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THE ANALYSIS AND CONTROL OF INFANT VOCAL AND MOTOR BEHAVIOR.
BY- SHEPPARD, WILLIAM CLARENCE, JR.
MICHIGAN UNIV., ANN ARBOR,CTR.FOR RES.LANG.AND BEH
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IN EXPERIMENT 1, DEVELOPMENTAL CHANGES IN THE PROSODIC FEATURES OF INFANT VOCALIZING WERE STUDIED WITH NOVEL ELECTRO-ACOUSTIC TECHNIQUES. COMPLETE AND CONTINUOUS RECORDINGS OF ALL THE VOCALIZATIONS OF TWO INFANTS DURING THE FIRST FIVE MONTHS OF LIFE WERE COLLECTED AND SYSTEMATICALLY SAMPLED FOR ANALYSIS. COMPOSITE STATISTICS, DESCRIBING THE THREE PROSODIC FEATURES OF THE VOCALIZING IN EACH SAMPLE (FUNDAMENTAL FREQUENCY, RELATIVE AMPLITUDE, AND DURATION), WERE PLOTTED SEPARATELY AS A FUNCTION OF AGE AT THE TIME OF SAMPLE. PARAMETER VALUES AND TRENDS IN THE PROSODIC FEATURES OF INFANT VOCALIZATION ARE REPORTED. IN EXPERIMENT 2, CONTROL OF INFANT VOCAL AND MOTOR OPERANT BEHAVIOR WAS STUDIED DURING AN EXPERIMENT CONDUCTED IN THE INFANT'S HOME. DAILY EXPERIMENTAL SESSIONS WERE HELD FROM THE TIME THE SUBJECT WAS 10 DAYS OLD UNTIL HE WAS THREE MONTHS OLD. VOCALIZATION AND LEG KICK WERE STUDIED UNDER A NUMBER OF CONDITIONS. FOUR REINFORCERS WERE EMPLOYED--A RECORDING OF THE MOTHER'S HEARTBEAT, A VIBRATOR TAPED TO THE INFANT'S PALM, TWO FLASHING LIGHTS, AND A RECORDING OF THE MOTHER'S VOICE. SCHEDULE CONTROL OVER RESPONDING AND DIFFERENTIAL RESPONDING UNDER DISCRIMINATIVE CONTROL FOR BOTH VOCAL AND MOTOR OPERANTS IN AN INFANT LESS THAN THREE MONTHS OF AGE WAS ACHIEVED. THIS DISSERTATION APPEARS IN COMPLETE FORM IN "SUPPLEMENT TO STUDIES IN LANGUAGE AND LANGUAGE BEHAVIOR, PROGRESS REPORT V," SEPTEMBER 1, 1967, PUBLISHED BY THE CENTER FOR RESEARCH ON LANGUAGE AND LANGUAGE BEHAVIOR, 220 EAST HURON STREET, ANN ARBOR, MICHIGAN 48108. (AUTHOR/AMM)

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Studies in Language and Language Behavior

The Analysis and Control of Infant Vocal and Moto Behavior

William C. Sheppard, Jr

CENTER FOR RESEARCH ON LANGUAGE AND LANGUAGE BEHAVIOR

The Analysis and Control of Infant Vocal and Motor Behavior[1]

William Clarence Sheppard, Jr.

In Experiment 1, developmental changes in the prosodic features of infant vocalizing were studied with novel electro-acoustic techniques. Complete and continuous recordings of all the vocalizations of 2 infants during the first 5 months of life were collected, beginning with the birth cries and continuing uninterrupted as the infants were moved into plexiglass "air-cribs" at home. These recordings were systematically sampled for analysis. The prosodic features of vocalizing were analyzed by extracting 3 acoustic parameters: fundamental frequency (cps), relative amplitude, and duration (msec), during each of the 108 samples. The outputs of the parameter extractors (analog electronic devices) were measured every 25 msec by an analog-to-digital converter, then processed by an on-line digital computer. Composite statistics, describing the 3 prosodic features of the vocalizing in each sample, were plotted separately as a function of age at the time of sample. Parameter values and trends in the prosodic features of infant vocalization are reported.

In Experiment 2, control of infant vocal and motor operant behavior was studied. The experiment was conducted in the infant's home. Daily experimental sessions were held from the time the S was 10 days old until he was 3 months old. Vocalization and leg kick were studied under a number of conditions. 4 reinforcers were employed: a recording of the mother's heartbeat, a vibrator taped to the infant's palm, 2 flashing lights, and a recording of the mother's voice. Experimental conditions included operant level, continuous reinforcement, fixed-ratio reinforcement, extinction, differential reinforcement of zero responding, noncontingent reinforcement, and 2 concurrent multiple schedules.

Schedule control over responding and differential responding under discriminative control for both vocal and motor operants in an infant less than 3 months of age was achieved.

Footnote

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Chapter I: DEVELOPMENT OF THE PROSODIC FEATURES OF INFANT VOCALIZING

INTRODUCTION

The vocal behavior of an infant during the first few months of life is the matrix for later language development. Therefore, the differentiation and organization of infant vocalizing as a function of maturational and environmental factors holds considerable interest.

Previous research in this area consists almost entirely of descriptions by a single observer transcribing the utterances of a single infant in naturalistic settings. Two abridged biographical reports will be sampled: one from a "pre-objective" period, that of the late 19th century, and one from recent decades, employing "more refined techniques" (McCarthy, 1946). The earlier writer, a keen observer of behavior, is Charles Darwin. The contemporary writer, a linguist, is W. F. Leopold.

"The noise of crying is uttered in an instinctive manner . . . After a time the sound differs according to the cause, such as hunger and pain . . . he soon appeared to cry voluntarily. . . When 46 days old, he first made little noises without any meaning to please himself, and these soon became varied . . . At exactly the age of a year, he made the great step of inventing a word for food, namely mum . . . and now, instead of beginning to cry when he was hungry, he used this word in a demonstrative manner . . . implying 'Give me food'" (Darwin, 1877, p. 292).

"During the first few weeks the only sounds produced were cries of dissatisfaction . . . in the seventh and eighth weeks the sound ceased to be purely incidental. She uttered more arbitrary sounds of satisfaction . . . cooing as an articulated expression of feelings of satisfaction was therefore well established by the end of the second month . . . By the seventh month there was a good deal of babbling . . . prevalently ranging from [a] to [ɛ], long, without many tongue movements . . . At the end of the eleventh month, her active vocabulary consisted of two words" (Leopold, 1939, p. 16).

Linguistic studies in this field have focused on providing a description of the language of a particular child at different levels of development. The units of analysis have been phonemes, morphemes, words and sentences. The procedures for data collection usually begin with phonetic transcription of the infant's vocal behavior by a trained observer. The most extensive studies of this type are those of the linguists Gregoire (1937), Leopold (1939), Cohen (1952), Velten (1943) and Lewis (1938). The work of Irwin and Chen in the 1940's is notable for the refinements they introduced. These investigators began the practice of using two observers rather than one; this allowed them to obtain measures of observer agreement. They also increased the numbers of subjects observed and selected a more adequate sample of subjects.

Psychologists have tended to study more molar aspects of language development. The main interest has been to provide normative data on various indices of development, e.g., use of form class, size of vocabulary, mean sentence length, and the like, although more recent research (summarized by McNeill, 1966) emphasizes the rule governed nature of child language. The procedure for data collection is again transcription (usually alphabetic) by a trained observer using cross-sectional and longitudinal sampling. Among the classic studies of this type are those of Davis (1938), Fisher (1934), McCarthy (1929), Shirley (1933) and Templin (1939).

The most striking feature of the research literature on infant vocalizing is the lack of advancement in the field. The basic drawback is the reliance on transcriptions obtained by observations in naturalistic settings. Consider the difficulty of transcribing infant speech sounds. Because the infant is in the process of learning to articulate, the sounds he utters are unlikely to fit neatly into any classificatory system. There is the danger that the trained observer filters the variegated vocal behavior through his own classificatory categories--categories developed with adult vocal behavior--and thus rejects much of importance. Moreover, the infant utters sounds rapidly and sporadically, making it difficult for the observer to keep an accurate or complete record.

The obvious sampling problems have also limited the generality of the findings of previous studies. It has been recognized that when investigator and subject are also mother and child, experimental rigor receives little nourishment. In those less numerous studies in which the investigator has intruded into the home, the schedule of observation and transcription usually has been, to be most charitable, unsystematic. In summing up the results reported up to 1941 Irwin says:

"It will be apparent from this review of the more important studies . . . that there does not exist a large body of data secured from adequate samplings of infants for purposes of a statistical analysis . . . Usually no systematic research methods were formulated; statistical techniques essential to the analysis of mass data are practically absent, no reliabilities of observers have been established, many observers used alphabetical rather than phonetic systems of symbols for recording; and most reports indulge in an inordinate amount of interpretation supported by very little empirical material" (Irwin, 1941, p. 285).

In her classic review of the literature on language development in the child, McCarthy writes: "Although this wealth of observational material has proven stimulating and suggestive for later research workers, it has little scientific merit, for each of the studies has employed a different method, the observations have for the most part been conducted on single children who were usually either precocious or markedly retarded in their language development; the records have been made under varying conditions, and most of the studies are subject to the unreliability of parents' reports" (McCarthy, 1946, p. 478).

In his latest review of the area's progress, Irwin states: "Until recently the speech behavior of the infant has had only occasional attention. The reports of it in the literature are quite casual, they are very sporadic, and not at all acceptable from a systematic scientific standpoint" (Irwin, 1957), p. 403).

Attempts to ameliorate one or more of the methodological problems that we have reviewed have waited upon advancements in instrumentation. In Part II of her 1929 review McCarthy described some of the early attempts to record speech by means other than transcription by an observer. The first device she described was the manometric flame, invented by Koenig in 1862. With this device, the flame of a gas jet is disturbed by the sound wave and these disturbances are recorded photographically.

The phonautograph, invented by Scott in 1859, recorded the speech wave by means of a stylus attached to a diaphragm. The best device of this general type was the phonodeik, which consisted of a horn and a diaphragm; a small platinum wire attached at one end to the diaphragm was passed around a jewel-mounted spindle to a delicate spring. Attached to the spindle was a tiny mirror which reflected a fine beam of light onto a moving photographic film. The phonodeik could respond up to 10,000 cps but the horn and diaphragm introduced a certain amount of distortion.

In 1893 Blondel had devised the oscillograph and with improvements in amplifiers it promised to be a very useful piece of apparatus. However, even before the oscillograph had been developed to the point where it gave a practically perfect representation of the sound wave, it became clear that, once recorded in all its complexity, the waveform was virtually impossible to analyze in ways that were useful for studying speech.

Sound recording devices, the phonograph and later the wire and tape recorders, even when developed further than they were in 1929, solved only part of the problem. The actual speech sounds could then be recorded and replayed, but an observer still had to rely on his judgment as a perceiver of sound and speech in order to analyze the data.

Two years after the introduction of the sound spectrograph, in 1949, Lynip published a report of the use of this device in the study of infant speech. He recorded the speech sounds of a little girl, beginning with the birth cry and sampling at intervals ending at 56 weeks when intelligible speech began. A spectrographic analysis of these recordings revealed nothing which resembled the spectrograms of phonemes produced by adults.

In 1960, Winitz published a data-garnished polemic on the subject of the spectrographic analysis of infant vocalization. He argued that the fact that the infant's spectrograms didn't look like spectrograms of adult speech simply proved that the spectrograph isn't a good device for the study of infant vocalizations. "The basic data against which any instrumental method of phonetic analysis must be validated are the phonetic analyses made by competent observers whose validity Lyaip questions" (Winitz, 1960, p. 173).

Without resolving the question of the validity of spectrographic description, it must be acknowledged that for each two-second sample of vocalization approximately fifteen minutes are required to process, calibrate, crudely quantify, and classify each spectrogram--and that the problems of observer interpretation remain, although transferred from auditory to visual modes.

This brief account of the techniques that have been employed so far for collection and acoustic analysis of infant vocal behavior indicates that an extension of our knowledge of vocal development requires new techniques. Accordingly, I undertook, a year ago, to collect permanent, complete and continuous records of all vocalizations of two infants, one male and one female, and then to process these records by novel electro-acoustic techniques. My initial concern was to measure the acoustic correlates of the prosodic features of speech--namely, duration, intensity and fundamental frequency. In this report these measures are analyzed as a function of age and the techniques used to obtain them are described.

METHOD

Subjects

The first-born child of the experimenter was subject I in this experiment. The delivery was full-term, normal and easy. The birth weight was 7 1/2 pounds, which is average for male infants in the middlewest. He was five months and 17 pounds when the experiment ended.

Subject II was the first-born child of a research assistant at the Center for Research on Language and Language Behavior. The delivery was full-term, normal and easy. The birth weight was 6 1/2 pounds, which is average for female infants in the middlewest. She was five months and 16 pounds when the experiment ended.

