

METHODS AND FINDINGS IN AN ANALYSIS OF A VOCAL OPERANT

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The relations among acoustic parameters of a vocal operant were considered and some methods for their measurement are described. Four human subjects (*Ss*) and one chick were employed in an experiment on the relations among vocal rate, vocal topography, and schedules of reinforcement. The earlier finding that schedules of reinforcement control human and infra-human vocal responding as they do other operants was replicated and extended to the case of variable-interval reinforcement. An analysis of response amplitude, pitch, and duration showed that the mean and variance of these parameters typically increase from CRF to VI, from VI to EXT and, for a second group of *Ss*, from CRF to EXT. The topography of the chick's vocal response appears to stand in the same relation to reinforcement operations as does the human vocal response.

Lately, there has been a considerable increase in research in two heretofore unrelated areas: the rate of emission of vocal operants (Flanagan, Goldiamond and Azrin, 1958; Lane, 1960, 1961; Shearn, Sprague and Rosenzweig, 1961; Starkweather, 1960; Starkweather and Langsley, 1961) and the topographical properties of non-vocal behavior (Goldberg, 1959; Margulies, 1961; Millenson, Hurwitz and Nixon, 1961; Notterman, 1959; Schaefer and Steinhorst, 1959).³ It has been established, in the first area cited, that the rates of emission of human and infra-human vocal responses are amenable to reinforcement control. Research in the second area has shown that there are systematic functional relations among response topography, response rate, and contingencies of reinforcement. It has not been shown to what extent these relations apply to vocal behavior.

There is a certain irony, therefore, in observing that the vocal response may be pre-

ferred, on several counts, to any other operant for an inquiry into the topographical properties of operant behavior in general. Unlike many other operants, whose muscular constituents are relatively inaccessible for measurement, "the complex muscular responses of vocal behavior affect the verbal environment by producing audible 'speech'. This is a much more accessible datum" (Skinner, 1957). The usefulness of this datum is predicated on substantial evidence (Fant, 1960) that changes in the complex muscular responses of vocal behavior are closely correlated with changes in the acoustic parameters of speech. Measurement of the vocal response is facilitated by the availability of advanced instrumentation, both for the recording of acoustic signals and for the analysis of signal parameters.

Aside from the role that vocal topography may play as a vehicle for a more general inquiry, it warrants research in its own right. In the prediction and control of vocal behavior, a single instance of the operant must often be dealt with. In this case, frequency of emission cannot be employed as an index of "response strength", and interest centers upon such topographical properties of the response as amplitude, pitch, and duration.

This article includes a consideration of various methods for measuring vocal topography and a description of its relation, on the one hand, to vocal rate and, on the other, to non-vocal topography under schedules of reinforcement.

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METHOD

The relation of measurement parameters to vocal topography

It was not desirable in the present research to define the response exclusively as the closure of a voice-operated relay suitably juxtaposed with a subject, because interest centered on the subclasses of this operant. Alternatively, the response could have been defined as some voltage function of time, but a more general and useful definition would be in terms of the acoustic signal radiated from the subject's mouth. This vocal response, or acoustic event, may be represented by a large number of parameters, of which the following were selected in the present study: peak average amplitude, mean duration of the initial 10 periods of the fundamental frequency, and duration of the total acoustic event. These parameters are neither exhaustive nor independent. Although the choice of response parameters may be determined eventually by the degree to which they relate systematically to experimental variables, it was made initially in view of their relation to the speech production mechanism. To a large extent, the speech pressure function of time is predictable from the configuration of the vocal source and tract; the converse is also true (Delattre, 1951).

(1) *Peak average amplitude.* It is generally thought that the laryngeal tone is produced by the alternating force exerted on the vocal folds, initially by the subglottal pressure and then, following the spread of the folds, by the negative pressure or Bernoulli effect, caused by the stream of air through the folds. The major determinant of the peak average amplitude (hereafter called amplitude) is the peak subglottal pressure which, in man, is caused by the contraction of the respiratory muscles. Ladefoged and McKinney (1962) report that the sound pressure level of sustained vowels is proportionate to the corresponding subglottal pressure raised to the 1.5 power.

