TITLE

CETACEAN COMMUNICATION
SMALL GROUP EXPERIMENT

REPORT NO.	DATE	MODEL NO.
LR 17184	9-16-63	-----

SUBMITTED UNDER (CONTRACT, SPEC., ETC.)

Form 375-3

LOCKHEED
CALIFORNIA
COMPANY
a Division of Lockheed Aircraft Corporation

BURBANK, CALIFORNIA, U.S.A.

REPORT NO. 17184

DATE September 16, 1963

MODEL None

COPY NO. ______

TITLE

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

REFERENCE ______

CONTRACT NUMBER(S) Nonr 3680 (00)

PREPARED BY John J. Dreher, Ph. D.
John J. Dreher, Ph. D.

APPROVED BY
DEPARTMENT MANAGER

APPROVED BY
DIVISION ENGINEER

APPROVED BY B. A. O'Laughlin*
CHIEF LABORATORY ENGINEER

*Specific Approval Required

LOCKHEED
CALIFORNIA COMPANY

L.R. 17184

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

John J. Dreher
Lockheed-California Company
Burbank, California

I. INTRODUCTION

Whether or not meaning has a relation to linguistic structure has long been a bone of contention. Certainly for the problem of automatic translation meaning and structure are intimetely related. For the basic sound-frequency analysis of a language, much can be accomplished without regard to structure, subject mainly to the error of allophone discrimination, which may be tied to meaning. In the lay sense, however, when we investigate another language we hope eventually to crack the meaning of the code, and there are highly skillful ways of doing this. Thus far, most of the language thinking has involved people, whether the target language is generated by a lone informant or a vast library of written material; some degree of concept liberalization may be in order, therefore, before we tie the term "language" to an infra-human system. Casting aside for the moment, if we may, the implication that "language is something exclusively reserved for humans," we have now found it useful to apply a more basic yardstick, namely, that "language" may be considered as any series of symbols that appear in a time-ordered syntactic sequence and which obey predictable rules. Armed with this perhaps iconoclastic but useful definitional club, we have been able to bring many infra-human systems into our linguistic fold with entirely satisfying results. We can, in short, speak effectively about "a language" whether the "words" are coded pulses, number, letter, or other symbols--just as long as they obey predictable rules and encode information that may serve in some fashion to modify the behavior of an emitter and/or a receiver.

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

I. INTRODUCTION - cont.

In working with a human informant the experimenter can usually count on some degree of cooperation, and although the dolphin can hardly be branded as uncooperative, there are knotty physical problems that intervene. Because of the different medium, the difficulty of maintaining them, and because of our still primitive knowledge of their social dynamics, any communication experiment with dolphins can be criticized in the classical sense. To this extent we shall be unsatisfied with our progress for a long time to come. What has been done thus far is encouraging, and some blueprints for the future are emerging. There is no doubt that we can communicate with the dolphin in many ways, either with signs or with spoken language. There is little doubt that he in turn communicates with us on the response level, and to a limited degree (and here the shame is ours) perhaps even in English. It is the only gracious thing to do that we, as the king of beasts, attempt to talk to him in his own code. To date the effort in this field has been minimal, and there are probably many more things that have been done than have been so far reported. In relation to the body of literature in other fields it should show rapid growth in the near future.

Before we get to the description of one of these studies it might be well to recall briefly some of the methodology that we have employed at Lockheed on previous occasions. We have been working for some time now with Marineland-of-the-Pacific, and thanks to their fine cooperation now have an excellent setup for communication studies. The animals are unpressured with training schedules, the tank is roomy, the water clear, an effective underwater monitoring system has been installed, and there are several viewing ports for observers. Before this facility was available and because of our Research vessel Sea Quest, it was feasible

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

I. INTRODUCTION - cont.

to use some of the large sound sample gathering techniques by which we come eventually to describe a language structure. On several cruises Mr. Eberhardt and Mr. Evans were able to obtain hours of recordings of large herds of cetacea and observe generally what they were doing at the time. Consequently, statistical comparisons of some of the species' whistle contours have been analyzed and reported (Refs. 1-4) with more to follow. Fig. 1 gives the results of some of these analyses for four types of cetacea. The contours in the left column represent somewhat standardized versions of the whistle excursions as grossly transcribed by ear from slowed-down tapes, in effect, a pitch-time representation. The word "USED" indicates that the contour on that same line has been recorded with the animal which is noted at the column head. A blank box indicates that as yet no observation of the particular contour has been made. This could obviously be a sampling deficiency, or it could mean that the referenced contour is not produced by the animal in question. It will be seen that certain whistle shapes appear to be used by all four types of animal represented, while in some instances a number of contours appear to be peculiar to a species. Based upon subsequent evidence, a more comprehensive chart is in preparation.