Subject II was born three days after subject I. According to a periodic series of medical examinations made by the University of Michigan Child Care Center the infants grew and developed within the average range. Subject I was breast-fed and subject II was bottle-fed. Neither infant had any digestive disturbances or experienced any illnesses for the duration of the study.

Recording and sampling of vocalizing.

During the deliveries of the infants whose vocalizing is the subject of this study, medical personnel wore lapel microphones[1] whose outputs were recorded on magnetic tape. All subsequent vocalizing by the infants at the hospital was recorded by placing them in private rooms containing a microphone[2] wired to a fast-acting voice-operated switch (Miratel) and to a tape recorder (Tandberg).[3] After leaving the hospital, both children were cared for at home in plexiglass "air cribs" (T.M.I.) that provided no sources of sound within the crib and attenuation of external sounds[4]--hence, a good recording environment. The parents of the children were paid to keep a detailed record on prepared forms of major environmental events affecting the infant. These records were synchronized with the tape recordings by writing down the reading of the footage indicator on the tape recorder.

Complete recordings of all vocal behavior during the first five months of life constitute a formidable tape library, which was sampled for analysis in the following way. A master tape was prepared for each child which contained three 95-sec samples of the vocal behavior during every fourth day of life for the first 141 days. For the samples taken from the first month (in which the infant had no regular sleeping times) the three daily samples were excerpted from the recordings for 12 a.m. to 8 a.m., 8 a.m. to 4 p.m., and 4 p.m. to 12 p.m., respectively. This was accomplished by listening to the recording, beginning at the start of each period, and copying the first 95-sec onto the master tape. In some cases undesired noises intruded and the first 95-sec excluding these intrusions was copied. For the samples of vocalizing in the following four months, the three daily periods from which 95-sec samples were taken were: time at awakening (T) to T + 4 hours; T + 4 hours to T + 8 hours; and T + 8 hours to T + 12 hours. These sampling procedures yielded 108 95-sec samples for the initial acoustic analysis.

Analysis of the prosodic features.

The development of the prosodic features of the infant's vocal behavior was analyzed by extracting three acoustic parameters of the vocalizing, fundamental frequency (cps), relative amplitude, and duration (msec), during each of the 108 samples, using analog electronic devices. The outputs of these parameter extractors were sampled every 25 msec by an analog-to-digital converter, then processed by an online digital computer (PDP-4, Digital Equipment Corp.).

The frequency analysis was limited to the fundamental component of the speech wave form because of the technological limitations currently existing in regard to large scale spectral analysis of speech. The amplitude measure is relative since the position and orientation of the infant in reference to the microphone were variable. Therefore only measures of variability within utterances in amplitude are reported; it is extremely unlikely that changes in the spatial location of the infant which would affect the measurement of amplitude occured within utterances.

The changing fundamental frequency of the vocalizing was extracted by filtering tape-recorded signals into two frequency ranges. Since the harmonics of the fundamental frequency often have more energy than the fundamental itself, a range-control voltage is generated when there is energy in the lower range which turns off the upper range to exclude the harmonics. If no energy exists in the lower range, however, the fundamental frequency in the upper range is processed unimpeded. In either case, the nearly sinusoidal output from the filters is amplified in a mixer and read on a frequency meter which provides a DC voltage output proportional to the frequency of the fundamental sine wave at its input. A DC amplifier then adjusts the voltage range and polarity for input to the computer.

The changing amplitude envelope of the vocalizing was extracted by applying the recorded signals to a full-wave rectifier followed by a low-pass filter. The output of this device is a DC voltage that is proportional to the absolute value of the amplitude of the vocal waveform integrated over approximately one period of the fundamental (cf. Peterson and McKinney, 1961).

The duration of each utterance within a sample, the third prosodic parameter, was determined in the computer by processing the input from the amplitude extractor. When the amplitude dropped below a threshold value (zero) and remained there longer than the silence threshold ($\underline{t}_o$), the end of an utterance was logged at the time of the initial drop. The start of a new utterance was recorded when the amplitude exceeded threshold again.

In addition to defining the beginning and end of utterances, the computer performed the following preliminary processing. Whenever the amplitude fell below a minimal threshold value ($\underline{a}_o$), or the frequency fell below a minimal value ($\underline{f}_o$), in a 25 msec sample, the values of $\underline{a}$ and $\underline{f}$ were set to zero. This eliminated spuriously low readings due to noise as well as vocal sounds without voicing at the glottis and hence without prosodic value. It also eliminated false frequency readings that would result from the rise-decay time of the frequency meter in response to instantaneous onset or cessation of voicing.

After sampling and then correcting the amplitude and frequency inputs in this fashion, the digital values were reconverted to voltages and plotted as a function of time on a strip-chart recorder. These records of the amplitude and frequency contours, after preliminary processing, were compared with those obtained directly from the parameter extractors (before computer processing) so as to choose values of $\underline{a}_o$ and $\underline{f}_o$ that did not distort the orginal records.

The percentage of time spent vocalizing was not studied for two reasons: first, the use of the voice-operated relay precludes this since the silent time is not recorded; second, this measure is so highly determined by irrelevant factors, such as the latency with which diapers are changed, environmental temperature, promptness in feeding the infant, etc., that it is of questionable value.

RESULTS AND DISCUSSION

Defining an utterance.

Three parameters of the technique of prosodic analysis determine the definition of an utterance in this study and, hence, the magnitude of various response statistics. These are the amplitude, frequency, and temporal thresholds. The appropriate values of the first two are reasonably specified by considerations discussed earlier, but the most suitable setting of the temporal threshold ($\underline{t}_o$) seemed more equivocal and was explored. Four values of the temporal threshold were studied: four out of five samples, 100 msec (four samples), 200 msec (eight samples) and 400 msec (sixteen samples). This range of $\underline{t}_o$ values was established with reference to both physiological and statistical considerations. Neuromuscular constraints on the respiratory and vocal apparatus probably set a lower bound to inter-response times in the region of 100 msec (Rothenberg, 1966)[5]. On the other hand, when utterances separated by more than 400 msec are pooled, the measures of within utterance variance in the parameters are greatly inflated. Tables 1 and 2 show the effects on several measures of infant vocalizing of varying this parameter of the analysis. A comparison of the data obtained from infant I, using the 400 msec $\underline{t}_o$ (Table 1) and 100 msec $\underline{t}_o$ (Table 2) shows that the statistics for most of the parameters are relatively unaffected by the choice of the $\underline{t}_o$ within this range. (The results for the four out of five samples $\underline{t}_o$ were almost identical with those for the 100 msec $\underline{t}_o$; the results for the 200 msec $\underline{t}_o$ were intermediate between those for the 400 msec $\underline{t}_o$ and the 100 msec $\underline{t}_o$.) The

Table 1

Statistics describing the prosodic features of infant vocalizing of infant I (male)

for $\underline{t_o}$ of 400 msec., averaged over blocks of nine samples and also over all samples (Σ).

Blocks of Nine Samples

	1	2	3	4	5	6	7	8	9	10	11	12	Σ
M(MF)	486	409	405	407	442	476	450	478	446	450	450	455	446
G(MF)	.253	-.323	.081	.410	.260	.433	.789	.549	.568	.790	.332	.054	.350
CV(MF)	.096	.095	.090	.112	.090	.101	.088	.098	.093	.114	.088	.079	.095
M(CVF)	.111	.097	.114	.110	.099	.125	.109	.129	.104	.124	.123	.101	.112
G(CVF)	-.001	-.232	.057	.015	.309	-.235	.062	.034	-.029	.118	.014	.118	.019
M(CVA)	.372	.351	.373	.337	.446	.435	.447	.439	.430	.445	.454	.438	.414
G(CVA)	.376	.103	-.111	.202	-.189	-.124	-.364	-.276	-.139	-.273	-.202	-.298	-.128
M_a(D)	1195	784	809	546	847	899	1012	1621	1142	879	1027	1222	993
G(D)	1.66	1.62	1.93	1.83	1.44	1.44	.975	1.14	.961	.908	1.06	1.09	1.34
CV(D)	1.15	1.12	1.08	1.17	.982	.936	.923	.902	.820	.773	.780	.771	.951
M_g(D)	495	341	398	266	457	481	508	770	543	539	635	719	513
r(MF,MA)	.272	.379	.392	.149	.240	.050	.079	-.013	.304	.221	.281	.178	.211
r(MF,SF)	.438	.447	.523	.481	.451	.561	.556	.500	.559	.586	.566	.330	.500
r(MF,SA)	.324	.460	.430	.177	.265	.074	.112	.072	.291	.253	.288	.208	.246
r(MF,D)	.235	.326	.383	.252	.178	.129	.126	.123	.213	.197	.169	.162	.208
r(MA,SF)	.217	.410	.275	.194	.293	.222	.245	.246	.327	.246	.215	.188	.257
r(MA,SA)	.831	.803	.787	.809	.894	.901	.897	.884	.900	.913	.900	.908	.869
r(MA,D)	.559	.613	.571	.545	.487	.541	.505	.489	.578	.530	.485	.540	.537
r(SF,SA)	.362	.517	.384	.287	.367	.272	.326	.363	.391	.307	.249	.265	.341
r(SF,D)	.263	.363	.278	.368	.382	.371	.395	.440	.406	.334	.254	.259	.343
r(SA,D)	.523	.611	.476	.548	.501	.592	.528	.543	.662	.565	.507	.599	.555

Table 2

Statistics describing the prosodic features of infant vocalizing of infant I (male)

for $\underline{t}_o$ of 100 msec., averaged over blocks of nine samples and also over all samples (Σ)

Blocks of Nine Samples

	1	2	3	4	5	6	7	8	9	10	11	12	Σ
M(MF)	438	411	404	408	442	477	454	481	447	451	452	456	443
G(MF)	.495	.007	.316	.462	.189	.478	.747	.781	.846	.713	.579	.175	.482
CV(MF)	.126	.121	.122	.130	.112	.122	.124	.119	.106	.136	.120	.096	.120
M(CVF)	.096	.088	.102	.099	.086	.104	.102	.113	.092	.107	.104	.086	.098
G(CVF)	.269	.108	.161	.242	.446	.183	.332	.277	.419	.308	.363	.546	.305
M(CVA)	.316	.293	.309	.291	.382	.362	.380	.380	.363	.364	.376	.367	.349
G(CVA)	.502	.186	.117	.336	-.062	.003	-.205	-.093	-.125	-.091	-.004	-.145	.035
$M_a(D)$	613	466	477	327	518	502	604	729	548	565	629	623	550
G(D)	1.71	1.51	1.62	1.77	1.39	1.63	1.15	1.26	.744	1.08	1.12	1.02	1.33
CV(D)	1.23	1.10	1.08	1.08	.964	.988	1.01	.934	.815	.091	.940	.909	.996
$M_g(D)$	267	229	250	179	186	284	294	385	322	314	330	342	290
r(MF,MA)	.357	.219	.225	.101	.204	-.013	-.057	.030	.199	.169	.132	.130	.141
r(MF,SF)	.540	.483	.536	.458	.359	.446	.436	.409	.442	.514	.422	.303	.446
r(MF,SA)	.433	.383	.335	.183	.218	.008	.003	.067	.203	.179	.145	.153	.193
r(MF,D)	.062	.242	304	.236	.135	.087	.047	.033	.149	.131	.073	.094	.133
r(MA,SF)	.278	.304	.188	.173	.305	.216	.207	.195	.292	.305	.284	.253	.250
r(MA,SA)	.845	.752	.761	.776	.901	.902	.905	.861	.909	.923	.919	.921	.865
r(MA,D)	.488	.614	.625	.573	.564	.577	.626	.472	.597	.592	.586	.678	.583
r(SF,SA)	.432	.446	.321	.281	.359	.274	.282	.311	.359	.351	.312	.312	.337
r(SF,D)	.105	.273	.243	.328	.418	.388	.360	.341	.366	.351	.309	.296	.315
r(SA,D)	.410	.639	.539	.559	.535	.597	.609	.492	.647	.626	.585	.677	.576

first exception is the higher arithmetic mean duration of utterances, $M_a(D)$, for the 400 msec $\underline{t}_o$ than for the 100 msec $\underline{t}_o$. The second exception is the higher measures of within utterance variability in fundamental frequency, M(CVF), and amplitude, M(CVA) for the 400 msec $\underline{t}_o$ than for the 100 msec $\underline{t}_o$. Since most of the statistics reported are remarkably stable over a wide range of $\underline{t}_o$, and since an increase in $\underline{t}_o$ only increases the duration and within utterance variability of utterances, both of which indicate that two or more distinct vocal responses are being compounded into one utterance, 100 msec was chosen as the temporal threshold.

Statistical analysis.

