% of their keypecks closest to a particular deviation clockwise or counterclockwise from the previous keypeck, or Response. The pigeons shaped to a particular

Response were B8P, B11P, B6L, B10L, B13T, and B15T. The target Response was chosen to be approximately 90o from each pigeon's mean angle for Response on the last session of FR 1''.

Following 30 sessions of TP, each pigeon was given 10 daily sessions of FR 1 (FR 1''') and, finally, 2 daily sessions of EXT (EXT'').

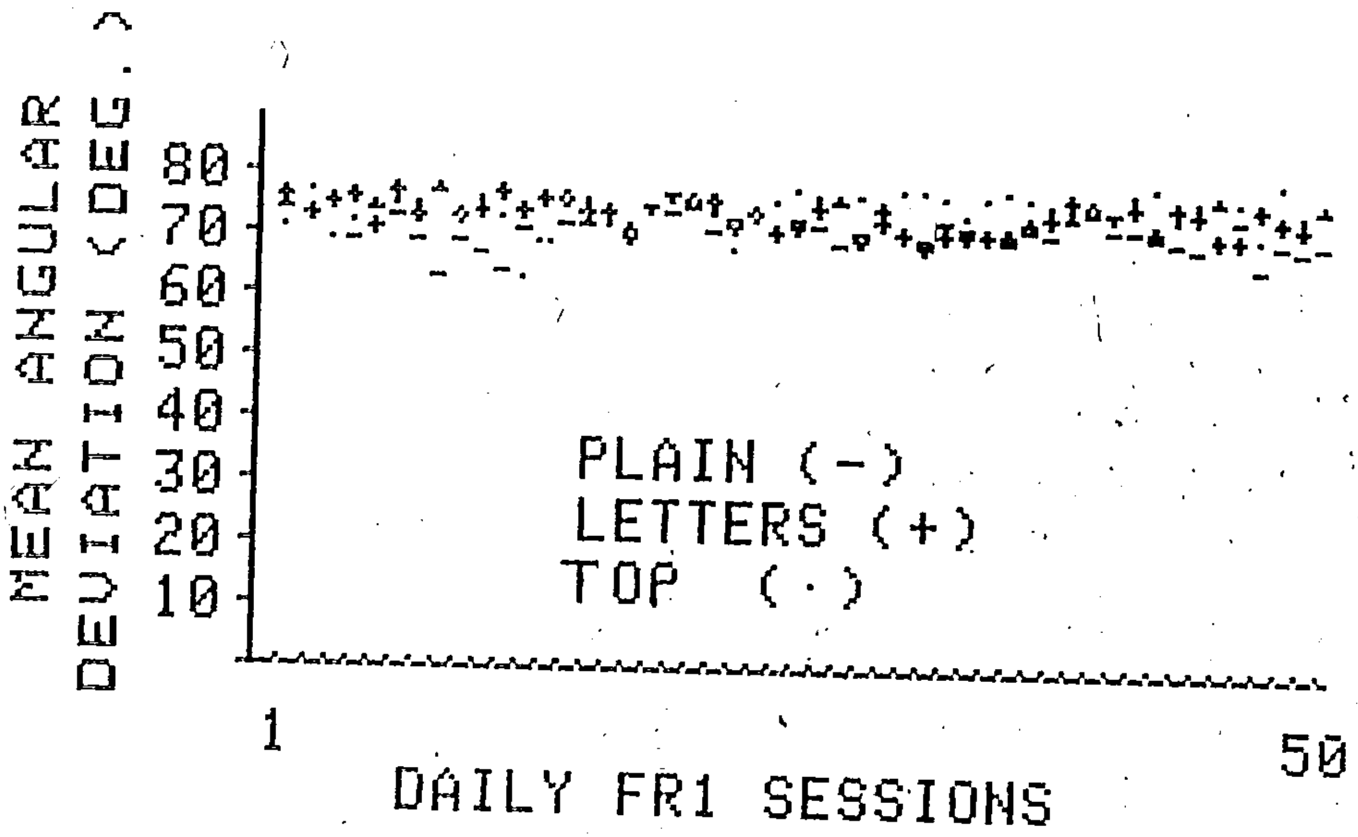
## RESULTS: PLACE

### Fixed Ratio 1

Daily group mean angular deviations for Place for Groups P, L, and T are given in Figure 24. These data were subjected to an analysis of variance with Groups as a between-subjects variable and Sessions as a within-subjects variable. Neither Groups, nor Sessions, nor Groups x Sessions approached statistical significance (all *F*s < 1.0). This analysis confirms the impression given by Figure 24 that variability of the Place measure did not differ systematically between the three cue groups, nor did it differ over daily sessions of FR 1 for any of the three groups.

Even though the mean vector length did not change as a function of number of sessions of FR 1, it is possible that each pigeon was concentrating its responding

Figure 24. Group mean angular deviations for Place for Groups P, L, and T for each daily session of FR 1 in Experiment 2.


MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
DAILY FR1 SESSIONS
PLAIN (-)
LETTERS (+)
TOP (·)

at a number of places scattered around the apparatus. In this way the pigeons could display progressive stereotypy of location of pecking at a number of locations without showing an increase in mean vector length. A measure which should be sensitive to Place stereotypy of any sort is the number of different keys used in a session. This was computed for each of the 12 pigeons in Experiment 2. The data for mean number of different keys used per daily session are shown in Figure 25, for Groups P, L, and T. An analysis of variance was performed with Groups as a between-subjects variable and Sessions as a within-subjects variable. Again, no Fs were greater than 1.0. This analysis shows that the number of different keys used per day did not differ between groups, nor decrease over days, but remained stable.

Since the three stimulus conditions had no apparent effect upon Place stereotypy, the data were summed over all 12 pigeons rather than breaking them down further into three groups when analyzing general tendencies.

Figure 26 shows mean vectors for Place summed over all 50 sessions of the first phase of FR 1 for each pigeon, as well as the grand mean vector for Place. They are quite short, and do not appear to be biased in any direction.

Figure 25. Group mean number of different keys used per daily session of FR 1 in Experiment 2.

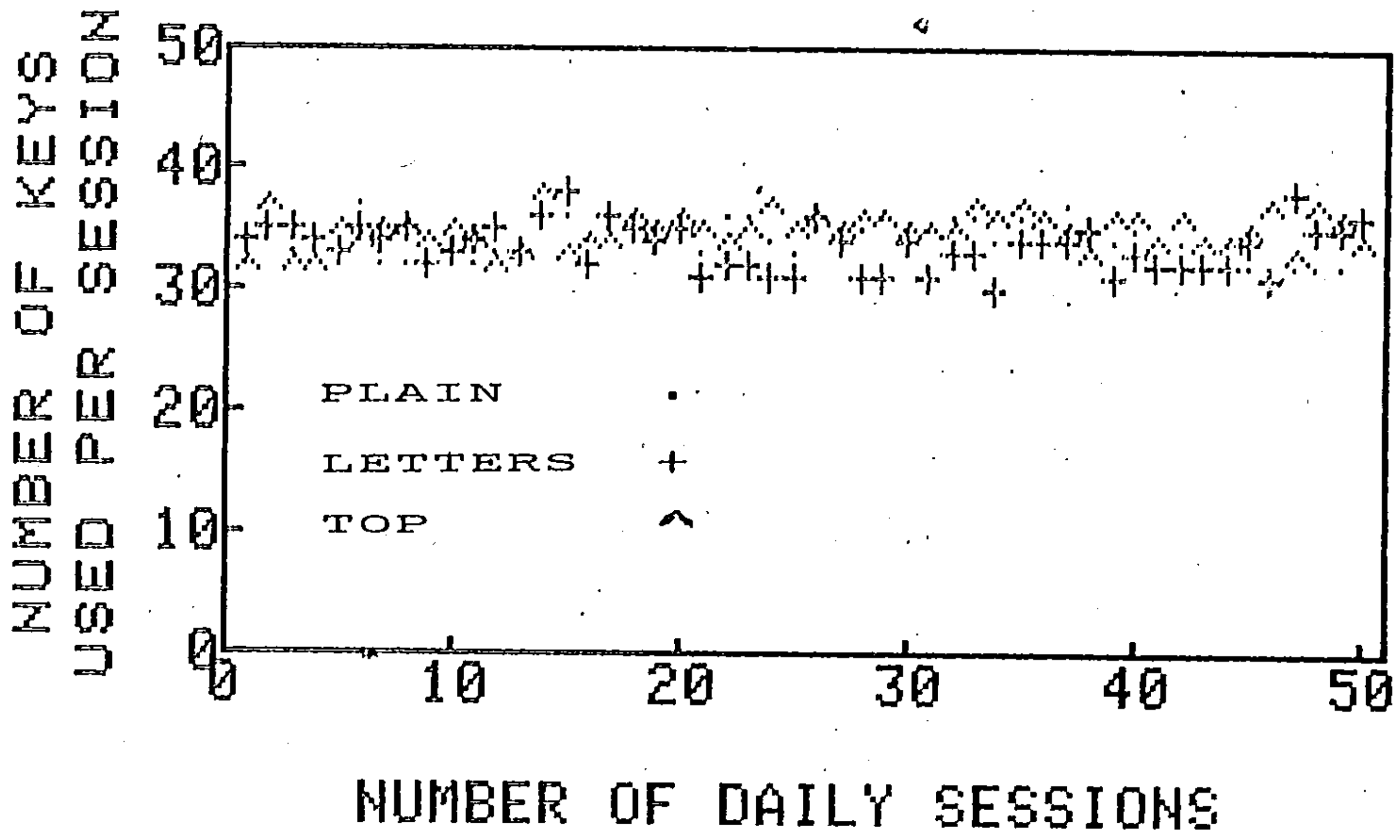
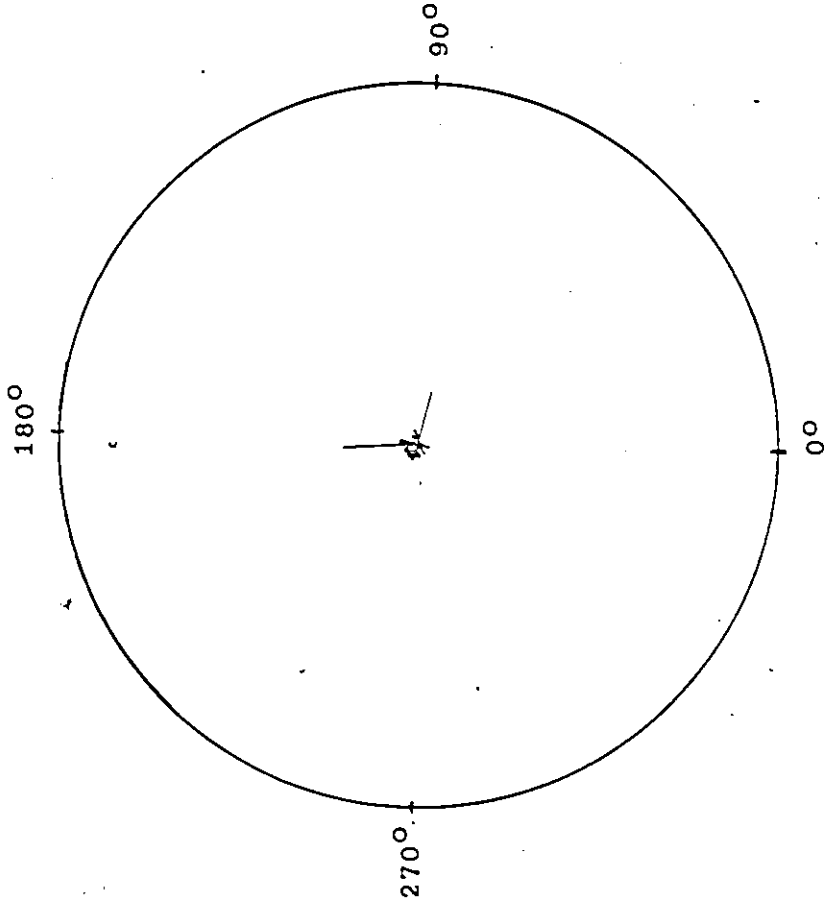

NUMBER OF KEYS USED PER SESSION
50
40
30
20
10
0
0
10
20
30
40
50
NUMBER OF DAILY SESSIONS
PLAIN .
LETTERS +
TOP ^

Figure 26. Mean vectors for Place averaged over all 50 daily sessions of FR 1 for each pigeon and the grand mean vector (represented by the dot) for all 12 pigeons in Experiment 2.


90°
180°
0°
270°

In order to determine whether there was a general preferred Place or direction for all twelve pigeons taken as a group, which might reflect an asymmetry in the apparatus, or some other biassing factor, responses on each key were summed across all 12 pigeons and all 50 sessions. This yielded the circular distribution of per cent pecks per key shown in Figure 27. The mean vector for all 30,000 trials of FR 1 was (182°, .024), showing that the pigeons as a group did not have an overall preferred Place.

To determine whether any one of the pigeons had an enduring preferred Place or direction over the course of FR 1, responses on each key were summed for the 50 days of FR 1 for each pigeon. These data are presented in Figure 28. Only pigeon B11P appeared to have a consistent directional tendency, and it was not very strong (195°, .226). Pigeon B6L had the next highest fifty-day mean vector (76°, .135). The other 10 pigeons had mean vectors with lengths of .056 or less. Pigeons B6L and B5L seemed to peck some keys less, and some keys more, than would be expected by chance, despite not having a preferred direction. The other nine pigeons had, apparently, isotropic or "random" distributions of pecks per key.

As in Experiment 1, the data for Place summed over

Figure 27. Per cent pecks per key averaged over all 50 daily sessions of FR 1 and all 12 pigeons in Experiment 2.

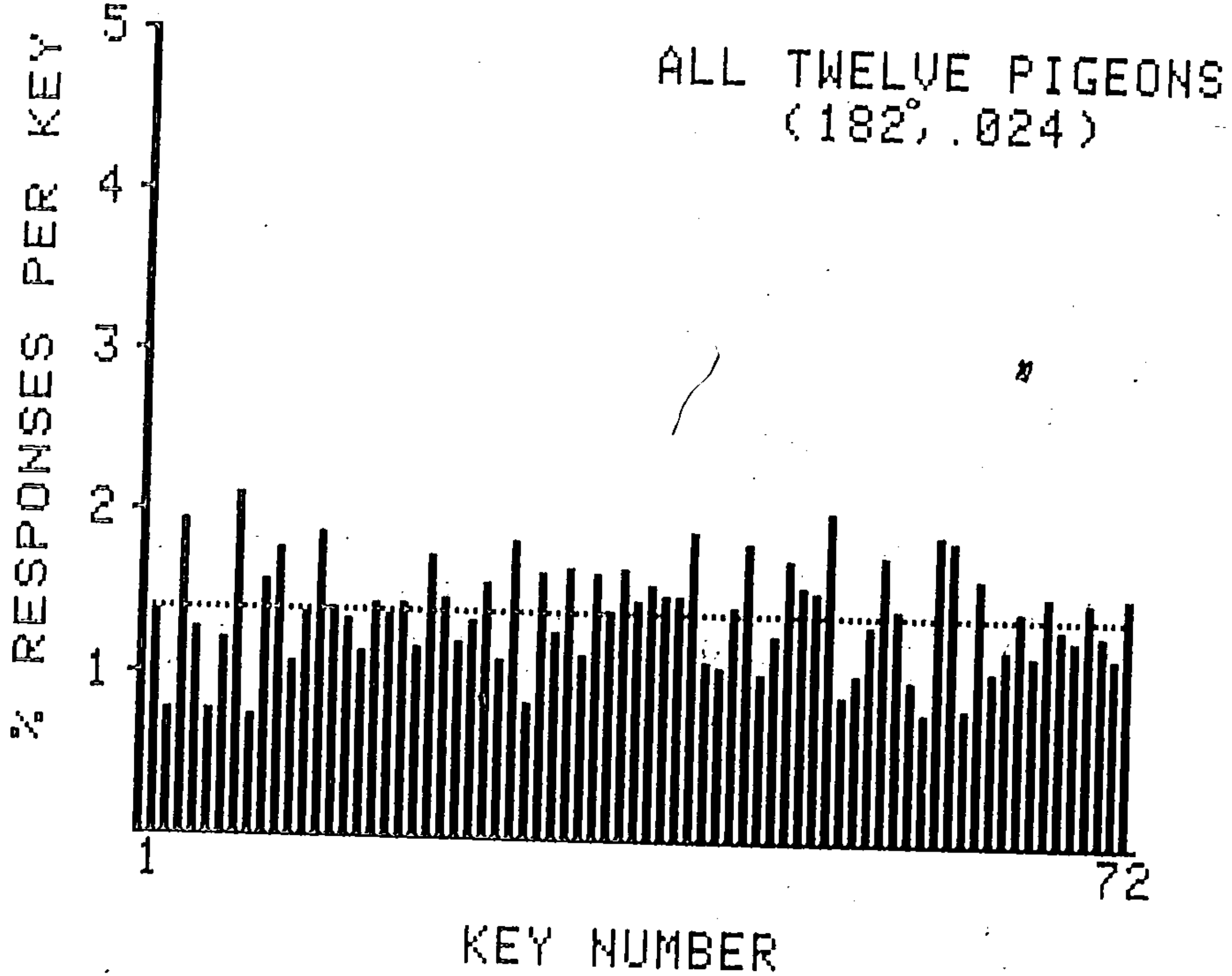
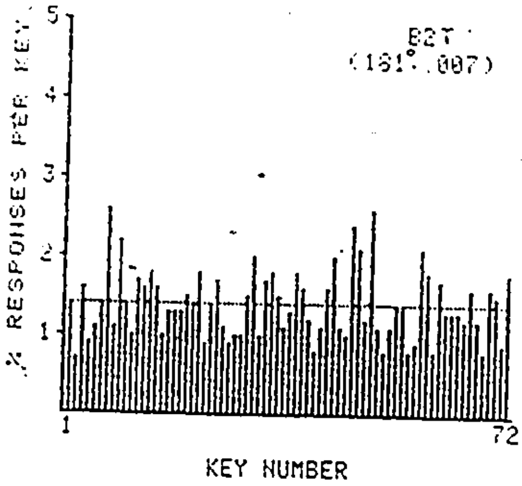
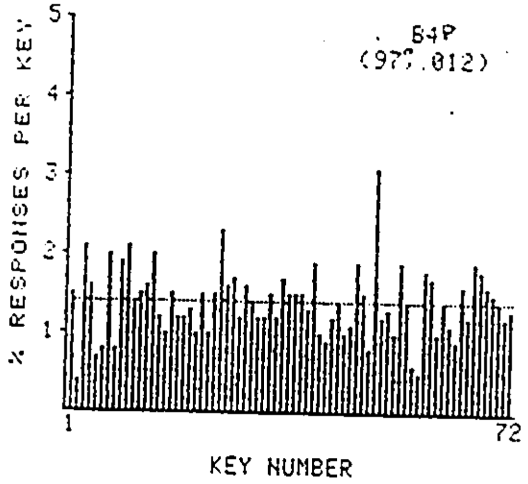
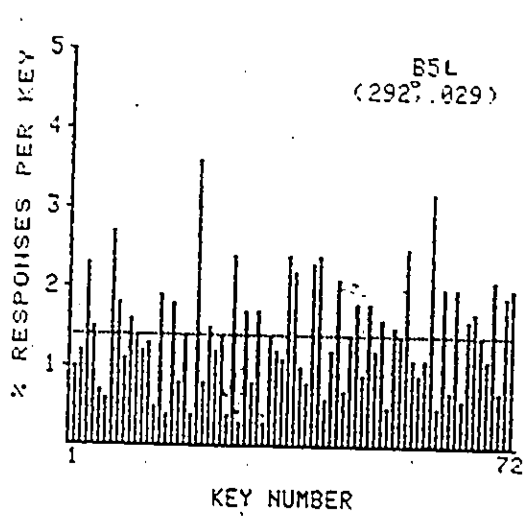

ALL TWELVE PIGEONS
(182°, .024)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER

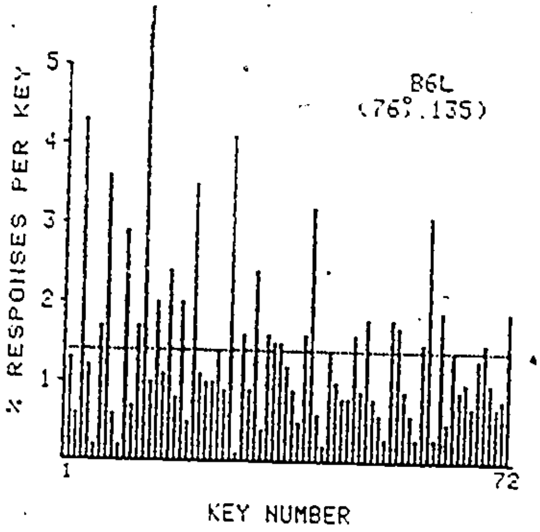
Figure 28. Per cent pecks per key averaged over all 50 daily sessions of FR 1 for each of 12 pigeons in Experiment 2.

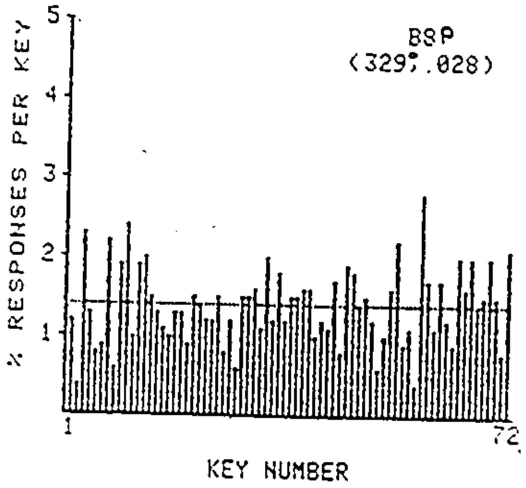
P

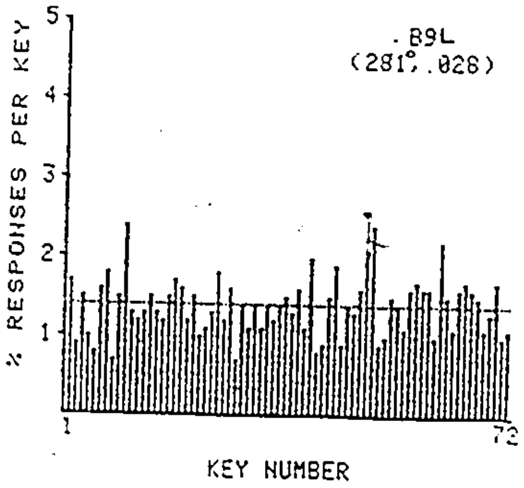

B2T
(161°,.007)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER

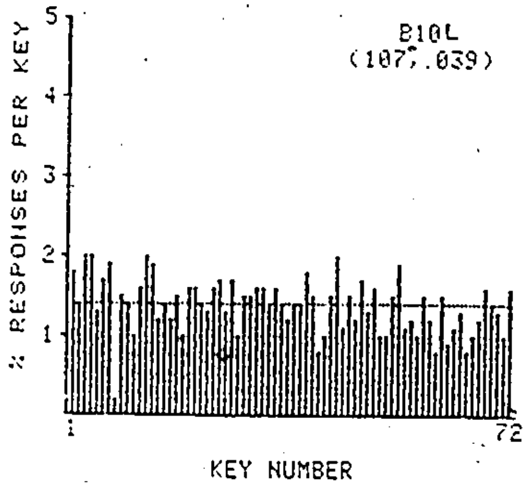

B4P
(97°,.012)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER

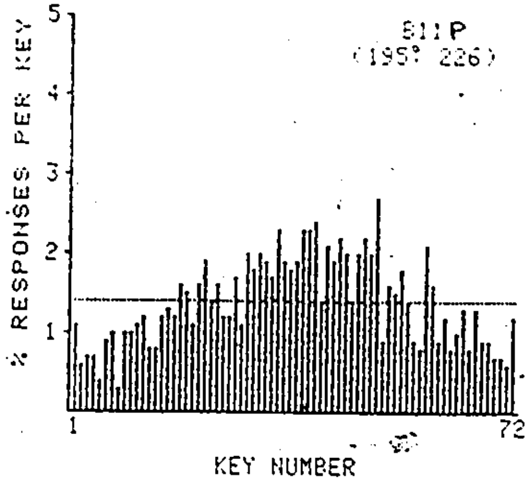

B5L
(292°,.029)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER

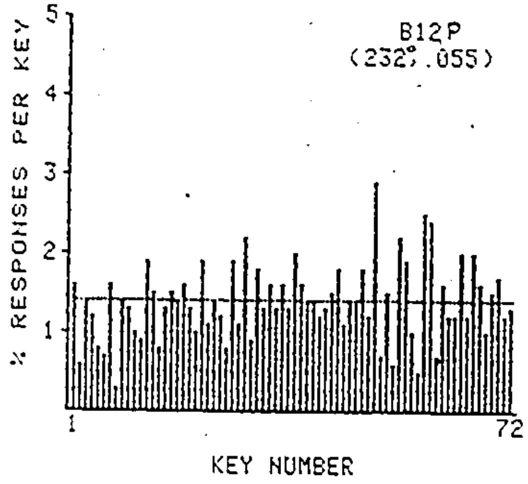

B6L
(76°,.135)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER

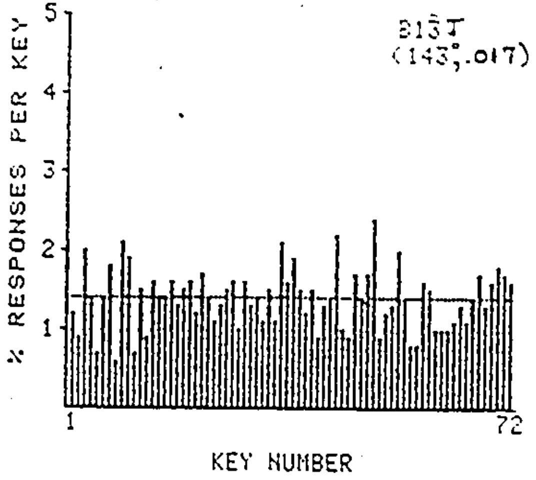

B8P
(329°,.028)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER

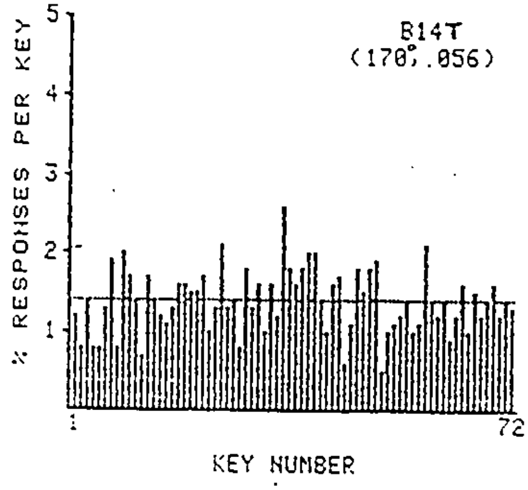

B9L
(281°,.028)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER

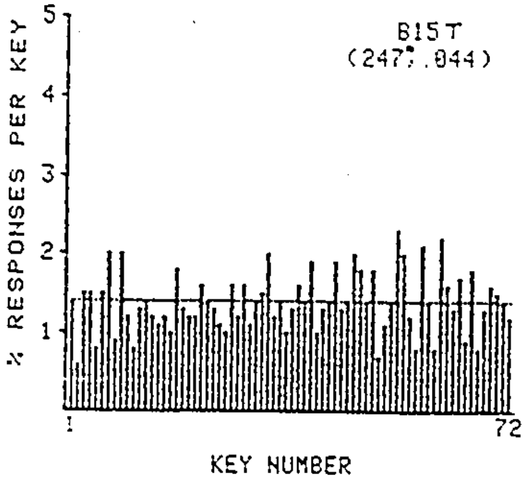

B10L
(107°,.039)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B11P
(195° .226)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B12P
(232°,.055)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B13T
(143°,.017)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B14T
(170°,.056)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER


B15T
(247°,.044)
% RESPONSES PER KEY
5
4
3
2
1
1
72
KEY NUMBER

all of FR 1 show whether there was an overall tendency to peck in a particular place or direction, but these measures would not detect a directional preference that changed widely over daily sessions. Again, the first step is to determine whether the pigeons as a group showed regular changes in preferred place of pecking over sessions. The daily group mean vector was calculated for all 12 pigeons for each day of FR 1. These data, shown in terms of mean angle and mean angular deviation in Figure 29, display close to the maximum possible mean angular deviation for every session, and do not seem to indicate any particular directional preference or trend. The Pearson product-moment correlation between direction and days was .35, which indicates that there was no statistically significant linear relationship between number of sessions on the FR 1 schedule and preferred direction or Place. The corresponding data for individual pigeons are shown in Figure 30. The pigeons showed little if any consistency in direction, combined with near-maximum variability, with the exception again of Pigeon B11P.

In order to show possible changes in Place variability over sessions more clearly, the daily mean angular deviations for individual pigeons are shown in Figure 31. There were no consistent changes in mean

Figure 29. Group mean vectors for Place for each of 50 daily sessions of FR 1 averaged over all 12 pigeons in Experiment 2. The data are plotted in terms of the mean angle ± the mean angular deviation.