Because of the mass of data, constituting in some instances the acoustic output of very large herds of animals, lack of a real-time contour analyzer has prevented any attention being paid to minimal changes or variations which very well might have real meaning for the animals. In other words, these contours correspond to the first strike at a phonemic transcription of a human language. A phonetic transcription, on the other hand, would pay attention to the small variations, and here is an important deviation of our technique. The "etic" analysis has been delayed until after the "emic" phase, -- just the reverse of the usual process. This was

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

I. INTRODUCTION - cont.

done, obviously, because we had no control over the communication situation and because we had no precedents in the way of tonemes upon which to base our original analysis. There are two fallouts from this: we are at present constructing a real-time pitch-contour writeout to speed up the analysis, and Miss Rugh Haugen will shortly publish some physical data on dolphin contours taken from the sound spectrograph. This will give a more accurate picture of the inherent replicability and variation in these sound. Fig. 2 is Pike's description (Ref. 5) of the basic structure on known human tone languages using contour glides.

Type I, which we have originally assumed might characterize delphinese, depends only on changes in direction for its lexical meaning. The others become progressively more complex, eventually involving beginning and endpoint, slope, time of utterance, and, although not seen here, register. Our analyses to follow have retained our original assumption, although a considerable feeling has developed among us recently that, in view of the responses elicited during our first controlled communication test, time of production, slope, grouping, relative intensity of parts of the whistle, and perhaps even cesura may well have meaning of some sort.

II. EXPERIMENTAL DETAILS

Fig. 3 shows the six contours which constituted the stimuli for this study. Because of the high frequency of occurrence of these shapes in previous monitoring, it was assumed that the introduction of these into the tank would be sufficiently credible not to induce chaos, a point considered worthy of consideration in view of some extremely erratic behavior observed at an earlier time when sounds were inadvertently

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

II. EXPERIMENTAL DETAILS - cont.

broadcast to a lone animal. The sharply falling distress contour described earlier by Lilly (Ref. 6) was not included in this set.

Fig. 4 is a schematic of the experimental setup showing the oval tank housing the six experimental animals (Tursiops truncatus). One was an adult male, three were adult females, and two were immature females. Observers were stationed at the viewing ports, a University underwater speaker was mounted in the tank, and a short distance away were mounted two hydrophones, one for the tape recording, one for the sound track of a concurrent movie. Directly across the tank was another hydrophone connected in parallel with that used for the tape recording. The test contours were presented individually in a six-replication group. After each of the six replications a lapse of five minutes was allowed, during which the reactions were monitored both visually and acoustically. The five-minute guess appeared to be approximately correct, since the initial reactions seemed to extinguish after that length of time.

Before the test began, an hour's recording of the ambient sound production was made to get some baseline for assessing subsequent changes in the umber and type of contours produced. The analyses, this time again made by ear, then constituted a base period and six experimental phases which will be considered in detail below.

Pretest Ambient Environment

Monitoring was started at 0900 hours. Few people were gathered around the tank since the public is not admitted to the tank area until later. The six animals were engaged in normal play, with some activity displayed toward a photographer

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

II. EXPERIMENTAL DETAILS

Pretest Ambient Environment - cont.