The pulsating airflow through the glottis is a saw-tooth shaped periodic time function which can be expressed as a harmonic spectrum, according to the Fourier transform. The vocal tract above the glottis may be considered a variable filter system. Its effects are represented by multiplying the amplitude of each harmonic of the source spectrum by the gain

factor of the filter function at each frequency. The resultant spectrum envelope is the Fourier transform of the pressure function of time radiated from S's mouth. Amplitude, then, is determined not only by the subglottal pressure but also by changes in the spectrum of the glottal waveform such as would be caused by a change in the elasticity of the vocal folds, and by changes in the vocal tract filter system, caused by a change in the positions of the articulators. Thus, pitch and vowel quality also influence amplitude.

In order to measure the amplitude of the vocal response, the pressure function of time was transduced by a calibrated dynamic microphone (Altec 633A) and tape recorded (Ampex 300). The recorded signal was applied to an intensity meter⁴ that, first of all, introduced full-wave linear rectification. Such a signal has a high information rate which must be reduced for parametric representation; typically, a filter with bandwidth less than that of the original wave is employed. The cutoff frequency must be low enough to attenuate the ripple components due to the quasi-periodic voice source, but high enough to permit accurate measurements of speech transients. A bandwidth of 32 cps (11 msec integrating time) was used for human voice measurements and one of 150 cps (2 msec integrating time) for chick voice measurements. The meter had linear amplitude compression and no prefiltering. Its output was applied to a DC amplifier with flat frequency response (Krohn-Hite DCA-10R) and thence to a peak reading voltmeter (Control Devices PTM-7-R). This device read and stored the peak of the average amplitude function of time and applied a proportionate voltage to a DC VTVM (Hewlett-Packard 405CR), which, in turn, encoded the impressed signal and transferred the information to a printout counter (Hewlett-Packard 560 AR). The counter recorded the voltage (to three digits) and cleared the peak meter. It was not necessary in the present study to calibrate the measurement system with respect to sound pressure levels at the source. The units of response amplitude are arbitrary, therefore, and only relative values are considered.

(2) *Fundamental frequency.* Changes in the fundamental frequency of the voice are de-

⁴For a discussion of circuit design, see Peterson and McKinney (1962).

terminated primarily by the degree of contraction of the thryo-arytenoid muscles, which regulate the elasticity of the glottal margins, and secondarily by the subglottal pressure.

A simplified analysis of the mechanics of the sound source described above suggests that the period of the laryngeal tone (or excursion of the vocal folds) is inversely proportional to the square root of the subglottal pressure, in the absence of any compensatory adjustment of the vocal folds. A psychophysical determination of this relation showed that the relative frequency was proportional to the 0.2 power of the relative amplitude (Lane, 1962). Thus, these two parameters of the vocal response normally covary. The fundamental frequency may also be influenced by major constrictions in the vocal tract; this is not of concern in the present study where the vocal response was a vowel sound.

In human phonation, the fundamental frequency may be considered a population pa-

rameter inferred from a distribution of sample period durations of the laryngeal tone; this because of the *quasi*-periodic vibration of the vocal folds. In chick phonation, the concept of a fundamental frequency is particularly inappropriate since the period of vibration of the tympanic membranes in the syrinx is constantly changing (see Fig. 1). Although the term fundamental frequency is used in the present study, it should be understood that the mean duration of the initial 10 periods was measured and then converted to cycles per second. The fundamental frequency was selected from the complex speech wave by applying the tape-recorded signal to two band-pass filters in series (Krohn-Hite 310AB; 48 db/octave). The filter settings were determined initially by spectrographic analysis (Western Electric BTL 2) and then adjusted by the junior author to provide better than 30 db rejection of the first harmonic. The filtered signal was sent to the "10 period