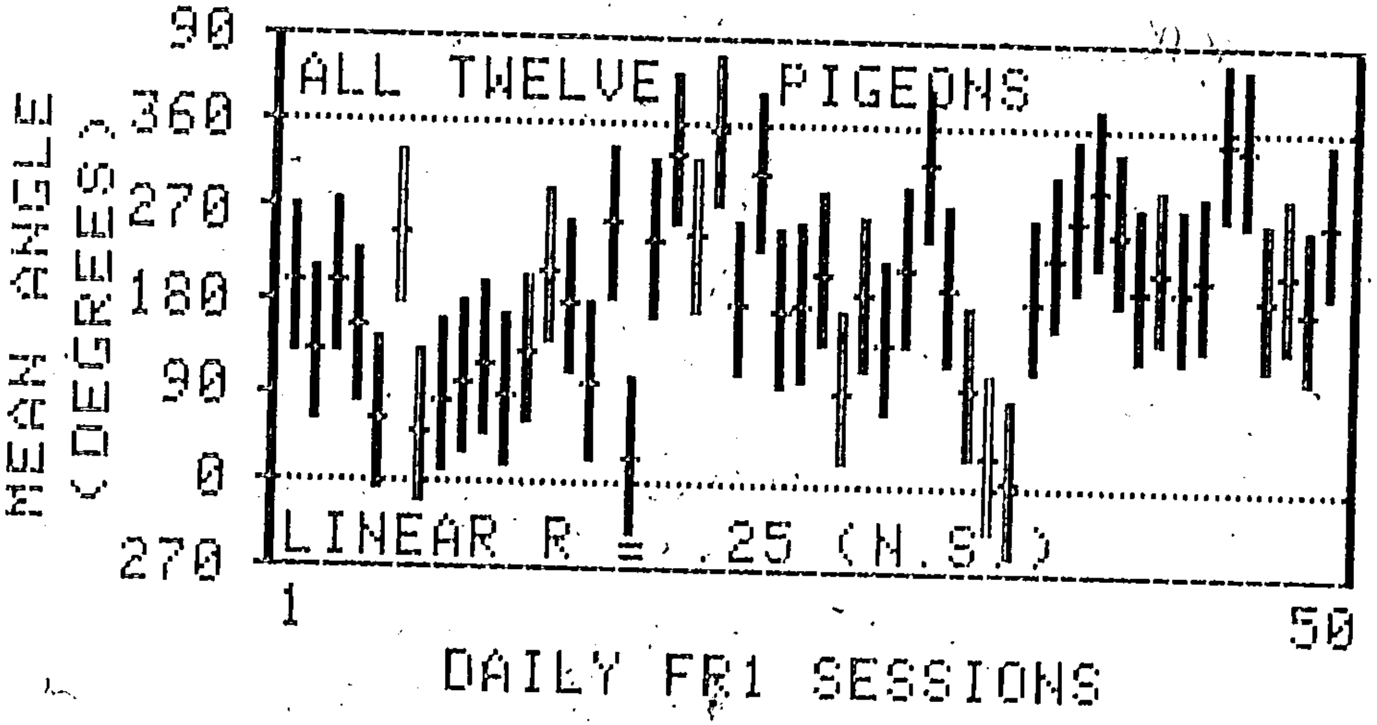
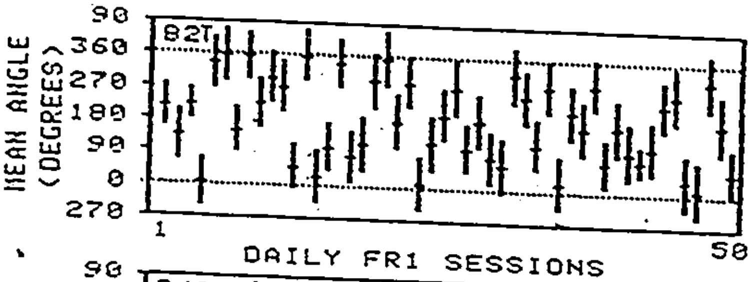
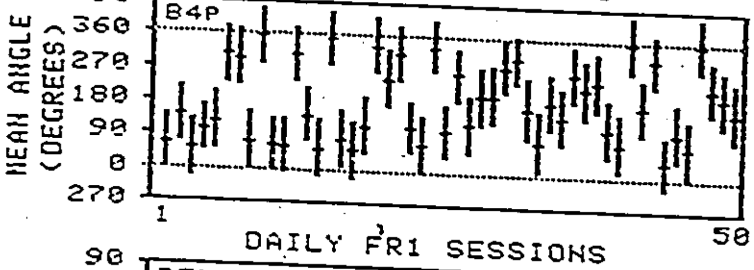
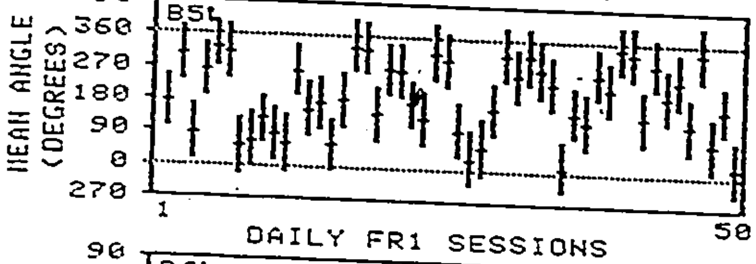
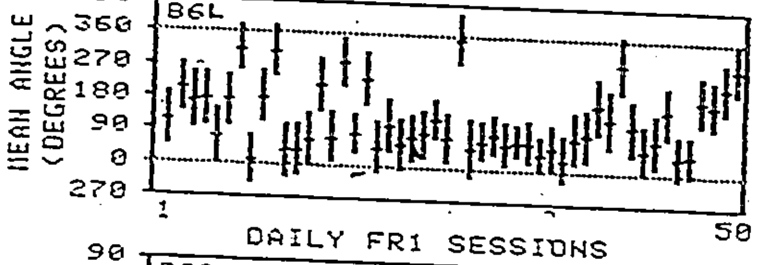

ALL TWELVE PIGEONS
LINEAR R = .25 (N.S.)
MEAN ANGLE (DEGREES)
90
360
270
180
90
0
270
1
50
DAILY FR1 SESSIONS

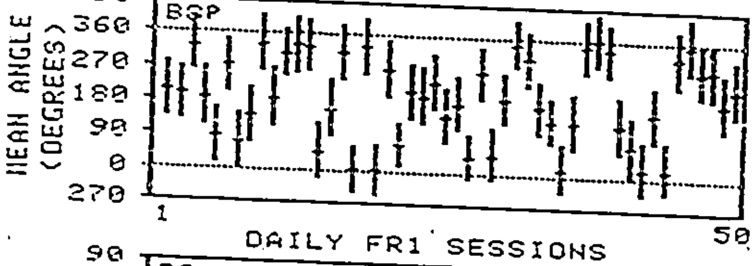
Figure 30. Mean vectors for Place for each of 50 daily sessions of FR 1 for each of 12 pigeons in Experiment 2. The data are plotted in terms of the mean angle ± the mean angular deviation.

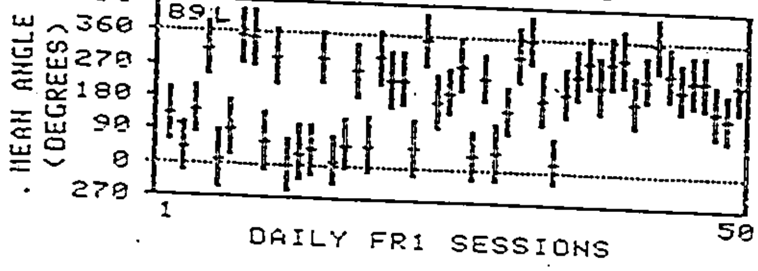

B2T
90
360
270
180
90
0
270
MEAN ANGLE (DEGREES)
1
50
DAILY FR1 SESSIONS

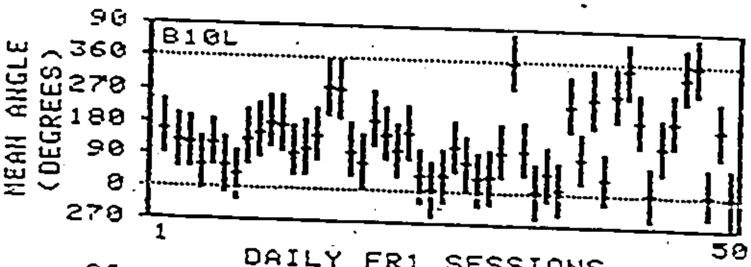

B4P
90
360
270
180
90
0
270
MEAN ANGLE (DEGREES)
1
50
DAILY FR1 SESSIONS

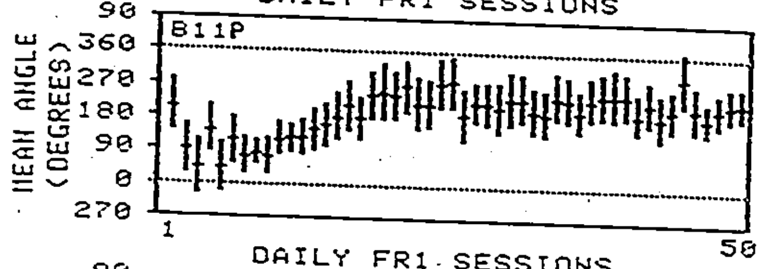

B5L
90
360
270
180
90
0
270
MEAN ANGLE (DEGREES)
1
50
DAILY FR1 SESSIONS

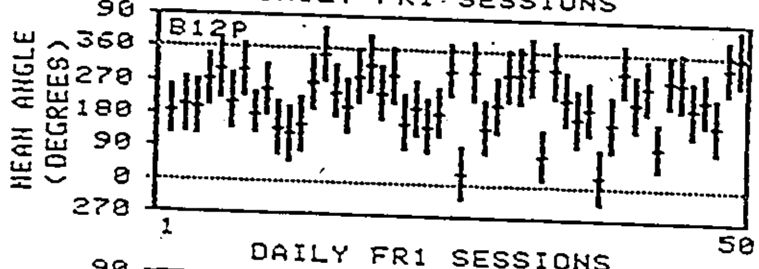

B6L
90
360
270
180
90
0
270
MEAN ANGLE (DEGREES)
1
50
DAILY FR1 SESSIONS

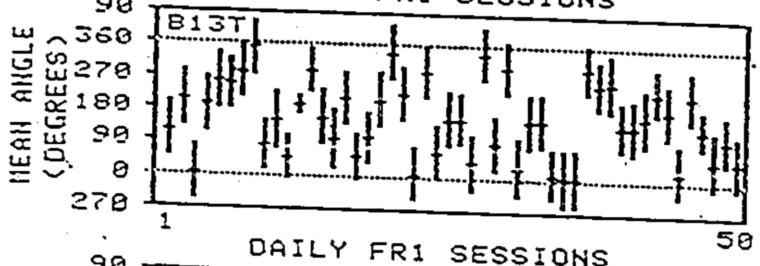

B8P
90
360
270
180
90
0
270
MEAN ANGLE (DEGREES)
1
50
DAILY FR1 SESSIONS

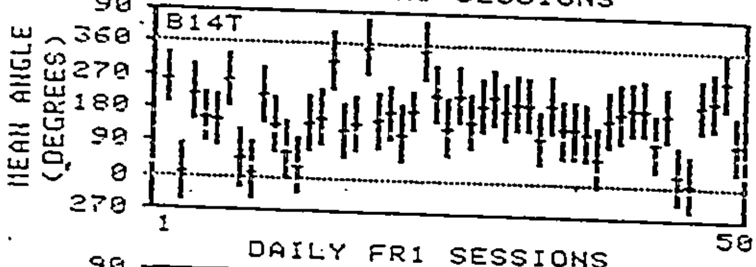

B9L
90
360
270
180
90
0
270
MEAN ANGLE (DEGREES)
1
50
DAILY FR1 SESSIONS


B10L
MEAN ANGLE (DEGREES)
90
360
270
180
90
0
270
1
50
DAILY FR1 SESSIONS


B11P
MEAN ANGLE (DEGREES)
90
360
270
180
90
0
270
1
50
DAILY FR1 SESSIONS


B12P
MEAN ANGLE (DEGREES)
90
360
270
180
90
0
270
1
50
DAILY FR1 SESSIONS


B13T
MEAN ANGLE (DEGREES)
90
360
270
180
90
0
270
1
50
DAILY FR1 SESSIONS


B14T
MEAN ANGLE (DEGREES)
90
360
270
180
90
0
270
1
50
DAILY FR1 SESSIONS

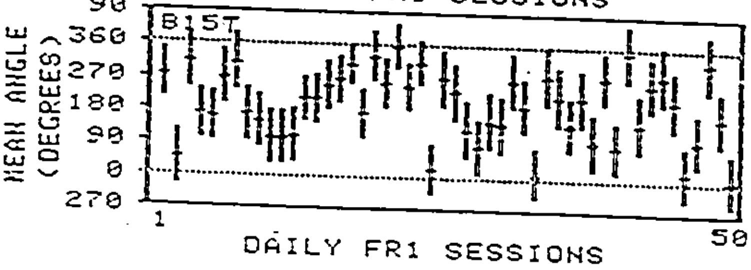
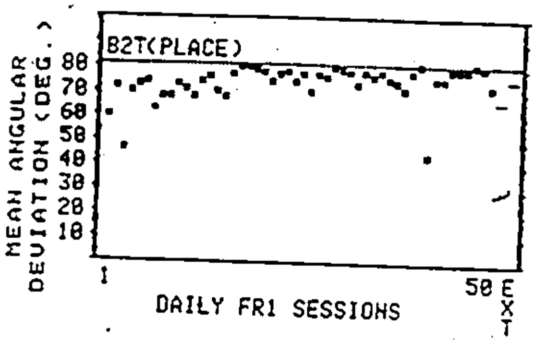
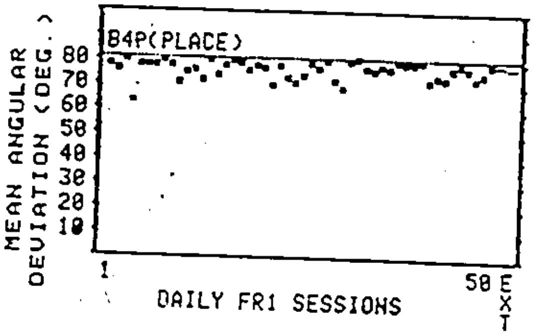
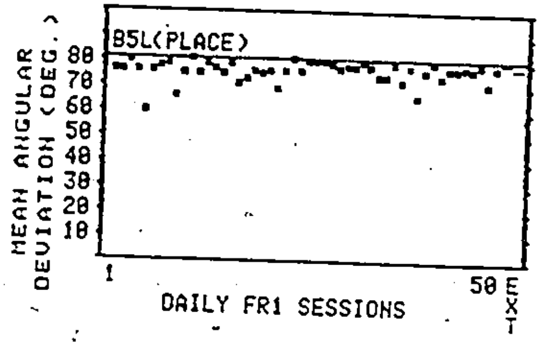
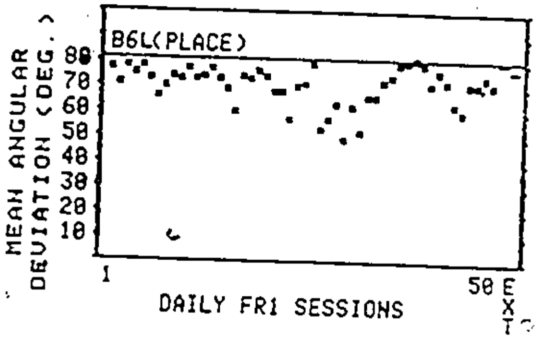

B15T
MEAN ANGLE (DEGREES)
90
360
270
180
90
0
270
1
50
DAILY FR1 SESSIONS

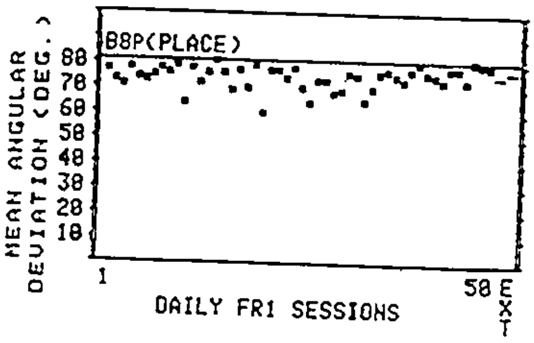
Figure 31. Mean angular deviations for Place for each of 50 daily sessions of FR 1 and 2 daily sessions of EXT for each of 12 pigeons in Experiment 2.

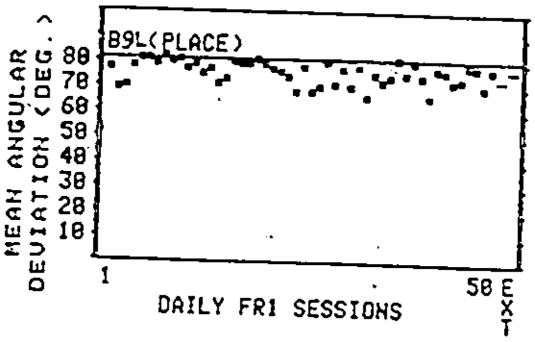

B2T(PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

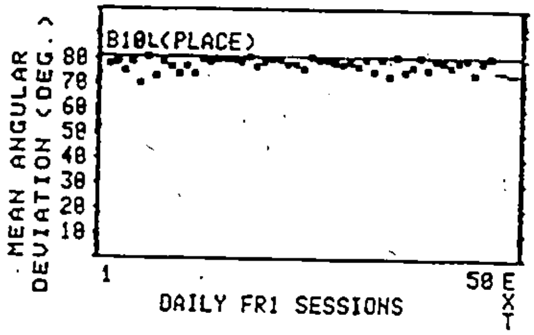

B4P(PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

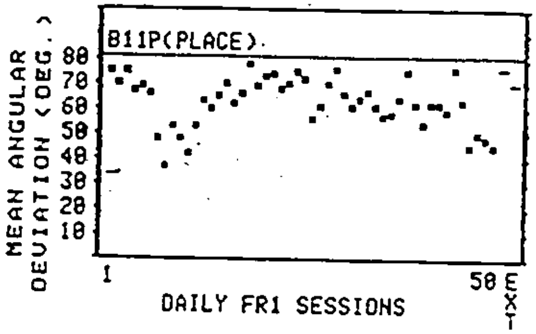

B5L(PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

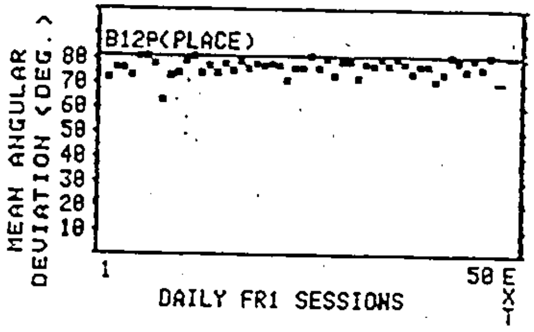

B6L(PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

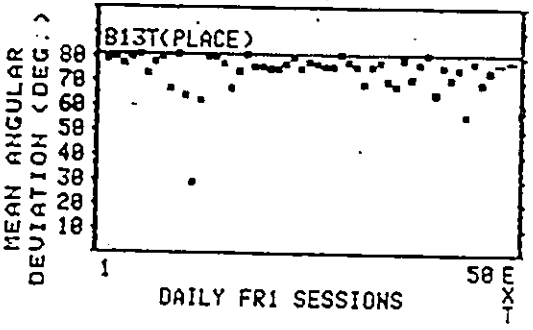

B8P(PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

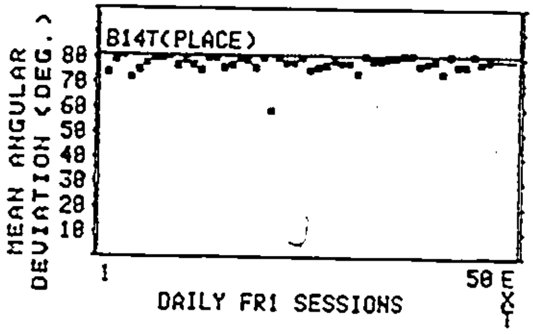

B9L(PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

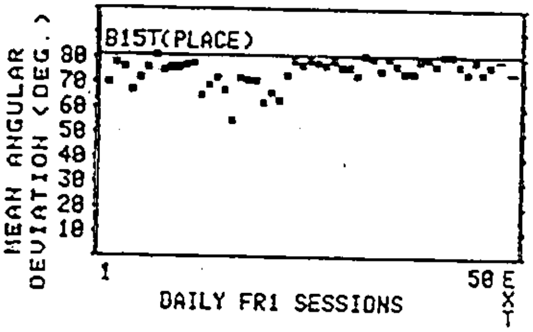

B10L(PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS


B11P(PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS


B12P(PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS


B13T(PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

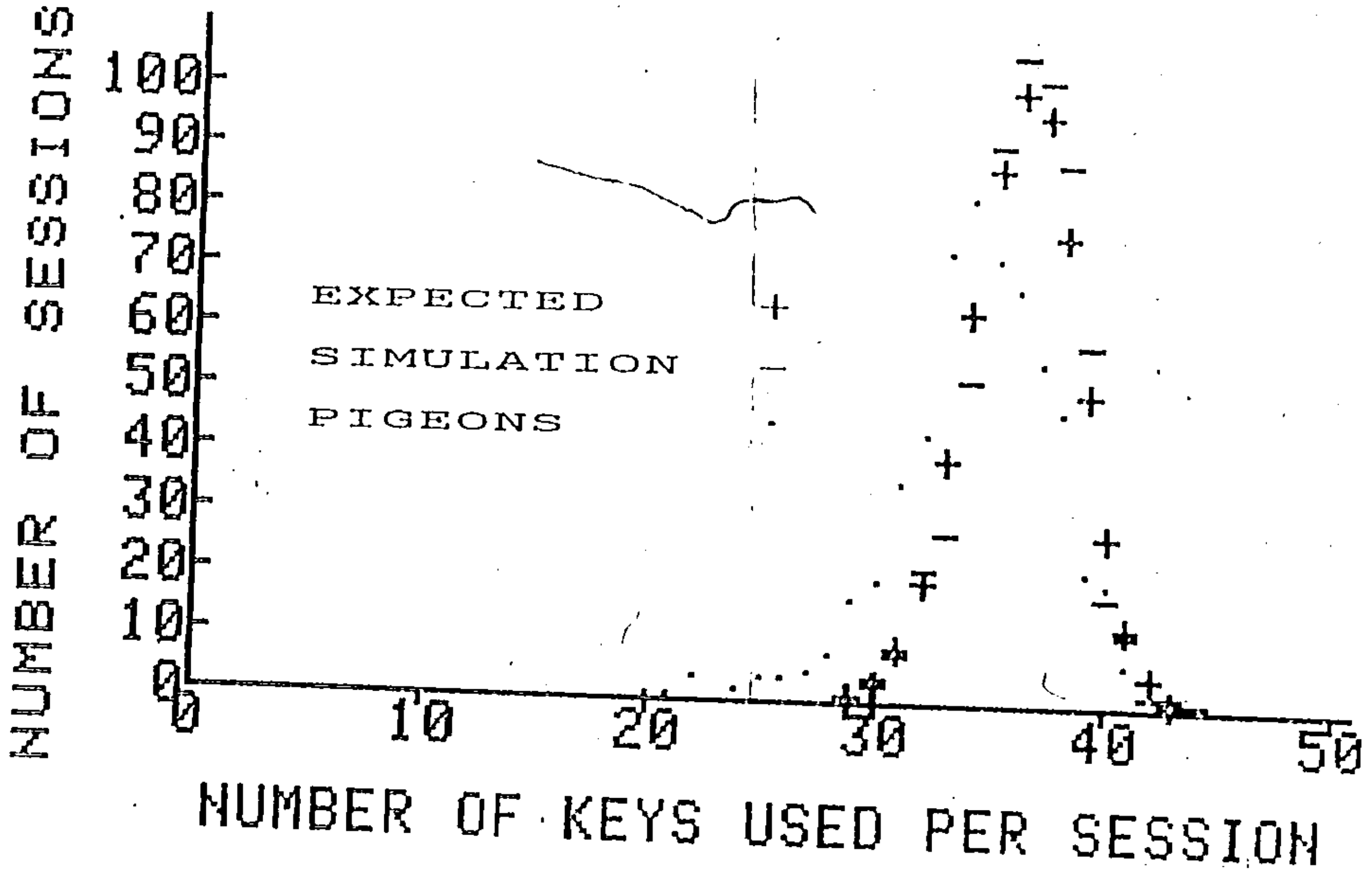

B14T(PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS


B15T(PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

angular deviation over sessions, and the values of *s* were generally around the maximum possible variability.

Figure 32 presents the data, summed over all 12 pigeons and all 50 days, for number of sessions with a given number of different keys pecked in that session. Given for comparison are the expected distribution based upon independent random trials, and a Monte-Carlo simulation based upon random keypecking. These three distributions were calculated using the same number of trials per session (50), the same number of choices (72), and the same number of sessions (600). The pigeon data were biassed toward a lower number of keys per session, compared to both the expected values and the random simulation data, which are apparently indistinguishable. Thus, the pigeons in Experiment 2 used fewer keys than would be expected by chance, showing some sort of Place stereotypy. It should be noted that although the two pigeons which displayed some Place stereotypy, B6L and B11P, contributed the majority of very low sessions (those using less than 30 keys), most of the other 10 pigeons also had some very low sessions. The simulation had no sessions with less than 30 different keys used, and the expected probability of obtaining less than 30 keys given independent random responding is .003. The distribution of pecks per key for B6L was cited above as suggesting

Figure 32. Number of sessions with a particular number of different keys used, averaged over all 50 daily sessions of FR 1 and all 12 pigeons in Experiment 2.


NUMBER OF SESSIONS
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
NUMBER OF KEYS USED PER SESSION
EXPECTED +
SIMULATION –
PIGEONS ·

that this pigeon might have formed local progressive stereotypies around particular keys. This pigeon did have the lowest mean number of different keys used per session, but did not display progressive stereotypy, since number of keys used per session decreased irregularly until around Session 35, then increased.

### Extinction

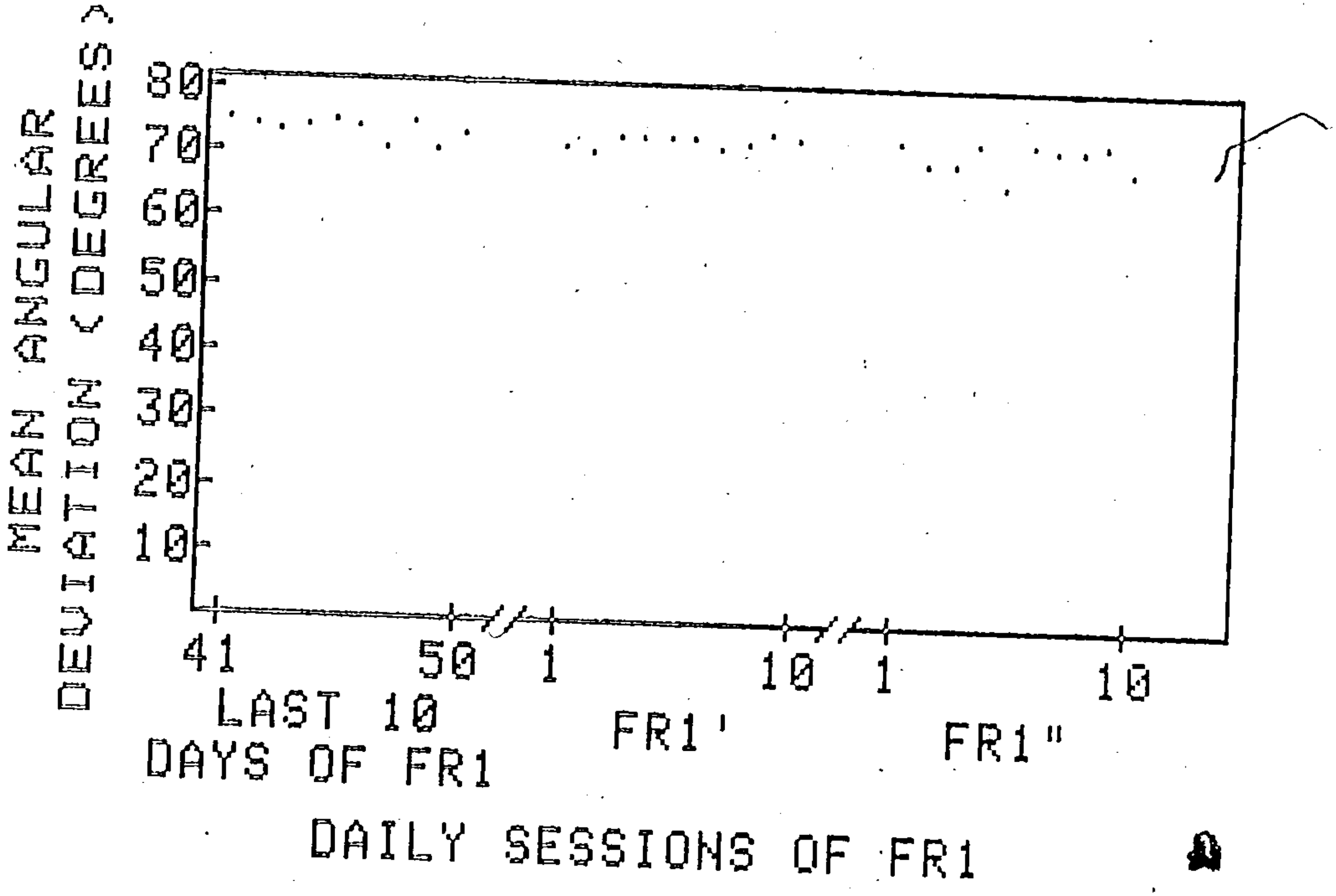
As shown in Figure 31, EXT had no discernible effect upon the variability of Place, at least for 10 of the pigeons. These 10 pigeons had very low concentrations of pecks in FR 1, and continued to produce low concentrations of pecks in EXT. The two pigeons that had some tendency to peck in a particular location or direction, B6L and B11P, showed an immediate decrement of r for Place upon institution of EXT, although their mean angles were close to those produced on the last day of FR 1, at least for Session 1 of EXT.

### Fixed Ratio 1', Extinction', and Fixed Ratio 1''

Analysis of variance comparing mean angular deviations for all pigeons on the last 10 days of FR 1, the 10 days of FR 1', and the 10 days of FR 1'', showed no statistically significant effects of Repetition (FR 1 vs FR 1' vs FR 1''), Sessions, or Repetition x Sessions. These data are shown in Figure 33.

### Targeted Percentile

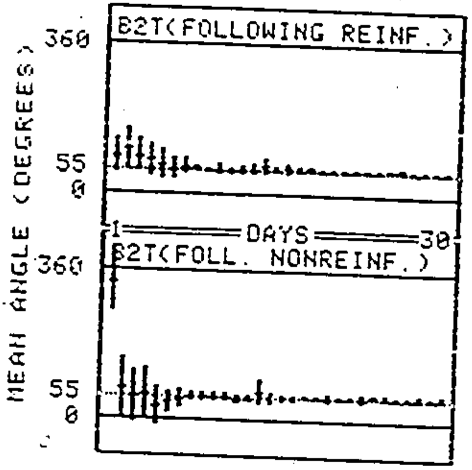
Figure 33. Mean angular deviation for Place on each of the last 10 daily sessions of FR 1, each of the 10 daily sessions of FR 1', and each of the 10 daily sessions of FR 1'', averaged over all 12 pigeons in Experiment 2.

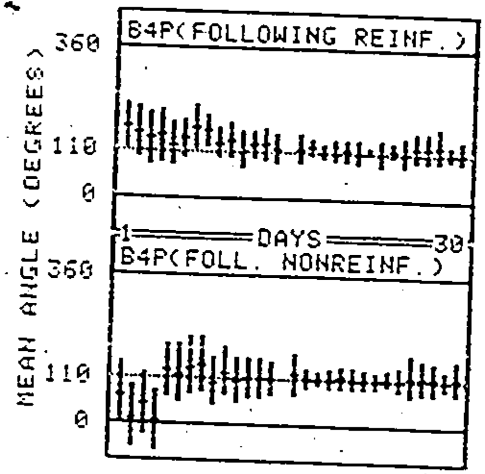

MEAN ANGULAR DEVIATION (DEGREES)
80
70
60
50
40
30
20
10
41
50
1
10
1
10
LAST 10 DAYS OF FR1
FR1'
FR1"
DAILY SESSIONS OF FR1

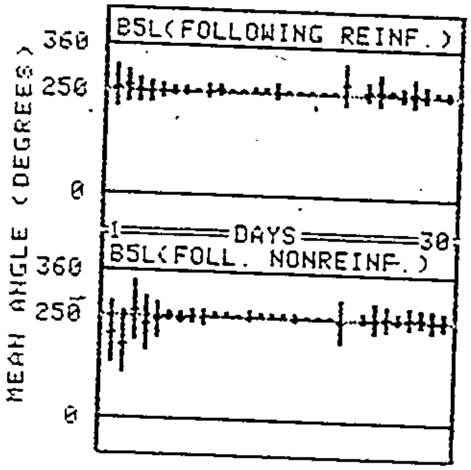
As in Experiment 1, the data were separated into trials following reinforced trials and trials following nonreinforced trials, and daily mean vectors were calculated for each type of trial. The data for the 30 sessions are presented in Figure 34, in terms of mean angle and mean angular deviation, s. As in Experiment 1, mean angle will be taken to indicate "accuracy", while mean angular deviation will be taken as an index of "variability". In order to show variability more clearly, Figure 35 presents mean angular deviation alone, following reinforced and nonreinforced trials, as a function of sessions.

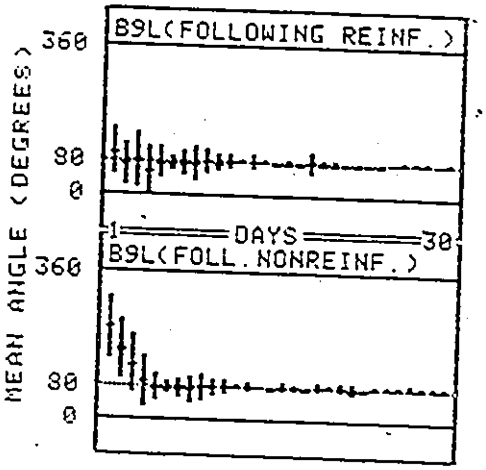
Pigeons B4P and B12P were run under the same conditions as the six pigeons in Experiment 1, Target 1. Pigeon B4P was initially more accurate following reinforced trials than following nonreinforced trials, but both trials following reinforced trials and trials following nonreinforced trials were very close to the target from Session 5 to the end of TP. Variability was lower for trials following reinforced trials than for trials following nonreinforced trials up to around Session 18, after which the variability of trials following reinforced and following nonreinforced trials was approximately the same for both sorts of trials. Pigeon B12P was slightly more accurate following reinforced

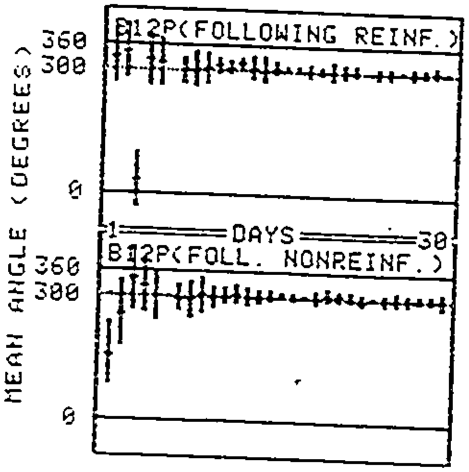
Figure 34. Mean vector for Place for trials following reinforced trials and for trials following nonreinforced trials for each daily session of TP shaping of Place for each of 12 pigeons in Experiment 2. The data are plotted in terms of the mean vector ± the mean angular deviation.