and an observer, who was throwing a plastic ring into the tank for retrieval. Several of the dolphins were coming to the side from time to time to be patted, and in general the scene appeared normal. At the start of recording the animals were left alone and the sound monitoring commenced. The distribution of calls heard during a typical 5-minute period in the pretest phase is shown in Fig. 4. While different samples would reveal different distributions, it was not felt that sufficient variation existed to justify display of the entire set of calls produced during the one-hour pretest period. Comparatively, vocalization of the group was low, with a whistle density of 1.33 calls per animal per minute. Very long periods of silence were noted, broken occasionally by isolated bursts of slow echolocation. Many of the sounds consisted of very short upward or downward chirps, which we have previously associated with very young animals. Outside of the gentle encircling and interweaving of the animals there was nothing remarkable about their activity. Occasionally, one or more long, sweeping, upward whistles associated with search activity was heard, and there was a marked scarcity of multihumped whistles. The very short upward chirp was not heard in any of the succeeding recording periods after the tests began.

Contour One

First, what might one expect logically from the injection of taped signals? There are a number of possibilities. In an earlier test a violently neurotic reaction had been elicited from a lone animal who was acoustically linked to a tank containing several others that were actively echoranging and whistling. A repetition of this reaction might occur. On the other hand, they might become silent altogether. If they answered, the answer might be

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

II. EXPERIMENTAL DETAILS

Contour One - cont.

a parroting of the stimulus, or it might be a bona fide answer involving different calls. From visual observation the six dolphins here gave no indication that they were aware of the sounds having been presented. Vocally their behavior showed a change, and the results are summarized in Fig. 5. The first response was a serious of upward glides, the same signal as the stimulus. Whether this was a parroting or a query cannot be definitely stated as yet, although the appearance of 9 falling distress contours within the first 3 minutes and only two during the remainder of the test period may indicate at least an initial mild concern on their part about what happened. The call density immediately jumped from 1.3 to 2.9 calls per animal per minute, and several occurrences of very slow echolation were heard, distributed fairly evenly throughout the period. Repetitions of the stimulus call accounted for over half of the signals produced by the animals. It may be possible that the sudden occurrence of the stimulus made it impossible for the animals to determine the source, since no orientation toward the speaker was apparent.

Contour Two

Hard and heavy echolocation, both slow and fast, led off the reaction to Contour Two. Only 59 calls were produced during this session, with 11 being the falling distress countour. The distribution is shown in Fig. 6. The call density fell from a previous 2.9 to 1.9 calls per animal per minute, and long periods of silence intruded, broken usually by bursts of relatively fast echolocation. A sharp increase now appeared in the use of the double-humped call, and at no time was the stimulus sound used as a reply. The double-humped whistle has occurred during other activities almost invariably associated with impatience,

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

II. EXPERIMENTAL DETAILS

Contour Two - cont.

annoyance, or irritation. Several long sequences of echolocation, in all instances terminated by a single hump, double hump, or fall-rise-fall contour, occurred. In general, swimming behavior was not markedly different from that of the preceding session. Some sexual posturing appeared during this period. Swimming assumed an "S" pattern and 4 or 5 animals oriented toward the speaker.

Contour Three

A strong upsurge in activity followed injection of Countour Three. Simultaneously with the end of projection, the male, in front of the observation windows opposite the speaker, had an erection, turned and swam toward the loudspeaker, where he stopped abruptly. The other animals, or perhaps this male, responded instantly with three upward search calls. Slow echolocation and 6 separate, single-humped whistles were produced. Following this the animals alternated groups of the upward sweeping contour with a single instance of the triple-humped whistle. After approximately three minutes, some 19 upward single calls were given in succession. It is interesting to note that this contour was not a simple upward rise, but a rise, a plateau, and a further rise. This same sound had been noted during shows in the Marineland Sea Arena and was emitted by animals not at the time performing but offstage, so to speak, and attempting to attract the attention of the trainer. It may, therefore, be some sort of attention-call. The series of 19 upward sweeps was terminated by a three-hump and a single-hump whistle. Following this, periods of silence, interspersed with slow echolocation, a series of 9 upward whistles, and a termination group consisting of a single hump, and up-down-up

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

II. EXPERIMENTAL DETAILS

Contour Three - cont.

(the stimulus contour) and a double-humped signal was heard. The call density now had risen to over 3-1/2 calls per animal per minute, with the distribution shown in Fig. 7.