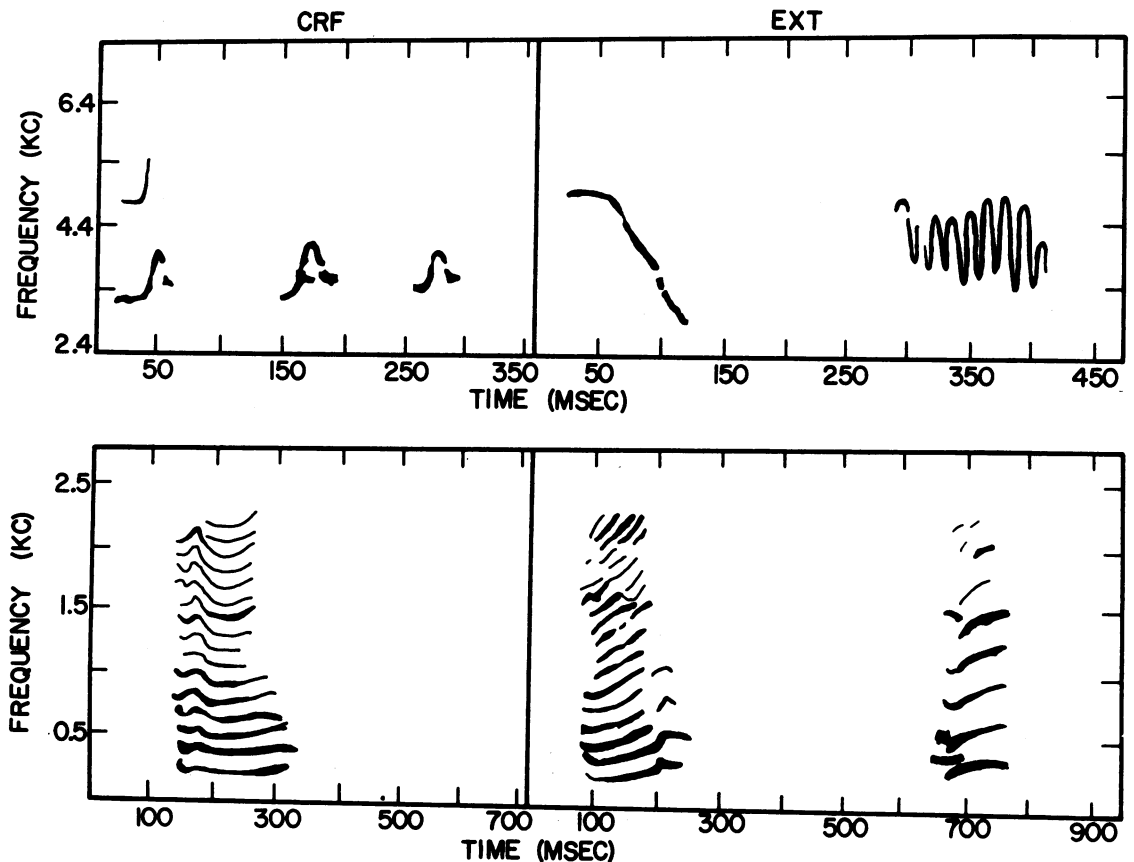


Fig. 1. Retouched spectrograms of chick (upper) and human (lower) vocal operants during continuous reinforcement (left) and extinction after CRF (right).

average" circuit of a frequency counter (Hewlett-Packard 522 B). The mean period was read in milliseconds to two decimal places and recorded by a parallel printer (Hewlett-Packard 560 A). Figure 1 shows that the 10-period average reflects the fundamental frequency reasonably well for human vocal responses during CRF but poorly under the other conditions of the experiment. Information reduction was bought at the cost of omitting other marked changes in the topography of the vocal response.

(3) *Duration.* The duration of the vocal response was measured from the tape-recorded signal by a calibrated voice-operated relay (Miratel), consisting essentially of an amplifier, full wave rectifier, peak regulator, and a relay. Although the circuit design of this and other VORs incorporates a peak regulator to provide drop-out time independent of signal level, this condition holds only for waveforms of relatively rapid rise and decay times. In the voicing of isolated vowels, the rise time may exceed 10% of the vowel duration. The measured duration of a signal with a non-rectangular waveform will depend on the relation of signal amplitude to VOR threshold. If signal duration is to be measured independent of amplitude fluctuations, input signals must either be processed with a fast-acting automatic volume control, or extensively peak clipped. In the present study, the input signals were amplified and the VOR threshold level was set 33 db below maximum input level. When the VOR was operated, the relay applied a DC voltage to the trigger circuit of the time interval section of a frequency counter (Hewlett-Packard 522B). The duration was read in milliseconds by the counter and then recorded by the parallel printer.

(4) *Rate of responding.* A voice-operated relay was also employed to provide a cumulative record of the number of responses as a function of time. These data were collected during the experimental session by applying the transduced acoustic signal to the VOR, which operated a cumulative recorder. It is important to note that the VOR threshold was set sufficiently low to respond to all voiced signals. Examination of concurrent tape recordings revealed that "false counts" resulting from non-vowel sounds (coughs, *etc.*) were infrequent.

Subjects

Two male and seven female University of Michigan undergraduates and one Bantam chick, were used.