B2T(FOLLOWING REINF.)
360
55
0
1 DAYS 30
B2T(FOLL. NONREINF.)
360
55
0
MEAN ANGLE (DEGREES)


B4P(FOLLOWING REINF.)
360
110
0
1 DAYS 30
B4P(FOLL. NONREINF.)
360
110
0
MEAN ANGLE (DEGREES)


B5L(FOLLOWING REINF.)
360
250
0
1 DAYS 30
B5L(FOLL. NONREINF.)
360
250
0
MEAN ANGLE (DEGREES)


B9L(FOLLOWING REINF.)
360
80
0
1 DAYS 30
B9L(FOLL. NONREINF.)
360
80
0
MEAN ANGLE (DEGREES)


B12P(FOLLOWING REINF.)
360
300
0
1 DAYS 30
B12P(FOLL. NONREINF.)
360
300
0
MEAN ANGLE (DEGREES)

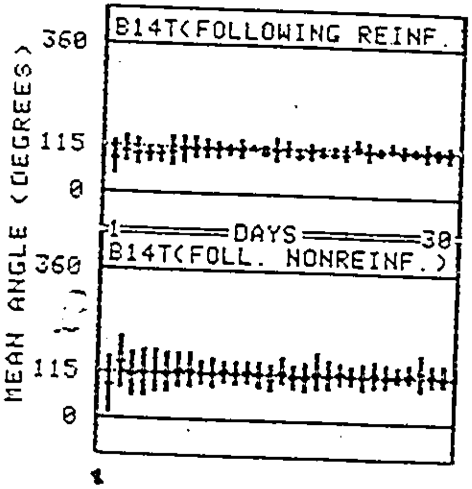
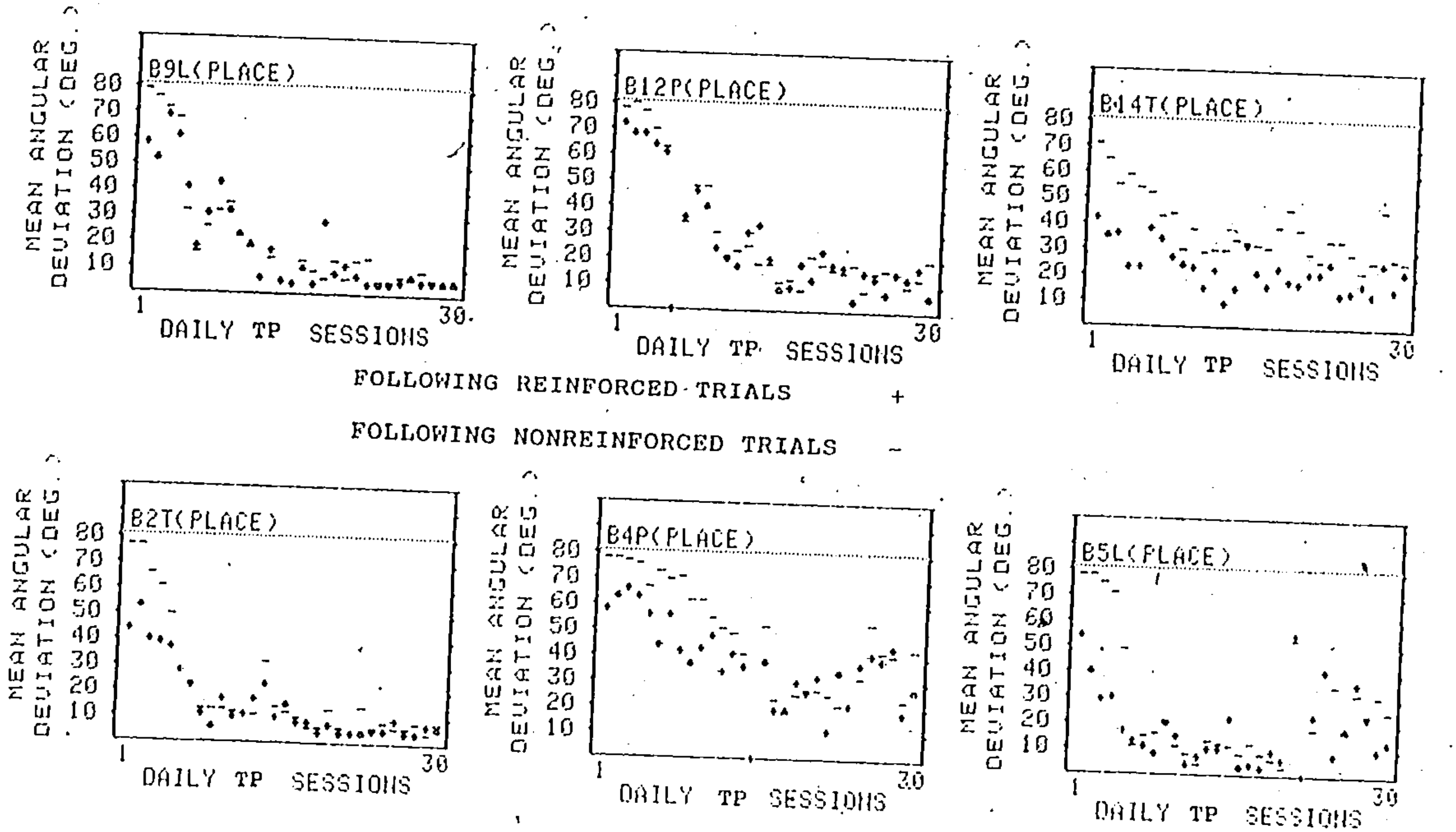

B14T(FOLLOWING REINF.)
360
115
0
1 DAYS 30
B14T(FOLL. NONREINF.)
360
115
0
MEAN ANGLE (DEGREES)

Figure 35. Mean angular deviation for Place for trials following reinforced trials and for trials following nonreinforced trials for each daily session of TP shaping of Place for each of 6 pigeons in Experiment 2.


B9L(PLACE)
B12P(PLACE)
B14T(PLACE)
B2T(PLACE)
B4P(PLACE)
B5L(PLACE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
30
DAILY TP SESSIONS
FOLLOWING REINFORCED TRIALS +
FOLLOWING NONREINFORCED TRIALS -

trials than following nonreinforced trials for the first three days, but after Session 5, trials following reinforced and trials following nonreinforced trials were equally accurate. Variability was lower for trials following reinforced trials than for trials following nonreinforced trials up to Session 11, after which it was approximately the same for both.

Pigeons B5L and B9L displayed a similar pattern to that of B4P and B12P. Pigeon B5L was accurate following reinforced trials from Session 1, and following nonreinforced trials from Session 5, to the end of TP. Variability was lower following reinforced trials than following nonreinforced trials up to Session 6, after which it was approximately the same for both sorts of trials. Pigeon B9L was somewhat more accurate following reinforced trials than following nonreinforced trials up to Session 4 or 5, after which both types of trials were equally accurate. Variability was lower following reinforced trials than following nonreinforced trials up to Session 5, following which it was approximately the same for both.

Pigeons B2T and B14T differed somewhat from the pattern so far. Pigeon B2T may have been more accurate following nonreinforced trials than following reinforced trials up to Session 6, although there is not much to choose between the two. Following Session 6, they were equally accurate. Variability was lower following reinforced trials than following nonreinforced trials up to Session 7, after which it was approximately the same for both. Pigeon B14T was always more accurate following <u>nonreinforced</u> trials than following reinforced trials. Pigeon B14T showed less variability of Place following reinforced trials than following nonreinforced trials on every day.

Variability on trials following both reinforced and nonreinforced trials declined steadily for one of the pigeons in each group- B12P, B9L, and B2R. For the other three birds- B4P, B5L, and B14R, variability showed a u-shaped function, decreasing for some number of days and then increasing and generally becoming more variable between days. In the case of B5L this increase in variability may be understandable, since B5L pecked two letters off their keys during Session 21. This was the only time this happened in the experiment. From Session 21 on, B5L showed much more variability than it had since the first few days of TP. There is no explanation for the similar behavior of B4P and B14R.

In sum, the mean angle was more accurate following reinforced trials than following nonreinforced trials, for the pigeons in Groups P and L. In Group T, pigeon B2T was inaccurate following both types of trials, while B14T was more accurate following <u>nonreinforced</u> trials. This difference in accuracy following reinforced and nonreinforced trials was evident for approximately the first six days of TP, following which accuracy was equivalent following both types of trials. Variability around the mean angle was lower following reinforced trials than it was following nonreinforced trials, for all six pigeons. This difference in variability following reinforced and nonreinforced trials was, as with the accuracy difference, evident at the start of TP. For Groups L and T, the differences in accuracy and variability lasted about the same number of days. In Group P, however, the accuracy difference lasted about 5 days, while the variability difference lasted 11 and 18 days.

### Fixed Ratio 1'''

When switched back to FR 1''' following TP, three pigeons continued to peck with mean angles for Place close to the former target direction. Pigeon B9L not only maintained the mean angle within 2°, but also retained a low variability, throughout the 10 days of FR 1'''. Pigeon B12P gradually drifted from the target angle, and also gradually increased in variability, but was accurate and low in variability for the first 5 days. Pigeon B5L was quite accurate and low in variance on Session 1 of FR 1''', but showed a high variability and some drift around the target direction from then on. Both of these pigeons stayed close to the target throughout FR 1'''.

Pigeon B2T was quite accurate and low in variance for the first two days of FR 1''', but drifted counterclockwise and increased drastically in variability from then on. Pigeons B4P and B14T both showed an immediate loss of accuracy of mean angle and increase in variability on Session 1 of FR 1''', which continued through Session 10.

Thus, when shifted from a TP schedule shaping to a particular Place, to an FR 1 schedule, only one pigeon out of six maintained the target angle with low variability for all 10 days. On the other hand, three out of the six pigeons maintained the target angle within 45°, with some increase in variability.

Extinction''

For every pigeon except B9L, EXT'' produced more accurate mean angles (compared to the target angles in TP) and lower variability than had been produced in FR 1'''. Pigeon B9L could not get more accurate, and not much less variable, than in FR 1'''. This pigeon did maintain the same mean angle, and the same low variability, increasing in variability somewhat on Session 2 of EXT''.

## DISCUSSION: PLACE

Neither the presence of local cues nor the presence of configurational cues affected the level of Place stereotypy on FR 1 in Experiment 2. Indeed, there was no apparent tendency for the pigeons in Experiment 2 to respond in any particular place or direction during FR 1, as shown by individual Place mean vectors. There also was no progressive increase in concentration of responding, as shown by daily Place mean vectors. These findings suggest that the slight transient Place stereotypies found in Experiment 1 were due to avoidance of relatively difficult keys, rather than being due to the action of the Law of Effect.

Possible exceptions were pigeons B11P and B6L, which had the only Place mean vectors for all of FR 1 which were longer than .1. Pigeon B11P produced a unimodal, symmetrical distribution of pecks centered around 195°. Probably, the actual center of the distribution was Key #40 (i.e., 200°), which had a slightly different tint from the other keys. It is likely, despite the pains taken to avoid this sort of confound, that B11P formed a mild "sensory superstition"

(Brown and Jenkins, 1968) during FR 1. If so, this was the only pigeon that did. (None of the pigeons in Experiment 1 produced a similar graded distribution of responding around Key #40. However, B63, uniquely for both experiments, pecked Key #40 twice as frequently as the next most frequently used key (see Figure 3). The rest of the distribution of per cent pecks per key produced by B63 was essentially rectangular. This would be accounted for by Baum (1974) as a color preference.)

Pigeon B6L did not show a clearly defined distribution of pecks around one central tendency, but rather a number of separate preferred keys. Pigeon B6L apparently had a mean vector for Place greater than .1 simply because of having a greater number of strongly-preferred keys in one broad area of the chamber than in the rest of the chamber. The pattern of pecking shown by B6L, and to some extent, B5L, (and to a much lesser extent, all of the pigeons in both experiments), suggests that the pigeons, while circling around the box, might form local (perhaps temporary) Place stereotypies at more than one spot on the response continuum. This suggestion is strengthened by B6L and B5L both being members of the group which had a different symbol fixed to each key. This condition was intended to make the keys more distinguishable from each other, and thus possibly more conducive to stereotypy. However, neither B6L, nor any of the the other pigeons, showed the progressive decrease in number of keys used per session which would be the consequence of a progressive Place stereotypy at numerous places on the response continuum. The most likely explanation for the behavior of pigeons B5L and B6L is a preference for certain of the symbols.

The distribution of mean number of keys used per session looks perfectly reasonable, but it is not the distribution predicted by independent random key selection. Aside from the slight skew toward low numbers of keys used, the pigeons appeared to use about two less keys during a session than they ought to, if they were paying no attention to Place. However, number of keys used in a session did <u>not</u> show a progressive decrease, either for groups, or, with more day-to-day variability, for individual pigeons. One way that the pigeons could produce the obtained distribution of number of keys used per day would be to, in effect, only run 46 trials in a session. They could do this by repeating some key four different times, on the average, in each session. Checking this possibility involves inspection of the Response data for values of $0^{\circ}$. A greater-than-expected proportion of Response values of $0^{\circ}$ is evidence of Place stereotypy, of a very transient sort, even in the absence of any other indications of Place stereotypy. Discussion of these data will be postponed until the results for Response have been presented. Keep in mind, however, that data for Response of 0° will be evidence bearing upon Place stereotypy.

In sum, contrary to the predictions of the Law of Effect, there was no progressive stereotypy of Place due simply to repeated nondifferential reinforcement in Experiment 2. Indeed, there seemed to be no great stereotypy of Place at all on an FR 1 schedule.

Not only did the 12 pigeons in Experiment 2 not show a progressive decrease in daily mean vector length over 50 days of FR 1, but repeated extinction and reconditioning (EXT, FR 1', EXT', and FR 1'') did not produce Place stereotypy either, at least according to this measure.

Three of the pigeons showed good retention, in FR 1''', of the strong Place stereotypy induced by TP shaping, while the other three pigeons lost this stereotypy quite rapidly. These data are similar to those of Davis and Platt (1983), who found that half of their rats maintained a Place stereotypy induced by a TP schedule when shifted to RR 5, while the other half lost the stereotypy.

## RESULTS: RESPONSE

### Fixed Ratio 1

As in Experiment 1, the analysis of Response will generally parallel that for Place. Inspection of Figure 36 reveals that the mean angular deviation of the Response measure, for Groups P, L, and T, was essentially unchanged over Sessions. This is borne out by analysis of variance on mean angular deviation, which showed no significant effect of Sessions, Groups, or Groups x Sessions (all Fs < 1). Since the data for the cue groups showed no effects of this manipulation upon the Response measure, analyses of general trends were conducted using data summed over all 12 pigeons, rather than data divided by groups.

Figure 37 shows the mean Response vectors summed over all 50 daily sessions of FR 1 for each pigeon, as well as the group mean Response vector. These vectors show substantial Response stereotypy, particularly compared to the corresponding vectors for Place.

The distribution for Response, summed over subjects and sessions, for all 29,400 trials of FR 1, is given in Figure 38. The grand mean vector for all of FR 1 was (14°, .252). The distribution is smooth, with a mode around 30°, and weighted slightly toward negative

Figure 36. Group mean angular deviations for Response for Groups P, L, and T for each daily session of FR 1 in Experiment 2.

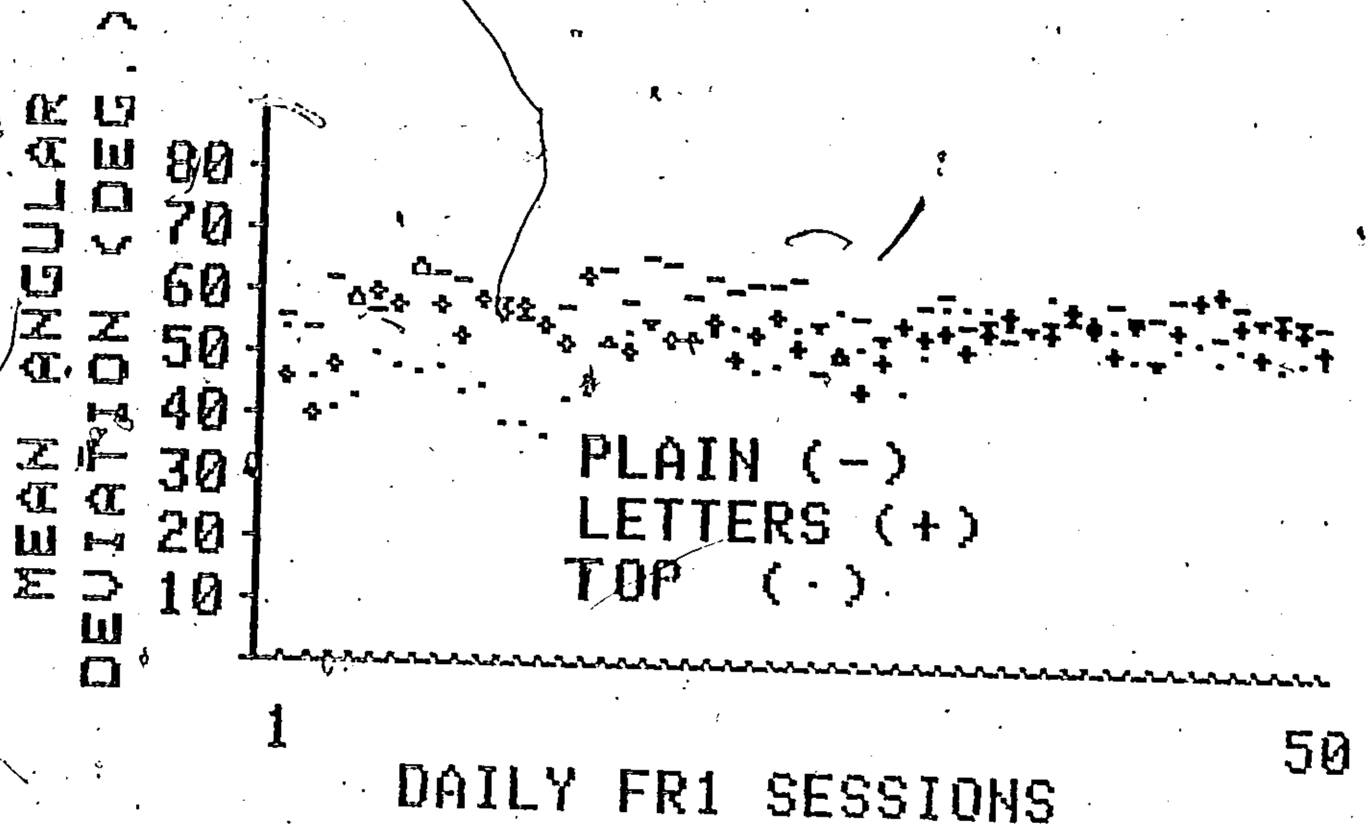

MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
DAILY FR1 SESSIONS
PLAIN (-)
LETTERS (+)
TOP (·)

Figure 37. Mean vectors for Response averaged over all 50 sessions of FR 1 for each pigeon, and the grand mean vector (represented by the dot) for all 12 pigeons in Experiment 2.

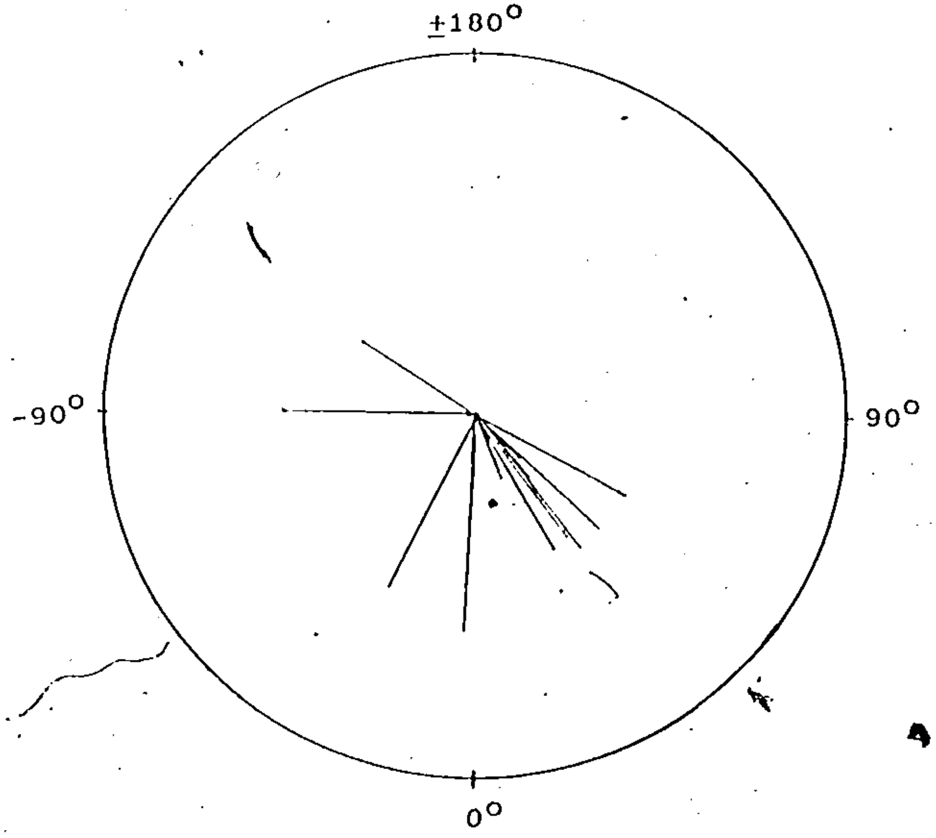
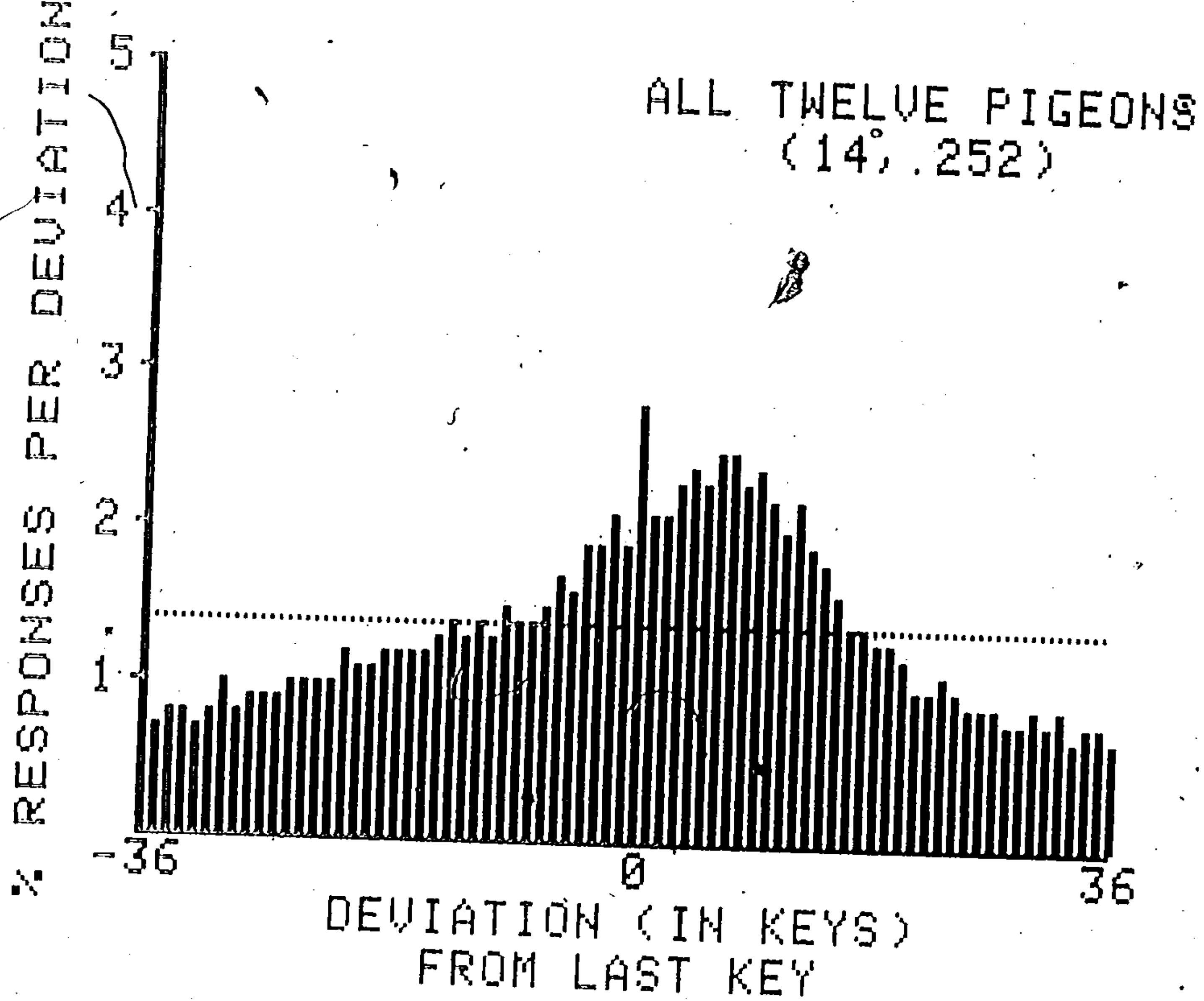

±180°
-90°
90°
0°

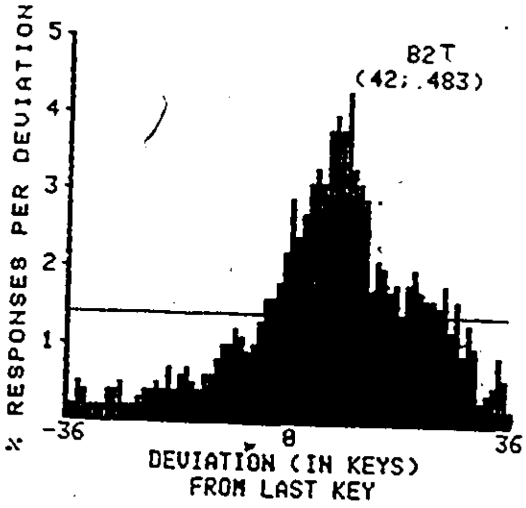
Figure 38. Per cent Response per 5o interval, averaged over all 50 daily sessions of FR 1 and all 12 pigeons in Experiment 2.

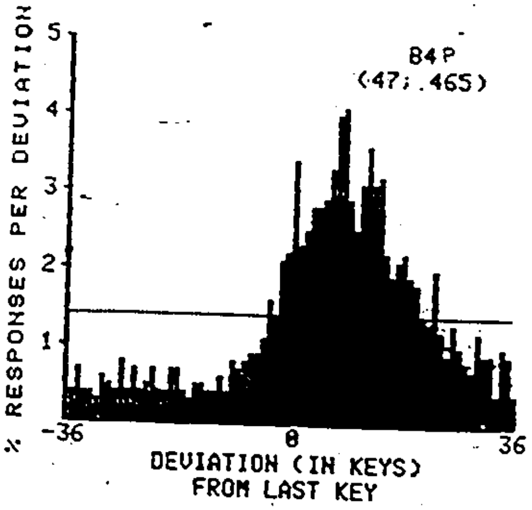

ALL TWELVE PIGEONS
(14°, .252)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

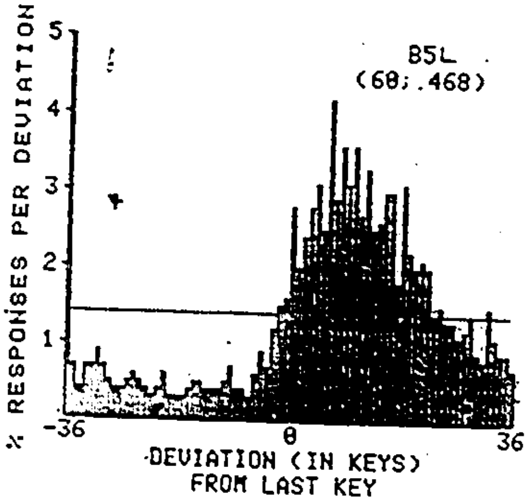
deviations. The most popular deviation, however, is one of 0°. (The most popular deviation in FR 1 for Experiment 1, by a narrow margin, was also 0°; see Figure 14.)

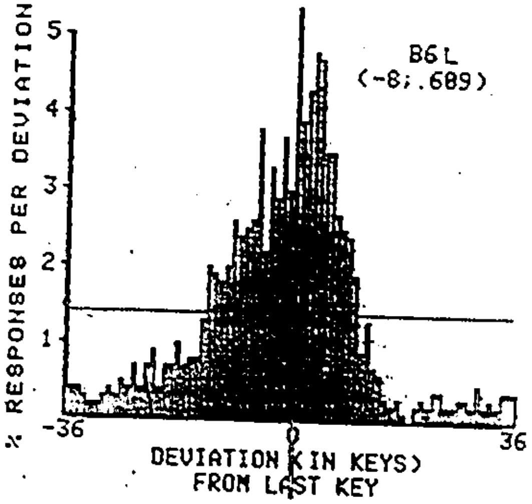
Distributions of Response cumulated over the 50 Sessions of FR 1 are presented for each pigeon in Figure 39. Of the 12 distributions, 9 possess a distinct central tendency, with frequency of Responses falling away smoothly to either side. The highest mean vector length for 50 Sessions of FR 1 for these nine pigeons is .609 (B6L), and the lowest is .437 (B11P). However, even the distribution with the lowest mean vector length clearly seems to represent a distribution around a central tendency. The Response distribution for B15T is bimodal. This is not an artifact due to summing over sessions with different central tendencies, but rather was caused by summing over a number of daily Response distributions, most of which were bimodal. The Response distributions for the remaining two pigeons, B9 and B12, seem to have a modal Response with gradients to either side, but they are relatively small and the flat tails suggest that they are mixed with a "random" or uniform distribution. <u>All</u> of the distributions, even the weakest, appear to reflect some behavioral regularity. None of the distributions appears to have a central tendency at 0°, although

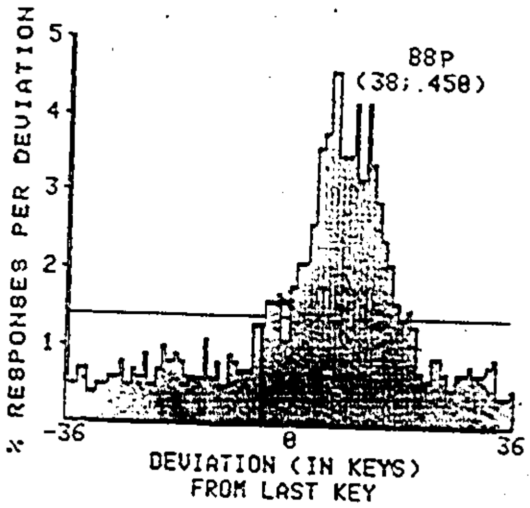
Figure 39. Per cent Responses per 5° interval averaged over all 50 daily sessions of FR 1 for each of 12 pigeons in Experiment 2.