Contour Four

The stimulus here was a double-humped whistle, a form seen before as associated with a certain amount of excitement and irritation. The occurrence now of a series of six of these might be expected to mean something fairly drastic. At any rate, the effect was immediate and electrifying upon the animals. After a single-humped response, a furious burst of echolocation was heard, a downward distress whistle, and much thrashing about in the water. As though in some sense to imitate, or tease out a repetition of the sound from the loud speaker, the animals gave out immediately with two five-humped calls, a six-hump, and a four-humped variation following this with wild echolocation, squawks, and upward calls. For the remainder of the session the animals interspersed 5,2,3, and one-humped whistles with echolocation. Contour Two, the upward glide with the downward hook, was heard repeated in a series of 8, although this form was never produced when the same form was used as a stimulus. One dolphin was seen to go to the bottom of the tank, rub its head on the floor, and peer into the open drain. In addition to some chasing and leaping at various times, there was further evidence of this curiosity about the drain on the part of some. The call-density had now soared from 3-1/2 to almost 5 calls per animal per minute. Fig. 8 gives the responses to Contour Four.

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

II. EXPERIMENTAL DETAILS - cont.

Contour Five

To human ears this signal seems to be a sort of mirror-image of Contour Three, the latter being an up-down-up shape, while Number Five is a simple down-up-down pattern. At any rate, it elicited very little physical activity from the dolphin colony, with the vocal responses displayed in Fig. 9. As soon as the sounds were played, one of the animals swam directly to the speaker, three others oriented toward it, and their subsequent behavior seemed quite subdued in contrast with that of the previous period. After a short period of silence, some short chirps resulted, and then silence. Twice they responded with the same stimulus whistle, and three times with Contour Three, its mirror image. A few single-humped replies were attempted, this time varied greatly in shape, being flattened in excursion and greatly spread out time-wise in relation to the customary sharp, bell-shaped hump produced previously. Again the upward, search calls were tried. Call-density in this session dropped markedly from the five of the preceding test period to 2.9 per animal per minute.

Contour Six

This time the stimulus was a triple-humped signal, and like its two-humped counterpart, aroused a high degree of excitement in the colony. As soon as the six replications were injected into the tank, all animals turned toward the speaker with heavy echo-location. Two of them swam together past the speaker location, turning their heads as they went by to give it closer examination. Vocal activity promptly hit its height after this call was presented, reaching almost 6 whistles per animal per minute, and producing the set shown in Fig. 10. The double-humped response was now used heavily, together with the upward search call, which

LOCKHEED
CALIFORNIA COMPANY

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

II. EXPERIMENTAL DETAILS

Contour Six - cont.

was produced 125 times during the five-minute test period. Variations of the three- and four-humped whistles were interspersed with heavy and frequent echolocation bursts. It was in this session that the animals showed wide variation in the formation of the humped calls, changing the usual time base, flattening the height of the whistles, accenting at one time the rising part and at other times the falling parts.

By way of summary, Fig. 11 relates the call densities of the pretest phase, the test periods, and the post-test feeding session. In marked contrast to the relative absence of echolocation during pretest and the preponderance of heavy, powerful, and very slow pulses during the tests, the feeding session was characterized by extremely fast, continuous echoranging of deafening intensity. The whistles, it will be observed, apparently had some function not required by the rather aimless activity preceding the tests, since in addition to the feeding echolocation, a fairly high whistle density was maintained throughout.

Information Content of Responses

By totalling up all the whistle occurrences during the test periods as well as the pre-test play period, we arrive at an ensemble of 20 different shapes and a total array of 694 calls. Knowing the number generated in each test period, we may thereby generate an average information value per symbol for each test phase, as well as an average

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

II. EXPERIMENTAL DETAILS

Information Content of Responses

symbol value for the whole observation period. This was done according to the expression:

$$H(x) = \log_2 N - \frac{1}{2} \sum_{i=1}^{r} n(x_i) \log_2 n(x_i)$$

where:

H = Average information content

N = Total number of symbols in set considered

n = Frequency of occurrence of the x_i^{th} symbol.

When dealing with a test sub-set, rather than the whole ensemble, the formula is modified by insertion of the appropriate test session total under consideration.