After the preliminary processing, the computer determined, for each 95-sec sample, the number of utterances as defined above, the duration of each utterance, and the mean and standard deviation of the fundamental frequency and amplitude of each utterance. Pooling these statistics for each of the utterances in a sample, the computer then determined their frequency distributions over the entire sample. The computer determined next the means and standard deviations associated with these composite distributions. Consequently, there were two kinds of statistics reported for each 95-sec sample: (1) within utterance measures of central tendency and variability, averaged over utterances, and (2) between utterance measures of central tendency and variability.

These studies revealed that the frequency distribution of duration was highly right-skewed, whereas the frequency distributions of fundamental frequency and amplitude were not. Accordingly, the statistics presented here are based on the linear values of these parameters, with the exception of duration for which both arithmetic and geometric means are reported.

Trends in prosodic features.

Table 2 and Table 3 present several statistics that describe the prosodic features of infant vocalizing, averaged over blocks of nine samples and also over all samples. Statistics reported for the distribution of the mean fundamental frequencies of utterances are its central tendency, M(MF), skewness, G(MF), and variance expressed as the coefficient of variation between utterances, CV(MF) = S(MF)/M(MF). Also shown is the average coefficient of variation within utterances in the fundamental frequency measures, M(CVF) = M(SF/MF), and the skewness of the associated distribution, G(CVF); the average coefficient of variation within utterances in the amplitude measures, M(CVA) = M(SA/MA), and the skewness of the associated distribution, G(CVA). For the frequency distribution of utterance durations, Table 2 and Table 3 show the central tendency, M_a(D), the skewness, G(D), and the variance expressed as the coefficient of variation, CV(D) = S(D)/M(D); the geometric mean, M_g(D), is also given, since the distribution turns out to be highly right-skewed. Product-moment correlations are reported among the following statistics, as shown in Table 2 and Table 3: utterance duration (D), mean utterance fundamental frequency (MF), mean utterance amplitude (MA), within utterance variability in fundamental frequency (SF), and within utterance variability in amplitude (SA).

All of the statistics reported in Table 2 and Table 3 (except measures of skewness and correlations) are plotted in Fig. 1 as a

Table 3

Statistics describing the prosodic features of infant vocalizing of infant II (female) for t_0 of 100 msec., averaged over blocks of nine samples and also over all samples (Σ).

Blocks of Nine Samples

	1	2	3	4	5	6	7	8	9	10	11	12	Σ
M(MF)	401	384	401	426	397	423	423	440	400	437	413	424	414
G(MF)	.328	.145	-.022	-.160	.260	-.084	-.003	.019	.192	.252	.055	.099	.090
CV(MF)	.110	.134	.121	.130	.139	.130	.136	.136	.116	.143	.152	.166	.134
M(CVF)	.100	.094	.104	.125	.103	.112	.117	.128	.118	.126	.135	.135	.116
G(CVF)	.059	-.017	-.122	-.191	.512	-.408	-.114	-.297	.233	-.012	-.121	.126	-.029
M(CVA)	.303	.253	.333	.341	.350	.326	.355	.382	.417	.350	.417	.411	.353
G(CVA)	-.087	.267	-.151	-.247	.050	.083	-.091	-.079	-.370	-.177	-.080	-.248	-.094
M_a(D)	1130	409	615	881	227	282	383	614	473	664	449	492	552
G(D)	1.98	2.26	2.29	2.02	2.44	1.68	1.74	1.32	.871	1.16	.971	1.45	1.68
CV(D)	1.27	1.39	1.35	1.25	1.20	1.01	1.07	.900	.743	.844	.744	.870	1.05
M_g(D)	432	165	238	293	131	148	199	309	304	351	299	304	286
r(MF,MA)	.423	.548	.388	.386	.487	.345	.480	.335	.320	.538	.406	.496	.429
r(MF,SF)	.582	.736	.653	.647	.656	.569	.655	.661	.647	.745	.678	.680	.659
r(MF,SA)	.392	.527	.442	.381	.479	.333	.506	.347	.368	.540	.430	.535	.440
r(MF,D)	.379	.459	.374	.320	.457	.420	.485	.318	.388	.383	.396	.498	.406
r(MA,SF)	.307	.567	.337	.412	.470	.347	.453	.353	.311	.554	.591	.560	.439
r(MA,SA)	.865	.920	.922	.900	.924	.939	.879	.898	.895	.854	.886	.871	.896
r(MA,D)	.702	.709	.645	.587	.520	.600	.429	.479	.432	.504	.373	.409	.532
r(SF,SA)	.376	.587	.422	.490	.492	.372	.496	.414	.423	.588	.638	.641	.495
r(SF,D)	.321	.537	.329	.365	.456	.381	.528	.368	.516	.471	.511	.561	.445
r(SA,D)	.685	.706	.685	.604	.621	.663	.488	.548	.509	.568	.482	.554	.593

function of age and sample number, averaged over blocks of nine samples. Inspection of the developmental changes in the fundamental frequencies of utterances over the first 141 days shows that the M(MF) of infant I (male) at birth was 436 cps; then it decreased to 411 cps by sample number 18 (approximately 21 days), and remained there until sample number 36 (approximately 45 days); and then it rose and stabilized at about 455 cps for the duration of the study. The average skewness for the associated distributions, $\overline{G(MF)}$, reported in Table 2 is .482, indicating that the distributions are slightly positively skewed.

The M(MF) of infant II (female) at birth was 401 cps; then it decreased to 384 cps by sample number 18 (approximately 21 days); and then it rose and stabilized at about 420 cps for the duration of the study. The average skewness for the associated distributions, $\overline{G(MF)}$, reported in Table 3 is .090, indicating that the distributions are not skewed. A comparison of the developmental trend of M(MF) of infants I and II reveals that the M(MF) of infant I is approximately 30 cps higher than infant II throughout the study, and that both infants show a decrease from their initial values by sample number 18 (approximately 21 days), then an increase to a value that exceeds their initial level, and finally stability for the duration of the study.

Fairbanks (1942) found that the mean fundamental frequency of experimentally induced hunger wails of one infant increased consistently from 373 cps at one month of age, to 415 cps at two months, to 485 cps at three months, to 585 cps at four months, and then stabilized for the next five months. The magnitude of the fundamental frequency and the increase in fundamental frequency from age one month to age four months and the subsequent stabilization is in agreement with the present findings.

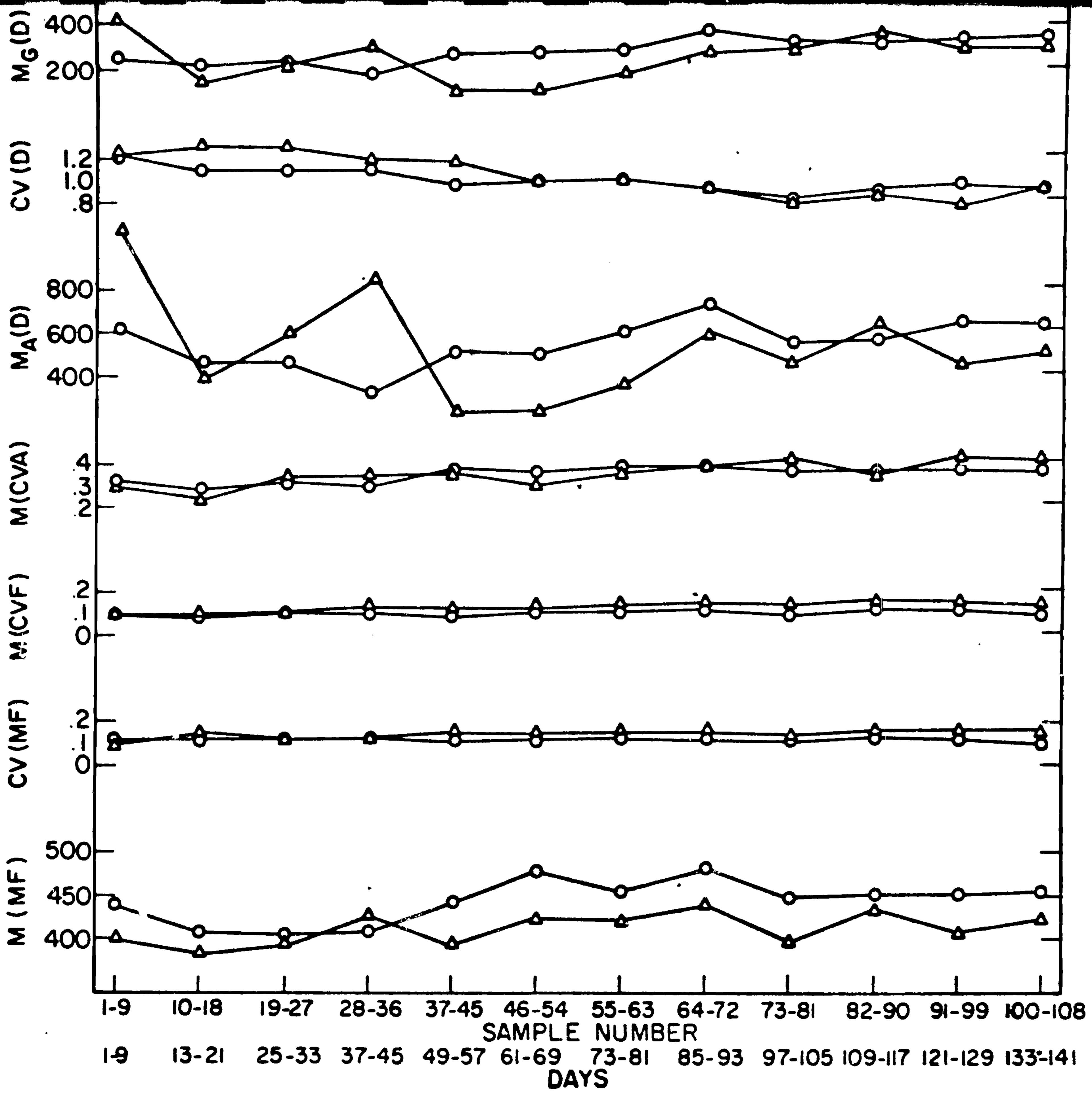

Fig. 1. Developmental trends in the prosodic features of infant vocalizing.

The coefficient of variation between utterances in fundamental frequency CV(MF), of infant I remained nearly constant (.096-.136) over the entire study, as did the CV(MF) of infant II (.110-.166). That is to say, the infant's utterances did not become more (or less) variable in pitch as he grew older: approximately two-thirds of the utterances in a typical sample had fundamental frequencies within about ten percent of the mean value. The average coefficient of variation within utterances in fundamental frequency, M(CVF), of infants I and II remained similarly constant (.086-.113) and (.094-.135) respectively; the associated distributions are not appreciably skewed, $\overline{G(CVF)} = .305$ and -.209. We may conclude that the infant's pitch did not fluctuate during an utterance more (or less) as he grew older: approximately two-thirds of the readings of his fundamental frequency during a typical utterance were within ten percent of the mean frequency of that utterance.

The average coefficient of variation within utterances in amplitude, M(CVA), of infants I and II also remained nearly constant (.291-.382) and (.253-.417); the associated distributions are not skewed $\overline{G(CVA)} =$ .035 and -.094. The $\overline{M(CVA)}$'s of infants I and II, reported in Table 2 are .349 and .353; this is considerably higher than the $\overline{M(CVF)}$'s, .098 and .116, showing that the variability in amplitude within utterances is greater than the variability in fundamental frequency within utterances.

The arithmetic mean duration of utterances, $\overline{Ma(D)}$ of infants I and II, reported in Tables 2 and 3, is 550 msec and 552 msec, respectively. The average skewness for the frequency distributions of utterance durations, $\overline{G(D)}$, of infants I and II is 1.33 and 1.68, indicating that the distributions are highly positive skewed. Thus, there were, in addition to many responses of short duration, a number of long ones, although, as can be seen from Table 2 and Table 3, this spread was reduced somewhat with increasing age. Indeed, some of the distributions showed slight bimodality; however, it proved impossible to find a non-arbitrary value of one or a number of parameters in combination that would sort the responses into two (or more) classes. The coefficient of variation between utterances in duration, CV(D), of infants I and II respectively decreased from 1.23 to .909 and from 1.27 to .870 over the study indicating that the average duration of utterances within a sample became more uniform as a function of age. The geometric mean duration of utterances, $\overline{Mg(D)}$ of infants I and II, reported in Tables 2 and 3 are 290 msec and 286 msec. The magnitude of the geometric mean duration is smaller than that of the arithmetic mean duration, since the frequency distributions of the utterance durations are highly positive skewed. Ringwall, Reese, and Markel (1965) report that 81 percent of the utterances in four-minute segments of vocalizing obtained from 40 three-day-old infants were judged by trained listeners to be shorter than the word "pit" as it is normally pronounced. Measurement of the word "pit" produced by several different speakers shows its duration to be approximately 350 msec. Thus, this measure of the duration of infant utterances agrees with the present findings. Murai (1960) analyzed spectrograms of vocal responding by four Japanese infants approximately two months old and reported an average duration of 400 msec.