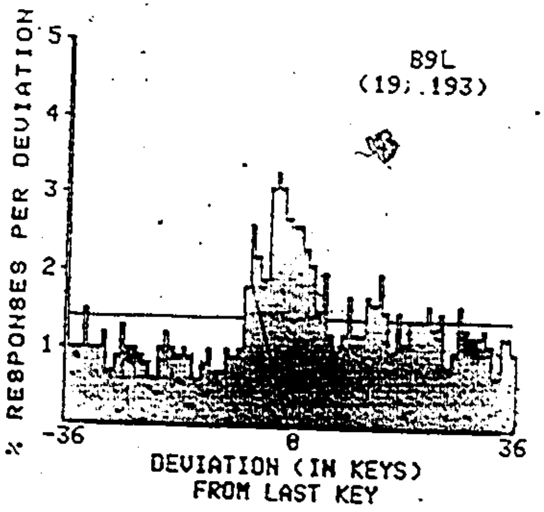

B2T
(42; .483)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

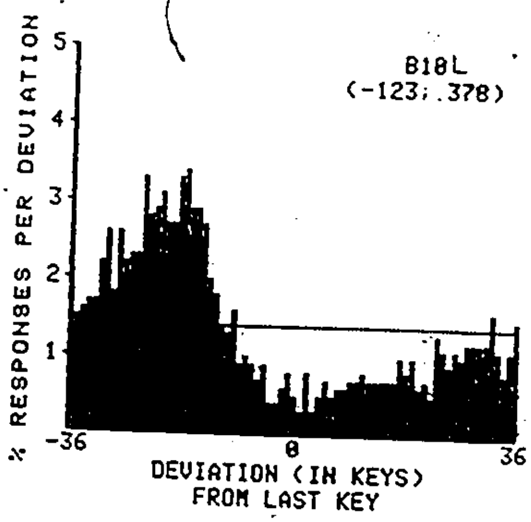

B4P
(47; .465)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

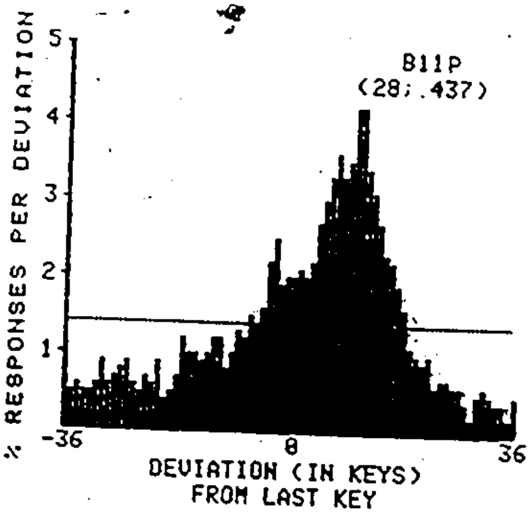

B5L
(68; .468)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

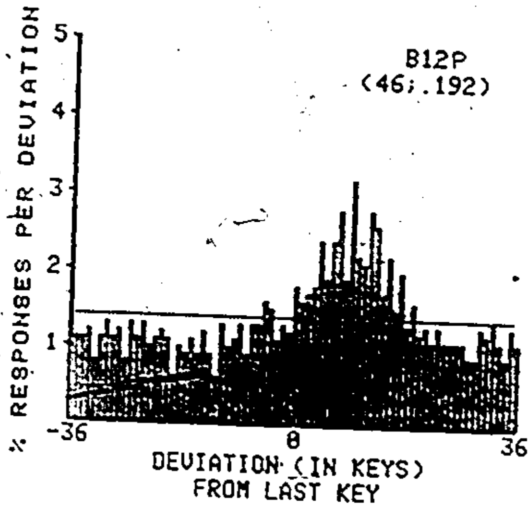

B6L
(-8; .689)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

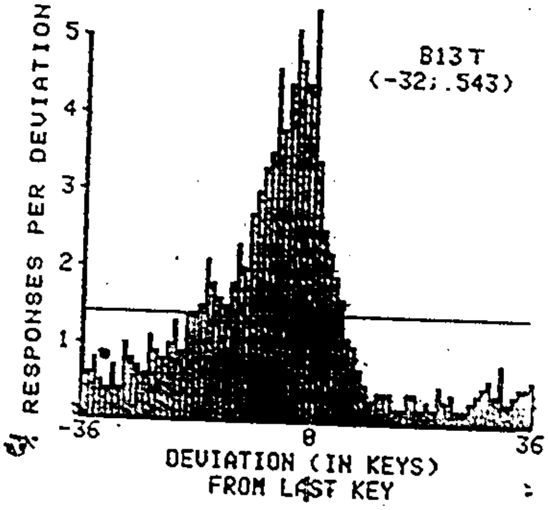

B8P
(38; .458)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

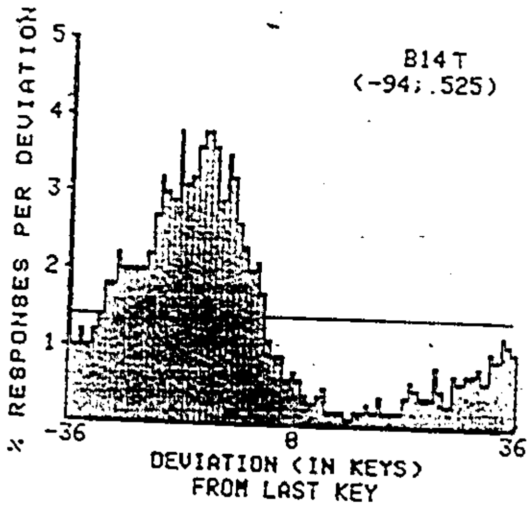

B9L
(19; .193)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

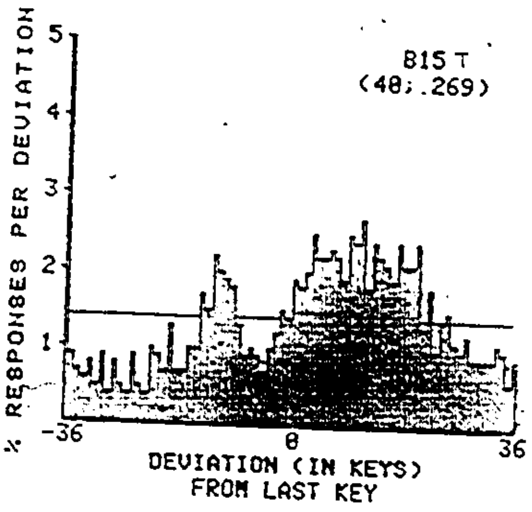

B18L
(-123; .378)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY


B11P
(28; .437)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY


B12P
(46; .192)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY


B13T
(-32; .543)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

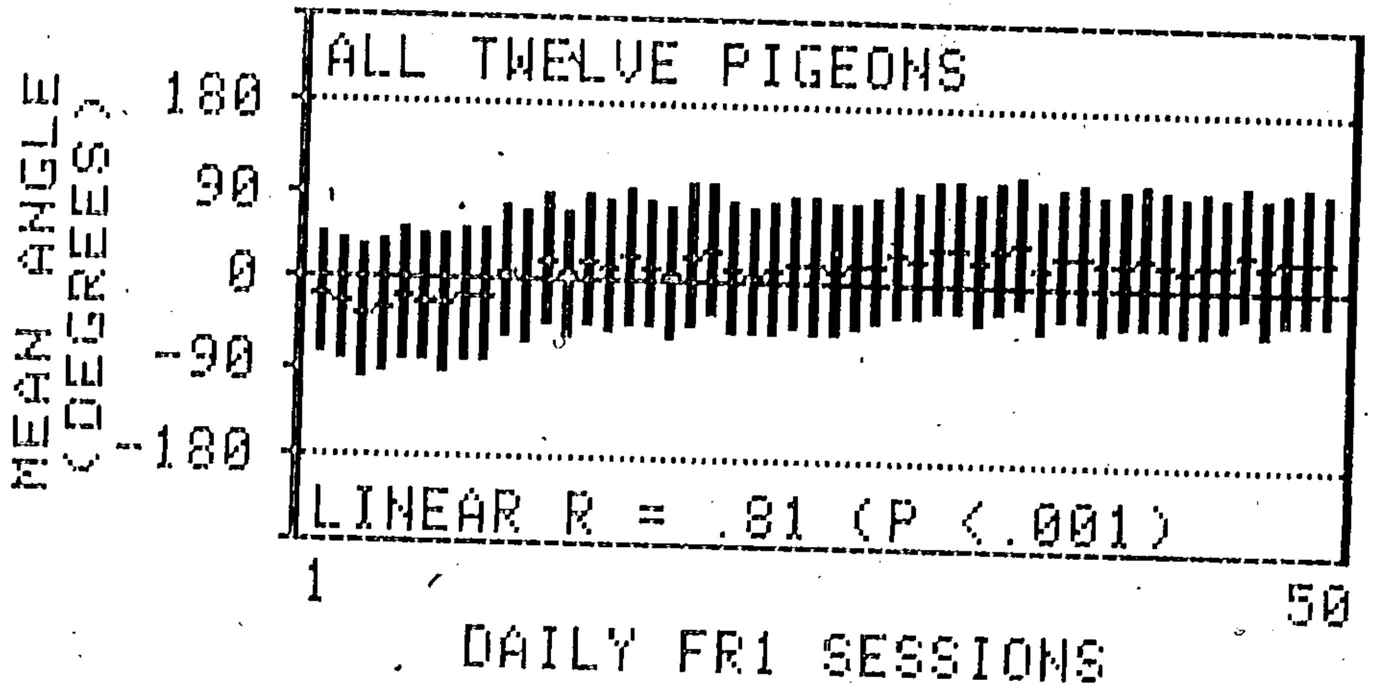

B14T
(-94; .525)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY


B15T
(48; .269)
% RESPONSES PER DEVIATION
5
4
3
2
1
-36
0
36
DEVIATION (IN KEYS)
FROM LAST KEY

$0^{\circ}$ is clearly the modal Response for B6L and B13T. Pigeons B2T, B4P, and B5L seem to favor a Response of $0^{\circ}$ over neighboring deviations.

A daily group mean vector was calculated from the individual daily mean vectors of all 12 pigeons for each session of FR 1. This was done in order to determine whether there were progressive changes in Response over FR 1 for the pigeons as a group. These data are presented in Figure 40. There appeared to be such an overall change, although no session produced a group mean vector length large enough to be significantly different from chance by the Rayleigh test with a=.05 and n=12 ($\underline{r} > .50$ is required). However, the group mean vectors for Response are quite sizable compared to those for Place. The daily group mean angle for Response did not vary greatly from $0^{\circ}$, and hence could be considered a linear variable (Batschelet, 1981). Therefore, a linear correlation was performed on daily mean angle and Session number, and a best-fitting straight line calculated. The linear correlation between mean Response angle and Session number was .81. The equation for the best-fitting straight line was: (mean vector angle) = (1.14 x Session #) - 15. Whatever may be the cause of this apparent regularity, it should be noted that the slope of this best-fitting straight line is almost identical with the slope of the

Figure 40. Group mean vectors for Response for each of 50 daily sessions of FR 1 averaged over all 12 pigeons in Experiment 2. The data are plotted in terms of the mean angle ± the mean angular deviation.



ALL TWELVE PIGEONS
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
LINEAR R = .81 (P < .001)
1
50
DAILY FR1 SESSIONS

corresponding function calculated from the FR 1 data for Experiment 1 (i.e., 1.17). The grouped data for Place show nothing remotely similar.

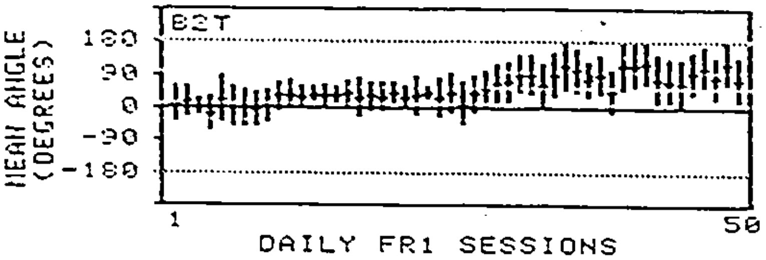
Daily mean vectors for Response for all 50 sessions of FR 1 are given for each pigeon in Figure 41. The mean vector length has been converted into the mean angular deviation, s. The angles of the daily mean vectors are seldom the same for two sessions in a row, but they seem to show gradual changes from session to session, unlike the daily mean vectors for Place. The variability of the individual daily Response vectors was consistently lower than that for Place.

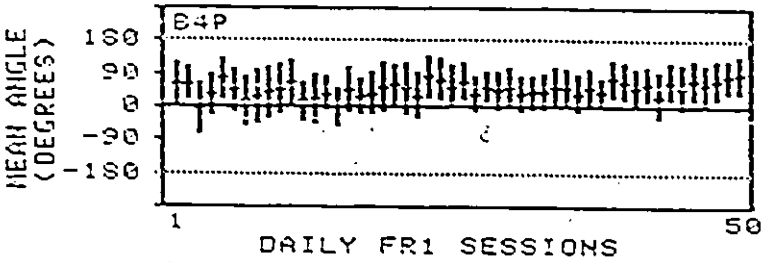
Individual daily mean angular deviations are presented in Figure 42, to show any changes in Response variability over sessions. Some pigeons displayed increases in variability over sessions, some showed decreases, and others remained constant. There appeared to be no consistent trend.

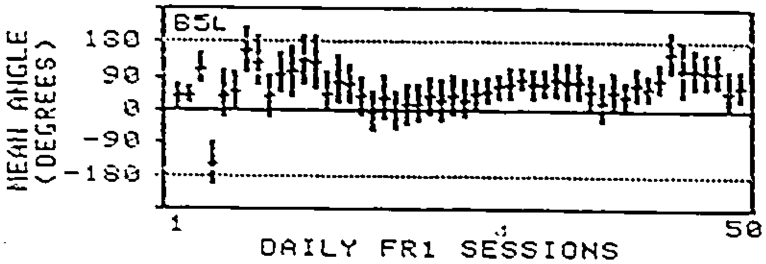
Extinction

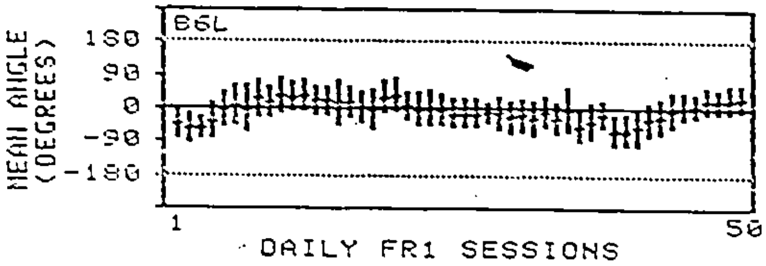
Unlike Place, Response showed a dramatic increase in variability upon institution of EXT, as shown in Figure 42. Nine of the pigeons had increases in s, compared to FR 1, on both sessions of EXT. Of the other three pigeons, B10L showed an increase on Session 1 of EXT, but a recovery on Session 2. Pigeons B5L and B8P , on the

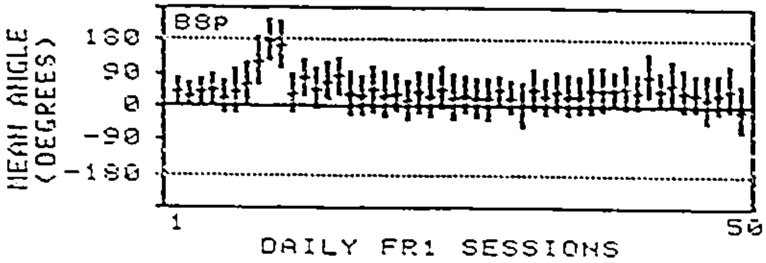
Figure 41. Mean vectors for Response for each of 50 daily sessions of FR 1 for each of 12 pigeons in Experiment 2. The data are plotted in terms of the mean angle ± the mean angular deviation.

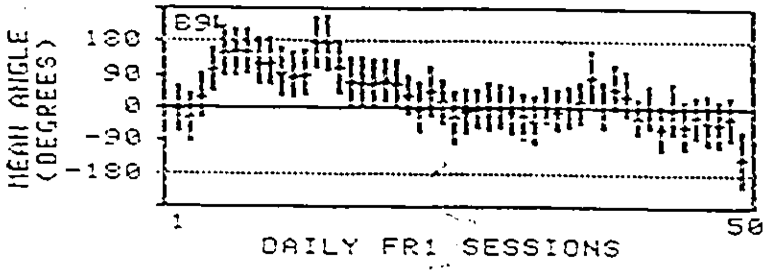

B2T
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
1
50
DAILY FR1 SESSIONS

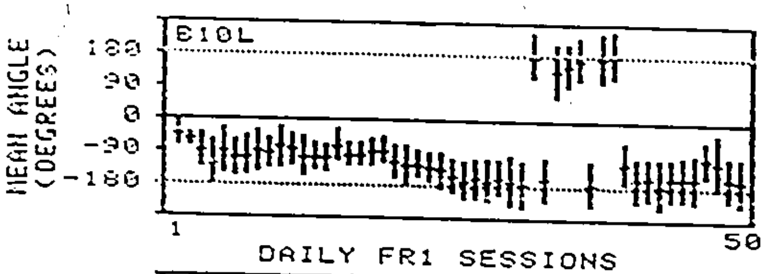

B4P
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
1
50
DAILY FR1 SESSIONS

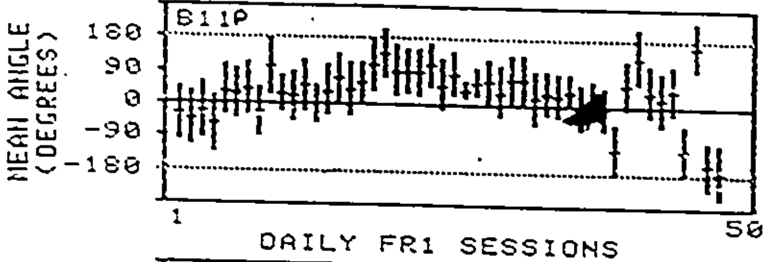

B5L
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
1
50
DAILY FR1 SESSIONS

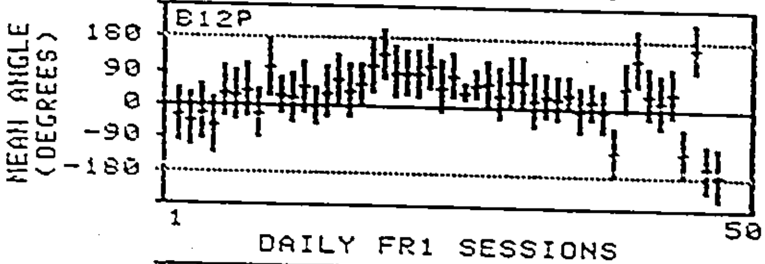

B6L
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
1
50
DAILY FR1 SESSIONS

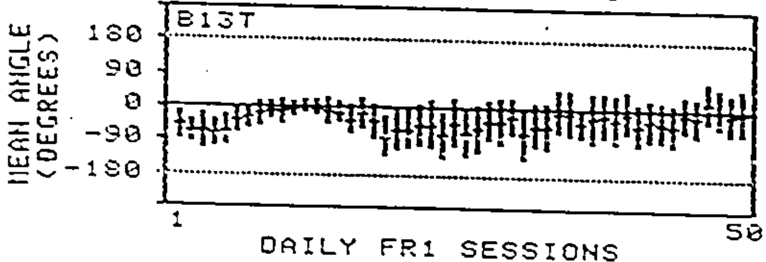

B8P
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
1
50
DAILY FR1 SESSIONS

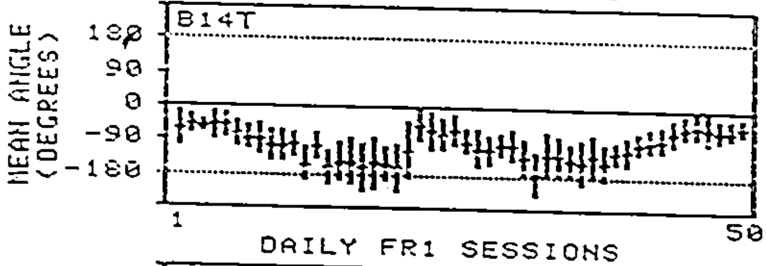

B9L
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
1
50
DAILY FR1 SESSIONS


B10L
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
1
50
DAILY FR1 SESSIONS


B11P
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
1
50
DAILY FR1 SESSIONS


B12P
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
1
50
DAILY FR1 SESSIONS


B13T
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
1
50
DAILY FR1 SESSIONS


B14T
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
1
50
DAILY FR1 SESSIONS

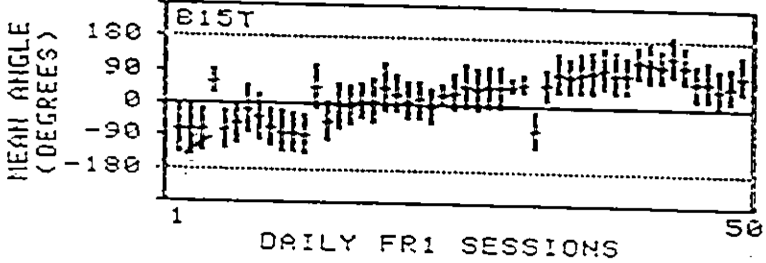
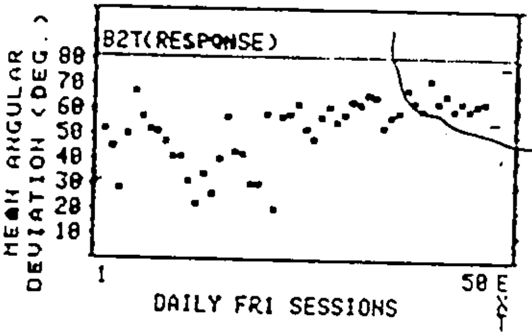
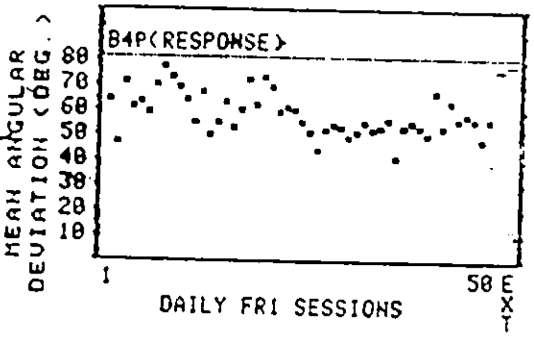
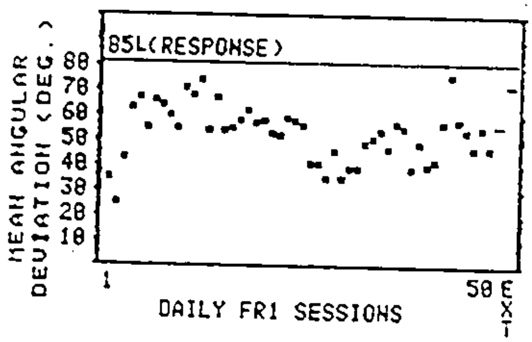
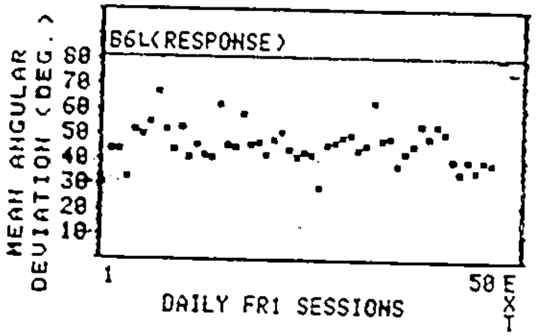

B15T
MEAN ANGLE (DEGREES)
180
90
0
-90
-180
1
50
DAILY FR1 SESSIONS

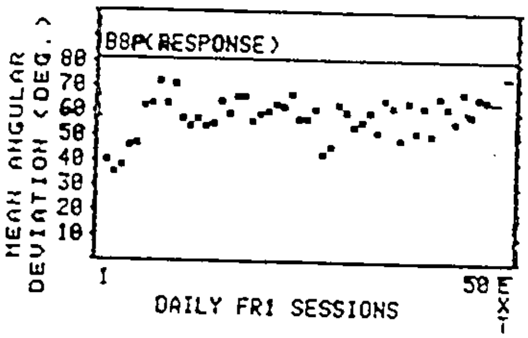
Figure 42. Mean angular deviations for Response for each of 50 daily sessions of FR 1 and 2 daily sessions of EXT for each of 12 pigeons in Experiment 2.

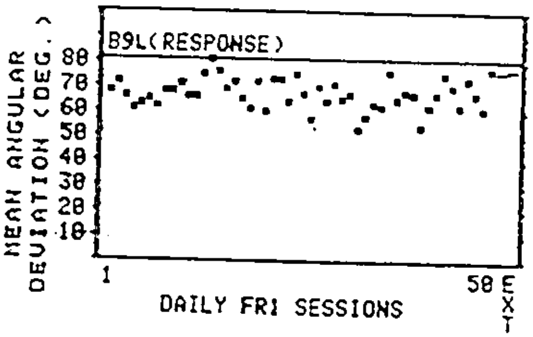

B2T(RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

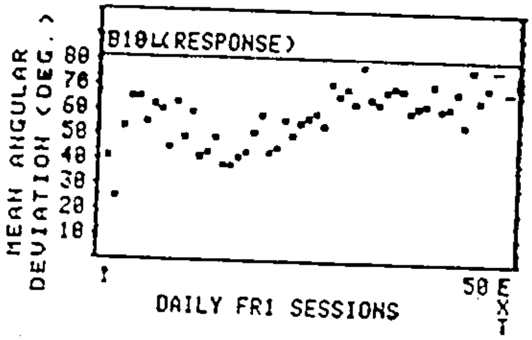

B4P(RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

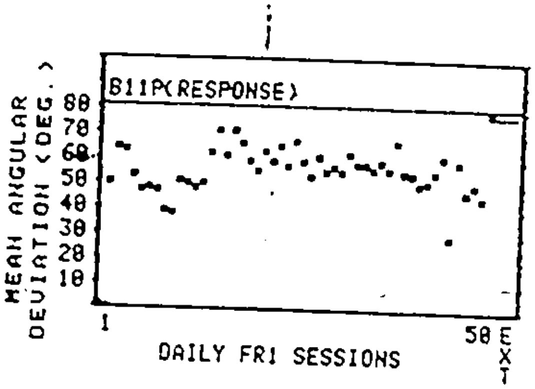

B5L(RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

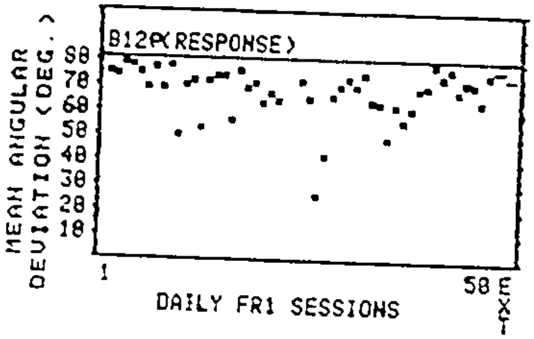

B6L(RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

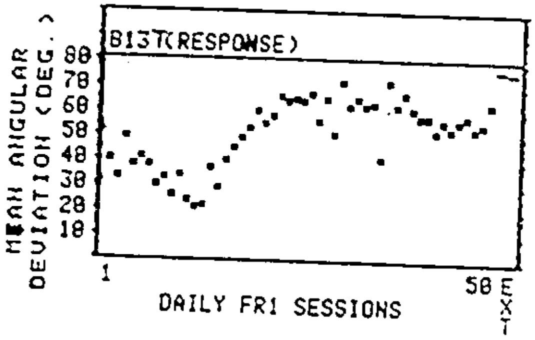

B8P(RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

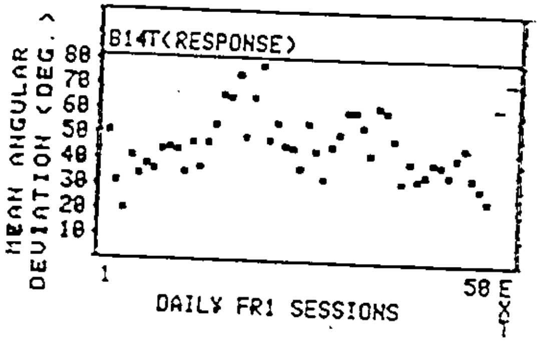

B9L(RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

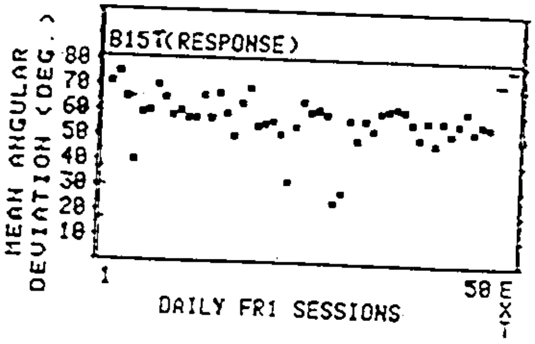

B10L(RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS


B11P(RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS


B12P(RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS


B13T(RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS


B14T(RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS


B15T(RESPONSE)
MEAN ANGULAR DEVIATION (DEG.)
80
70
60
50
40
30
20
10
1
50
EXT
DAILY FR1 SESSIONS

other hand, showed no apparent increase on Session 1 of EXT, but did on Session 2.

There appeared to be a tendency toward higher mean Response angles during EXT. Nine of 12 pigeons displayed mean Response angles greater than ±90° for Session 1, and 8 of 12 had mean Response angles greater than ±90° for Session 2. That is, although only 2 pigeons out of 12 had <u>any</u> daily mean vector angles for Response greater than ±90° out of 50 days of FR 1, at least 8 of 12 had mean vector angles for Response greater than ±90° on both days of EXT.

## Fixed Ratio 1', Extinction', and Fixed Ratio 1''

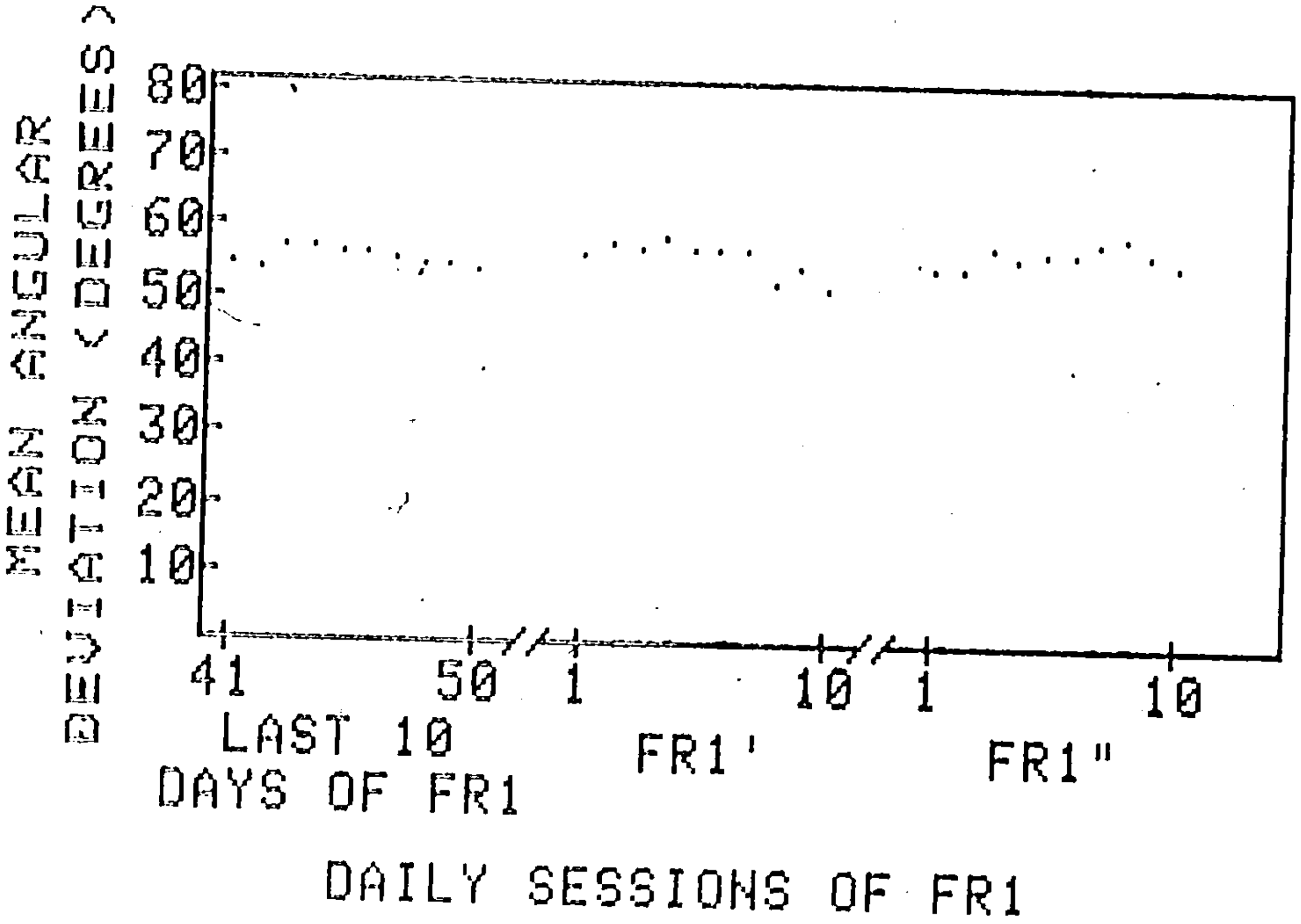
Figure 43 shows daily group mean angular deviation for all 12 pigeons, for the last 10 days of FR 1, FR 1', and FR 1''. The function appears to be flat. This was confirmed by analysis of variance, which found no significant effect of Repetition (FR 1 vs FR 1' vs FR 1''), Sessions, or Repetition x Sessions.