According to this method of calculation, the information content per symbol for the whole recording session amounted to 2.17 bits. Table I lists the values per symbol for the individual sessions.

TABLE I

INFORMATION CONTENT PER SYMBOL FOR WHISTLES PRODUCED BEFORE AND DURING COMMUNICATIONS TEST WITH SIX T. TRUNCATUS

CONDITION		BITS/SYMBOL
Pre Test period		2.55
Responses to Contour	I	2.02
" " "	II	2.84
" " "	III	1.11
" " "	IV	2.13
" " "	V	1.62
" " "	VI	1.61

CETACEAN COMMUNICATION - SMALL GROUP EXPERIMENT

II. EXPERIMENTAL DETAILS

Information Content of Responses - cont.

It is interesting to note that the overall test value is not greatly different from the value of 2.02 bits that has been previously advanced as an estimate of the information in English letters, although no connection between the two ensembles is implied.

It will be observed that the lowest informational content of the signals occurred after presentation of Contour 3, and it was here that the greatest violence of physical activity was noted. The prevalence of chasing behavior, coupled with heavy use of the upward glide, which obviously seemed to be serving as some sort of provocative call or invitation, introduces some ambiguity in the interpretation. Did the stimulus evoke this reaction, or was the activity unconnected with it? The structure of this particular experiment does not allow a test of either hypothesis, although it was apparent that humped stimulus whistles evoked humped whistles in return. It was also apparent that the humped whistle form acted as an effective stimulus for strong physical activity, with the further possibility that certain forms may be involved in, or induce, sex behavior.

It is hoped that refinements to such communication tests as this can be made in the near future, optimally aided by real time contour analyzers and eventually by some sort of programmable whistle ensemble device to allow immediate composition of whistle series to fit the changing experimental situation.

JJD:bls

REFERENCES

1. Evans, W.E. and J. J. Dreher, Physiological and Communicative Aspects of Porpoise Sound Production, PCSRM #1979, Lockheed-California Company, Sept. 1960.

2. Dreher, J. J., Linguistic Aspects of Porpoise Sounds, J. Acoust. Soc. Amer., 33:12, Dec., 1961.

3. Evans, W. E. and J. J. Dreher, Observations on Scouting Behavior and Associated Sound Production of the Pacific Bottlenosed Porpoise (Tursiops gilli Dall)., Bull. Cal. Acad. of Sciences, Part 4, Oct-Dec., 1962.

4. Dreher, J.J. and W. E. Evans, Linguistic Considerations of Cetacean Sound Production - II, L.R. #16175, Sept. 11, 1962.

5. Pike, K.N., Tone Language, U. of Mich. Press, 1946 (Ann Arbor).

6. Lilly, J.C. and A.M. Miller, Sounds Emitted by the Bottlenosed Dolphin, Science, 133, 1961.

PORPOISE WHISTLE CONTOURS

CONTOUR	ANIMAL							
	ATLANTIC BOTTLENOSE		PACIFIC BOTTLENOSE		DELPHINUS BAIRDI		PILOT WHALE	
1.	USED	1	USED	6.	USED	3.	USED	1
2.	USED	2.			USED	8.		
3.	USED	3.	USED	1.	USED	1.	USED	2
4.	USED	4.	USED	3.	USED	7.		
5.	USED	5.	USED	6.	USED	5.	USED	6
6.	USED	6.	USED	3.	USED	6.	USED	5
7.	USED	7.	USED	6.	USED	17.		
8.	USED	8.	USED	2.	USED	2.		
9.	USED	9.					USED	4
10.	USED	10.			USED	9.		
11.	USED	11.	USED	6				
12.	USED	12.	USED	6	USED	4.	USED	3
13.	USED	13.			USED	14.		
14.	USED	14.						
15.	USED	15.						
16.	USED	16.						
17.			USED	6				
18.			USED	5				
19.			USED	4				
20.			USED	5				
21.			USED	5				
22.			USED	4				
23.			USED	2				
24.					USED	11.		
25.					USED	18.		
26.					USED	13.		
27.					USED	16.		
28.					USED	16.		
29.					USED	12.		
30.					USED	15.		
31.					USED	10.		
32.							USED	6

Fig. 1 - Cetacean Whistle Contours. Ordinate gives pitch vs. time representation of whistle excursions. Horizontal lines show "USED" if associated whistle has been observed in that species.