Possible sources of developmental trends.

The developmental trend of the M(MF) of both infants presented in Figure 1 is of interest. This parameter shows a decrease from its initial value by sample number 18 (approximately 21 days), then an increase to a value that exceeds its initial level, and finally stability for the duration of the study.

Three possible explanations of these developmental trends suggest themselves. First, the observed trend in this measure could be the result of chance fluctuations. This explanation seems rather unlikely in view of the consistency of the trend across both subjects, and the magnitude of the fluctuations. It must also be remembered that each data point in Figure 1 is based on 34,200 values.

A second possible explanation is based on considerations of the infants' physiological development. Increases in the area, thickness, and length of the vocal cords with age, would lead (other things equal) to a decrease in fundamental frequency which could account for the initial drop in the value of this parameter. However, an increase with age in the subglottal pressure that the infant can develop (owing to neuromuscular and anatomical development of the respiratory mechanism) would contribute to an increase in fundamental frequency. The successive occurrence of these two antagonistic developments could produce the observed trends.

A third possible explanation involves the greater fundamental frequency of crying responses than those of non-crying responses. The initial high level of this measure is due in this interpretation to the relative frequency of unconditioned-reflex crying responses; the values of the M(MF) then decrease as the relative frequency of unconditioned-reflex crying decreases with age (Lenneberg, Rebelsky and Nichols, 1965). Later, a new class of operant crying responses appears. These responses occur more often as they come to be controlled by environmental events. Thus, there is something of a time-lag between the gradual disappearance of reflexive crying and the gradual appearance of motivated crying.

It should be recalled that it proved impossible to find a non-arbitrary value of one or a number of parameters that would sort the responses into two or more classes. It is possible that a sequential analysis of the response patterning would allow the responses to be separated into discrete classes.

Of course, both behavioral and physiological changes may enter into the final account of the development trends observed.

The detailed records kept by the parents were related to the data where developmental trends were observed. They were examined to find if they contained any clues as to the possibility of environmental determinants of the observed trends. Nothing was found in the records that correlated with the trends.

Correlations among parameters.

The overall correlations for infant I, reported in Table 2, between (MF, MA), (MF, SA), (MF, D) and (MA, SF) are .25 or less; between (SF, SA) and (SF, D) they are greater than .25 but less than .35; and between (MF, SF), (MA, SA), (MA, D) and (SA, D) are greater than .35. The corresponding overall correlations for infant II, reported in Table 3, are .44 or less; greater than .44 but less than .50; and greater than .50. The major observation is that the size-order of the correlations is the same for both infants, but the magnitudes of the correlations for infant II are greater than those for infant I. All of the correlations involving the mean utterance fundamental frequency, MF, show only a slight relationship except (MF, SF). This suggests that the mean fundamental frequency of an utterance is not a good predictor of the other parameters reported, except for the variance in fundamental frequency. The correlations between the standard deviation within utterances in fundamental frequency, SF, and all four other variables are moderately high. The correlations between the mean utterance amplitude, MA, the standard deviation within utterances in amplitude, SA, and the duration of utterances, D, are high. One can predict from this that if one of these measures is high that the others are likely to be also high. It is particularly interesting to note that longer utterances typically have greater amplitude and shorter utterances have less amplitude.

Recommendations for future research.

The stability and regularity of the various measures suggests that comprehensive recording is not necessary. Since the relation between the onset and development of language and correlated changes in prosody is of great interest, sampling at longer intervals, once every two weeks or every month, and extending the duration of data collection for a single child to four years or more would be highly desirable.

In the early months the occasional use of a throat microphone to provide a stable absolute measure of the sound pressure level of infant vocalizations is recommended.

Future studies will no doubt advance only as far and as fast as the relevant technologies allow. Exciting avenues for future research include the spectral analysis of developmental changes in the harmonic structure of infant vocalizations and the sequential pattern analysis of the prosodic features of infant vocalizations. The former would likely yield a more complete picture of language acquisition in the child than prosodic data alone since the differentiation of the harmonic structure underlies the development of speech. This analysis awaits the quantification of spectrographic data for computer processing.

The latter research is necessary to separate the two vocal response classes, operant and respondent, on the basis of prosodic information; deterring this study is the lack of knowledge concerning prosodic patterning.

Chapter II: CONTROL OF INFANT VOCAL AND MOTOR BEHAVIOR

INTRODUCTION

The behavior of the human infant has been of interest to psychologists for many years. Previous research has most often focused on describing developmental changes in behavior and occasionally on the experimental manipulation of the behavior. The early experimental studies were concerned with the conditionability of infants and concentrated exclusively on respondent behavior; that is to say, behavior correlated with specific eliciting stimuli (vide Skinner, 1938). The most extensive studies of respondent conditioning with infants have been conducted by Russian investigators. Razran (1933), and Brackbill (1960, 1962) have reviewed a number of the Russian studies. Most of this work, however, has not been available in English translation and much that is available is often incomplete with respect to experimental procedures, the use of controls, and the extent of parametric investigation (Lipsitt, 1963). For a review of both the Soviet and American literature dealing with respondent conditioning of infants see Lipsitt (1963).

It is only in the past ten years that rigorous studies of infant operant behavior (vide Skinner, 1938) have been conducted. This review is addressed to the generalizations emerging from studies of operant conditioning of infants under six months of age. The members of the response class termed operant have the defining characteristics of not being correlated with specific identifiable eliciting stimuli, operating upon the environment, and being amenable to control by stimuli presented immediately following a response. A stimulus that affects the probability of occurrence of the operant that it follows is designated a reinforcing stimulus, and the operation of its presentation following an operant is designated reinforcement.

The experimental task in studying infant operant behavior is threefold: first, one must select a response class that is not tied too closely to eliciting stimuli; second, it is necessary to identify a stimulus that will affect the probability of occurrence of the operant without also having strong eliciting properties for other perhaps incompatible responses; and third, it is necessary to demonstrate that the behavior change in the experiment is a function of operant as opposed to respondent control. All of these tasks are problematic when studying infants, which no doubt accounts in large measure for the deficit of experimental studies in this area.

The requirement that the response selected for study not be closely tied to eliciting stimuli, severely limits one's choice since an infant has only a relatively limited behavioral repertoire, the majority of which is highly reflexive or is subject to multiple sources of control (for example, vocalization is perhaps controlled operantly as well as by eliciting stimuli).

The difficulty of identifying a reinforcing stimulus is compounded by the constraints imposed upon investigations of infant behavior. Primary reinforcers such as food, water, warmth, etc., that have been shown to be effective reinforcers for more mature humans and numerous other species require prior deprivation which no investigators as yet have been willing to use with human infants. The procedural difficulties involved in their delivery have also been a limiting factor. The choice of possible reinforcers has been confined, therefore, to either sensory reinforcers (Kish, 1966) such as tones, lights, vibrations, etc., or secondary reinforcers (Kelleher and Gollub, 1962), usually social. A further constraint is that the reinforcing stimulus should not have strong eliciting properties for the behavior under study or other incompatible behaviors.

Finally, the demonstration of operant control requires that the possibility of alternative forms of control be rejected. As mentioned earlier, the behavioral repertoire of the human infant is highly reflexive. It can be argued that in an operant conditioning experiment, in which stimuli are presented following a response, that the stimuli presented are in fact eliciting the behavior and that any increase in the frequency of responding is attributable to this. There are several ways of meeting this argument. The most convincing refutation is the establishment of differential responding under discriminative control in two or more conditions in which the reinforcing stimulus is presented with equal frequency and only the contingencies of reinforcement are varied. Since the frequency of reinforcement is the same in all conditions any differential responding can be attributed solely to the control exercised by the contingencies of stimulus presentation.

It should also be pointed out that the argument of possible respondent control becomes a bit tenuous when the response being studied is clearly motor and is not subject to known sources of multiple control.

I have been able to locate twelve experimental studies of operant behavior in infants under six months of age in the psychological literature that have succeeded, more or less, in overcoming the aforementioned difficulties in this area of research.

The most common experimental design used in operant conditioning studies with infants has been the baseline technique in which the operant level of a response is first measured (baseline), then a stimulus is presented contingent upon the response (conditioning), and finally the stimulus is no longer presented contingent upon the response (extinction). The limitations of this design are discussed below.

A. Vocal behavior

Rheingold, Gewirtz, and Ross (1959) used the baseline design in their study of the conditioning of vocalization in 3-month old infants. Twenty-one institutionalized infants (S̲s) were studied. The experimenters worked in pairs with one experimenter (E̲) and one observer-recorder (O) and exchanged roles for half the S̲s. The unit of observation was a 3-min period, usually grouped in blocks of three, separated by 2-min rest periods. In each day, for 6 days, there were nine such 3-min periods. During the first two days (operant level), E̲ leaned over the crib looking at the S̲ with an expressionless face for 18 3-min periods. During the second two days (conditioning), each of S̲'s vocalizations was reinforced by E̲ smiling, saying "tsk, tsk, tsk", and touching the infant's abdomen with thumb and fingers briefly during 18 3-min periods. With a few S̲s whose rate of vocalization increased sufficiently, reinforcement was given successively on fixed-ratio schedules of 2 and 3. This was shortly discontinued and CRF was again used since the intermittent reinforcement seemed to depress the response rate. During the third two days (extinction), E leaned over the crib with an expressionless face and made no response to S's vocalizations during the 18 3-min periods.

The following response definition was adopted, "Every discrete, voiced sound produced by the S was counted as a vocalization. A number of other sounds characteristically made by very young infants, e.g., straining sounds and coughs, whistles, squeaks, and snorts of noisy breathing, were not counted as vocalizations. Sounds falling under the categories of protests, fusses, and cries were recorded separately. No attempt was made to record the phonetic characteristics of any of the sounds or their duration." (p. 69)

Observer reliability was checked occasionally by having two O's record responses. Their percentage of agreement ranged from 67 percent to 100 percent, with a median of 96 percent over 27 3-min periods.

The E's found a statistically significant increase in the number of vocalizations during conditioning over the baseline level and a decrease in the number of vocalizations during extinction to near the baseline level. Under baseline conditions the Ss gave about 13 to 14 vocalizations in a 3-min period. During conditioning the rate increased to 18 the first day and 25 the second day, a total increase of 86 percent over the baseline rate. Removing the reinforcer during extinction reduced the rate to 17 vocalizations during the first and to 15 during the second day.

The E's also reported the observation of emotional behavior, "protests, fusses, cries, etc.," during extinction. These were recorded separately and not counted as a vocal response.

The E's concluded that infants' vocal behavior in a social situation can be brought under experimental control, that a social event composed of an everyday complex of acts can function as a reinforcing stimulus, and that the incidence of vocal behavior can be very quickly modified in as young an organism as the three-month old infant.

As Weisberg (1963) points out, however, the question of whether vocalizing in the Rheingold et al study was operantly conditioned is equivocal since the reinforcing stimulus, per se, may have acted as an arousing stimulus or as a social releaser. In order to control for the reinforcing event serving as a possible eliciting stimulus for the vocal response Weisberg extended the procedure of Rheingold et al by adding several conditions in addition to contingent social reinforcement to the conditioning phase of his study of infant vocalization. The experiment involved thirty-three 3-month-old institutionalized infants (Ss) divided into 6 groups. The unit of observation was a 10-min period. There were two such 10-min periods each day for 8 days.

The operant level period was 4 days consisting of 2 days of two 10-min periods with the experimenter (E) observing S from behind a partition unobserved by S and 2 days of two 10-min periods with E seated approximately 2 feet away facing S with an expressionless face. E recorded the number of vocalizations in each case.

During days 5 and 6, the conditioning phase of the study, the Ss were divided into the following six experimental groups: I, Contingent social reinforcement, as in the Rheingold et al study. Each of S's vocalizations was reinforced by E rubbing S's chin with thumb and forefinger followed and overlapped by an open-mouthed "toothy" smile and an aspirated "yeah" sound; II, Noncontingent social reinforcement, the reinforcing events described above were given randomly four times a minute; III, Contingent nonsocial reinforcement, a door chime was sounded by E immediately after each vocalization by S; IV, Noncontingent nonsocial reinforcement, the chime was sounded on the same schedule as that followed with noncontingent social reinforcement; V, No E present, no experimental manipulation; VI, E present, no experimental manipulation.

Groups I and III were used to explore whether vocalizing was amenable to operant conditioning. Groups II and IV were used to determine whether the reinforcing stimuli had eliciting properties. Group V controlled for changes in the operant rate of vocalizing with time in the experiment independent of an E being present and Group VI served as a second control group, to indicate whether the presence of a human acted as a discriminative stimulus for vocalization.