## Targeted Percentile

Six pigeons, two each from groups P, L, and T, were given 30 daily Sessions of TP, with a target deviation (Response) chosen to be approximately + or - 90° from their customary Response at the end of FR 1.

Mean vectors were calculated for trials following reinforced trials and trials following nonreinforced

Figure 43. Mean angular deviation for Response on each of the last 10 daily sessions of FR 1, each of the 10 daily sessions of FR 1', and each of the 10 daily sessions of FR 1'', averaged over all 12 pigeons in Experiment 2.

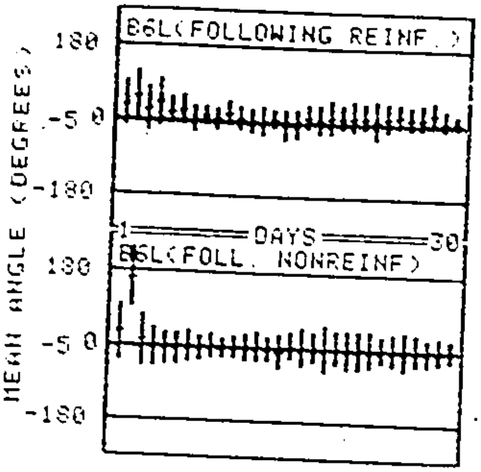

MEAN ANGULAR
DEVIATION (DEGREES)
80
70
60
50
40
30
20
10
41
50
1
10
1
10
LAST 10
DAYS OF FR1
FR1'
FR1"
DAILY SESSIONS OF FR1

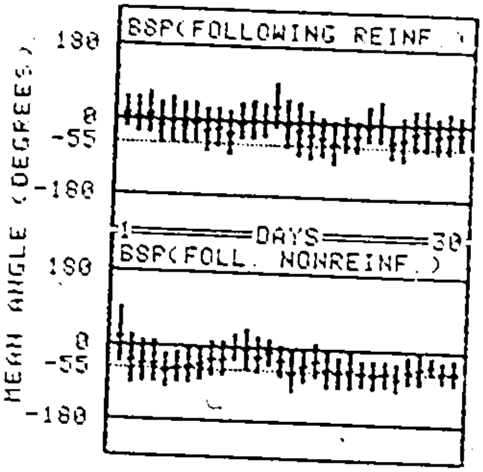
for each daily Session. These data are presented, in terms of mean angle and mean angular deviation, in Figure 44. Again, mean angle is taken to represent "accuracy", while mean angular deviation is taken to represent "variability". Figure 45 represents s alone, corrected for n, as a function of sessions, in order to show changes in variability more clearly.

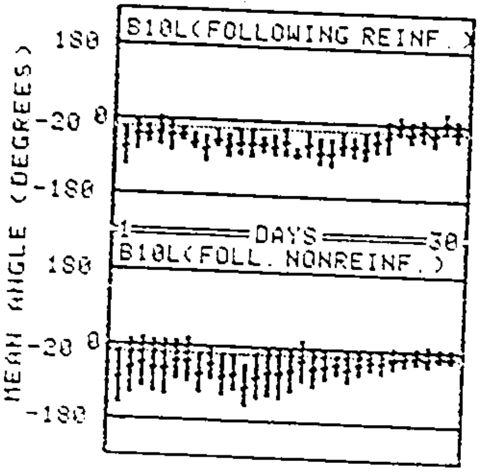
Pigeon B8P was more accurate on trials following nonreinforced trials, throughout TP. Variability was lower following reinforced trials for Sessions 1 and 2, and then generally lower following nonreinforced trials for the rest of TP. Pigeon B11P was more accurate on trials following nonreinforced trials. Through Session 12, variability was lower following reinforced trials. For the rest of TP, variability was lower following nonreinforced trials.

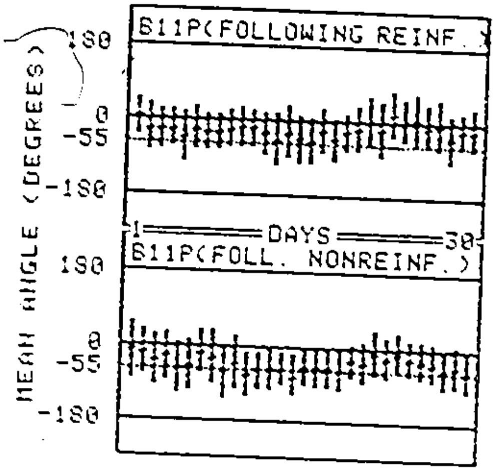
Pigeon B6L was quite accurate following nonreinforced trials, and generally inaccurate (20-30° off target) following reinforced trials. Variability for B6L was generally lower on trials following reinforced trials. Pigeon B10L was not very accurate following either reinforced or nonreinforced trials, but was generally slightly more accurate following nonreinforced trials. Pigeon B10L showed lower variance following reinforced trials up to Session 21, then lower variance

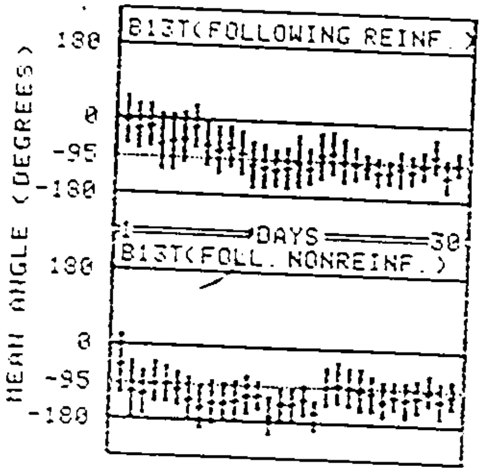
Figure 44. Mean vector for Response for trials following reinforced trials and for trials following nonreinforced trials for each daily session of TP shaping of Response for each of 6 pigeons in Experiment 2. The data are plotted in terms of the mean vector ± the mean angular deviation.


B6L(FOLLOWING REINF.)
MEAN ANGLE (DEGREES)
180
-5 0
-180
1 DAYS 30
B6L(FOLL. NONREINF)
180
-5 0
-180


B5P(FOLLOWING REINF.)
MEAN ANGLE (DEGREES)
180
0
-55
-180
1 DAYS 30
B5P(FOLL. NONREINF.)
180
0
-55
-180


B10L(FOLLOWING REINF.)
MEAN ANGLE (DEGREES)
180
-20 0
-180
1 DAYS 30
B10L(FOLL. NONREINF.)
180
-20 0
-180


B11P(FOLLOWING REINF.)
MEAN ANGLE (DEGREES)
180
0
-55
-180
1 DAYS 30
B11P(FOLL. NONREINF.)
180
0
-55
-180


B13T(FOLLOWING REINF.)
MEAN ANGLE (DEGREES)
180
0
-95
-180
1 DAYS 30
B13T(FOLL. NONREINF.)
180
0
-95
-180

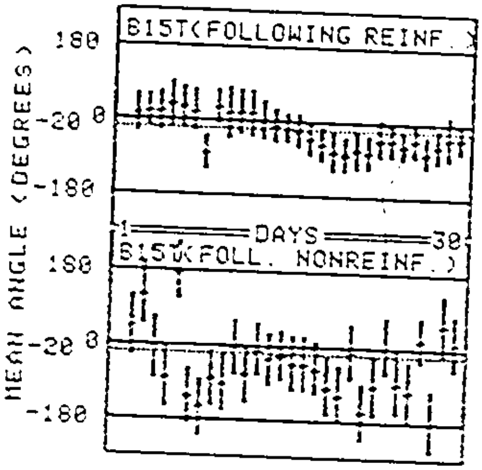
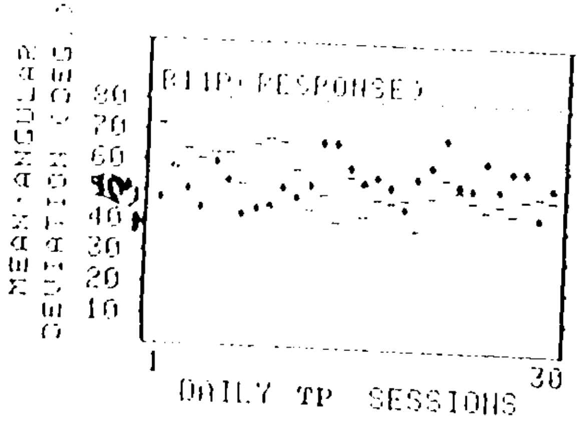
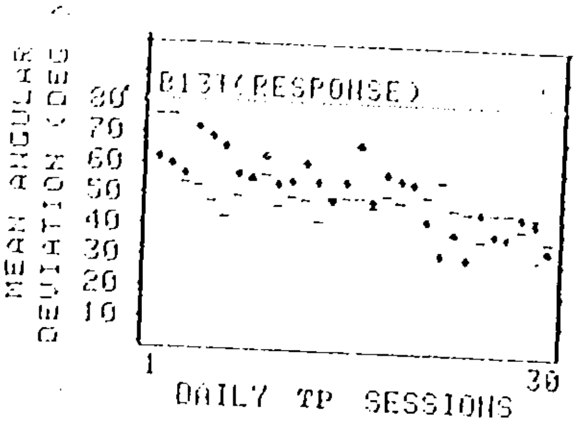
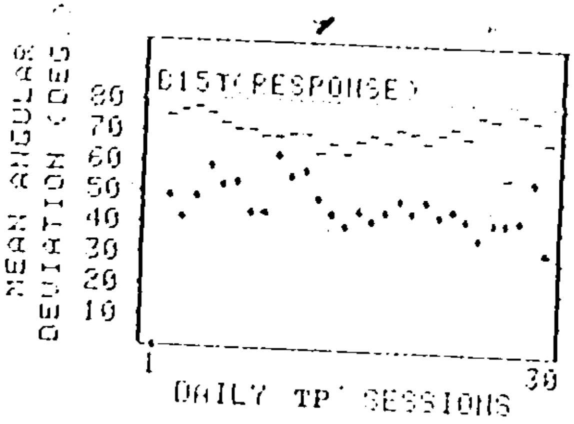

B15T(FOLLOWING REINF.)
MEAN ANGLE (DEGREES)
180
-20 0
-180
1 DAYS 30
B15T(FOLL. NONREINF.)
180
-20 0
-180

Figure 45. Mean angular deviation for Response for trials following reinforced trials and for trials following nonreinforced trials for each daily session of TP shaping of Response for each of 6 pigeons in Experiment 2.

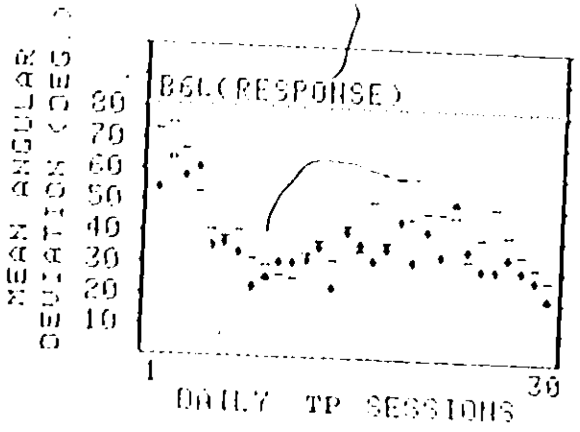


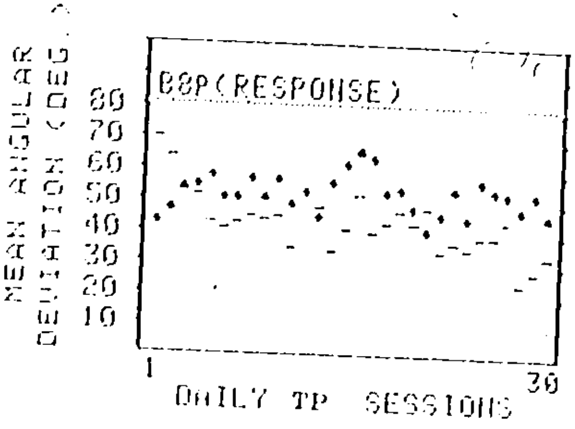


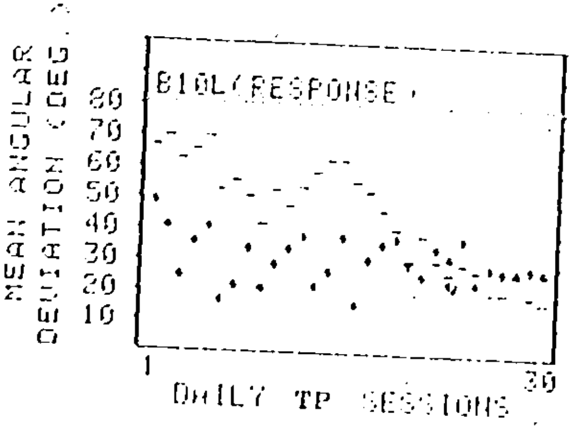


FOLLOWING REINFORCED TRIALS +

FOLLOWING NONREINFORCED TRIALS –







following nonreinforced trials through Session 30.

Pigeon B13T was more accurate following nonreinforced trials for Sessions 1-7, more accurate following reinforced trials for Sessions 8-18, and varied between the two for the remaining 12 days. Variability was lower following reinforced trials for Sessions 1 and 2, then lower following nonreinforced trials for Sessions 3-20. Variability on Sessions 21-30 was frequently but not always lower following reinforced trials. Pigeon B15T was not very accurate following either reinforced or nonreinforced trials, but was somewhat more accurate following reinforced trials. Variability was lower following reinforced trials on all 30 days.

To summarize, accuracy was better following nonreinforced trials for the Response shaping subjects, at least early in acquisition, although variability was lower following reinforced trials. Variability decreased over sessions following both reinforced and nonreinforced trials, for all pigeons with the exception of pigeon B15T, which displayed erratic changes in variability following nonreinforced trials throughout TP.

### Fixed Ratio 1'''

When shifted back to FR 1 following TP shaping of Response, only one pigeon, B15T, maintained its reinforcement-produced Response over the 10 sessions of FR

1'''. This is a surprising finding, since B15T demonstrated by far the worst level of Response shaping. Pigeon B10L took 3 sessions to return to pre-shaping Response values, producing intermediate values of mean angle and variability on the first two days. Pigeon B8P took two sessions to return to pre-shaping Response levels, producing an intermediate level of mean angle, but with high variability, on Session 1. The other three pigeons, B6L, B11P, and B13T, returned to the pre-shaping Response pattern on Session 1 of FR 1''', and continued this pattern throughout FR 1'''.

Extinction''

Four of the six pigeons were more "accurate" for Response in EXT'' than in FR 1''' (compared to the target angle to which each pigeon had been conditioned in TP): B6L, B8P, B10L, and B11P. Three of these four pigeons, B6L, B8P, and B10L, also showed a decrease in variability in EXT'' following FR 1'''. Pigeons B15T and B13T had the same mean angle for Response in EXT'' as in FR 1''', which for B15T had been the target angle. Both B15T and B13T showed an increase in variability in EXT'' compared to FR 1'''.

## DISCUSSION: RESPONSE

The cue manipulation (Groups P, L, and T) had no effect upon Response. This was not unexpected, since this manipulation was intended to affect Place stereotypy.

As in Experiment 1, Response can be considered to be a stronger organizing principle for understanding pecking on FR 1 in Experiment 2 than can Place. However, the level of Response stereotypy did not increase (nor did it decrease) over 50 days of FR 1.

Possibly, the pigeons were moving in terms of Response (i.e., they were orienting themselves by keeping track of "turns" (e.g., Smith, 1974a)) rather than in terms of Place. The daily mean vector for Response shows less variability than that for Place for every pigeon on almost every day. Observation of the pigeons during Experiment 1 yielded a strong impression that the pigeons were moving to the keys with respect to their bodily orientation at the time the trial began; that is, when they poked their beak in the magazine. In sum, the behavior of the pigeons seemed to be organized around Response, and this behavior was much more stereotyped than Place responding.

I was tempted to hypothesize that the Response stereotypy in FR 1 was an example of superstition, that is, that it was a product of reinforcement of particular deviations early in acquisition. The mean vectors for Response have different angles for each pigeon, the angles drift during FR 1, they become highly variable in extinction, and they can be shaped by reinforcement. All of these findings are consonant with the hypothesis that the high concentration (stereotypy) of Response vectors in FR 1 is caused or maintained by reinforcement. (Bond, Cook, and Lamb (1981) found a turning stereotypy, which they attributed to "response bias" (which they did not define), in pigeons in a radial arm maze. Interestingly, they found that this bias disappeared following the first trial on which their pigeons were not reinforced. This behavior is consistent with the hypothesis that the turn stereotypy had been maintained by reinforcement, and became highly variable upon institution of extinction or nonreinforcement.) However, since Response stereotypy was present from the first FR 1 session of Experiment 2, and did not show a progressive increase over FR 1 sessions, it is likely that Response stereotypy in the present study is actually due to a pre-existing Response bias.

The Response value of 0°, that is, repeating the key last pecked, was quite popular in both experiments. This finding, together with the nearness of the <u>group</u> mean vector to 0°, suggests that the true parameter mean for Response (for pigeons in this situation) may actually be $0^{\circ}$. This was the conclusion that was drawn by Smith (1974a), who analyzed the paths of robins and thrushes foraging for worms in a meadow- i.e., that robins and thrushes as populations have a tendency to move straight ahead when foraging.

Inspection of the overall distribution of Response in FR 1 in Experiment 2 yields the impression of a graded, reasonably symmetrical distribution, centered around $30^{\circ}$ or so, but with the percent deviations of $0^{\circ}$ sticking up like a sore thumb. (Experiment 1 shows a similar effect in FR 1, although not quite as clearly; Response appears to be symmetrically distributed around $-10^{\circ}$, but $0^{\circ}$ is the most frequent Response.) Response values of $0^{\circ}$ indicate that the pigeon is repeating the same key, possibly because of transient "Place-fixing" effects of reinforcement. Thus, Response values of $0^{\circ}$ are evidence of a very temporary Place stereotypy. In Experiment 2, five of the twelve pigeons showed $0^{\circ}$ to be a preferred deviation, at least compared to neighboring deviations in the distribution. However, although this effect seems to be real, its magnitude is small, it does <u>not</u> increase over sessions, and it is not present in all of the pigeons.

A confidence ellipse (Batschelet, 1981) for either

Experiment 1 or Experiment 2 would certainly include 0°. Thus, the possibility that 0° is the true population mean cannot be rejected. In addition, in extinction there seems to be a bias toward large deviations, suggesting that Response may approach 0° following reinforcement and approach 180° following nonreinforcement.

If the population value for Response in the present situation _were_ 0°, it would be evidence for stereotypy, either a group Response stereotypy, or individual Place stereotypies. Perhaps the pigeons are "attempting" to produce 0° Responses, but are just inaccurate, or they are being repelled from 0° by some inhibitory process such as conditioned inhibition (e.g., Keller and Schoenfeld, 1950).

However, there is evidence that, although 0° is a special case of Response, it is not the true mean Response for pigeons in this situation. Individual pigeons have distinctive ideosyncratic distributions of Response, which have central tendencies distinct from 0°. For example, it would be stretching things quite a bit to maintain that the true mean angle of Response for B10L or B14P were 0°. Also, the individual distributions of mean angles over sessions show that the mean angle can approach and even cross 0°, repeatedly, without becoming fixated at 0° (see Figure 40). Most importantly, there is no trend toward 0° over sessions, either for the pigeons as a group or for individual pigeons. There _is_ a group trend for Response, which is to turn more and more clockwise over sessions of FR 1.

It is quite possible that the "forward tendency" reported by Smith (1974a) is an artifact of his averaging the Response ("turning") tendencies of a large number of individual robins or thrushes over a number of different days, and that there are stable idiosyncratic Response tendencies for individual robins and thrushes. In addition to my agreement with Sidman (1960) that all response variability is potentially accountable for, and that unexplained variability is a synonym for ignorance, there are important practical implications of finding stable individual Response patterns. For example, a hunter who acted upon the assumption that rabbits tend to move straight ahead would be handicapped in stalking rabbits compared to a hunter who assumed that if a rabbit turned clockwise 60° this time it will tend to turn 60° next time, provided that is actually how individual rabbits behave.

Smith's analysis also ignores changes in group or individual Response over time, for example, seasonal changes. The present series of experiments found gradual changes in Response over time, for both individuals and groups of pigeons. The slopes of the group changes in Response were consistent with a circannual (i.e., approximately yearly) rhythm. A circannual rhythm of turn sizes within food patches could be expected to have survival value, provided the average density of food in a patch also had a circannual rhythm. It is unlikely, however, that the results of these two experiments reflect a circannual rhythm in foraging patterns (or of Response). Experiment 1 was conducted from September 24 through November 8; while Experiment 2 was conducted from December 30 through April 5 (since the pigeons in Experiment 2 were not started on FR 1 simultaneously). If a 360° circannual rhythm were being displayed in both experiments, we would expect that the two daily group mean functions would fall on the same straight line. Instead, the two functions appear to be parallel. In any event, 42-day and 50-day samples are far too short to establish the existence of a circannual rhythm. Samples of at least 730 days or preferably 1095 days are necessary for this. The only conclusion that can be drawn is that group mean Response was clockwise during the beginning of FR 1, and became more counterclockwise as a function of number of sessions, being counterclockwise at the end of FR 1, *in both experiments*.

The orderly change in daily group mean angle for Response which was found in both experiments has at least two implications. First, the daily mean Response for a particular bird is not the product of a simple idiosyncratic bias. If it were a simple bias, for example if each bird had one short leg, the mean angle should stay constant over days. Second, it suggests that the true (population) mean angle for Response is not 0°. If the true mean for Response *were* 0°, it is not likely that the daily group mean angle for Response would show regular, replicable changes over sessions.

Another indication that Response stereotypy is not the product of a simple bias is that institution of FR 1''' following TP shaping of Response did not cause an abrupt shift from the target Response, but rather a gradual change. In addition, EXT following FR 1''' produced higher target components than had been seen on any session of FR 1''' after Session 1, showing that both groups "remembered" their target behavior. It also suggests that EXT may have stimulated output of the former target behavior because of similarity of EXT to TP.

## RESULTS: COMPARISON OF PLACE AND RESPONSE

Figure 46 presents daily mean angular deviation for Place and for Response in FR 1, averaged over all 12 pigeons. Analysis of variance showed no effect of Sessions or Measures x Sessions. Response was significantly less variable than Place: *F* (1, 9) = 106.37, *p* < .001.

Figure 47 shows mean target components for all six pigeons given TP for Place and for all six pigeons given TP for Response. Both Place and Response shaping produced typical learning curves. Response shaping produced a higher target component for the first 4 sessions of TP, while Place shaping produced a higher target component for the last 26 sessions of TP. The target component for Place attained an asymptotic value of greater than .9 after about 16 sessions of TP, whereas the target component for Response, which reached .6, was still increasing through 30 sessions of TP. Analysis of variance showed Measures (Place vs Response) differed significantly, *F* (1, 10) = 9.48, p < .025, as did Sessions, *F* (29, 280) = 17.90, p < .001, and Measures x Sessions *F* (29, 280) = 4.43, p < .001.

When shifted to FR 1''', both groups displayed an orderly and gradual decline in group mean target

Figure 46. Mean angular deviations for Place and for Response for each of 50 daily sessions of FR 1 averaged over all 12 pigeons in Experiment 2.

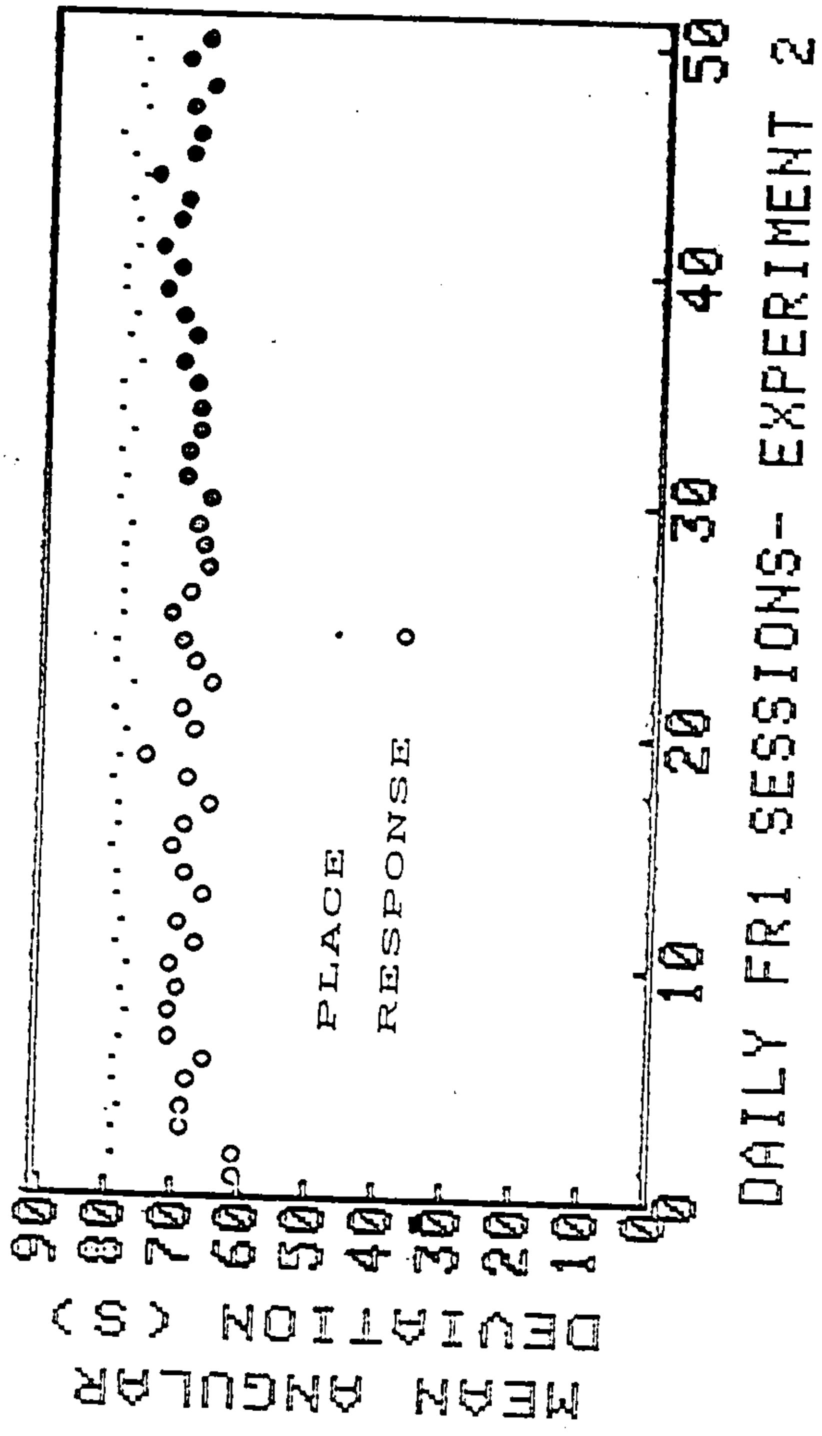
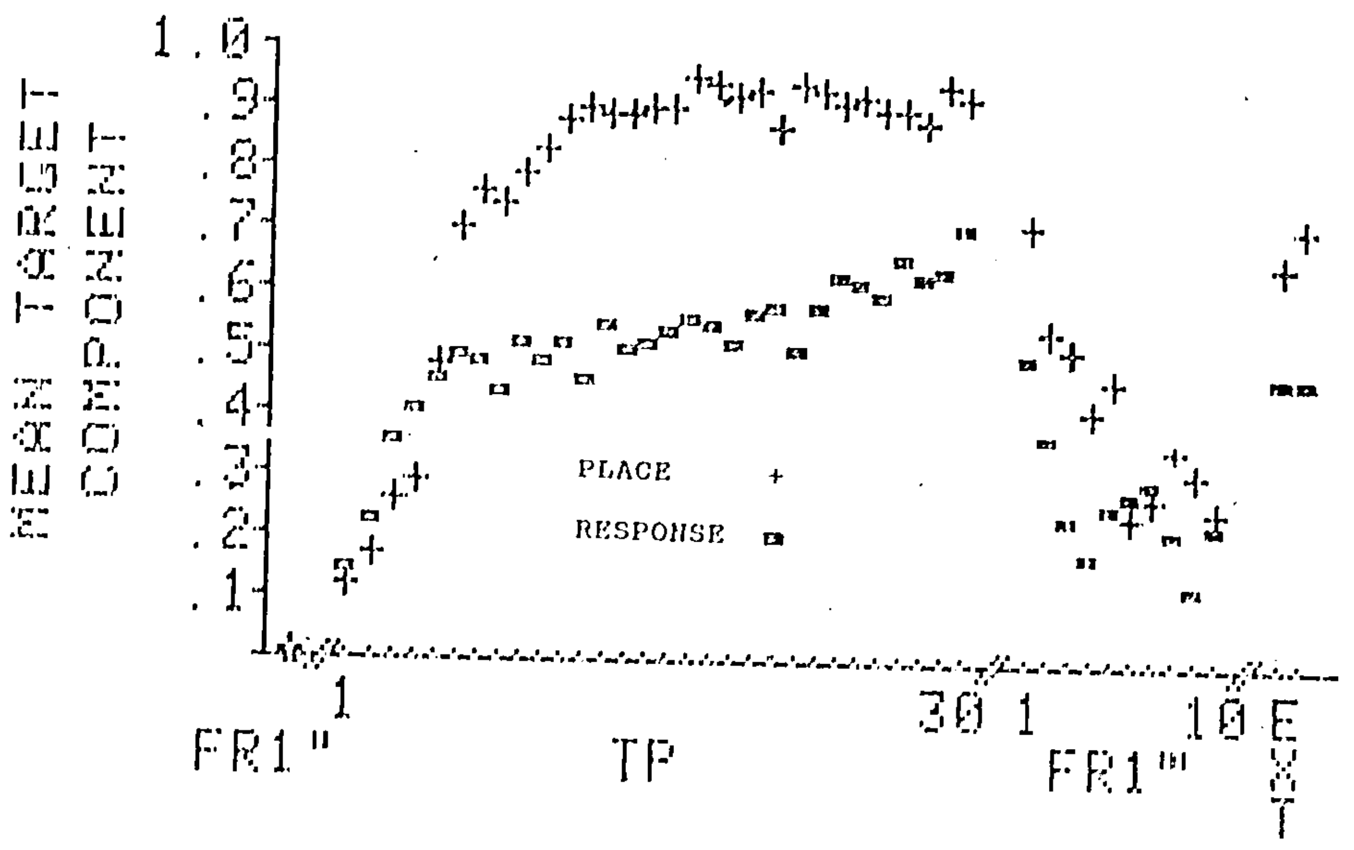

MEAN ANGULAR DEVIATION (S)
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
DAILY FR1 SESSIONS- EXPERIMENT 2
PLACE
RESPONSE

Figure 47. Group mean target components for the 6 pigeons given TP shaping to Place and the 6 pigeons given TP shaping to Response in Experiment 2. Data are presented for the last day of FR 1'', the 30 days of TP, the 10 days of FR 1''', and the 2 days of EXT''.