Apparatus and procedure

(1) *Human.* A modification of Holland's procedure (1957) for the study of observing behavior was used. *S* sat in a sound-insulated chamber, facing a dynamic microphone (Altec, 633A), with head fastened in a headrest, to insure that the distance from mouth to microphone remained constant throughout the experiment. A loudspeaker was located behind *S*'s chair. Pencil and paper were presented and the following instructions read:

"This is an experiment in speech. You will hear numbers read to you over the loudspeaker in groups of about five or six. Each time a group of numbers is read, your job is to write down the numbers in a row of cells on your response sheet. Start a new row for every group of numbers. Numbers are presented only when you say /u/ into the microphone in front of you. Try not to make any other sounds at all, as this may disturb the experiment. The object is to see how many numbers you are able to write down correctly during the experiment, which will last about 3 [2] hr. Try and stay in the position the experimenter puts you in, throughout the experiment. Are there any questions? The experiment will begin a few seconds after I leave the room." (Questions were answered by repeating the instructions.)

Recording and control apparatus were located in an adjacent room and arranged in the following way: *S*'s vocal responses were transduced, sent to a tape recorder, and also to a voice-operated relay governing the reinforcement circuit. A second tape recorder, which ran continuously during the experiment, contained a tape on which random numbers had been recorded at intervals of about 1 sec. Reinforcement occurred when an electronic switch (Grason-Stadler 821) closed for 6.25 sec, allowing the Uher output to reach the loudspeaker located behind *S* and, at the same time, disconnecting the microphone in front of *S*.

There were two experimental conditions. In the first, which lasted about 3 hr, *S* was given 15 min of continuous reinforcement

(CRF), followed by 40 reinforcements on a variable-interval schedule (VI), followed by 73 min of extinction (EXT). In the VI schedule of reinforcement there were eight intervals each of 16, 32, 64, 128, 256 sec in random order. The second experimental condition, which lasted about 2 hr, was identical to the first, except that CRF extended beyond the