Extinction with the E present was in effect on days 7 and 8 for the contingent social and nonsocial reinforcement groups. Noncontingent reinforcement was continued during days 7 and 8 for the noncontingent social and nonsocial reinforcement groups. Conditions in the no E present and E present groups remained the same on days 7 and 8.

The response definition was the same as that used in the Rheingold et al study. Observer reliability for 20 sessions between E and another person trained to discriminate vocal behavior was 97 percent agreement.

Results showed a significant increase in the rate of vocalization for the contingent social reinforcement group during conditioning and a slight decrease during extinction. Under baseline conditions with E present, Ss gave an average of 11 responses in a 10-min period. During conditioning the rate increased to an average of 31 responses in a 10-min period. Extinction lowered the rate to an average of about 20 responses in a 10-min period.

None of the other conditions produced an increase in vocalization during conditioning. The results indicated that the presentation of an unresponsive human did not serve as a social releaser or discriminative stimulus for vocalization. The fact that the group receiving noncontingent social reinforcement showed no increase in the rate of vocalization and behaved like those responding under all other conditions except for the contingent social reinforcement group vitiates the possibility that the reinforcement in the Rheingold et al study and this study was functioning as an eliciting stimulus. The failure to condition vocalization using contingent nonsocial reinforcement only demonstrated that the particular nonsocial stimulus chosen did not function as a reinforcer.

Smith and Smith (1962) failed to achieve conditioning in infants in an exploratory study of infant vocalization. Infants from 4-months of age upward were placed in a playpen which could be made to revolve once every 26-sec, either independently of the child's behavior, or contingent upon a vocal response. Each subject spent 20-min in the playpen, half of the time on continuous rotation and half under a condition in which the playpen rotated once for every vocal response. Older subjects gave significantly more vocalizations during the contingent phase than during the continuous-rotation phase, but children under 12-months showed no vocalization differences in the two periods.

Etzel and **Gewirtz** (1966) studied the experimental modification of operant vocalization of two institutionalized infants, 6 and 20 weeks of age, by using extinction of crying combined with social reinforcement for incompatible smiling behavior. Both infants were selected for the study on the basis of their high rate of crying. The experimental procedure for the twenty-week-old infant consisted of operant level observation for 12-min a day for three days, followed by extinction of crying combined with social reinforcement for smiling for 12 min a day for three days and finally extinction of smiling as well as crying for 12 min for one day. The experimental procedure for the second infant was similar with only the number of days in each condition increased to six days of operant level, nine days of extinction of crying and reinforcement of smiling, and 16 days of extinction of both crying and smiling. The results showed that during the second condition, extinction of crying and reinforcement of smiling, the rate of crying decreased and the rate of smiling increased. In the final condition, extinction of both crying and smiling, the rate of crying increased to the operant level and the rate of smiling decreased.

B. Motor behavior

Brackbill's (1958) study of smiling in infants was one of the first to utilize operant procedures in the investigation of infant behavior. Eight infants (Ss) between the ages of 3 1/2 to 4 1/2 months served as subjects. The Ss were tested individually in their homes. The Ss were assigned to either a continuous reinforcement (CRF) or intermittent reinforcement (IR) group.

For both groups, the experimental procedure was divided into three periods: In the first period the experimenter (E) stood motionless above S, and observed him for 5-min intervals to ascertain the operant level of smiling. In the second or conditioning period, reinforcement was given contingent upon S's smile. Reinforcement was a return smile from the E, who in addition spoke softly to the S, picked him up, patted, and jostled him for 30 sec. For the CRF group every smile was reinforced, the IR group was initially reinforced continuously and then was switched to a variable-ratio of 2, then 3, and finally a VR 4. In the third or extinction period, the Ss were again observed as in the operant level period. Brackbill's major findings were that conditioning increased the response rate from 2 1/2 responses per 5-min period to 5 responses and that the use of intermittent reinforcement resulted in a greater resistance to extinction. The rate of protesting (crying and fussing) was observed to decrease during conditioning and increase during extinction.

Friedlander (1961) studied the cord pulling behavior of two infants 3 1/2 and 7 months. The infant's fist was loosely tied to a cord which was suspended from the leaf of a microswitch mounted above the crib.

The number and duration of pulls were recorded in set time periods under different response-feedback conditions. Different reinforcers were studied, such as a white lamp flashing at the foot of the crib, a small light going on near the child's fist, or two red lights being activated alternately with the beginning and end of a response. Friedlander also utilized the mother as a reinforcing stimulus, with the reinforcement light illuminating her as the child responded. One experiment involved two alternating conditions, continuous reinforcement (CRF), with the reinforcement continuing for as long as the S held down the microswitch, and no reinforcement (EXT). In a second experiment, the two conditions were CRF and a fixed-ratio of 4 (FR 4), with the duration of reinforcement again unlimited in both conditions. In a third experiment, the reinforcement schedule was again varied, CRF and FR 4 combined with a 2-sec reinforcement duration for each response versus unlimited reinforcement duration for each as in the other conditions.

In the first experiment there was a greater mean response duration during reinforcement phases, although there was no difference in number of responses per minute under CRF and EXT conditions. Acquisition data reported did not show an increase in differential responding during the two conditions. Over a four-session period, differentiation in fact seemed to decrease. This might be attributed either to a failure of conditioning or to satiation with the reinforcer over time. In the second experiment the infant's responses were of greater duration under the CRF than the FR reinforcement condition. In the third experiment, the imposition of a limited reinforcement duration for each response increased the number of responses made under both the CRF and the FR reinforcement conditions. Friedlander concluded that significant changes in performance by both infants were associated with experimentally controlled changes in the reinforcing stimuli.

Rheingold, Stanley, and Cooley (1962) reported the design of an experimental crib for use in studying the exploratory behavior of the human infant. The apparatus allows measurement of a specific response and provided for automatic sensory feed-back from such responses. The infant, supported in a canvas seat inside a special cubicle, faces a movie screen 30-in. away. A 4-in. diameter sphere mounted on an adjustable rod serves as the manipulandum just within reach of the infant's hands. Control equipment in an adjacent room activates the stimulus-producing equipment and records responses. The reinforcing effects of visual stimuli on exploratory behavior can be studied by comparing the infant's behavior, displacement of the sphere a minimum distance, under a noncontingent reinforcement condition with a contingent reinforcement condition in which a response activates a filmstrip showing brightly colored and moving geometric figures. Sample data presented by the authors indicated that for some Ss discrimination between the two reinforcement conditions occurred, such that more responses were emitted during the contingent reinforcement phases.

Clayton and Lipsitt (Lipsitt, 1963) failed to achieve avoidance conditioning with newborns. The newborns were run in tandem, each lying on a mattress with a plastic kick-panel at his feet. Each panel, when kicked, triggered its own microswitch, and recorded the number of kicks for each infant separately on cumulative response recorders. A pair of electrodes attached to each infant's leg enabled simultaneous delivery of a mild shock to both infants. After a basal period during which the operant kicking level of each infant was measured, kicking of the panel by Baby A delivered a 2-sec shock (or less, if Baby A withdrew his leg) to both Baby A and Baby B. Thus, Baby A received shock specifically for kicking his panel, while Baby B received the same shock on a noncontingent basis. The intent was to determine whether Baby A would learn to refrain from kicking the panel and thereby reduce the number of shocks received, relative to Baby B who might not be expected to refrain from kicking the panel. According to the experimenters, the procedure proved fruitless under the conditions employed, perhaps because the aversive stimulation tended to increase activity, working in an opposite direction to the change in behavior sought.

Bower (1966) utilized operant conditioning procedures in the study of slant perception and shape constancy in infants. The infant was placed in a reclining position with his head between two yielding pads. By turning his head as little as half an inch to the left he was able to close a microswitch that operated a response recorder. Reinforcement consisted of a "peekaboo": an experimenter pops up in front of the infant, smiling, nodding, speaking and then quickly disappears from view. Subjects, aged 50 to 60 days, responded at a rate as high as one response per 2.0-sec on a variable-ratio schedule on which every fifth response, on the average was reinforced. The infants were conditioned to respond in the presence of a specific stimulus and were then tested for generalization. The results of the experiment show that this technique can be successfully used in studies of infant perception, as well as studies of infant learning.

Heid's (1965) dissertation study focused on the effects of visual and auditory consequent stimuli on the response class of general activity. The subject (S) was the daughter of the experimenter. The experimental apparatus was set up in the infant's home; 20-min sessions were conducted daily from the time the S was two weeks old until she was 3-months old. Mexican marimba music and a movie of a Christmas bulb mobile were presented for 1-sec when reinforcement was programmed. Conditions, sequenced chronologically, included 28 sessions of operant level, four sessions of continuous reinforcement (CRF) contingent upon activity, six sessions of alternating 2-min intervals of reinforcement and extinction, seven sessions of differential reinforcement for not responding (DRO 5-sec), seven more sessions of alternating 2-min intervals of reinforcement and extinction, 13 sessions of alternating 2-min intervals of contingent and noncontingent reinforcement, and 12 sessions of alternating 4-min intervals of CRF and punishment, whereby a continuously present reinforcer was interrupted for 5-sec following each response. In early sessions with alternating intervals a light was present as a discriminative stimulus during the reinforcement phase for several sessions but was discontinued when discrimination did not develop. The response rate during operant level sessions was extremely high, averaging 20 responses per minute, and quite variable from session to session. When reinforcement contingent upon activity was presented there was no increase or change from the instability of the operant rate. Differential responding was statistically evident in those sessions when contingent reinforcement was paired with noncontingent reinforcement and with punishment. The differential responding that was obtained proved to be extremely unstable. No differential responding was observed during the other conditions. In fact the rate of responding increased during the DRO sessions and also during the extinction component which was paired with CRF. Crying was also observed to occur during extinction.

In two recent papers, Watson (1966, 1967) has discussed and studied the concept of contingency awareness in early infancy. He has proposed that learning is dependent on the infant's memory span for contingency experiences. An extension of this is his hypothesis that the first three months of the human infant's life amounts to a period of natural deprivation of contingency experiences which may produce debilitating intellectual effects and result in a decline in the ability of the infant to handle contingency information during the first three months of life.

To test these hypotheses a study was conducted which attempted to alter the relative rate of visual fixation on the left versus the right side of the infant's visual field by making certain auditory and visual stimulation, a 1000 cps tone and a picture of a human face, contingent on looking at one of two latterly distributed spatial positions. Thirty-two infants, 13-14 weeks old, comprised the Ss for the first part of the study. In the second part of the study were 24 infants, 9-10 weeks old.

He concluded from the data that the effect of rewarding a specific fixation response in infants about 3 months of age has a negligible effect for the determination of the infant's next fixation, if that fixation occurs less than 3-sec or more than about 5-sec following the initial response. But if the next fixation occurs between these two points in time, the effect of the reward is a considerable increase in the likelihood that the response will be a repetition of the particular fixation rewarded. He also concluded that the data offer substantial support for the contention that the younger infants may well have performed contingency analysis more quickly than the older infants.

It should be clear from the prior review that rigorous experimental procedures have not as yet been sufficiently developed to allow an extensive analysis of infant operant behavior.

The present study is designed to develop experimental procedures that will facilitate research in this area as well as to yield data contributing to the analysis and fuller understanding of infant operant behavior.

METHOD

Subject

The second-born child of the experimenter was the subject in this experiment. The delivery was full-term, normal and easy. The birth weight was 9 3/4 pounds, which is slightly above average for male infants in the Middlewest. He was 10 days old and weighed 9 3/4 pounds when the experiment began and was 3 months and 17 pounds when the experiment ended. According to a periodic series of medical examinations made by the University of Michigan Child Care Center the infant grew and developed within the average range. He was breast-fed, had no digestive disturbances and experienced no illnesses for the duration of the study. The subject slept and was cared for in a plexiglass "air crib" (T.M.I.) that also served as the experimental chamber. The infant was frequently out of the crib on excursions with the family and for play experiences at home. When the infant was in the crib, bells, stuffed animals and mobiles were provided. The infant rarely cried and presented every evidence of being an unusually alert, comfortable, and happy infant.

Apparatus

The experimental chamber was a commercially available plexiglass "air-crib" (T.M.I.) that also served as living quarters for the infant. The crib provided no source of sound from within and attenuated external sounds.

During experimental sessions a 24" by 36" piece of red translucent plastic was placed along one side of the crib and a 100 watt red light was placed behind the red plastic.

Two response transducing devices were used. To measure the rate of vocalization a highly sensitive directional microphone (Altec, 633A)[6] was placed in the crib approximately 4-in. from the infant's head. The microphone was connected to a magnetic tape recorder (Tandberg, Model 64) and also to a fast-acting voice-operated switch (Miratel, Model V-1005-X) which was sensitive to and could separate all responses with an inter-response time of 175 msec or greater.