MEAN TARGET COMPONENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
PLACE +
RESPONSE
1
30
1
10
FR1"
TP
FR1'"
EXT

component. The pigeons shaped to Place took six sessions to decrease to an apparently asymptotic target component between .2 and .3. Those pigeons shaped to Response took four sessions to decrease to an apparently asymptotic target component between .2 and .3 (perhaps slightly below the level for Place). Neither group declined to a target component of 0 or below during the 10 sessions of FR 1'''.

When given two days of EXT'', target components for both groups increased to around the levels they had shown on the first day of FR 1'''.

## DISCUSSION: COMPARISON OF PLACE AND RESPONSE

The comparison of Place and Response in FR 1 reaffirmed that making particular turns was a much stronger tendency in this situation than was pecking in a particular location.

Both Place and Response were sensitive to the effects of differential reinforcement- that is, both behaviors were shapeable. They both displayed evident acquisition curves, in both cases the shaped behavior declined but did not disappear when switched to nondifferential reinforcement, and the institution of EXT recalled the shaped behavior for both conditions.

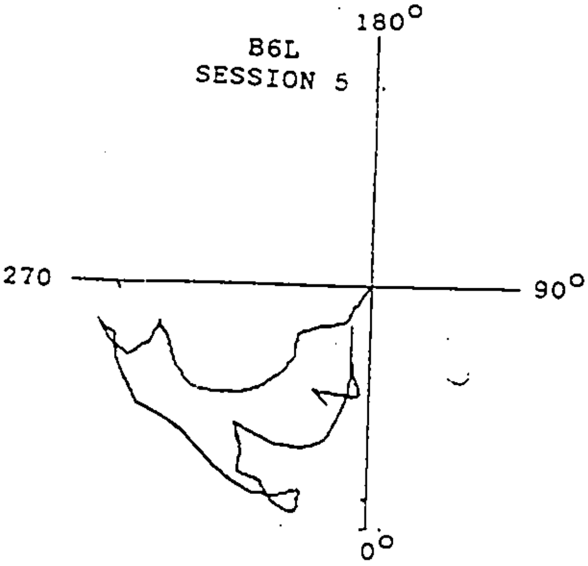
# RESULTS: GEOMETRIC ANALYSES

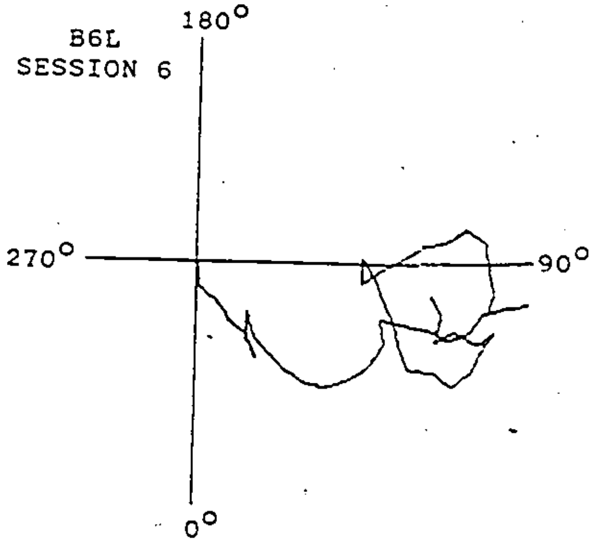
The primary statistic used in the present experiments was the mean vector, which is simply the resultant vector (i.e., the sum of a number of vectors), divided by the number of constituent vectors. The mean vector can be calculated either trigonometrically or geometrically. In the present studies, the mean vector was routinely calculated using trigonometry. However, although this method yields the <u>overall</u> tendency to, for example, favor a particular direction, it tells nothing about directional tendencies over successive trials or successive days. In order to check the trigonometric calculation of mean vectors, they were also calculated geometrically. This involves plotting successive vectors with the tail of each vector originating at the tip of the previous one. The first vector is plotted with its tail at (0,0). The resultant vector is that vector originating at (0,0) and terminating at the tip of the last vector plotted. The actual plot of the successive vectors will be referred to as the "vector path" or "vector track".

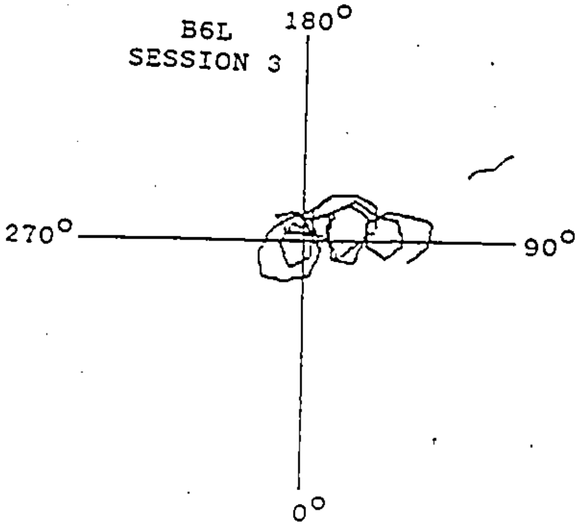
The mean vectors were of course identical using the two methods, but the geometric method yielded, in addition, a visual representation of how the performance of the pigeon produced each resultant vector. Figure 48 shows the vector tracks for Place for the first 6 days of FR1 for pigeon B6L. If the pigeon's return from the key to the feeder can be ignored; arguing that the key has come to represent food, then these vector tracks <u>might</u> be taken to represent the path this pigeon would take in a large area with small amounts of food evenly distibuted within it. If this is a plausible interpretation, it would suggest that the usual path of a lone pigeon in a patch of food that would be represented by this situation would be a spiral, which would cover a small area intensively, but not move far from the starting point.

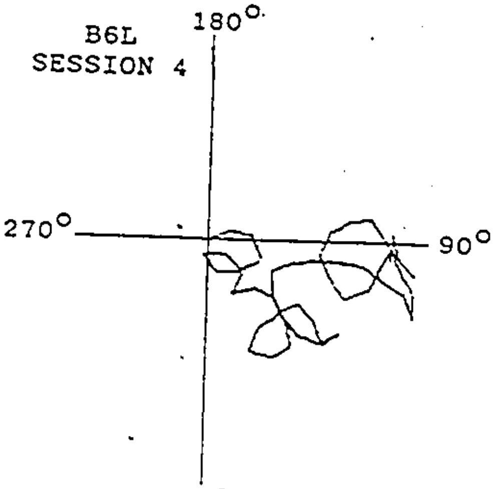
The vector paths were calculated for all the pigeons for the 50 daily sessions of FR 1, both for Place (Figure 49) and for Response (Figure 50). As argued above, the vector track for Place <u>might</u> plausibly be taken to represent the path that a given pigeon would take in walking along the ground and eating. (The vector track for Response cannot be interpreted in this fashion, instead representing changes in Response (turning) tendency over the course of FR 1.) It is evident from Figure 50 that only B11P and B6L had a tendency to move consistently in a particular direction. This tendency was not very strong even in these two pigeons, showing a lot of variability early in FR 1 for B6L, and changing

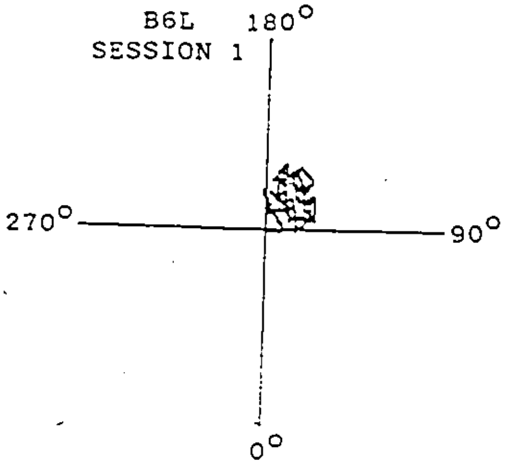
Figure 48. Vector paths for the first six days of FR 1 for pigeon B6 in Experiment 2. The 0o axis is marked at 15 unit vectors.


B6L
SESSION 5


B6L
SESSION 6


B6L
SESSION 3


B6L
SESSION 4


B6L
SESSION 1

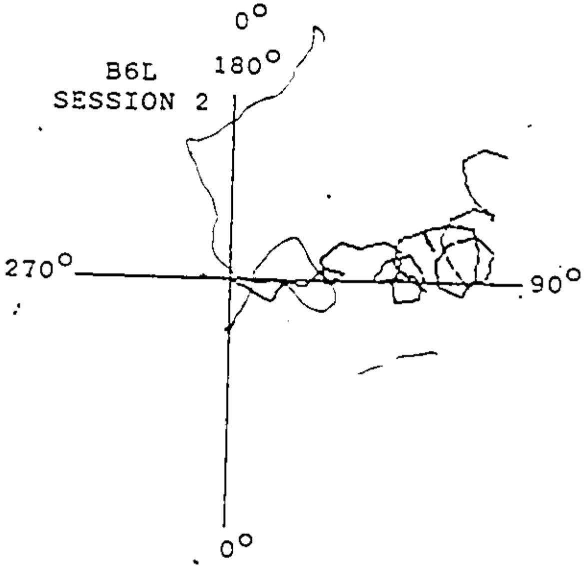
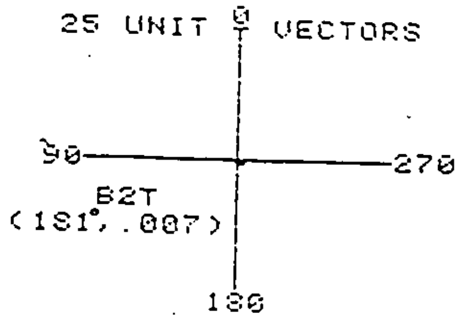
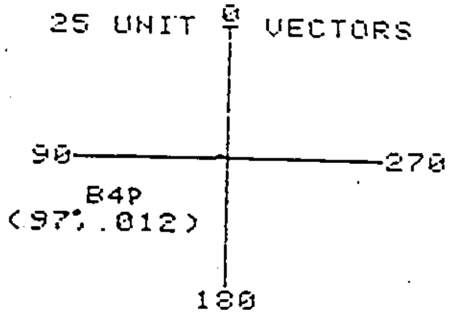
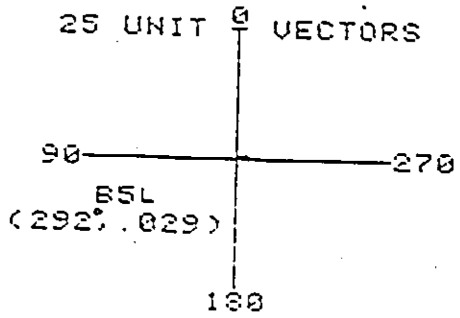
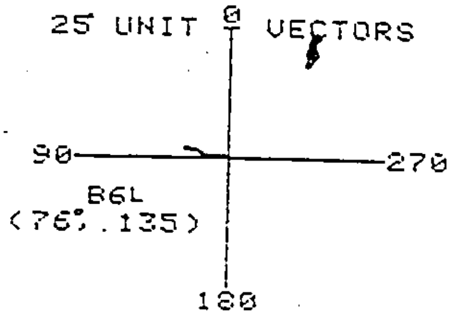

B6L
SESSION 2

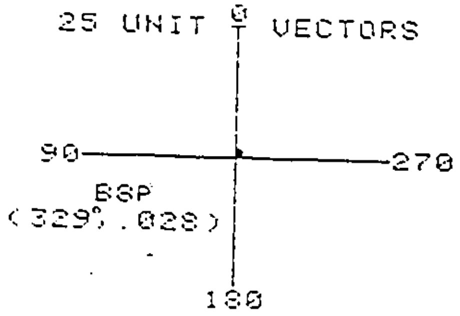
Figure 49. Vector paths for Place for all of FR 1 for each of 12 pigeons in Experiment 2.

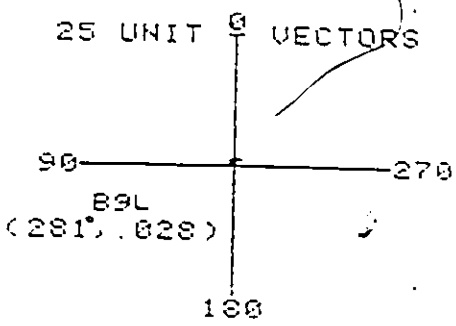

25 UNIT 0 VECTORS
90
270
B2T
(181°, .007)
180

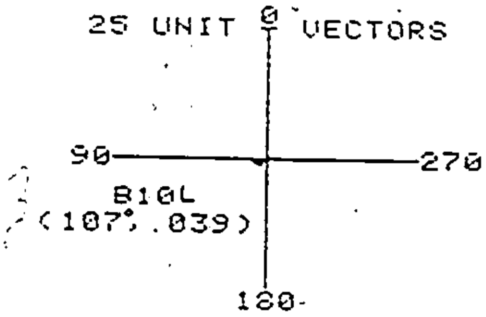

25 UNIT 0 VECTORS
90
270
B4P
(97°, .012)
180

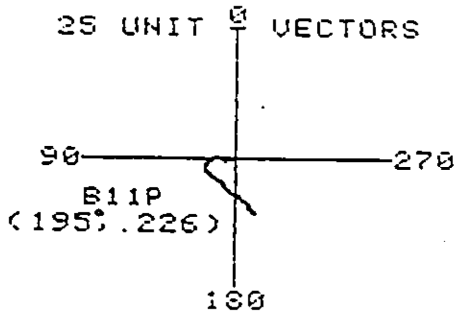

25 UNIT 0 VECTORS
90
270
B5L
(292°, .029)
180

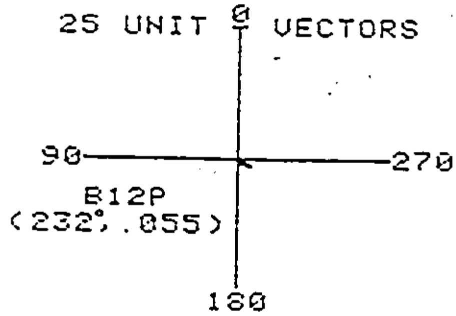

25 UNIT 0 VECTORS
90
270
B6L
(76°, .135)
180

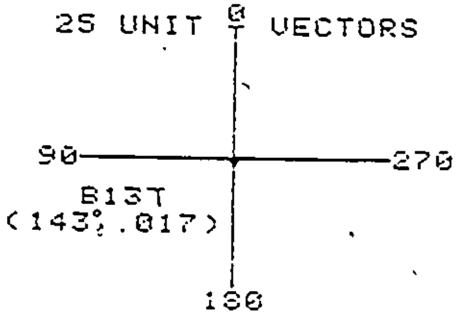

25 UNIT 0 VECTORS
90
270
B8P
(329°, .028)
180

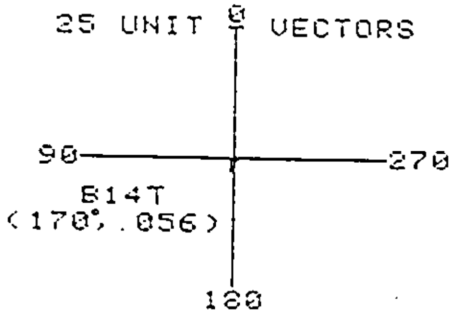

25 UNIT 0 VECTORS
90
270
B9L
(281°, .028)
180


25 UNIT VECTORS
0
90
270
180
B10L
(107°, .039)


25 UNIT VECTORS
0
90
270
180
B11P
(195°, .226)


25 UNIT VECTORS
0
90
270
180
B12P
(232°, .055)


25 UNIT VECTORS
0
90
270
180
B13T
(143°, .017)


25 UNIT VECTORS
0
90
270
180
B14T
(170°, .056)

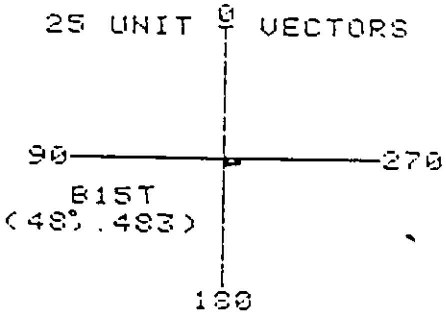
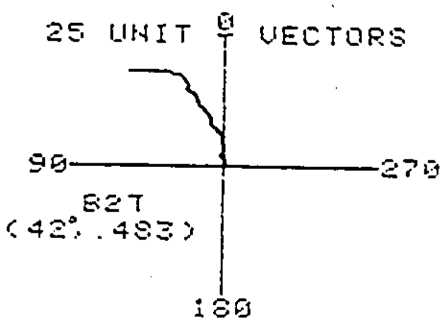
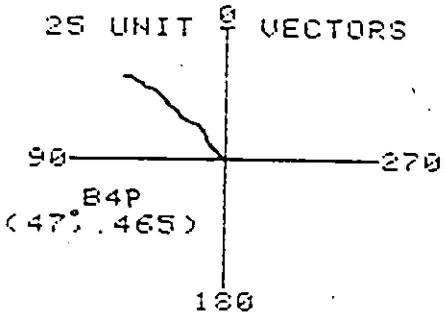
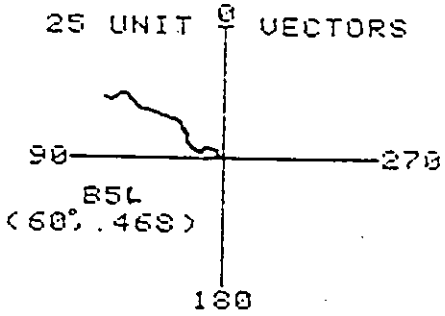
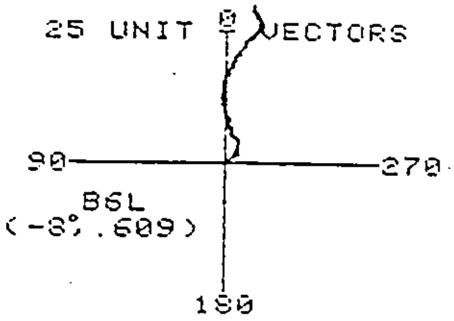

25 UNIT VECTORS
0
90
270
180
B15T
(48°, .483)

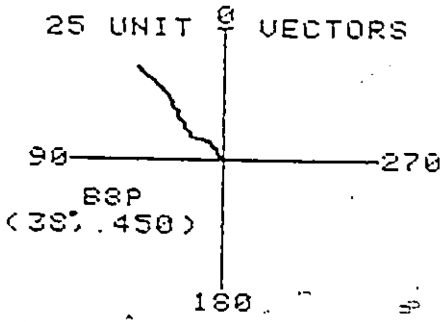
Figure 50. Vector paths for Response for all of FR 1 for each of 12 pigeons in Experiment 2.

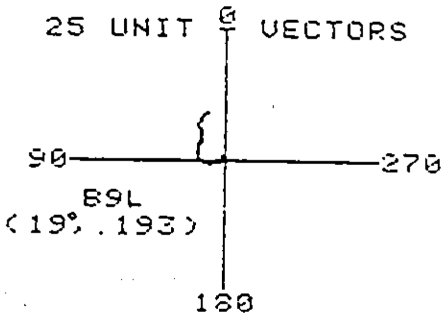

25 UNIT 0 VECTORS
90
270
180
B2T
(42°, .483)

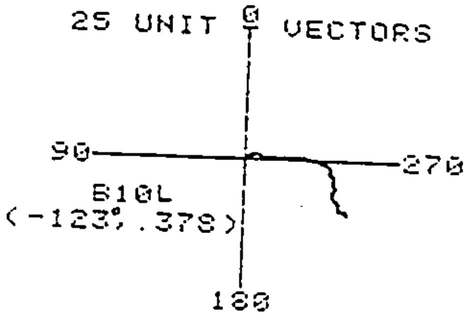

25 UNIT 0 VECTORS
90
270
180
B4P
(47°, .465)

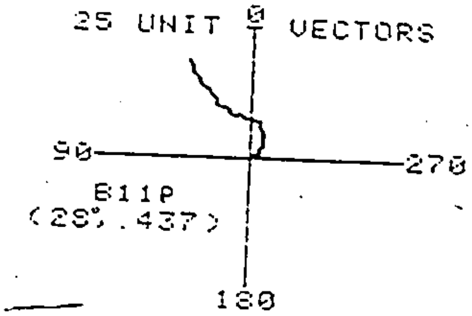

25 UNIT 0 VECTORS
90
270
180
B5L
(60°, .468)

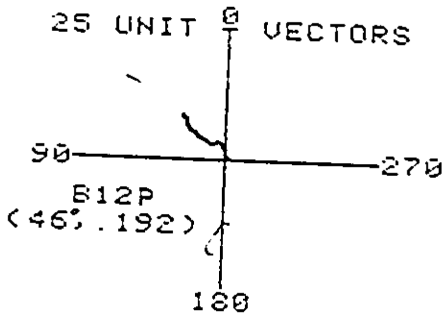

25 UNIT 0 VECTORS
90
270
180
B6L
(-8°, .609)

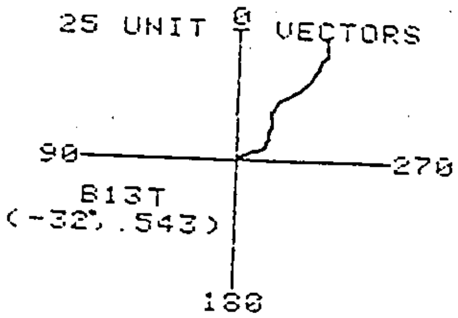

25 UNIT 0 VECTORS
90
270
180
B8P
(38°, .450)

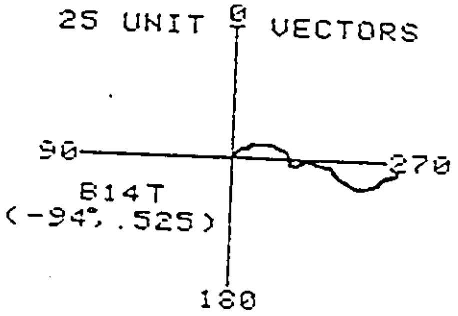

25 UNIT 0 VECTORS
90
270
180
B9L
(19°, .193)

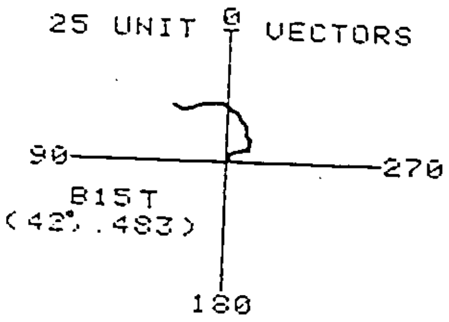

25 UNIT 0 VECTORS
90
270
180
B10L
(-123°, .378)


25 UNIT 0 VECTORS
90
270
180
B11P
(28°, .437)


25 UNIT 0 VECTORS
90
270
180
B12P
(46°, .192)


25 UNIT 0 VECTORS
90
270
180
B13T
(-32°, .543)


25 UNIT 0 VECTORS
90
270
180
B14T
(-94°, .525)


25 UNIT 0 VECTORS
90
270
180
B15T
(42°, .483)

direction by about 45° after 17 sessions for B11P. The Place vector paths for the other 10 pigeons do not show any directional trends, instead being consistently "random".

The Response vector paths are potentially more interesting, since here, perhaps, is where reinforcement-produced stereotypy might be found. If a particular value of Response is produced or maintained by nondifferential reinforcement, one would expect that value to be selected early in FR 1, and not to change, or to change very slowly. Figure 50 shows that none of the pigeons produced only one value of Response throughout FR 1. The pigeons that most nearly responded at one value were B4P, B8P, and B12P. Pigeons B5L, B6L, B13T, and B14T appeared to be responding around some central tendency, but with a mild (30-40°) oscillation superimposed. The remaining five pigeons, B2T, B9L, B10L, B11P, and B15T, displayed Response vectors that shifted abruptly (60-90°) during the 50 days of FR 1. Furthermore, inspection of the vector tracks for Day 1 of FR 1 for each of the 12 pigeons showed no particular tendency for the first value of Response produced to be repeated on the next trial, or for the first value of Response produced to become the eventual modal Response value.

Since this method of analyzing successive unit vectors seemed to yield interpretable results, it was

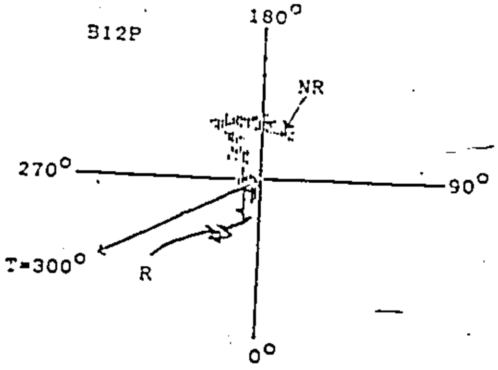
8

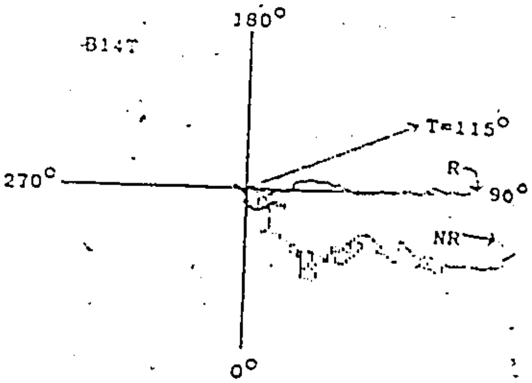
applied to the data for trials following reinforced and following nonreinforced trials in percentile shaping. From the data presented in Figure 34, we already know that pigeons shaped to Place on a percentile schedule are more accurate and less variable following reinforced trials than following nonreinforced trials, at least for the first few days of shaping.

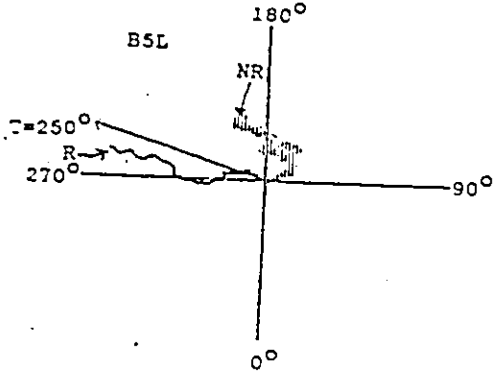
Figure 51 shows the vector tracks for Session 1 of percentile shaping for the six pigeons shaped to a particular Place. Keeping in mind that there were approximately 200 nonreinforced trials and 50 reinforced trials, it is evident that the direction of pecks following nonreinforced trials was much more variable than those following reinforced trials. It is also evident that pecking was *directed* following reinforced trials, in a direction close to, but not identical to, the target (i.e., reinforced) direction. What is somewhat surprising is that pecks following nonreinforced trials, which might have been expected to describe a random walk, never moving far from the origin, also appear to have a preferred direction which is distinct from the direction preferred following reinforced trials. Indeed, in the cases of B9L and B12P, the preferred direction of pecking following nonreinforced trials is approximately 180° from (i.e., opposite to) the target direction. In addition, although

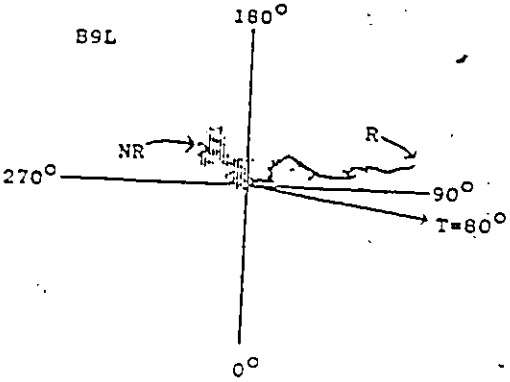
Figure 51. Vector paths for Place following reinforced and following nonreinforced trials for Session 1 of TP shaping to Place for each of 6 pigeons in Experiment 2. A resultant vector is shown for trials following reinforced trials and one for trials following nonreinforced trials.

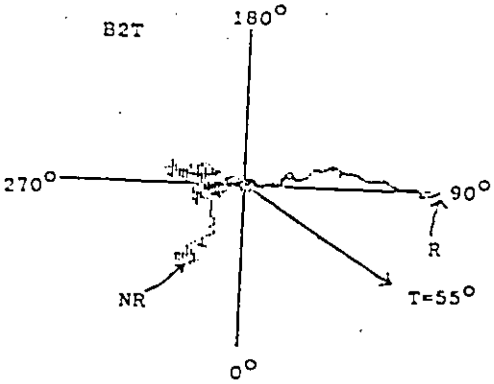
16a

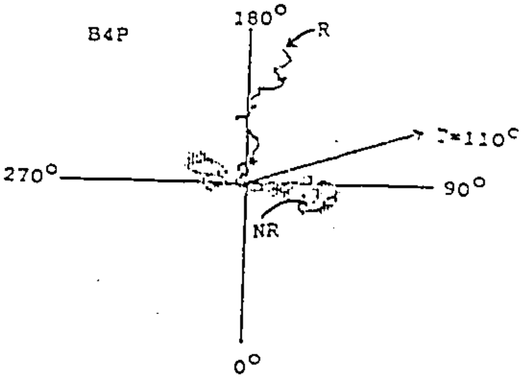

B12P
180°
NR
270°
90°
T=300°
R
0°


B14T
180°
T=115°
270°
R
90°
NR
0°


B5L
180°
NR
T=250°
R
270°
90°
0°


B9L
180°
NR
R
270°
90°
T=80°
0°


B2T
180°
270°
90°
R
NR
T=55°
0°


B4P
180°
R
T=110°
270°
90°
NR
0°

it is not evident from the figure, the track of directions following nonreinforced trials describes a series of tight spirals, similar to the pattern observed in FR 1. This method of analysis holds promise for the elucidation of targeted percentile shaping, and of shaping in general, at least on a spatial continuum such as that used in the present series of studies.

## DISCUSSION: GEOMETRIC ANALYSES

This method of analysis adds considerably to understanding the behavior of pigeons in this experimental situation, compared to consideration of mean vectors alone. First, it shows that on Session 1 of TP shaping of Place, the pigeons consistently (that is, throughout the session) pecked some number of degrees clockwise or counterclockwise of the target direction following reinforcement. Without this analysis, one might assume that the pigeons were oscillating around the target direction, or gradually approaching the target direction. Second, it suggests and permits some comparisons that probably would not be thought of otherwise. An example is the comparison of Figure 50, which shows daily mean Response, plotted over 50 Sessions of FR1, and Figure 51, which shows successive keypecks following reinforced and following nonreinforced trials during Session 1 of TP for Place. This would seem to be a classic "apples and oranges" comparison. However, what Figure 50 actually represents is what a given pigeon did, in terms of direction turned, following reinforcement. Being plotted over 50 days simply indicates to what degree the behavior is consistent. The vector path for trials following reinforcement during Session 1 of TP (Place) also represents what a given pigeon did, in terms of direction turned, following reinforcement. If the data for the six pigeons given TP for Place are compared to the data for the same six pigeons during FR 1, by lining up the target directions in Figure 51 with the 0° axis in Figure 50, a striking (although not perfect) correspondence is seen. The turns from the direction of reinforcement in the two situations are always in the same direction-counterclockwise for five of the pigeons, and clockwise for the other one. The direction of the vector path for TP trials following reinforcement is closer to the target than the Response vector path was to 0° for two of the pigeons. For all six pigeons there is a strong correspondence between strength of tendency to turn following reinforcement in the two different situations.

Thus, this unconventional comparison may actually demonstrate a general property of reinforcement for pigeons in a spatial response continuum. Rather than repeating the direction or Place that was reinforced, as would be predicted by the Law of Effect, pigeons tend to turn a particular amount clockwise or counterclockwise from the reinforced Place.

## Chapter 4:

## PROBE SUBJECTS

The data for the following pigeons represent the results of manipulations of variables of interest. These manipulations were performed in order to elucidate particular points which arose in the course of conducting the main experiments.

Three White King pigeons were obtained from a group of 30 pigeons that had been used in a one-semester undergraduate learning course. These pigeons had been exposed to a variety of conditions, with student experimenters, and had been maintained at 80% ad libitum body weight for six months. They were approximately 1 1/2 years old. Zack was notable during the course for its accuracy of temporal and visual discrimination, and its vigor of response. Midori was selected because of a propensity to respond differently from expectation in a number of experimental situations. Houdini was included because of an extraordinary ability to escape from its home cage, an ability which was displayed throughout the semester.