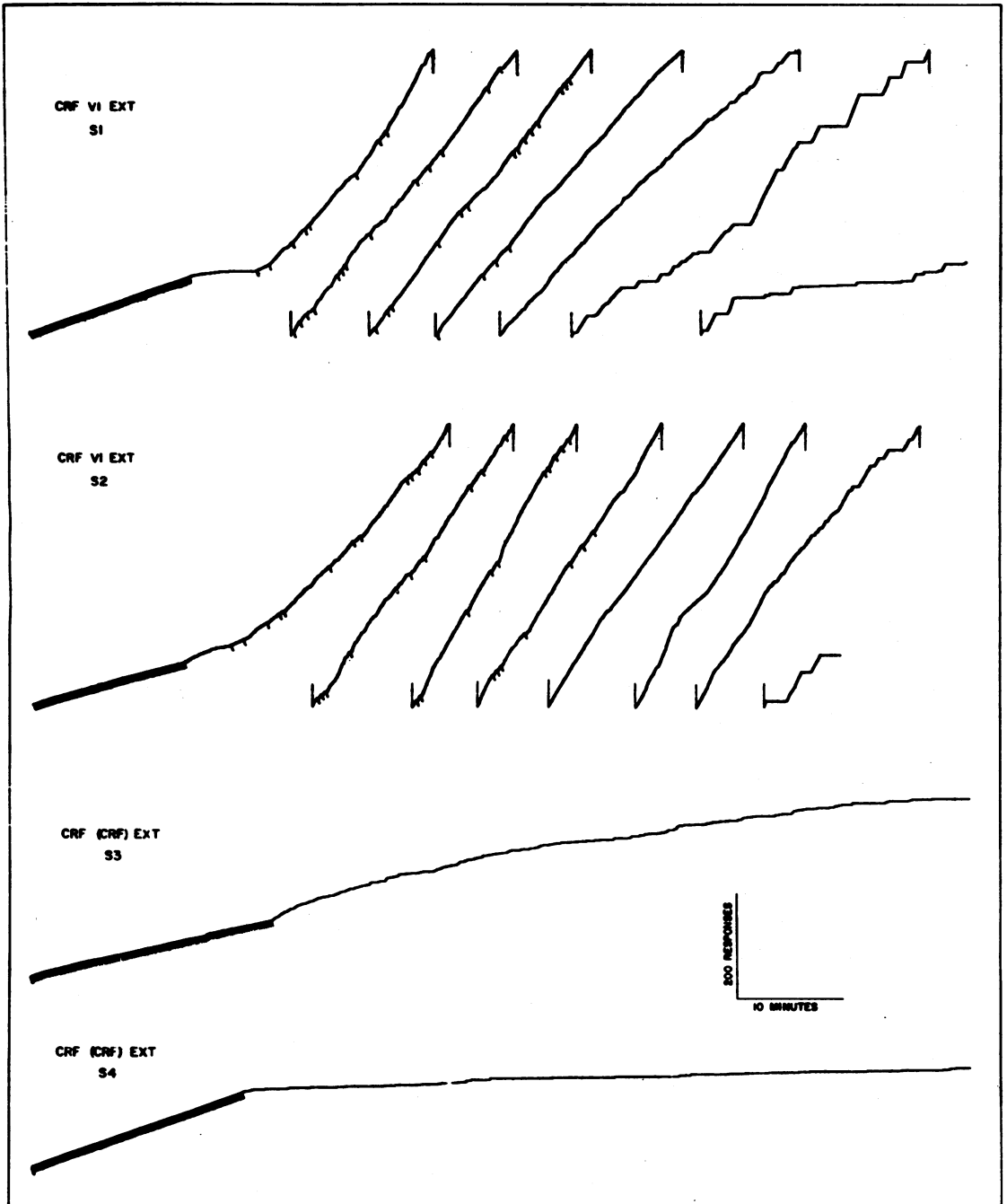


Fig. 2. Rates of vocal responding by four human female Ss under three schedules of reinforcement: continuous reinforcement (CRF), variable-interval 64 sec (VI), and extinction (EXT). The cumulative records for S1 and S2 have been collapsed.

initial 15 min to include 40 additional reinforcements, which replaced the VI reinforcements of condition 1.

Six Ss served in condition 1 (CRF-VI-EXT) and three Ss in condition 2 (CRF-CRF-EXT). An analysis of response topography was performed for two Ss from each group.

(2) Chick. The experimental procedure for the month-old Bantam chick was comparable to that for the human subjects. The vocal response (chirping) was observed to have a high operant level (2/sec) in the experimental space (modified pigeon chamber). To eliminate the noise generated by pecking, *etc.*, which triggered the VOR, most of the surfaces of the chamber were covered with a tough-skinned foam rubber while the remainder, including the food bin and water cup, were coated with room-temperature vulcanizing rubber. A light source and photocell were arranged in opposite walls of the food bin and a dynamic microphone was placed just above the bin, adjacent to the magazine light. The chick was conditioned with food reinforcement to hold his head in the bin, thus interrupting the light beam, during the course of the experiment. It was thus possible to insure that the chick's head was in a narrowly defined region around the microphone, allowing accurate amplitude measurements of the vocal response.

The chick was 24 hr food-deprived and at about 80% of free feeding weight when placed in the chamber on each of three experimental days. On day 1, 15 min of CRF was programmed: each vocal response produced 4 sec of food reinforcement (Wirthmore Chick Starter Crumbles). Responses occurring during the magazine cycle, however, had no effect. On day 2, the same VI schedule of reinforcement employed with the human subjects was programmed for the chick. On day 3, four VI reinforcements were presented and then extinction was in effect for 1 hr. Cumulative records and tape recordings were collected during the experimental sessions and subsequently analyzed in the manner described above.

RESULTS AND DISCUSSION

Rates of responding

Cumulative records were obtained from nine human Ss and one chick under the two

reinforcement sequences (CRF-VI-EXT and CRF-CRF-EXT). Typical records for the human Ss appear in Fig. 2; the conditioning and extinction records for the chick resemble those for S₂ (Fig. 2) and are not shown (but see Table 1). In the first VI interval, comparable to the first 256 sec of EXT for Ss 3 and 4, all Ss show a rapid decline in rate with about the same time course. Following the first reinforcement under the VI schedule, there is a rapid local, and gradual overall, increase in the rate of responding by Ss 1 and 2. These Ss received as many reinforcements prior to EXT as Ss 3 and 4 but their history of VI conditioning led to a much higher rate of responding in EXT.