The second response transducer was a micro-switch mounted behind a hinged panel, 8" high by 19" wide, that was placed at one end of the crib with the infant positioned such that he could kick it. The switch registered a response whenever it was depressed and released.

The outputs of both manipulanda were connected to control circuitry consisting of a cumulative response recorder (Gerbrands), timers, counters, and relay circuitry. The cumulative recorder stepped upward with each response, blipped down with each reinforcement, and marked condition changes. Counters recorded the total number of responses and reinforcements during each session. The recording and control circuitry were located in an adjoining room.

Four different potentially reinforcing events were used. A small, 1" by 1" by 1/4", vibrator, electrically pulsed six times a second was taped to the infant's right palm. A thin, flexible cord was used, allowing freedom of movement. A second device consisted of an aluminum box, 6" by 4" by 2", with two small light bulbs, one red and one yellow, mounted on it. The bulbs flashed in alternation once every second. The box was placed at eye level beside the infant. The third device was a magnetic tape repeater (Mag-Matic) placed at the end of the crib. The tape used was a recording of the infant's mother talking to the infant while nursing. The mother continued to repeat the same monologue to the infant on subsequent feedings for the duration of the study.

A recording of the mother's heartbeat, the fourth device, was used once.

Stimulus and response events were programmed so that a response could be followed by no consequence, by 5-sec of vibration, or by 5-sec of flashing lights and the recording of the mother's voice. The red light behind the red plastic could be turned on or off during either reinforcement condition as a discriminative stimulus (S^D). The control equipment determined the sequencing of the experimental conditions.

Procedure

Before each experimental session the infant was briefly removed from the crib along with the bells, stuffed animals and mobiles, the experimental equipment was placed in the crib, and the infant was then returned to the crib. The infant was placed in a supine position for all sessions, clothed in a diaper and shirt, with the temperature regulated at 81° F.

Sessions were usually run daily although there were several longer lapses between sessions as well as two sessions occurring in a single day. Early mornings after feeding proved to be the best time for the sessions.

Since the vocal response of an infant can be elicited by a number of conditions, which would interfere with and confound parts of this study, it was extremely important to remove all of the antecedents of respondent crying; special attention to feeding, burping, amount of sleep, and schedule of defecation and urination was required with the timing of the experimental sessions determined by these factors. The infant was observed during sessions from a concealed vantage point. Wet diapers were changed immediately. If the infant began to defecate or fall asleep the experimental session was terminated and the data not counted. These events occurred 2 and 3 times respectively.

There were 67 full sessions. The duration of the first thirty sessions was 30-min each. later sessions were 20-min each. Experimental conditions are described below in chronological order.

Vocalization

Operant level. The procedure described above was followed. The operant level of vocalizing was measured for five sessions during which the experimental apparatus was present in the crib. During these sessions no consequence followed the response.

Continuous reinforcement. Continuous reinforcement (CRF) contingent on vocalization was initiated during sessions 6 through 11. The red light (S^D) was on during all sessions.

The first reinforcement session explored the use of a recording of the mother's heartbeat as a reinforcer.

In sessions 7 through 11 the vibrator was presented for a duration of 5-sec contingent on each response.

Intermittent reinforcement. The conditioning of vocalization initiated using CRF and reinforced by the vibrator for 5-sec was extended during sessions 12 through 18 to intermittent reinforcement on a fixed-ratio of one reinforcement for every three responses (FR 3). The light was on during all sessions.

Multiple schedule [MULT(3)FR 3, DRO]. The two components of the multiple schedule used in sessions 19 through 33 were (3)FR3 and differential reinforcement of zero rate (DRO). The red light was correlated with the FR 3 component. The infant was reinforced with the vibrator for 5-sec, while the red light was on, contingent upon the emission of three vocalizations. This contingency was in effect for a total of three reinforcements. The light then switched off and the infant was reinforced with the vibrator for 5-sec if he remained quiet for 30-sec (this was reduced to 15-sec after session 20 and further reduced to 7-sec after session 27). Every vocalization while the red light was off reset the timer. At the end of the silent period the infant was reinforced and the red light switched on indicating a return to the FR component.

Starting with session 28 the flashing lights and the recording of the mother's voice were used as reinforcers replacing the vibrator and the red light was correlated with the DRO component.

The flashing lights and the recording of the mother's voice were used as reinforcers for the duration of the study.

Multiple schedule [MULT (3)FR3 NONCONT REIN]. The two components of the multiple schedule used in sessions 34 and 35 were (3)FR3 and noncontingent reinforcement. The red light was correlated with the noncontingent reinforcement component and no light was correlated with

Intermittent reinforcement. Vocalization was reinforced on a FR3 schedule during session 50 and 51. The red light was off.

Vocalization and leg kick

During sessions 52 through 67 both vocalization and leg kick were reinforced on two concurrent multiple schedules.

During sessions 52 through 54 in the first 10-min of the session vocalization was reinforced on a FR3 and the infant was moved away from the leg kick apparatus which was inactive. In the second 10-min of the session the microphone was removed and inactive, and the infant was moved near the leg kick apparatus and leg kicking was reinforced on a FR3. The red light was correlated with the leg kick component.

In sessions 55 through 57 both responses were reinforced as above but the reinforcement conditions were alternated every 5 min. Both the presence of the microphone and the proximity to the leg kick apparatus during the periods when they were inactive were faded in by allowing the infant to be closer to them during each successive session.

In sessions 58 through 67 both manipulanda were present. Responses were reinforced as above with the reinforcement conditions alternating every 5-min. During the first and third 5-min periods vocalization was reinforced on a FR3 and leg kicking was extinguished. In the second and fourth 5-min periods leg kicking was reinforced on a FR3 and vocalization was extinguished. The red light was correlated with the leg kick component. Reinforcement and extinction are reciprocal operations here since the stimulus correlated with reinforcement (S^D) for one response is correlated with extinction (S^Δ) for the other response, and vice-versa. Both the number of reinforced responses

(S^D responses) and the number of unreinforced responses (S^Δ responses) during all sessions were recorded.

RESULTS

Vocalization

Figure 2 shows the cumulative response records of vocalization in sessions 1 through 5, operant level; sessions 7 through 11, continuous reinforcement (CRF); and sessions 12 through 18, fixed-ratio reinforcement (FR3). The average number of responses during the operant level sessions was 43, during CRF sessions it was 100, and during FR3 sessions it reached 215. Responding in both CRF and FR3 sessions is marked by bursts of rapid responding followed by pauses. Towards the end of many sessions the response rate declines. This is perhaps attributable to satiation or possibly fatigue. The most common responses in these sessions were voiced and of short duration, although a number of other sounds such as coughs, snorts, and sneezes also occurred. No attempt was made to separate these. Cries, whines, and whimpers rarely occurred. Little responding was observed while the reinforcement was being delivered.

Although the average response rate during the FR3 sessions is five times greater than the operant level, this cannot yet be attributed to the reinforcing as opposed to the eliciting function of the stimuli presented. To remove this ambiguity by separating these possible functions a multiple schedule (MULT(3)FR3 DRO) was introduced in sessions 19 through 33. Differential responding during the two components of the schedule was not achieved. In fact the response rate remained greater during the DRO component. The time requirement initially selected

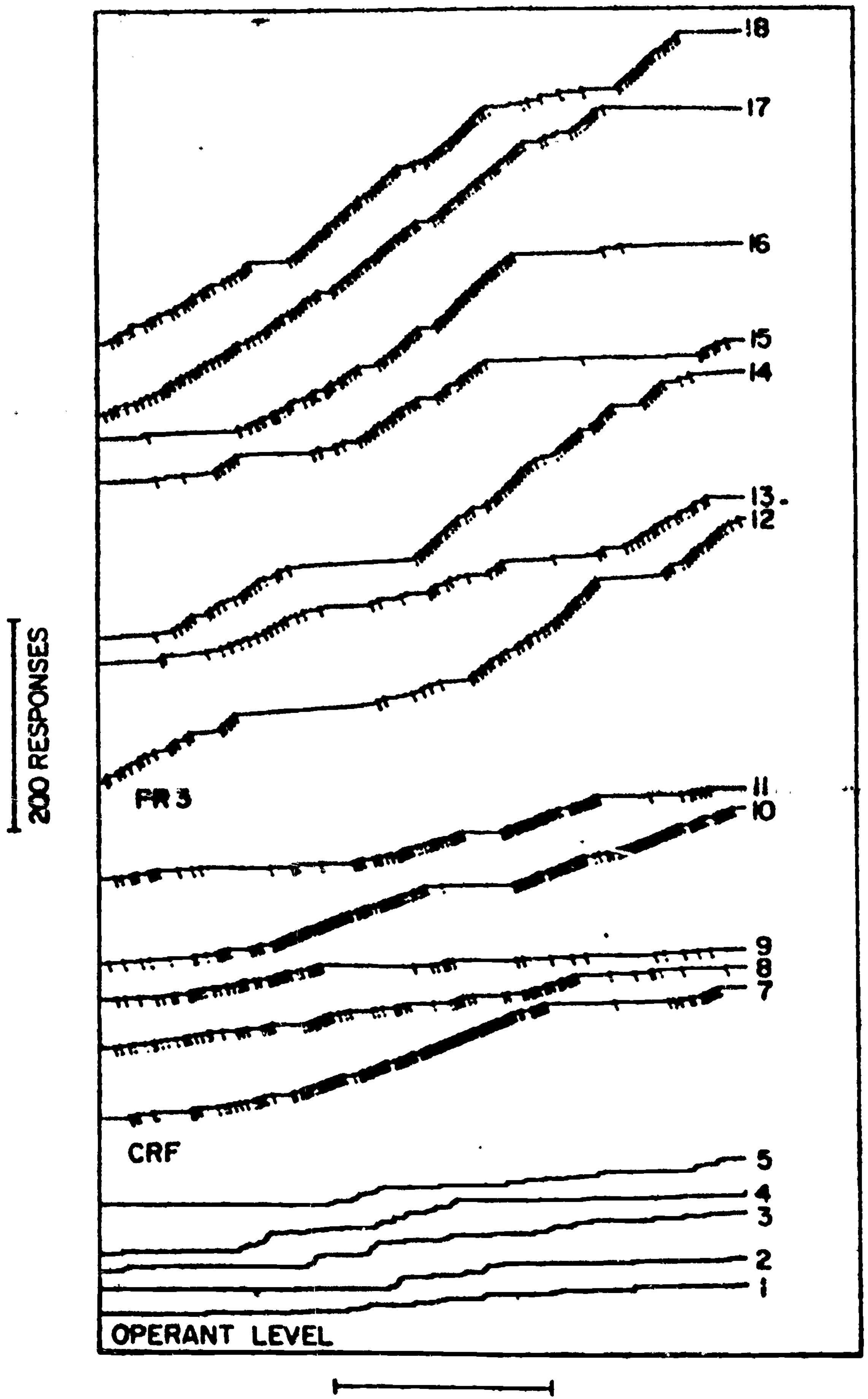

Fig. 2. Cumulative response records of vocalization in sessions 1 through 5 (operant level), 7 through 11 (CRF), and 12 through 18 (FR3).

for the DRO component, 30-sec, proved to be much too long. That is to say, the infant seldom satisfied the criteria for reinforcement during the DRO component. DRO, therefore, operationally resembled experimental extinction.

Vocalization in the first FR component of the schedule was similar to that in the conditioning phase. However, after several unreinforced responses during DRO the topography of the response changed to crying. Attempts to remove this problem by shortening the DRO requirement from 30-sec to 15-sec and later to 7-sec failed to eliminate the crying. The apparent elicitation of crying resulting from unreinforced responding in DRO completely interfered with the establishment of discriminative behavior.

In sessions 34 and 35 a second multiple schedule [MULT(3)FR3 NONCONT REIN] was introduced. Differential responding was not established. The response rate during the noncontingent reinforcement component was approximately the same as during the FR component. The response rate during the noncontingent reinforcement phase did not decrease since the infant continued to respond as in the FR component and therefore received reinforcement following vocalization. This served to increase the response rate and crying soon developed. The development of crying precipitated the abandonment of this schedule after two sessions. The research strategy was shifted at this point to achieving control over two operants, leg kick and vocalization, and then integrating these together into a schedule in which both operants are under discriminative control.