The ad libitum body weight of these three pigeons was redetermined, and they were maintained at 80% ad libitum body weight, on a diet of Purina Pigeon Checkers and tap water.

The apparatus was the same as that used in Experiment 1.

## AUTOSHAPING

Midori and Houdini were given eight daily sessions of autoshaping, each containing 50 pairings of a conditioned stimulus consisting of illumination of all of the keys for 8 sec, and an unconditioned stimulus consisting of presentation of the food magazine (containing Purina Pigeon Checkers) for 4 sec. The interval between pairings was 1 min. Zack was given two daily sessions of autoshaping with the same parameters.

None of the pigeons made any keypecks on any autoshaping trials. Observation of the pigeons' behavior disclosed that during the presentation of the conditioned stimulus they tended to circle the food magazine, midway between the magazine and the keys.

Since keypecking appeared to be at least difficult to obtain in this situation using autoshaping, the pigeons were shaped by successive approximations to peck the keys. This took less than one session of 50 reinforcements for each pigeon.

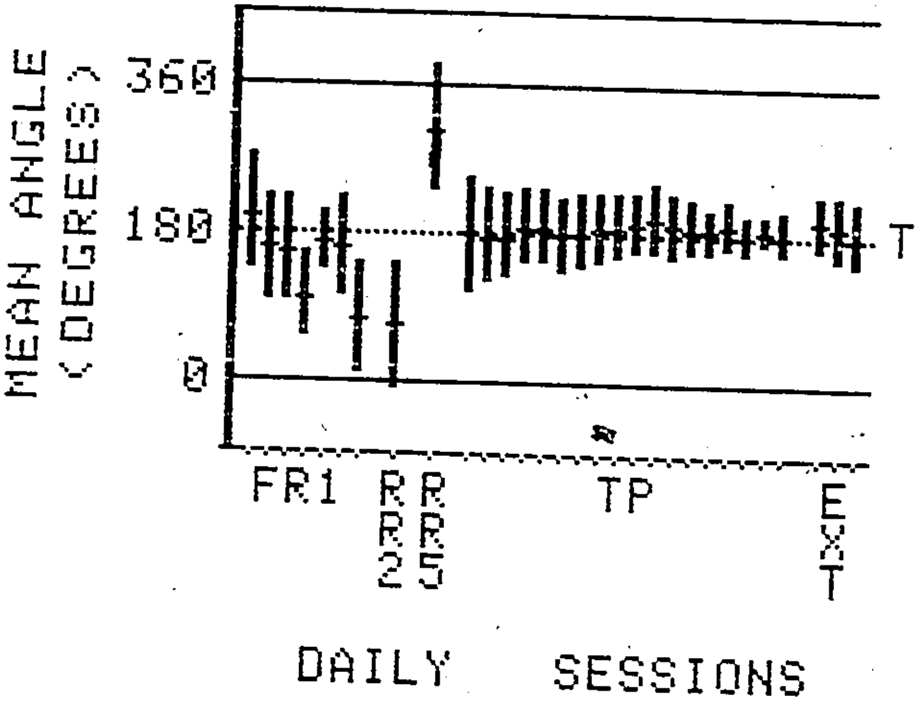
## OPERANT CONDITIONING AND EXTINCTION

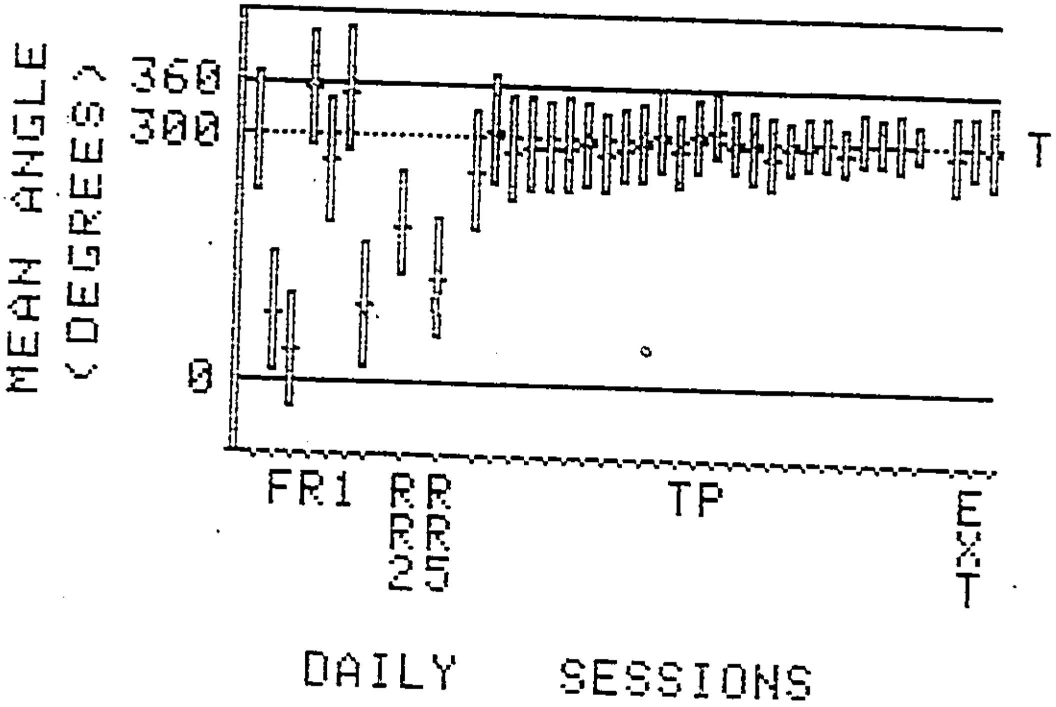
Midori was given 3 daily sessions of FR 1. On the first day, this pigeon emitted 50 responses in slightly over an hour; but on the second day it emitted 13 responses in 3 hours; and on the third day, 28 responses in 5 hours. Midori was run no further.

Houdini was given 7 daily sessions of FR 1 (50 trials), 1 session of RR 2 (100 trials), 1 session of RR 5 (250 trials), 18 sessions of TP (250 trials) with a target of 180°, and 3 sessions of EXT. Zack was given 7 daily sessions of FR 1, 1 session of RR 2, 1 session of RR 5, and 28 sessions of TP at 300°, followed by 3 sessions of EXT. A 250-trial or two-hour limit was placed on EXT sessions. Upon completion of EXT, Houdini was retired, but Zack was retained as a pilot subject for testing apparatus and schedule changes.

The results for FR 1, RR, and TP were unremarkable, but the data for EXT immediately following TP are the only examples of such in the present set of studies. The data for all of the conditions for Houdini and Zack are shown in Figure 52, in terms of mean angle and mean angular deviation (s).

Figure 52. Mean vectors for Place for Houdini (top) and Zack (bottom) for FR 1, RR 2, RR 5, TP shaping of Place, and EXT. The data are presented in terms of mean angle ± the mean angular deviation.


MEAN ANGLE
(DEGREES)
360
180
0
T
FR1
RR2
RR5
TP
EXT
DAILY SESSIONS


MEAN ANGLE
(DEGREES)
360
300
0
T
FR1
RR2
RR5
TP
EXT
DAILY SESSIONS

Houdini achieved a mean vector of (186°, .93) on the 17th Session of TP, and (183°, .87) on the 18th. When submitted to EXT Houdini emitted 250 responses on Session 1, with a mean vector of (196°, .81). On Session 2, Houdini emitted 197 responses, with a mean vector of (192°, .75) and on Session 3, 36 responses with a mean vector of (182°, .76).

Zack achieved a mean vector of (298°, .80) on the 26th Session of TP, and (298°, .89) on the 27th. In EXT, Zack emitted 250 responses on Session 1, with a mean vector of (287°, .59), 150 responses on Session 2, with a mean vector of (296°, .76), and 102 responses with a mean vector of (295°, .55) on Session 3.

These data show that although there was an increase in dispersion during three sessions of EXT following acquisition of responding to a particular location on a TP schedule, the central tendency was consistently quite close to the target value. Thus, accuracy was maintained, while variability increased. However, it should be noted that the increase in variability is not very great, although this is confounded with number of trials, which decreases over sessions. In addition, Zack displayed a more accurate and less variable mean vector for Session 2 of EXT than for Session 1.

despite having had 250 EXT trials in Session 1.

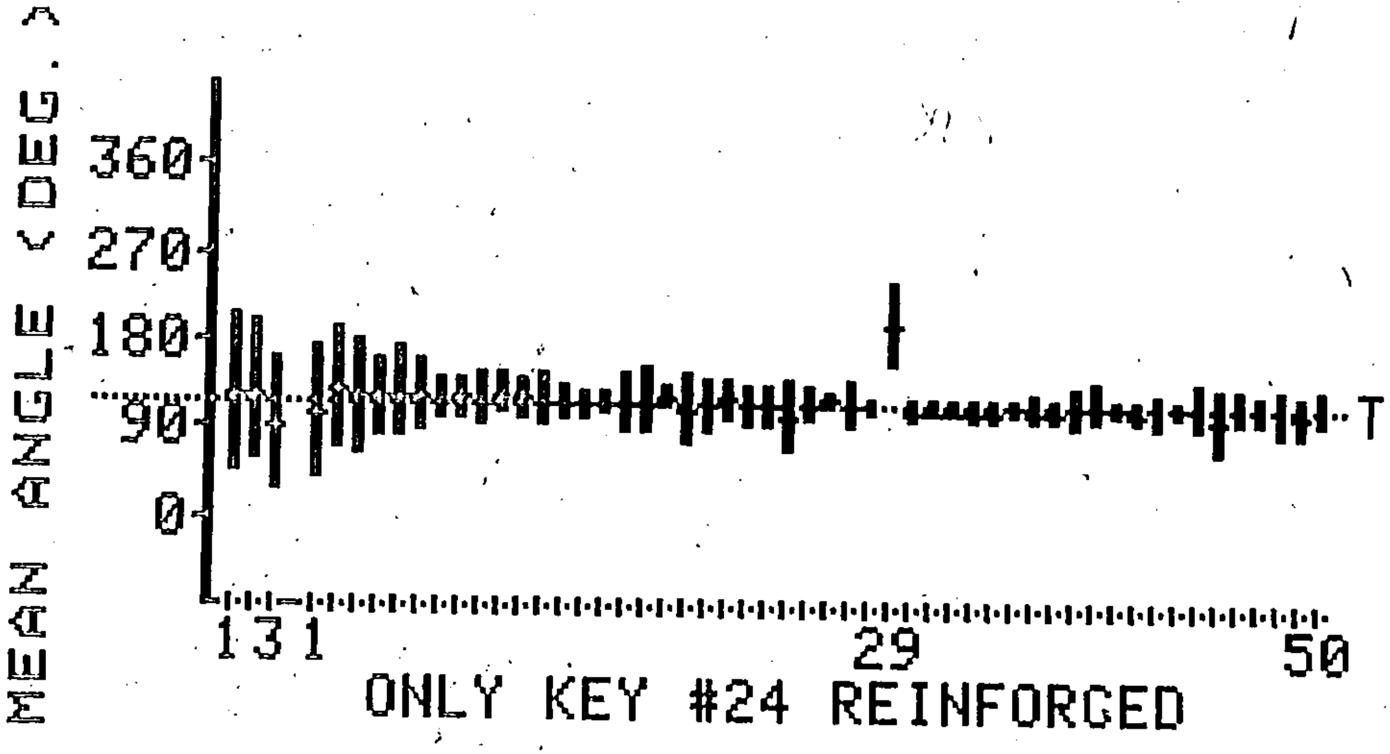
## SHAPING WITH ONE REINFORCED KEY

During Place shaping in Experiment 1, the pigeons apparently exhibited spatial generalization gradients around the target keys, which suggests that there is some "spread of effect", whether it is due to response induction or to stimulus generalization. This interpretation assumes that the reinforced target had a positive valence, as would be asserted by adherents to the Law of Effect (e.g., Hull, 1943, Spence,1956). Staddon and Simmelhag (1971), on the other hand, would attribute this gradient to a greater degree of extinction of responses farther from the target. However, since a symmetrical targeted percentile schedule was used, the distribution of number or per cent reinforced responses on each key also formed a gradient around the target keys. Thus, we cannot determine whether this variability around the central tendency is due to a propensity to generalize, or whether it is due to pecks on particular keys matching the reinforcement history for those keys (Herrnstein, 1961b). A schedule which reinforced pecks made to only 1 of the 72 keys would provide a baseline for generalization. If this condition produced a normal-appearing generalization gradient, it would indicate that the tendency to vary responding which might be attributed to generalization or induction is not, in this situation, simply an artifact of the schedule of reinforcement, but rather is an endogenous pattern of variability. It would also provide indirect support for the Law of Effect.

Zack had been used in the original testing of the experimental situation, and had experienced FR 1, RR 2, RR 5, TP (Place), and EXT. Thus, Zack had been both reinforced and nonreinforced for numerous pecks to every key in the apparatus. This pigeon was given 3 sessions of training during which three of the keys were reinforced-Keys #24, #25, and #26, followed by 150 sessions of training during which only pecks to Key #24 were reinforced ("one-key" or OK). The target key was chosen to be 180° from the target to which Zack had been shaped previously. This was done in order to minimize any tendency to peck Key #24 due to previous reinforcement history. Each daily session was terminated at the end of the trial upon which Zack obtained its 50th reinforcement. The reinforced keys were not marked, and the clear top was in place at the start of this procedure. In addition to attempting to find the asymptotic lower limit of variability and the shape of the distribution of pecks around the reinforced key, various manipulations were performed in an attempt to determine what cues were guiding responding. On Session 29 of OK, the entire apparatus was rotated 90° clockwise, and on Session 70, the entire apparatus was rotated 90° counterclockwise. On Session 83, the translucent top replaced the transparent one for the rest of OK. On Session 86, the schedule was modified so that only a random 50% of the responses to Key #24 were reinforced. The top of the apparatus was rotated 90° counterclockwise while the circular arena itself was rotated 90° clockwise on Session 91. On Session 98, the arena alone was rotated 90° counterclockwise, without changing the top. On Session 113, the schedule was changed back so that every response on Key #24 was reinforced. On Session 114, the white noise speaker in the experimental room was shifted 180°. On Session 122, the top of the box alone was rotated 90° counterclockwise. Key #24 was marked with a piece of black vinyl tape from Session 123 through Session 141, and Zack was run with no houselight on Session 150.

The first 50 sessions of OK are presented in Figure 53. The first two rotations, conducted while the transparent top was on the box, had dramatic effects upon location of pecking, suggesting that Zack was relying

Figure 53. Mean vectors for Place for Zack for 3 daily sessions with 3 reinforced keys and the first 50 daily sessions of OK. The data are presented in terms of mean angle ± the mean angular deviation.


MEAN ANGLE (DEG.)
360
270
180
90
0
T
1
3
1
29
50
ONLY KEY #24 REINFORCED

heavily on extra-maze cues at this time. Since the rotation on Session 29 might have caused a long-lasting bias in response direction, pecks on each key were summed for Sessions 25-29 and for Sessions 30-33. Both distributions show a gradient of pecks around Key #24, although only Key #24 had been reinforced for at least 24 sessions. Both distributions are skewed toward keys below Key #24. This skewed distribution of responses was found throughout OK. For example, responses were summed for four Sessions near the end of OK (Sessions 142-145), and essentially the same distribution was found. Zack had had a pronounced tendency to turn counterclockwise in FR 1 and RR 5, and had carried this tendency over to TP (Place). Over the course of 27 Sessions of TP, however, Zack had gradually reversed this tendency, so that at the end of TP, it was turning clockwise following reinforced trials. Possibly this tendency to turn clockwise following reinforcement was carried over into the OK situation, and caused the particular pattern of pecks.

Although each session of OK had a different number of trials, and a different number of nonreinforced trials, so that the problem of unequal *n*s arises, each of the three sessions of three-keys and the first 29 sessions of OK (i.e., prior to the first rotation) was analyzed for the Place mean vector following reinforced trials and following nonreinforced trials. These data are presented in Table 3. The length of the mean vector for trials following reinforced trials was over .9 on the first session, and was above .9 on every session but two, upon which it was over .85. The length of the mean vector for trials following nonreinforced trials was less than .1 on the first session, and was below .9 on 16 of 29 sessions. In addition, the mean vector for trials following reinforced trials was longer than the mean vector for trials following nonreinforced trials on every session but two.

Table 3 includes the Response mean vectors for the three Sessions of three-keys and the first ten Sessions of OK, for two reasons. First, it emphasizes that the Response measure is redundant in analyzing trials following reinforced trials when a subject is shaped to a target, since the mean vectors are equivalent, and that the Response mean angle rapidly approaches 0°. Second, it shows that on the first five sessions, when a tendency to respond in a particular Place following nonreinforced trials was very weak, there was a reasonably strong tendency to turn clockwise about 20-40° following nonreinforced trials.

Even after 150 sessions with only one key reinforced, Zack never had a perfect session consisting of

## Table 3

## Mean Vectors for OK for Zack, Following Reinforced Trials and Nonreinforced Trials

| SESSION NUMBER | RESPONSE | | PLACE | |
|---|---|---|---|---|
| | Nonreinforced Trials | Reinforced Trials | Nonreinforced Trials | Reinforced TrialS |
| THREE KEYS: | | | | |
| 1. | (-40°,.358) | (8°,.921) | (115°,.022) | (130°,.932) |
| 2. | (-21°,.717) | (-2°,.948) | (132°,.138) | (118°,.943) |
| 3. | (-29°,.698) | (-15°,.939) | (84°,.250) | (108°,.938) |
| ONE KEY: | | | | |
| 1. | (-38°,.452) | (7°,.982) | (114°,.143) | (127°,.982) |
| 2. | (-26°,.980) | (-4°,.980) | (104°,.980) | (116°,.980) |
| 3. | ---------- | ---------- | ---------- | ---------- |
| 4. | (-5°,.515) | (-4°,.865) | (122°,.477) | (127°,.955) |
| 5. | (-3°,.684) | (7°,.955) | (121°,.699) | (127°,.955) |
| 6. | (-7°,.726) | (-8°,.925) | (126°,.663) | (112°,.925) |
| 7. | (-2°,.694) | (-2°,.893) | (123°,.769) | (118°,.893) |
| 8. | (-2°,.911) | (0°,.978) | (118°,.916) | (120°,.978) |
| 9. | (0°,.895) | (-3°,.916) | (123°,.920) | (117°,.916) |
| 10. | (-2°,.741) | (0°,.943) | (119°,.838) | (120°,.943) |
| 11. | | | (125°,.915) | (125°,.961) |
| 12. | | | (122°,.907) | (122°,.969) |
| 13. | | | (118°,.819) | (121°,.981) |
| 14. | | | (119°,.923) | (116°,.982) |
| 15. | | | (114°,.981) | (119°,.959) |
| 16. | | | (115°,.975) | (121°,.978) |
| 17. | | | (117°,.839) | (122°,.937) |
| 18. | | | (118°,.753) | (125°,.945) |
| 19. | ---------- | ---------- | ---------- | ---------- |
| 20. | ---------- | ---------- | ---------- | ---------- |
| 21. | | | (118°,.859) | (114°,.967) |
| 22. | | | (121°,.918) | (120°,.984) |
| 23. | | | (115°,.912) | (116°,.986) |
| 24. | | | (113°,.904) | (119°,.984) |
| 25. | | | (98°,.705) | (120°,.991) |
| 26. | | | (118°,.994) | (120°,.994) |
| 27. | | | (124°,.971) | (120°,.997) |
| 28. | | | (116°,.866) | (119°,.997) |
| 29. | | | (119°,.991) | (118°,.991) |

50 pecks to Key #24. Incorrect pecks tended to occur early in a session, and most sessions ended with a run of reinforced trials. Throughout OK, nonreinforced pecks formed a graded distribution around Key #24. This result is consistent with the Law of Effect.

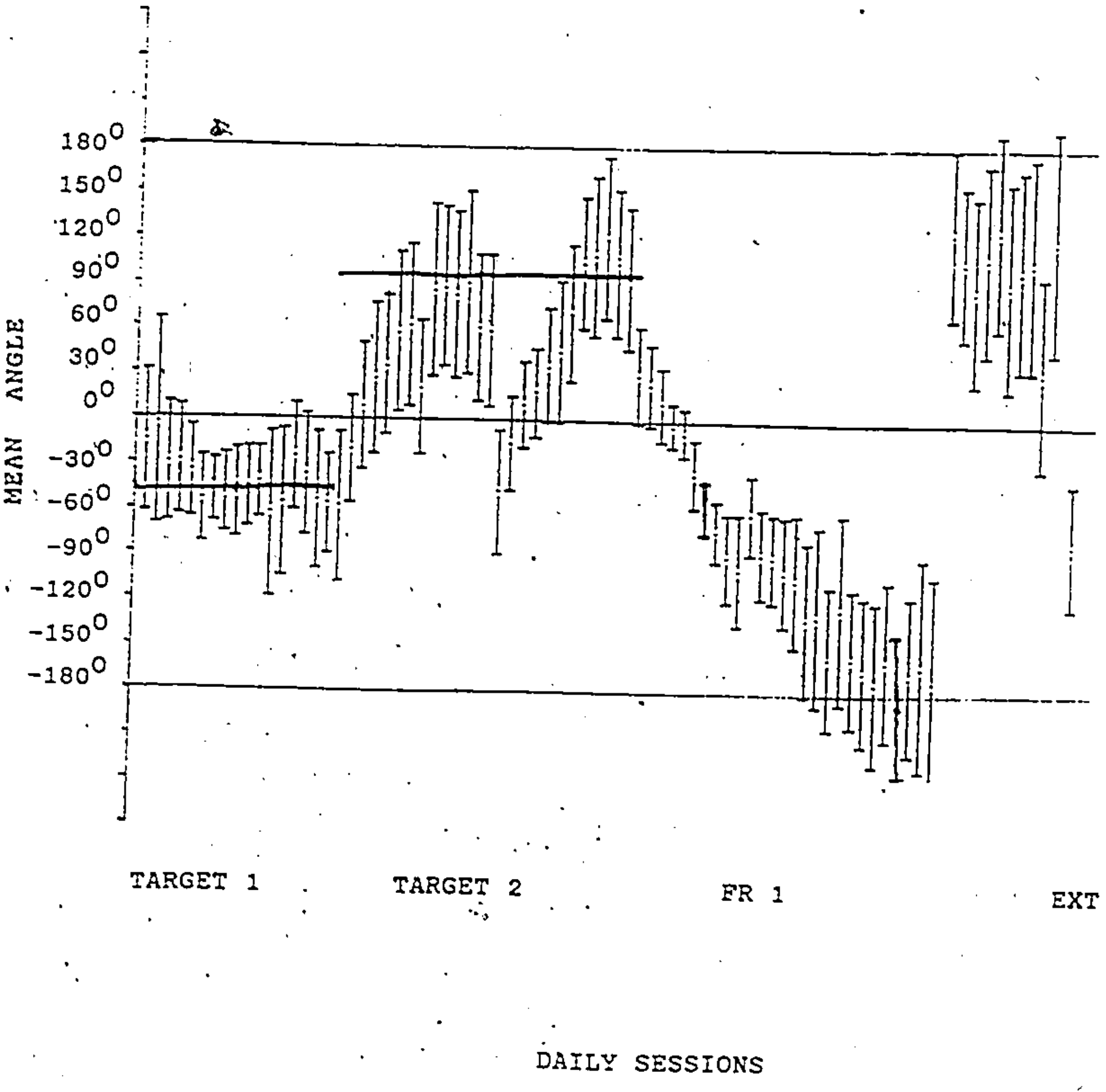
Even with the reinforced key marked, Zack still took about 60 trials to obtain 50 reinforcements. Apparently, however, marking the key did lower the number of incorrect trials in a session, despite the massive overtraining (124 sessions, or 6,200 reinforced trials) given before the key was marked. Thus, marking the key showed that although variability was quite low before marking the key, it could still be lowered further, and that even putting a large strip of black tape on the sole reinforced key did not eliminate variability.

## RESPONSE (DEVIATION) SHAPING

Since Response had been shown in Experiment 1 to be an aspect of pecking on a FR 1-schedule which might be produced or maintained by food reinforcement, it was necessary to determine whether Response was indeed sensitive to the effects of reinforcement. Zack was used to test a symmetrical targeted percentile schedule which reinforced, on the average, the 20% of the Response values (deviations) closest to a selected target value. Up to this point, Zack had experienced FR 1, RR 2, RR 5, TP (Place), EXT, and OK in this experimental situation. Zack was given 17 sessions of TP (Response) with a target Response of -50°, followed by 26 sessions of TP with a target Response of 100°, followed by 37 sessions of FR 1, and finally one Session of EXT. The translucent top was on the box for the entire procedure except for Sessions 11-31, when it was replaced with the transparent top so that Zack could be observed. These data are shown in terms of mean angle and mean angular deviation in Figure 54.

Zack learned the first target Response quickly, achieving a mean vector of (-53°, .88) on the sixth session. When the clear top was installed, the daily mean Response angle became less accurate, and the variability around this mean angle increased. When shifted to a target of 100°, Zack took nine sessions to come near the correct mean angle, achieving a mean vector on the ninth session of (86°, .49). After 14 sessions with the 100° target, the translucent top was replaced, without changing anything else, since Zack's behavior in this situation had been observed sufficiently. Zack immediately reverted to making the old target Response, even though the reinforced target was still 100°,

Figure 54. TP shaping of Response for Zack, to a target of $-50^{\circ}$ then to a target of $100^{\circ}$, followed by 37 sessions of FR 1 and 1 session of EXT. The sessions run with the clear top are between the two arrows.



180°
150°
120°
90°
60°
30°
0°
-30°
-60°
-90°
-120°
-150°
-180°
MEAN ANGLE
TARGET 1
TARGET 2
FR 1
EXT
DAILY SESSIONS

producing a mean vector on the first Session with the translucent top replaced of (-48°, .74). Zack then reacquired the Response, taking eight more sessions to attain a mean vector of (105°, .70). For both targets, the mean vector was longer (responding was less variable) with the translucent top than it was with the transparent top. On the 26th Session of target 2, Zack's mean Response vector was (94°, .67). When shifted to FR 1, Zack shifted its mean angle for Response counterclockwise in a regular manner, such that the daily mean angle for Response rotated through approximately 360° over 36 Sessions. The variability around the mean angle was initially quite low, and increased consistently over sessions. In EXT, Zack produced a mean vector for Response of (-80°, .73).

These data show that Response is a shapeable property of responding in this situation, although possibly not as precisely shapeable as Place. They also show that, for Zack, mean angle was more accurate and mean angular deviation was lower in Response shaping following <u>nonreinforced</u> trials, rather than following reinforced trials as in Place shaping.

These results suggest that Response may be performed better with a translucent top on the box than with room cues present, perhaps because some Place tendency is conditioned to room cues and interferes with Response shaping. They also suggest that all targets may not be equivalent in Response shaping, since Zack performed better on the first target than on the second.

The translucent top seemed to act as a contextual stimulus, since when the translucent top was replaced, Zack behaved in a manner which had been appropriate the last time the translucent top had been installed. If it had been Place that was being shaped rather than Response, the most plausible explanation would have been that Zack had been attending to room cues while the transparent top was on, and thus had to relearn the correct Place when these cues were removed. This explanation is not likely in the case of Response shaping, however.

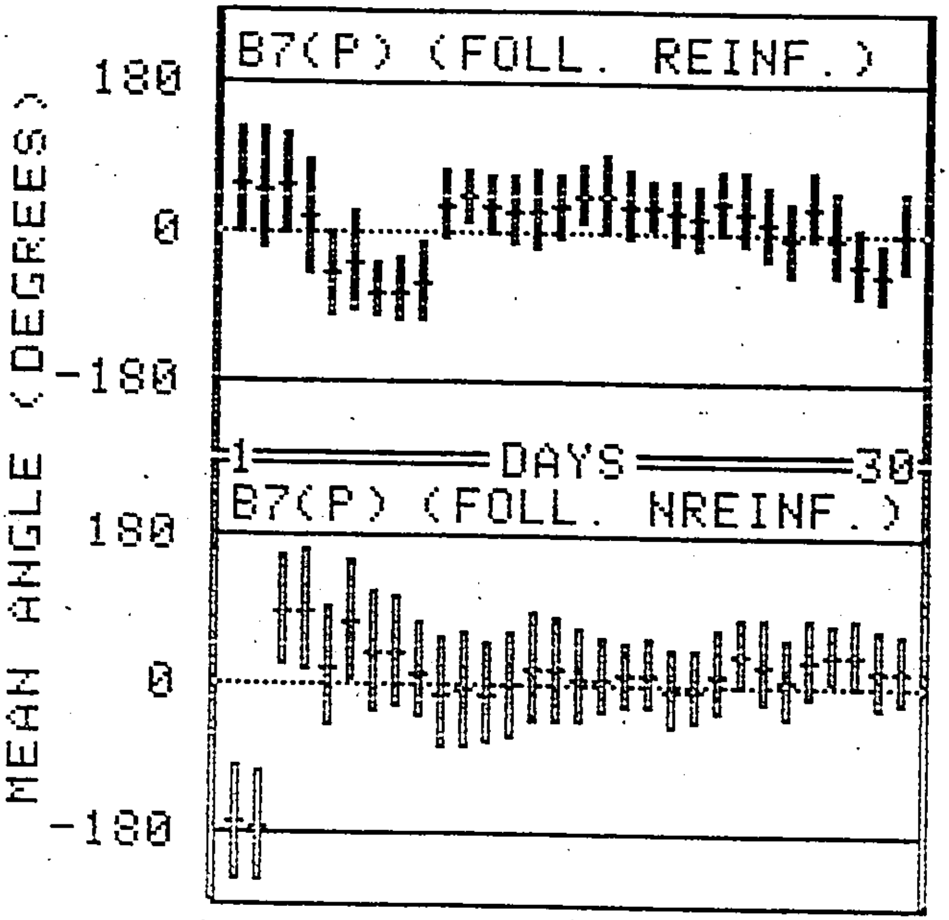
When Zack was switched from Response TP to FR 1, it did not continue making the last reinforced Response, nor did it return to its most recent Response from FR 1, but rather gradually shifted its mean angle for Response clockwise until the mean angle had cycled through 360°. It took 36 daily sessions for this 360° shift. The pigeons as a group in both Experiments 1 and 2 showed a tendency to shift about 1.1° <u>counterclockwise</u> per daily session, whereas Zack shifted 10° <u>clockwise</u> per daily session. I cannot suggest a cause for this strange behavior, but several other pigeons displayed complete 360° shifts of Response under conditions of FR 1.

## RESPONSE SHAPING TO 0°

Pigeon B7, the only one that autoshaped, was given Response shaping to 0°, for a number of reasons. First, the mean angle for this pigeon was -90° on the last day of FR 1'', so that 0° was 90° from this Response value. Second, it was believed that 0° might be a special case of Response, since it represents pecking the same key that was last pecked, and may be the "true" group mean Response value under nondifferential reinforcement. That is, a Response value of 0° might be a case of the Law of Effect in action, since it was the most popular Response in FR 1 in Experiments 1 and 2. Therefore, pigeon B7 might have been expected to show rapid and accurate acquisition, since an existing tendency would be reinforced (Herrnstein, 1966). It was also expected that pigeon B7 might be induced to form a Place stereotypy through shaping to 0°, showing that Place stereotypy could be affected by a Response contingency.

The data depicted in Figure 55 show that acquisition did not seem to be facilitated by shaping to 0°, compared to acquisition shown by the other pigeons

Figure 55. Mean vector for trials following reinforced trials and for trials following nonreinforced trials, for pigeon B7 (run under condition P), for each daily session of TP shaping of Response. The data are plotted in terms of the mean vector ± the mean angular deviation.


B7(P) (FOLL. REINF.)
180
0
-180
1
DAYS
30
B7(P) (FOLL. NREINF.)
180
0
-180
MEAN ANGLE (DEGREES)

shaped to Response values other than 0° (see Figure 44). This finding does not support the Law of Effect. In common with the other pigeons shaped to a particular Response, pigeon B7 was generally more accurate following nonreinforced trials, and less variable following reinforced trials.

# Chapter 5:

# GENERAL DISCUSSION

## REINFORCEMENT THEORY

Is it possible for reinforcement theory to deal with the failure to find progressive stereotypy of keypecking under nondifferential reinforcement in the studies reported above? The question boils down to: What does food reinforcement actually do? Thorndike's answer, (and Skinner's, and Herrnstein's), that reinforcement "stamps in" any behavior immediately preceding it, has the virtues of simplicity and universality, but it is seemingly incorrect, at least in the present experimental situation.