Inference from the rates of responding observed for Ss 1 and 2 when the session was terminated suggests that a number of additional responses would have been observed with prolonged extinction. The extinction session was considerably prolonged for S₅ (Fig. 3), contrary to the instructions that were read. The subject was left undisturbed in the closed audiometric room from the beginning of CRF, when his head was taped to the headrest, until 13.5 hr later, when the session was terminated and the tape removed.⁵ Following 117 reinforcements in CRF and 60 reinforcements in VI, S₅ emitted over 8,000 responses in 11 hr of extinction (Table 1). This considerable "resistance to extinction" is, of course, characteristic of operant behavior following VI conditioning. The time course of extinction for S₅ is similar to that obtained from pigeons in extinction after VI conditioning (Ferster and Skinner, 1957, p. 348 ff.).

Topography of responding

Three parameters of the topography of the vocal response were recorded concurrently and analyzed for four human Ss and one chick. Table 1 presents the mean and the variance of the amplitude, duration and fundamental frequency of reinforced responses in CRF and VI and unreinforced responses in EXT. The data for individual Ss are more comparable when normalized with respect to baseline values obtained during CRF. Table 2 presents the difference between the mean parameter

⁵The S was, of course, able to leave at any time, although the record showed that he did not. He expressed no concern when he was removed from the experiment and paid for his overtime participation.

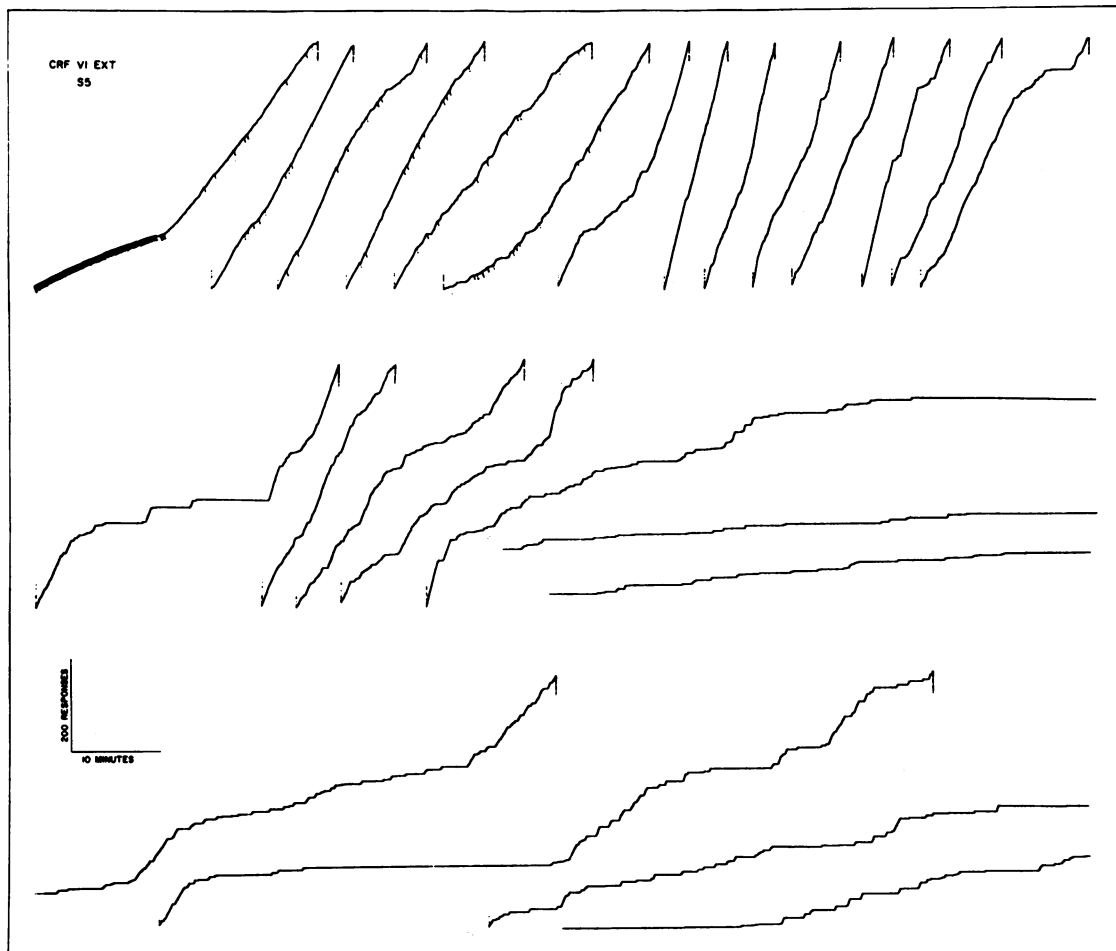


Fig. 3. Vocal responses emitted by one human male *S* during three successive schedules of reinforcement. The cumulative record has been collapsed.

values obtained from each *S* under VI, CRF and EXT and those obtained during the initial 15 min of CRF. Similarly, this table also shows the ratio of the variance of parameter values in VI, CRF and EXT to those obtained during the initial conditioning.