Leg kick

Figure 3 shows the cumulative response records of sessions 36

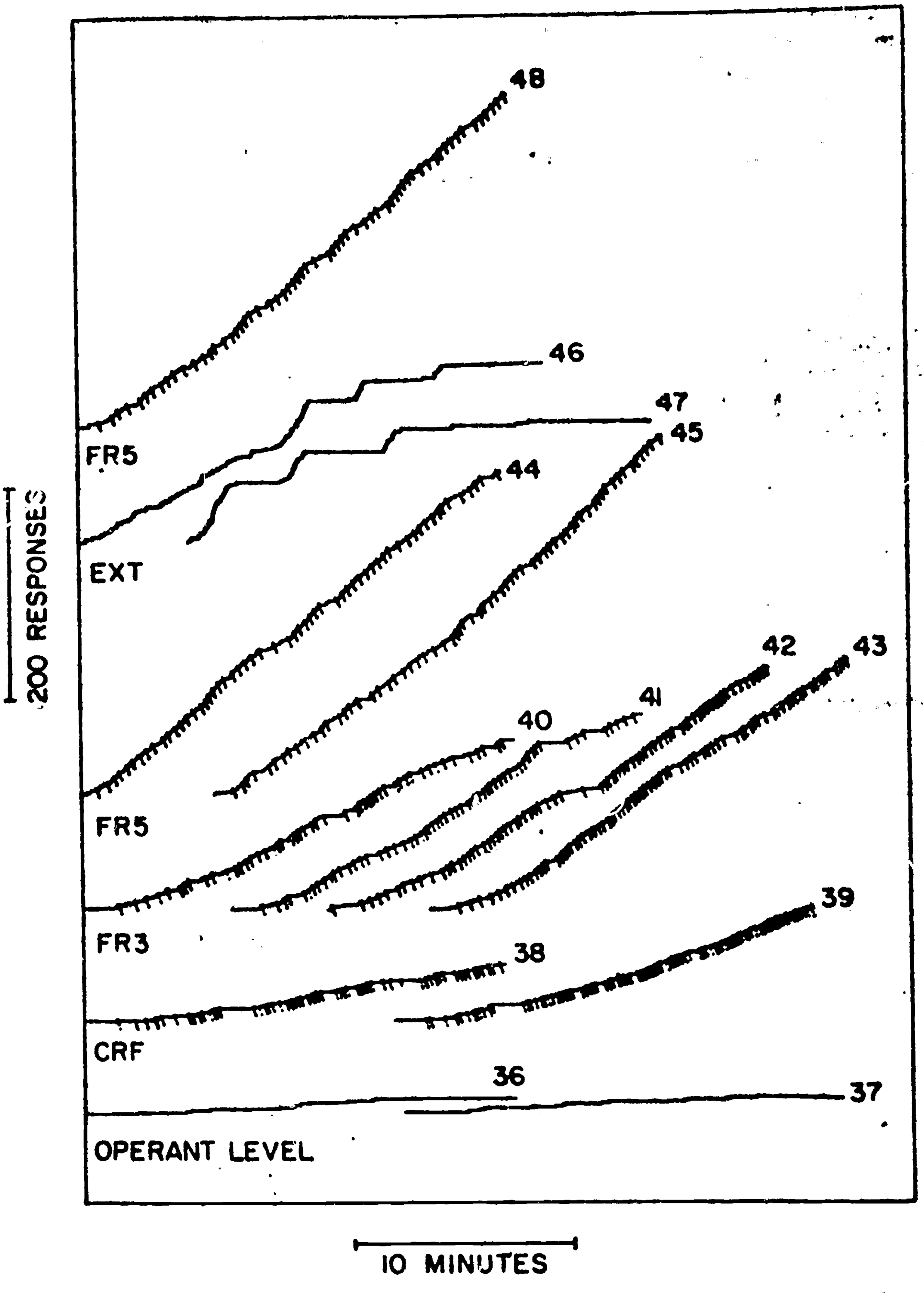

Fig. 3. Cumulative response records of leg kick in sessions 36 and 37 (operant level), 38 and 39 (CRF), 40 through 43 (FR3), 44 and 45 (FR5), 46 and 47 (EXT), and 48 (FR5).

through 48 in which the leg kick response was studied. The average number of responses during operant level (sessions 36 and 37) was 15. CRF contingent upon leg kick (sessions 38 and 39) increased the average number of responses per session to 78, intermittent reinforcement (sessions 40-45) further increased this to 193 during the FR3 sessions and 310 during the FR5 sessions. The average inter-response time[7] for the FR5 sessions is approximately 3-sec. This high response rate was maintained for the entire 20-min sessions with little apparent fatigue. Only a few, short, post-reinforcement pauses can be seen in Fig. 3.

The topography of the response became highly differentiated. Two distinct response patterns developed. The first was alternation with one foot pressing and releasing the panel followed by the other foot pressing and releasing the panel. The responses were quite vigorous, to the point of producing loud noises and vibrating the crib. During early sessions the infant occasionally kept one leg extended against the panel and failed to release the micro-switch and thereby register a response. This **later** dropped out and the response became a smooth extension, flexion movement. The second response pattern was executed with one foot, typically the right, resting on the heel with the toes in contact with the panel. A slight depression of the panel and its release was accomplished with little effort by the toes alone. Prolonged depression of the panel was not observed to occur as often as with the vigorous kicks. The second response pattern appeared to be somewhat more common although no measure of their relative frequency was made. There was little responding during the time when the reinforcement was being presented. However, in latter sessions the infant would often depress the panel during reinforcement and release it as soon as the reinforcement terminated, thereby registering a response.

Extinction of the response can be seen in Fig. 3. Examination of the cumulative response records of sessions 46 and 47 shows that most of the responses in extinction, an average of 142 responses per session, occurred early in the session in rapid bursts followed by prolonged breaks in responding. This is consistent with what is characteristically found in extinction following fixed-ratio reinforcement (Ferster and Skinner, 1957, p. 57). Spontaneous recovery at the beginning of the second extinction session is evident. During extinction the response topography shifted to vigorous kicking. The infant engaged in a number of alternative behaviors such as chewing on a fist, fixating on a feature of the environment and crying when he was not responding. Crying also occurred while he was responding during extinction.

Reconditioning of the response on a FR5, during session 48, returned the response rate to its previous level during FR5 reinforcement.

Vocalization

Vocalization was reconditioned in sessions 49 through 51 as shown in the cumulative response records presented in Figure 4. The response rates, 111 responses in CRF, 168 responses in the first FR3 session and 240 responses in the second, are somewhat higher than those in the prior vocalization sessions under the same schedules.

Vocalization and leg kick

During sessions 52 through 67 both vocalization and leg kick were studied. Sessions 52 through 57 were devoted to gradually introducing both manipulanda into the experimental situation. In Figure 5 is

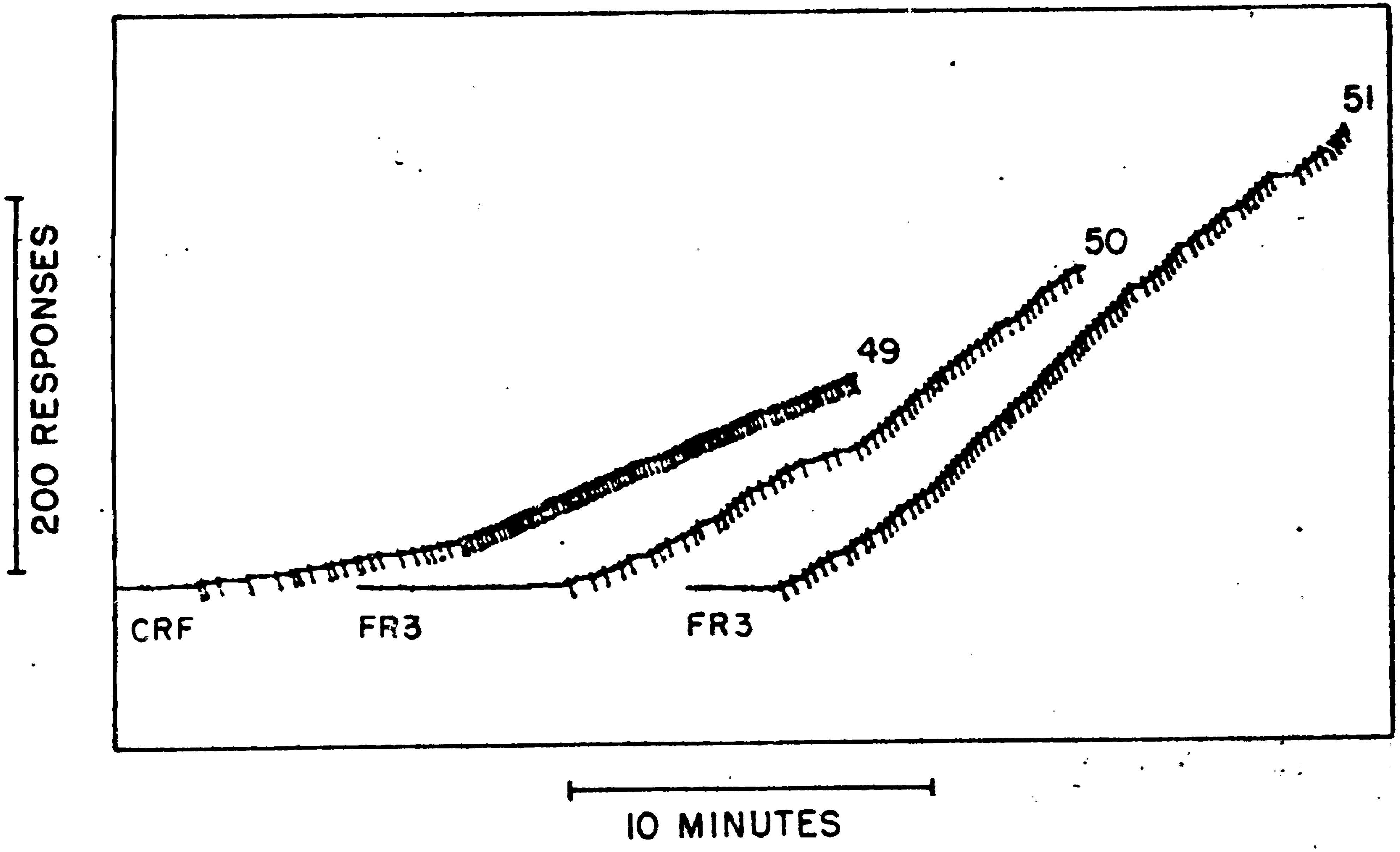

Fig. 4. Cumulative response records of vocalization in sessions 49 (CRF), 50 and 51 (FR3).

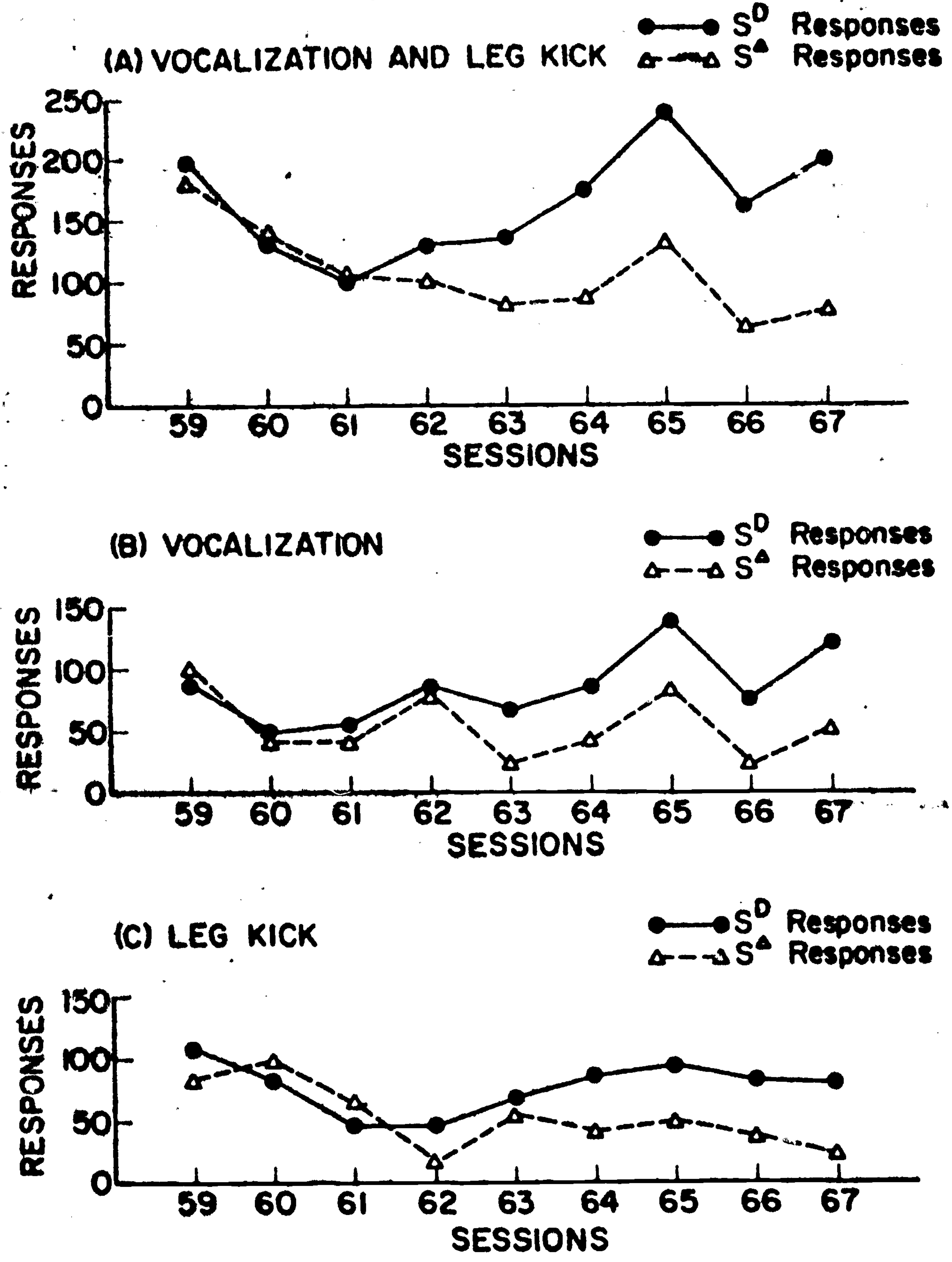

Fig. 5. S^D and S^Δ responses for A (vocalization and leg kick), B (vocalization), and C (leg kick).