The original intention of the present research was to study stereotypy of response location (Place) on a spatial dimension when reinforcement was not contingent upon location. Stereotypy of response location is predicted by the Law of Effect, and appeared to be a commonly-observed phenomenon (Antonitis, 1951; Herrnstein, 1961a; Ferraro and Branch, 1968; Eckerman and Lanson, 1969). It was disappointing to find Place stereotypy to be so ephemeral and to occur in only half of the pigeons in Experiment 1, and apparently not to occur at all in Experiment 2. A plausible explanation for the difference in findings is that previous studies had not used functionally equivalent operants; that is, some responses took less effort or less time than others.

When it was discovered that the pigeons in the present studies were apparently demonstrating a turn stereotypy (Response), this behavior was also examined for evidence of progressive stereotypy due to nondifferential food reinforcement. No evidence was found for progressive stereotypy of Response under nondifferential reinforcement.

Comparison of Place and Response in FR 1 between Experiments 1 and 2 confirmed that these measures were stable across studies. In Experiment 1, Place did show a slight decrease in variability, followed by a corresponding increase, but the mean variability for Place never got as low as the mean variability for Response for either experiment. Neither the Place nor the Response measure showed progressive stereotypy in either Experiment 1 or Experiment 2. If it can be assumed that variants of the same response are equivalent to different responses (e.g.; Skinner, 1938; Davis and Platt, 1983) and providing the present studies were conducted for a long enough time, the findings are not consistent with the Law of Effect.

Suppose, however, that each food presentation stamps in both a particular Place and a particular Response. The TP data from Experiment 2 demonstrated that both Place and Response were shapeable aspects of behavior in this situation, and suggested that Response initially shows faster shaping than Place. Therefore, under FR 1, the tendency to repeat Response might be stronger than the tendency to repeat Place, so that even though there was some tendency to repeat the last key pecked, there would be an even stronger tendency to repeat the last turn made. In the circular apparatus used in these experiments, this would lead to keypecks, and hence reinforced keys being scattered around the strip. This would probably preclude the buildup of response strength to any particular Place. Response, on the other hand, would not share this limitation, since a clockwise turn of 60° is a clockwise turn of 60° no matter what keys it is between. Response would thus be reinforced more consistently than Place, producing a stronger Response than Place tendency, in congruence with the present findings. Simultaneous conditioning of Place and Response would not only explain the data for FR 1, but also the overshoot past the target which occurred when targets were shifted in TP shaping of Place in Experiment 1.

There are some problems with this interpretation. One is how to deal with the first two trials. At the start of trial two, the pigeon has been reinforced for pecking only one particular key, giving that key some attractive power, but it has apparently not been reinforced for any Response. Why should the pigeons not re-peck the only key that had been reinforced? They did not. In Experiment 2 the pigeons were given 10 reinforced trials on Key #10 during shaping. When started on FR 1, they should have had a tendency to peck Key #10 preferentially. They should also have had some tendency to produce Response values of 0°, since they had been reinforced nine times for making a Response of 0°. They did neither. Furthermore, if Response were more sensitive than Place to the effects of reinforcement, the Response mean vector might have shown an increase in magnitude over sessions at the expense of the Place vector. This did not happen.

It is possible that classical conditioning of local cues associated with particular keys could account for the high stereotypy found in Place shaping. Classical conditioning probably would not contribute to Response shaping, since there are no stable local (i.e., key) cues in Response shaping. In any event, it should be kept in mind that Response is a shapeable characteristic of behavior in this situation, and may be reinforced when shaping to a particular Place, sometimes with detrimental effects on acquisition of responding to that Place.

The most important aspect of this experimental situation may be that it shows what food reinforcement <u>does</u>, in terms of direction taken to make the next keypeck following a reinforcement or a nonreinforcement. Response showed a higher degree of stereotypy than Place in FR 1 in all of the present studies. Indeed, while the Response measure was above chance expectation, the Place measure was consistently <u>below</u> chance. This suggests that the pigeons may have been orienting by means of intrinsic rather than extrinsic cues in this situation (Abelson and DiSessa, 1981). Biologists have traditionally analyzed the paths of organisms in this fashion, speaking in terms of "moves" and "turns" (see, for example, Barnard, 1983; Smith, 197[illegible]a). The proposal made by Olton, Handelman, and Walker (1981), that rats display an inherent "win-shift" strategy, is an example of a theory of reinforcement couched in these terms. It is incomplete, however, since it does not deal with the "lose" or nonreinforcement condition. Devenport (1983) has a similar theory of reinforcement, contending that rats show a "win-shift", "lose-shift more" strategy. This seems to be the strategy adopted by the pigeons in the present set of experiments, when run under conditions of noncontingent reinforcement.

However, both pigeons and rats can be shaped to respond at a particular location. How can this happen if reinforcement does not have a "stamping-in" effect? In other words, why does shaping to a particular Place reduce the size of the "win-shift"? For that matter, why does shaping to a particular Place reduce the size of the "lose-shift"? It can't be simply the number of repetitions of reinforced and nonreinforced trials, since RR 5 doesn't produce progressive stereotypy of Place. In any event, analysis of trials following reinforced and nonreinforced trials in TP Place shaping shows that there is a tendency to repeat reinforced keys long before there is any particular effect following nonreinforced trials. That is, Place shaping seems to change the "win-shift" very rapidly.

In addition, "shifts" themselves are shapeable through selective reinforcement. If reinforcement works through the mechanism of differently sized shifts, it seems strange that these shifts can be changed in size through reinforcement.

Although the present set of studies did not in general support the Law of Effect, there were some findings that suggest some sort of stamping-in due to reinforcement. Responses of 0° not only occurred more frequently than would be expected by chance, but they were the most popular Response value, suggesting at least a temporary stamping-in effect of reinforcement. The number of keys used per session was also lower than would be expected by chance, even when the proportion of repeated keys, represented by 0° Responses, is taken into account. This suggests that the temporary stamping-in lasted longer than just one trial. In the first few sessions of RR 5 and of targeted percentile shaping of Place, there seemed to be a tendency to approach reinforced keys and avoid nonreinforced keys, as shown by the Response vectors. In addition, both Place and Response shaping produced lower variability following reinforced trials than following nonreinforced trials.

I believe that the effect of reinforcement in the present set of studies was twofold. The first consequence was to a strong tendency to shift a particular amount clockwise or counterclockwise from the reinforced key on the next trial. This occurred in FR 1, RR 5, and the first few days of TP shaping of both Place and Response. (This is why the pigeons were less variable, but also less accurate, following reinforced trials during Response shaping.) This tendency was brought into the experimental situation by the pigeons. I suspect that it could be called innate, because the pigeons *as a group* changed their shifts as a function of number of sessions of nondifferential reinforcement, although each pigeon was run independently of the others. If this behavior were learned, it would require each of the pigeons to have learned the same tendency to shift from trial to trial, as well as the same tendency to change shifts from session to session.

The second consequence was a much weaker tendency to repeat the reinforced key on the next trial.The weakness of this tendency to repeat reinforced keys (see Figures 14 and 38) might argue against its being the mechanism for Place shaping, which is a very robust phenomenon. However, a very weak behavioral tendency can potentially be the basis of very strong phenomena. This was demonstrated by a number of theories, developed in the 1960s, that showed that random search together with a very small directional trend could explain the quite efficient homing behavior shown by salmon and pigeons (Brown, 1971; Matthews, 1968). However, it should be noted that 0° was the modal Response value for only 1 out of 6 pigeons in Experiment 1, and 2 out of 12 pigeons in Experiment 2. Additionally, shaping to a target Response of 0° was not facilitated compared to shaping to other Response values, as it should have been if the Law of Effect is correct.

The consequence of extinction was not simply an increase in variability. The effect of extinction depended upon what condition(s) preceded it. In the probe pigeons, extinction following targeted percentile shaping of Place produced an increase in variability, with no great change in central tendency. In Experiment 2 extinction following FR 1 produced no increase in variability of Place (which was close to maximum under FR 1); but it produced a marked increase in variability of Response, as well as a drastic shift in central tendency toward 180°. Later in Experiment 2 extinction, following FR 1, following targeted percentile shaping of either Place or Response, produced a <u>decrease</u> in variability combined with a higher accuracy (for the former target) compared to FR 1. For Zack, extinction following 37 days of FR 1 following percentile shaping to two target Responses produced much lower variability than had been shown for the last 21 sessions of FR 1, together with a central tendency very close to the first target Response.

## APPLICATIONS TO THE STUDY OF FORAGING

My first acquaintance with the predictions typical of a foraging (i.e., food acquisition) model came from a study by Pyke (1978). In this paper, Pyke hypothesized that a bumblebee that proceeded (for example) due east, toward a large pine tree, and straight ahead (measured with respect to its last flight), and found an inflorescence with more nectar than usual would not proceed due east again, nor toward the large pine tree, nor straight ahead. The bee would instead make a larger turn than it usually did when leaving an inflorescence. This prediction seemed to me to be contrary to the Law of Effect, which would say that the bumblebee should repeat whatever action immediately preceded receipt of a relatively large reward. However, Pyke's prediction was confirmed, rather than the Law of Effect. This study and others like it kindled my interest in foraging models.

According to Kamil and Sargent (1981), ethologists are turning to psychologists for more precision in testing their models. Biologists are discovering what psychologists have known all along- that even if one is sure of the existence, function, and ultimate cause of some behavior involving learning, it may still be difficult to study the nature of this learning by observation in the natural environment. The best way to study learning is through experimentation, wherein the investigator has some control over whatever variables he considers important to control. The best place in which to conduct experiments is a laboratory, which is designed for the control of variables.

Mellgren and Olson (1983) feel that laboratory study of foraging behavior is a natural development:

> "The analogy between foraging behavior as it occurs in nature and operant and maze behavior as it occurs in laboratories is quite obvious. The active forager in a patchy environment must search for food in space, and upon encountering it, harvest it in some fashion. Movement through space from a nonfood source to a food source (or potential one) is the major component of maze procedures. Harvesting food from the food source is the major component of operant procedures." (Mellgren and Olson, 1983, p.229)

How well is natural foraging reflected in or modelled by operant responding? For example, how well do the schedules of reinforcement used in typical operant conditioning experiments parallel actual schedules of "prey capture"/"attempts" encountered by particular species foraging in their particular ecological niches? In general, we do not have the answers to these questions.

Variable-interval schedules, which are often used to test foraging models (e.g., Collier and Rovee-Collier, 1981), are probably not appropriate for this purpose since they are temporal-based schedules seldom if ever encountered by animals in the real world. That is, there are few situations in which an animal simply stays in one place and performs a repetitive series of acts, some of which produce food. Usually, animals have to travel both to and within patches.

The present situation seems to be a better one in which to experiment with theories of foraging, since it involves a spatial rather than a temporal response dimension. It also includes both of the factors mentioned by Mellgren and Olson (1983).

In analyzing the Place measure, we have implicitly ignored the pigeon's return from the pecked key, and obtained a mean vector only for the unit vectors originating at the feeder and terminating at the key pecked. If we did not do this, the mean vector after any number of trials would always be zero, since the pigeon begins and ends each trial in the same place. This way of treating the data yields a perfectly good measure of tendency to respond in a particular direction or place, if the data are seen as representing successive directions travelled or places visited starting from a central point.

Another way of thinking about these data is as successive moves, but with each move starting where the last one ended (as in the geometric calculation of the resultant vector). If the data are thought of this way, it becomes tempting to take the Place vector tracks at face value, and assume that if one of the pigeons in this study were placed in a large, flat, featureless area with food scattered at intervals, he would take the sort of path described by the vector track for Place obtained in the present study. There are of course problems with this interpretation of the data. The pigeons actually did return to the feeder on every trial, rather than finding food at the end of every unit vector. This interpretation requires assuming that the pecked key can substitute for spatially-distributed food, and that the pigeon itself ignores its return to the feeder after pecking the key.

However, in order for the correspondence between this situation and an open-field situation to become more than a speculation, one would have to do cross-validation with pigeons in open-field foraging situations. Even if there is no correspondence between locomotion on an unrestricted plane and "movement" in this situation, the resultant vector is a useful way of viewing the data. This is because it displays changes occurring during a session, or during the course of FR1, which would not be shown by the mean vector.

The "path" of the pigeons on a FR 1 schedule in the present studies could be described as a series of spirals, which, for a given pigeon, are constant for a given session. They are also consistent for a given pigeon for a given <u>series</u> of sessions. It could be objected that, given the nature of the apparatus, there is not much else that the pigeon could do. There are at least four different types of "paths" that the pigeons could have displayed:

1. A random walk is the pattern which would probably be expected in a nondifferential reward situation.

2. Place stereotypy would be reflected by a "path" consistently heading in one direction.

3. Response stereotypy would be shown by a circular "path", either clockwise or counterclockwise.

4. The most likely "path" would be some combination of the three possibilities above. Indeed, the usual "path" for any given session was a combination of all three.

Baum (1983) gives the following definitions relevant to the application of operant techniques to the study of foraging:

> "Ecologists use the term 'patch' to refer to a local aggregate of prey. The term 'prey' refers to a range of items from animate and inanimate food to a parasite's hosts. by 'foraging' or 'predation' is meant the activity involved in seeking and handling (i.e., subduing or otherwise interacting with) prey. broadly speaking, 'prey' corresponds to 'reinforcement', 'foraging' to 'instrumental behavior', and 'patch' to 'programmed sources of reinforcement'." (Baum, 1983, p. 269)

In foraging terms, both FR 1 and RR 5 in the present situation simulate a "patch" in which food is randomly located with respect to turns within the patch.

The earliest and simplest model of patterns of movement in foraging is that the animal will wander, approximately in a straight line, until prey is encountered. Once prey is encountered the rate of turning will increase greatly, tending to keep the animal near the prey. This is referred to as area restricted searching (Barnard, 1983). Returning to the study by Pyke (1978) cited earlier, if a bumblebee searches for nectar in an environment in which flowers are distributed in patches, rather than homogeneously, a large turn following a large reward would tend to keep it within the patch, whereas repeating the last action (e.g., flying straight ahead) might cause the bee to fly beyond the patch. The same reasoning applies to a pigeon walking around on the ground and eating seeds, or a human being hunting for strawberries.

Smith (1974b) distributed artificial prey with either "high" or "low" density. Foraging thrushes made larger and more frequent turns on high-density distributions, both before and after obtaining a bait. On low-density distributions, the thrushes made larger turns after obtaining a bait, provided that the distribution of food was "patchy". If the distribution was low-density but homogeneous, the thrushes did not exhibit area restricted searching. Smith (1974b) shows a typical path of a single thrush foraging in a high-density distribution of artificial prey. This track strongly resembles the typical vector path produced by the pigeons on a FR 1 schedule in the present experiments. Thus, one possible way of accounting for the short Place vectors and long Response vectors in FR 1 is that the pigeons were engaging in area-restricted search. That is, they were making large turns (Response) in one direction, which would tend to keep them in a small area. The distance between the closest prey in Smith's (1974b) high-density regular distribution was 1.83 m, and the distance between prey was approximately twice as long in the low-density distribution. Since the conditioning chamber in the present studies had a diameter of 103 cm, the distance the pigeon had to walk between magazine presentations was just over 1 m. This was a very high prey density by the standards of Smith (1974b), and might be expected to trigger area restricted search, although the prey and the species studied differ. Another behavior displayed in the present set of studies, which seems to be consistent with area-restricted search, is moving 180° from the last-pecked key following nonreinforcement. If a pigeon that is walking along the ground and eating seeds takes another step forward, pecks, and finds no food, turning

$180^{\circ}$ and proceeding in that direction should take it back into the patch.

According to Staddon (1983), pigeons do engage in area-restricted search:

> "...When a pigeon foraging in nature finds some grain after a period of unsuccessful search, his rate of turning increases (that is, he continues to look in the vicinity)...." (Staddon, 1983, p.131, parentheses in original).

Unfortunately, he fails to cite any data supporting this assertion. Additionally, the term "area-restricted search" has little explanatory or predictive power. It would be quite useful to know the parameters of the search path.

If careful comparisons between the results using the operant paradigm reported in this thesis and open-field grid-type foraging studies showed a good correspondence, this operant technique could be quite useful and particularly economical of time and space in studying models of foraging. Indeed, it might be particularly good for studying <u>optimal</u> foraging models, which are highly simplified, with few parameters. As new factors were considered in the model, they could be added to the minimal situation.

## POSSIBLE CONFOUNDS AND RIVAL HYPOTHESES

Before hypothesizing that the consistent turning behavior (i.e., Response) that was found in the present experiments under FR 1 represents either superstitious conditioning or a "foraging strategy", alternatives should be considered. Human beings, if blindfolded and asked to walk straight ahead, will actually walk in a series of spirals (Schaeffer, 1928). If asked to walk 50 paces forward, then turn 180° and walk 50 paces backwards, and so on, they will still walk in spirals. Blindfolded human beings also swim, row a boat, and drive a car in spirals when asked to proceed straight ahead (Schaeffer, 1928). It is not known what causes this phenomenon, but it cannot be morphological asymmetry (Neville, 1976).

Beetles, woodlice, and millipedes, when allowed to locomote in the dark, also tend to move in a series of spirals which are consistently clockwise or counterclockwise (von Buddenbrock, 1917, cited in Fraenkel, 1961). In these cases, however, morphological asymmetry has not been ruled out.

Perhaps the experimental chamber was so homogeneous and devoid of cues that the pigeons were, in effect, blindfolded. If they did attempt to travel in a straight line, they might end up spiralling, as is the case with people. Since the pigeons displayed excellent Place shaping, showing that they could find their way around in the chamber, this explanation seems unlikely. However, the pigeons did take about 5-7 daily sessions of differential reinforcement to achieve a high level of Place shaping, so perhaps this explanation does have some validity.

In the 1950s, one plausible theory of homing in birds was that they spiralled out from the release point until they encountered familiar landmarks, which meant they were near home, and then visually navigated home. The times to return home, and the proportion of birds successfully homing, were consistent with this hypothesis, for the species that were studied (gulls and gannets). The spiral search hypothesis received some support when Griffin and Hock (1949) tracked displaced gannets by airplane and found that they flew in large, looping spirals.

> "Indeed, the behavior of these gannets was consistent with the hypothesis of spiral exploration..." (Griffin, 1964, p.109).

Further studies, on birds with more highly-developed homing abilities, such as homing pigeons and Manx shearwaters, established the existence of the sun-compass and true avian navigation, but gannets and gulls do tend to fly in spirals when homing.

Homing pigeons also typically spiral upon release, sometimes extensively, before setting off in some relatively set direction (Elsner, 1978). This spiralling may permit the pigeon to find and orient to particular types of cues, for example, distant landmarks (Kohler, 1978). Perhaps the pigeons in the present experiments began spiralling in order to get oriented, and never did, because of the scarcity of cues and the nondifferential reward. Therefore, they kept on spiralling.

All of the spiral paths noted above are depicted in published studies, and, at least as published, they all resemble the "tracks" of the pigeons in the present studies.

One possible source of Response (and possibly Place) bias in these studies is the position of the feeder. If the pigeons were reluctant to walk over the feeder, they would be restricted to the "back" half of the box, which would cause Response to be elevated. It would also tend to cause the mean angle for Response to be between +90° and -90°. This could also affect Place, perhaps raising the probability of a pigeon's fixing on a particular spot. However, B11P had a substantial Response mean vector at -123° for FR 1 in Experiment 2, B14R had one at -94°, and B7 had one at -127°. In addition, several pigeons cycled through the entire range of possible Response values over a number of daily sessions.

Another possible source of bias affecting both Place and Response is that on nonreinforced trials, the feeder was not presented, eliminating the cues associated with feeder presentation. If the pigeons approached the feeder directly on reinforced trials, but circuitously on nonreinforced trials, variability would tend to be increased following nonreinforced trials. A bias of this sort could explain the drastic increase in Response variability which occurred when EXT was instituted. However, observation of the pigeons on TP and EXT showed that they tended to approach the feeder directly even on nonreinforced trials.

Yet another possible source of bias is differences between the keys. This factor may well have contributed to the size of the daily mean vectors for Place in FR 1 and RR 5 in Experiment 1.

Because of problems associated with the keypeck response (difficulty in equating keys for effort and for stimulus properties), it is proposed that research in the area of response variability be continued using a purely locomotor response, but still using a circular continuum. This approach has several advantages- the elimination of behavioral variability due to variability of manipulanda, the ability to use the same response for any organism, and the intrinsic tie between locomotion and foraging behavior. In addition, this sort of research would require only a television camera, a microcomputer, a food magazine, and a pigeon.

Actually, what was studied in the present series of experiments, at least in the procedures other than Place shaping (i.e., those not relying to a great degree upon cue learning), may have been locomotor responding. Differences in the keypeck itself (e.g., force, duration, etc.) were not studied. Indeed, the actual response terminating the chain of responses may not be important. It is quite possible that if the keys had been removed, and that photocells had recorded beak-poking as the reinforced response, the results in terms of resultant vectors for Place and Response would not have differed greatly from those found using pecking.

## A POSSIBLE CIRCANNUAL RHYTHM

An interesting finding from the present set of studies is that, under FR 1, the effect of reinforcement upon Response is not constant, but is dependent upon number of previous sessions (or possibly day of the year). The evidence is slim, but the same effect was found in both studies, and the slope of the best-fitting straight line was very close in both cases to what would be expected for a circannual rhythm. Pigeons have been shown to demonstrate circannual rhythms in other sorts of behavior. Homing behavior is worse than average from January through June, and better than average from July through December, and performance shows a definite sine wave (Gronau and Schmidt-Koenig, 1970). More interestingly, direction of initial orientation upon release also showed a circannual rhythm, being in the opposite direction from the home loft during the first part of the year, and in the direction of the loft for the second half of the year (Gronau and Schmidt-Koenig, 1970). Again, there are gradual changes during the year, approximating an annual sine wave.

In order to determine whether there is a circannual rhythm in Response under FR 1, this procedure could be carried out in a group of pigeons for one year, or until it is clear that Response does not follow a circannual rhythm.

## SUMMARY AND SUGGESTIONS FOR FURTHER RESEARCH

The prediction, based upon the Law of Effect, that characteristics of a response which are sensitive to reinforcement will undergo progressive stereotypy under nondifferential reinforcement was not supported. Both the location of keypecking (Place) and the shift between keys from one trial to the next (Response) were shapeable using differential reinforcement, but neither underwent progressive stereotypy when every keypeck was reinforced, in two separate experiments. This lack of stereotypy was probably not due to the pigeons' inability to discriminate between the keys, since the same behavior was seen when every key was distinctively marked, and the pigeons shaped quite well to Place under differential reinforcement.

These data were consistent with Staddon and Simmelhag's (1971) notion of selection; i.e., the dropping-out of nonreinforced responses. However, the results of shaping with only one key reinforced did not support this view of learning, since despite thousands of trials, the nonreinforced responses did not drop out. The shape of the distribution of keypecks around the single reinforced key was interpreted as showing a positive influence of the reinforced key rather than a negative influence of the other keys. Devenport's (1983) concept of variability being added to the learned response, combined with Staddon and Simmelhag's selection mechanism, could produce the obtained results for shaping with one key. However, Devenport's concept of variability fits just as well with the Law of Effect. There was some slight evidence for the Law of Effect- Response values of

0° occurred more frequently than would be predicted by chance, and the number of keys used per session was lower than would be predicted by chance (even taking Responses of 0° into account).

My interpretation of food reinforcement in this situation is that it has two consequences. First, it produces a strong tendency to move a particular amount counterclockwise or clockwise from the reinforced key on the next trial (Response). This tendency does not depend upon learning in the experimental situation, and it may represent a foraging strategy triggered by the situation. Second, it produces a weaker tendency to repeat the reinforced key (Place). This tendency is also not learned in the experimental situation, and may represent the Law of Effect. The reason that there was no Place stereotypy under nondifferential reinforcement was that the Place tendency was masked by the Response tendency. The daily group mean data for Response suggest that Response is not ordinarily under the control of reinforcement, although it was shown that Response could be controlled (to some extent) by reinforcement. These hypotheses are very tentative, and require more evidence to be more than suggestive.

In order to investigate these hypotheses, the most useful conditions to study would be random ratio schedules such as RR 5, and shaping to one reinforced key. The random ratio schedules would provide data concerning the effects of reinforcement and nonreinforcement, in terms of direction of responding, independent of the particular locus of the reinforced or nonreinforced response. A circular response continuum is the only experimental situation in which this can be done. (These data might also be relevant to optimal foraging theories, representing behavior in patches of different density.) Shaping to one reinforced key before training on any other schedule would provide a test of Staddon and Simmelhag's idea of reinforcement selecting from a range of responses, at least for this situation.

# REFERENCES

Abelson, H., and DiSessa, A. Turtle Geometry. Cambridge, Mass.: MIT Press, 1981.

Antonitis, J. J. Response variability in the white rat during conditioning, extinction, and reconditioning. Journal of Experimental Psychology, 1975, 42, 273-281.

Barnard, C. J. Animal Behavior: Ecology and Evolution. New York: John Wiley and Sons, 1983.

Batschelet, E. Circular Statistics in Biology. London: Academic Press, 1981.

Baum, W. M. On two types of deviation from the matching law: Bias and undermatching. Journal of the Experimental Analysis of Behavior, 1974, 22, 231-242.

Baum, W.M. Studying foraging. In R.L. Mellgren (Ed.), Animal Cognition and Behavior. Amsterdam: North-Holland, 1983.

Blough, D. S. Pigeon perception of letters of the alphabet. Science, 1982, 218, 397-398.

Bond, A. B., Cook, R. G., and Lamb, M. R. Spatial memory and the performance of rats and pigeons in the radial-arm maze. Animal Learning and Behavior, 1981, 9, 575-580.

Brown, F. Jr., Moderator. Unconventional theories of orientation. Annals of the New York Academy of Science, 1971, 188, 331-358.

Brown, P. L., and Jenkins, H. M. Autoshaping of the pigeon's keypeck. Journal of the Experimental Analysis of Behavior, 1968, 11, 1-8.

Collier, G. H., and Rovee-Collier, C. K. A comparitive analysis of optimal foraging behavior: Laboratory simulations. In A. C. Kamil and T. D. Sargent (Eds.), Foraging Behavior: Ecological, Ethological, and Psychological Approaches. New York: Garland, 1981.

Davis, E. R., and Platt, J. R. Contiguity and contingency in the acquisition and maintenance of an operant. Learning and Motivation, 1983, 14, 487-512.

Dennet, D. C. Brainstorms: philosophical essays on mind and psychology. Montgomery, Vermont, Bradford Books, 1978.

Devenport, L.D. Spontaneous behavior: Inferences from neuroscience. In R.L. Melgren (Ed.), Animal Cognition and Behavior. Amsterdam: North-Holland, 1983.

Eckerman, D. A., and Lanson, R. N. Variability of response location for pigeons responding under continuous reinforcement, intermittent reinforcement, and extiction. Jounal of the Experimental Analysis of Behavior, 1969, 12, 73-80.

Elsner, B. Accurate measurement of the initial track (radius 1500 m) of homing pigeons. In K. Schmidt-Koenig and W. T. Keeton (Eds.), Animal Migration, Navigation, and Homing. Berlin: Springer-Verlag, 1978.

Ferraro, D. P., and Branch, K. H. Variability of response location during regular and partial reinforcement. Psychological Reports, 1968, 23, 1023-1031.

Fraenkel, G. S. and Gunn, D. L. The Orientation of Animals: Kineses, Taxes, and Compass Reactions. New York: Dover, 1961.

Griffin, D. R. Bird Migration. Garden City: The Natural History Press, 1964.

Griffin, D. R. and Hock, R. J. Airplane observations of homing birds. Ecology, 1949, 30, 176-198.

Gronau, J. and Schmidt-Koenig, K. Annual fluctuation in pigeon homing. Nature, 1970, 226, 87-88.

Herrnkind, W., and McLean, R. Field Studies of homing, mass emigration, and orientation in the spiny lobster, Panulirus argus. Annals of the New York Academy of Science, 1971, 188, 359-377.

Herrnstein, R. J. Stereotypy and intermittent reinforcement. Science, 1961, 133, 2067-2069 (a).

Herrnstein, R. J. Relative and absolute strength of response as a function of frequency of reinforcement. Journal of the Experimental Analysis of Behavior, 1961, 4, 267-272 (b).

Herrnstein, R. J. Superstition. In W. K. Honig (Ed.), Operant Behavior: Areas of Research and Application. New York: Appleton-Century-Crofts, 1966.

Hull, C. L. Principles of behavior. New York, Appleton-Century-Crofts, 1943.

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

Mellgren, R. L. and Olson, M. W. Mazes, Skinner boxes, and feeding behavior. In R. L. Melgren (Ed.), Animal Cognition and Behavior. Amsterdam: North-Holland, 1983.

Kohler, K. L. Do pigeons use their eyes for navigation? A new technique! In K. Schmidt-Koenig and W.T. Keeton (Eds.), Animal Migration, Navigation, and Homing. Berlin: Springer-Verlag, 1978.

Matthews, G. V. T. Bird Navigation . Cambridge University Press, London, 1968.

Neville, A. C. Animal Asymmetry. Camelot Press: Southampton, 1976.

Notterman, J. M. and Mintz, D. E. Dynamics of Response. New York: John Wiley and Sons, 1965.

Olton, D. S., Handelman, G. E., and Walker, J. A. Spatial memory and food searching strategies. In A. C. Kamil and T. D. Sargent (Eds.), Foraging Behavior: Ecological, Ethological, and Psychological Approaches. New York: Garland, 1981.

Platt, J. R. Percentile reinforcement: Paradigms for experimental analysis of response shaping. In G. H. Bower (Ed.), The Psychology of Learning and Motivation: Advances in Theory and Research, (Vol. 7). New York: Academic Press, 1973.

Platt, J. R. Personal communication, 1980.

Restle, F. Discrimination of cues in mazes: A resolution of the "place-vs-response" question. Psychological Review, 1957, 64, 217-228.

Schaeffer, A. A. Spiral Movement in Man. Journal of Morphology and Physiology, 1928, 45, 293-398.

Schou, G. Estimation of the concentration parameter in von Mises-Fisher distributions. Biometrika, 1978, 65, 369-377.

Scott, G. K., and Platt, J. R. Model of response-reinforcer contingency. Journal of Experimental Psychology: Animal Behavior Processes, 1985, 11, 152-171.

Schmidt-Koenig, K. Avian Orientation and Navigation. London: Academic Press, 1979.

Sidman, M. Tactics of Scientific Research. New York: Basic Books, 1960.

Skinner, B. F. 'Superstition' in the pigeon. Journal of Experimental Psychology, 1948, 38, 168-172.

Smith, J. N. M. The food searching behaviour of two European thrushes. I. Description and analysis of search paths. Behaviour, 1974, 48, 276-302 (a).

Smith, J. N. M. The food searching behaviour of two European thrushes. II. The adaptiveness of the search patterns. <u>Behaviour</u>, 1974, 49, 1-61 (b).

Spence, K. W. Behavior theory and conditioning. New Haven, Yale University Press, 1956.

Staddon, J. E. R., and Simmelhag, V. The "superstition" experiment: a reexamination of its implications for the principles of adaptive behavior. <u>Psychological</u> Review, 1971, 78, 3-43.

Staddon, J. E. R. <u>Adaptive Behavior and Learning</u>. Cambridge: Cambridge University Press, 1983.

Thorndike, E. L. <u>Animal Intelligence: Experimental</u> Studies. New York: Macmillan, 1911.

Wallraff, H.G. Preferred compass directions in initial orientation of homing pigeons. In K.Schmidt-Koenig and W.T. Keeton (Eds.), <u>Animal Migration,</u> Navigation, and Homing. Berlin: Springer-Verlag, 1978.

Zach, R. and Smith, J. N. M. Optimal foraging in wild birds? In A. C. Kamil and T. D. Sargent (Eds.), _Foraging Behavior: Ecological, Ethological, and_ Psychological Approaches. New York: Garland, 1981.

APPENDIX. Symbols affixed to each key for Group L in Experiment 2.

# APPENDIX

The symbol affixed to each key throughout Experiment 2 is given below, next to the number of the key.