The topography of the chick vocal response appears to stand in the same relation to reinforcement operations as that of the human vocal response. The relative mean and variance statistics for response parameters (Table 2) do not provide a basis for discriminating between the two species; hence, differences among species are assigned to inter-individual variance in the following discussion of changes in response topography.

Changes in the variance of response parameters. An important relation between the

schedules of reinforcement employed and their effects on variability in response topography is apparent from Table 2. Column 1 shows that the effect of VI conditioning following CRF was a significant increase in the variance of all response parameters for all subjects (there are two exceptions). Comparable findings have been obtained by Millenson *et al.* (1961) for the duration of bar-press in the rat during periodic reinforcement. The marked increase in the variance of response parameters during VI conditioning, recorded in several cells of Table 2, is consistent with the analysis presented by Goldberg (1959) in a discussion of the relation of response variability to intermittent reinforcement:

"In *periodic* or *a-periodic* reinforcement, however, . . . each response will be followed

Table 1

Parameters of response topography for the vocal operant. The mean and variance in amplitude, duration, and fundamental frequency are presented for reinforced responses under CRF and VI schedules of reinforcement and all responses in EXT.

		<i>Amplitude</i> (arbitrary units)	<i>Duration</i> (centiseconds)	<i>Fundamental</i> <i>Frequency</i> (cycles per second)	<i>Number of</i> <i>Responses</i>	<i>Number of</i> <i>Reinforcements</i>	<i>Time</i> (minutes)	
S ₁	CRF	Mean	3.2	82	264	107	107	15
		Variance	0.4	459	126			
	VI	Mean	4.4	84	291	1,708	40	74
		Variance	1.1	488	338			
	EXT	Mean	3.8	88	281	1,608	0	105
		Variance	1.4	836	470			
S ₂	CRF	Mean	3.7	38	224	81	81	15
		Variance	0.7	87	83			
	VI	Mean	5.0	51	229	1,950	40	73
		Variance	5.9	1,259	776			
	EXT	Mean	6.3	53	225	1,906	0	73
		Variance	7.7	921	353			
S ₃	CRF	Mean	3.4	55	216	72	72	15
		Variance	0.3	43	68			
	(CRF)	Mean	4.0	55	224	40	40	8
		Variance	0.9	48	164			
	EXT	Mean	6.1	79	277	248	0	73
		Variance	0.7	3,398	1,404			
S ₄	CRF	Mean	6.3	55	267	106	106	15
		Variance	1.0	151	124			
	(CRF)	Mean	6.2	54	269	40	40	6
		Variance	1.9	774	51			
	EXT	Mean	5.5	56	274	46	0	73
		Variance	3.6	2,977	208			
Chick VI	CRF	Mean	2.0	5.9	2,778	199	199	15
		Variance	13.0	21.6	109,018			
	VI	Mean	2.7	6.7	2,897	6,500	28	50
		Variance	14.6	47.4	166,793			
	EXT	Mean	3.8	11.6	3,721	2,664	0	60
		Variance	60.1	339.6	189,429			

by a period during which responses subsequent to the reinforced one will not be rewarded. This extinction of responses will have the consequence of decreasing the probability of the emission of response forms similar to each previously reinforced one. The resultant number of response forms which will be available for periodic reinforcement will be expanded and the variability of those responses which are periodically reinforced will be greater than the variability of regularly reinforced responses."

The prediction of greater variability among reinforced responses in VI than in CRF, con-

firmed by the present findings, is based on the assumption (supported by considerable evidence) that variability increases in extinction. Antonitis (1950) has shown that variability in the locus of a nose insertion response by the rat increases in EXT. Increased variability in force of bar-press during EXT has been reported by Skinner (1938), Notterman (1959), and Goldberg (1959). In the present study, variance ratios for the topography of the vocal response (Table 2, col. 3, 4) show that large increases in response variability occurred in EXT following CRF. The present findings therefore support both the general statement

Table 2

Effects of changing schedules of reinforcement on the topography of a vocal operant. An unbiased estimate of the mean and variance of each parameter, measured for each *S* during each schedule of reinforcement, was subtracted from, or divided by (respectively), the corresponding statistic for that *S* obtained during the initial 15 minutes of CRF.