plotted the number of reinforced (S^D) responses and the number of unreinforced (S^Δ) responses for (A) vocalization plus leg kick, (B) vocalization alone, and (C) leg kick alone. Initially the number of S^D and S^Δ responses were approximately the same for A, B, and C. In sessions 60 and 61 there was no differential responding as the response rate decreased to about one-half its level during session 59 as a result of both responses undergoing extinction during S^Δ. Greater S^D responding is evident starting in session 62 and continuing to increase through session 67. As can be seen in Fig. 5 the differential responding developed for both (B) vocalization and (C) leg kick. The percentages of all vocalizations and leg kicks that were S^D responses, all vocalizations that were S^D responses, and all leg kicks that were S^D responses in sessions 59 through 67 can be seen in Table 4. The proportion of S^D responses increases from chance level in the early sessions until about three out of every four responses in the final sessions are S^D responses.

DISCUSSION

This study has presented a clear demonstration of differential responding under discriminative control for both vocal and motor operants in a human infant less than three months of age; it has, also, developed an experimental procedure for the analysis of infant operant behavior, identified reinforcers, and achieved schedule control over responding.

This is the first demonstration of differential responding under discriminative control for both vocal and motor operants in a human infant under six months of age. Discriminative control of differential

Table 4

The Percentages of All Vocalizations and Leg Kicks That Were S^D Responses, All Vocalizations That Were S^D Responses, and All Leg Kicks That Were S^D Responses in Sessions 59 Through 67.

Sessions	VOCALIZATION AND LEG KICK	VOCALIZATION	LEG KICK
59	.52	.48	.56
60	.49	.54	.46
61	.49	.59	.41
62	.57	.51	.71
63	.63	.73	.55
64	.67	.65	.68
65	.64	.62	.66
66	.73	.76	.69
67	.72	.69	.77

responding in two concurrent responses is the strongest argument that can be advanced to establish that the behaviors under investigation are operant. The operants studied, vocalization and leg kick, will both likely be prominent in future studies of infant operant behavior. The vocal operant in infants is of great interest because of the obvious relationship it bears to the development of speech. The fuller analysis and understanding of the importance of environmental factors in the genesis of speech may provide us with the knowledge and techniques to facilitate its acquisition, development, and remediation. Along with this inherent interest, the vocal response is a rather difficult response class to focus on in a study of infant operant behavior because of the multiple sources of control over it. The problems surrounding its study are manifold, ranging from its measurement to procedural considerations involved in minimizing the probability of elicited vocalization.

The leg kick operant in infants has a great deal to recommend it. The response is not subject to multiple sources of control; infants can perform it rapidly with little effort, and no apparent fatigue; the operant level is above zero and the maximum response rate is quite high; and a transducer for the response is extremely simple and easily constructed. Given all of these characteristics it would be an excellent response to utilize in future studies.

The development of a successful experimental procedure for the analysis of infant operant behavior was arrived at only after several other procedures were employed and rejected. The problems encountered with the first multiple schedule were avoided through the use of two concurrent multiple schedules. The development of crying during the MULT (3)FR3 DRO as a result of the occurrence of unreinforced responses, although interesting in itself and worthy of investigation, completely thwarted early attempts to control operant vocalization. Infant crying as a result of unreinforced responding has been reported in other studies (Rheingold et al, 1959; Brackbill, 1958; Heid, 1965) and appears to be a general finding. This suggests that it would be wise to avoid the use of extinction sessions with infants when studying vocal behavior, unless one is specifically interested in the elicitation of crying under an extinction procedure.

The development of crying during the MULT (3)FR3 NONCONT REIN appeared to be related to the high rate of responding that occurred, although it should not be concluded that there is a definite relationship, since a high rate of vocalization was maintained in sessions 7 through 18, see Fig. 2, without the development of crying.

For studies whose primary purpose is to provide a demonstration that specific responses of an infant are subject to operant control the use of two concurrent responses, as in this study, is highly recommended.

We cannot tell from the data how age dependent were the failures and successes of this study. Because of the variation in the procedures employed, we do not know if conditions used late in the study would have been effective earlier; nor do we know if those conditions used earlier would have been effective if the infant had been older. The study of more infants within this age range would clarify this.

A facet of the procedure not to be overlooked or minimized in importance was the location and timing of experimental sessions.

A study of this nature would have been extremely difficult to conduct in any location other than the infant's home. The necessity of having the infant contented (i.e., free from noxious eliciting stimuli) and alert has previously been emphasized. It required careful observation for the entire study and constant attention and care prior to an experimental session to satisfy these requirements. Even then, it was not always possible to satisfy the requirements every day or to predict correctly that they were satisfied. The effort involved in arranging for a contented yet alert infant for even twenty minutes a day is much greater than one might anticipate.

There were four reinforcers employed in this research. The first, a recording of the mother's heartbeat played through a speaker in the crib, was only used once. Salk (1966) found that a similar recording when played continuously in the nursery had a quieting effect on newborns. It seemed plausible, therefore, that a recording of heartbeat played for 5-sec might function as a reinforcing stimulus. It was introduced in session 6 on CRF. Following the first response the heartbeat began, the infant appeared unusually alert while it continued for 5-sec, then when it terminated the infant emitted a scream that was quite unlike any it had produced before; this in turn started the heartbeat again and the infant was quiet until it terminated at which point he screamed. This pattern continued until the session was stopped and the infant removed. The possible reinforcing effects of the heartbeat were overwhelmed by the aversiveness of its termination.

The second reinforcer, the vibrator, appeared to be quite effective, the only exception being the decline in response rate observed at the end of some of the sessions between 7 and 18, which was perhaps attributable to satiation with the reinforcer. The fact that the decline could also be the result of fatigue led to the reduction of the duration of the sessions from 30-min to 20-min.

The vibrator was replaced by the flashing lights and the recording of the mother's voice in the continuing search for a strong reinforcer. This combination proved to be so effective that it was used for the remainder of the study. The strength of the mother's voice as a secondary reinforcer was maintained by having the mother repeat the same monologue on the tape to the infant during every feeding. The effectiveness of the lights alone or the mother's voice alone was not studied.

The success of the procedure was also dependent upon the choice of a suitable discriminative stimulus. To be most effective, a discriminative stimulus in studies with infants should not require an orienting response by the infant and the stimulus ought to affect a different sensory modality than the reinforcing stimulus does to avoid confusion. A tone, if an auditory reinforcer is not being used, or a pervasive light, as in the present study, are reasonable choices.

Previous research on the conditioning of infant vocal behavior (Rheingold _et al_, 1959; Weisberg, 1963) have been short-term studies, from six to eight days, with short experimental sessions, from 3 to 10-min, and have used 3-month-old infants. By contrast the present study spans two-and-a-half months, from two weeks of age to three months, and employed experimental sessions of 20-min and 30-min duration. Both prior studies found an increase in the number of vocalizations during conditioning sessions, using social reinforcements, from about four responses per minute to seven responses per minute in the first study and from one response per minute to three responses per minute in the second study. In the present study the rate of vocalization increased from a baseline of about 1 1/2 responses per minute to seven responses per minute in sessions 12 through 18, and during reconditioning of vocalization in sessions 49 through 51 to an average rate of twelve responses per minute in the final session.

In all three studies extinction lowered the response rate obtained during conditioning sessions, but not to the operant level. Crying during extinction was also observed in all three studies. A comparison of the present research with prior studies of the conditioning of motor operants shows, in terms of the response rates obtained, that the study by Bower (1966) bears the closest resemblance. The average inter-response time obtained in this study, 3-sec, is slightly higher than that obtained by Bower, 2-sec, in his study of head movement in infants. The procedure employed in Brackbill's (1958) study limited the increase in response rate to from 2 1/2 responses in 5-min to five responses in 5-min. In Heid's study (1965), the selection of an operant and the adjustment of the response transducer such that the operant level of the response was 20 responses per minute prevented an increase during conditioning since the response level was almost at its maximum.

Brackbill and Heid both reported crying in extinction sessions as in the present study.

Brackbill carried out extinction to zero and Heid discontinued extinction sessions because of the crying that developed. The present study did not extend the extinction sessions until no responding was obtained, although as can be seen in Fig. 3 there was little responding during the last 10-min of both extinction sessions.

SUMMARY AND CONCLUSIONS

These experiments have substantially increased our knowledge of infant behavior. Both studies have pioneered in developing experimental procedures applicable to the problems surrounding research in the areas of prosodic analysis of infant vocalization and operant control of infant vocal and motor behavior. The unity of these studies derives from their innovative approach to the study of infant behavior at both the descriptive and manipulative level.

The data of Experiment I constitute the first extensive measures of the prosodic features of infant vocalizing and their developmental trends. Future studies utilizing these procedures and the refinements suggested offer the possibility of greatly extending our knowledge of language acquisition in the normal child, as well as forming the basis of diagnostic techniques for assessing and measuring infant maladies.

The data of Experiment II clearly present the first demonstration of differential responding under discriminative control for both vocal and motor operants in a human infant less than three months of age. Research utilizing the procedure developed in this study holds the promise of extending our knowledge of infant operant behavior, as well as, facilitating its acquisition, differentiation, and modification.

Rigorous studies of infant behavior, although in their infancy, have a bright future.

NOTES

1. The lapel microphone was an Electro-Voice, model 649B, with a frequency response of 70 to 10,000 cps. This microphone was only used for the delivery recording.

2. The microphone used for the duration of the study was an Electro-Voice, model 654A, with a frequency response of 50 to 16,000 cps. The microphone had a flat frequency response from 50 to 16,000 cps.

3. The Tandberg, model 64, four track tape recorder had a frequency response of 30 to 20,000 cps. The speed accuracy was ± .2% or ± 3.6 seconds in 30 minutes. A recording level 10 db below maximum level results in 1/2 of 1% distortion of a 400 cps signal when played back.

4. Measurement of the sound attenuating quality of the air crib indicated that a moderately intense (80db) sound, from 100 cps. to 1000 cps, located two feet from the side of the crib was attenuated by approximately 1/2 (6db) within the crib.

5. Rach (1960) has shown that the delay between the appearance of a proprioceptive impulse during the execution of an arbitrary movement and the motor correction elicited was about 100 msec. This coincides with estimates by various authors of minimal syllable duration (Kozhevnikov and Chistovich, 1965).

6. The ALTEC 633A microphone had a frequency response of 30 to 12,000 cps and was flat over this range.

7. The average inter-response time was arrived at by subtracting the time the reinforcement was being presented (62 reinforcement X 5-sec = 5:10) from the duration of the experimental session (20 min - 5:10 min = 14:50 min) and dividing the average number of responses by this time ($\frac{310}{14:50}$ = 2.87-sec).

APPENDIX - Explanation of Figures

Fig. 1. Developmental trends in the prosodic features of infant vocalizing. Each statistic is presented as a function of age and sample number, averaged over blocks of nine samples, the data for Infant I (male) are represented by circles; those for Infant II (female), by triangles.

Fig. 2. Cumulative response records of vocalization in sessions 1 through 5 (operant level), 7 through 11 (CRF), and 12 through 18(FR3).

Fig. 3. Cumulative response records of leg kick in sessions 36 and 37 (operant level), 38 and 39 (CRF), 40 through 43 (FR3), 44 and 45 (FR5), 46 and 47 (EXT) and 48 (FR5).

Fig. 4. Cumulative response records of vocalization in sessions 49 (CRF), 50 and 51 (FR3).

Fig. 5. S^D and S^Δ responses for A (vocalization and leg kick), B (vocalization) and C (leg kick).

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