Column	1 Second Schedule VI					2 Third Schedule Extinction				
	<i>S</i> ₁	<i>S</i> ₂	Chick	<i>S</i> ₃	<i>S</i> ₄	<i>S</i> ₁	<i>S</i> ₂	Chick	<i>S</i> ₃	<i>S</i> ₄
Amplitude (arbitrary units)										
$\bar{X}_2 - \bar{X}_1$	1.2	1.3	0.7	0.6	-0.1*	0.6	2.6	1.8	2.7	-0.8*
S_2^2/S_1^2	2.7	8.2	1.1*	3.1	1.9	3.4	10.7	4.6	2.2	3.7
Duration (centiseconds)										
$\bar{X}_2 - \bar{X}_1$	2.0*	13.0	0.8	0.0*	-1.0*	6.0	14.0	5.7	24.0	1.0*
S_2^2/S_1^2	1.1*	14.3	2.2	1.1*	5.2	1.8	10.5	15.7	78.2	20.0
Fundamental Frequency (cycles per second)										
$\bar{X}_2 - \bar{X}_1$	27.0	5.0	119.0	8.0	2.0*	17.0	1.0*	943.0	61.0	7.0
S_2^2/S_1^2	2.7	9.2	1.5	2.4	0.4*	3.7	4.2	1.7	20.4	1.7*

*A *t*-test of the difference between means (or an *F*-test of the ratio of the variances) showed this difference (ratio) not to be significant at $p \leq .01$ (see Cochran and Cox, 1950 for a discussion of the significance of *t* when sample variances and sizes are not equal). The .01 significance level was adopted to compensate for the inflated overall probability of one or more type I errors, due to performing 30 tests of each kind.

that response variability increases in EXT after CRF and also the account of variability among reinforced responses in VI in terms of extinction effects. Schoenfeld (1950) employs these two statements in an analysis of the greater resistance to extinction found after VI conditioning than after CRF (cf. Fig. 2, 3).

Several authors have reported increasing stereotypy of response topography during CRF conditioning (Margulies, 1961; Notterman, 1959; Goldberg, 1959; Antonitis, 1950). In the present study, there is some evidence to the contrary since significant increases in the variance of some response parameters were observed when the second reinforcement schedule was also CRF (Table 2, col. 2). The departure may be related to the observations that the human vocal operant employed had a history of prior reinforcement, and that the properties of reinforcers such as signal detection and money are not identical with those of primary reinforcers such as food.

Changes in the central tendency of response parameters. The mean parameter values, as well as the variance, increase from CRF to VI conditions (Table 2, col. 1). In the light of the ranges of response amplitude, duration

and fundamental frequency typically observed in human and chick vocalizing, these mean differences are large and significant. Increases in mean parameter values may also be observed when EXT follows CRF conditioning (Table 2, col. 4), although the effect is not observed for the amplitude and duration of responding by *S*₄. It is interesting to note that this subject also showed very little resistance to extinction following CRF (Fig. 2).

Prior experimental evidence of the effect of schedules of reinforcement on mean parameter values of response topography is scant but tends to support the finding of an increase from CRF to EXT. Margulies (1961) observed an increase in the mean *duration* of bar-press by the rat in EXT after CRF, as did Hurwitz (1954) and Trotter (1956). The mean *force* of bar-press also increases in EXT after CRF (Notterman, 1959; Skinner, 1938). Skinner attributes the increase in force that he observed for his CRF-EXT animals to "the differentiation of intensity that results from the initial tension of the lever." He goes on to say: "The intensity of the response in an operant is significant only in relation to the differentiative history of the organism." (cf. Stanley and Aamodt, 1954.) An increase in the

mean amplitude of the vocal response was observed in the present study in EXT following CRF and following VI conditioning (Table 2, cols. 3, 4); however, the artifact of a manipulandum threshold, which might differentially reinforce response amplitude, was excluded by adjusting the voice-operated relay to respond to all vocal behavior.

The trend of the present data, in the light of comparable findings for other operants, permits the following generalization, which must be substantiated further: the mean and variance of the parameters of response topography increase under the reinforcement conditions CRF-VI-EXT in that order.

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