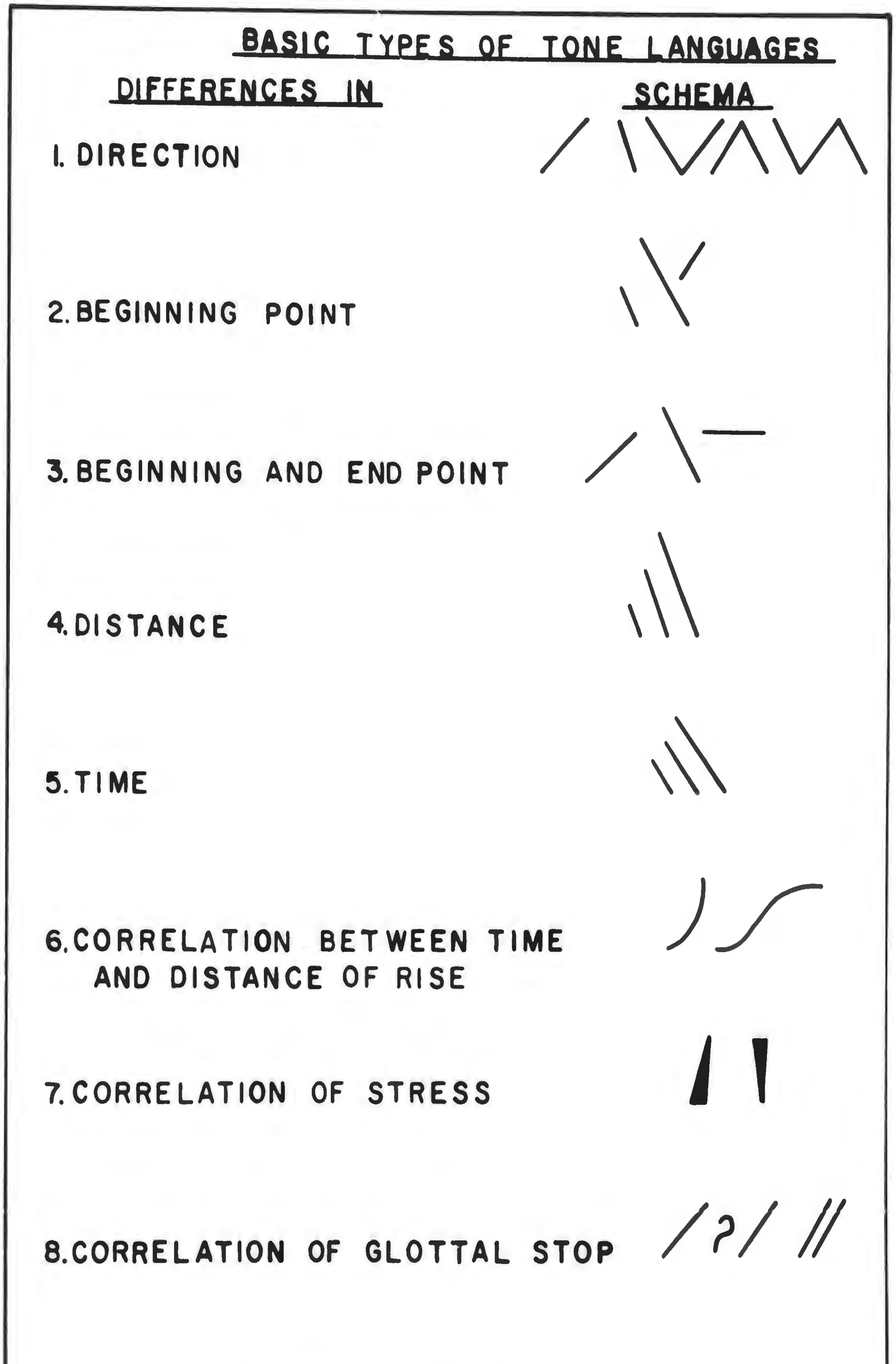

Fig. 2 - Pike's Schema

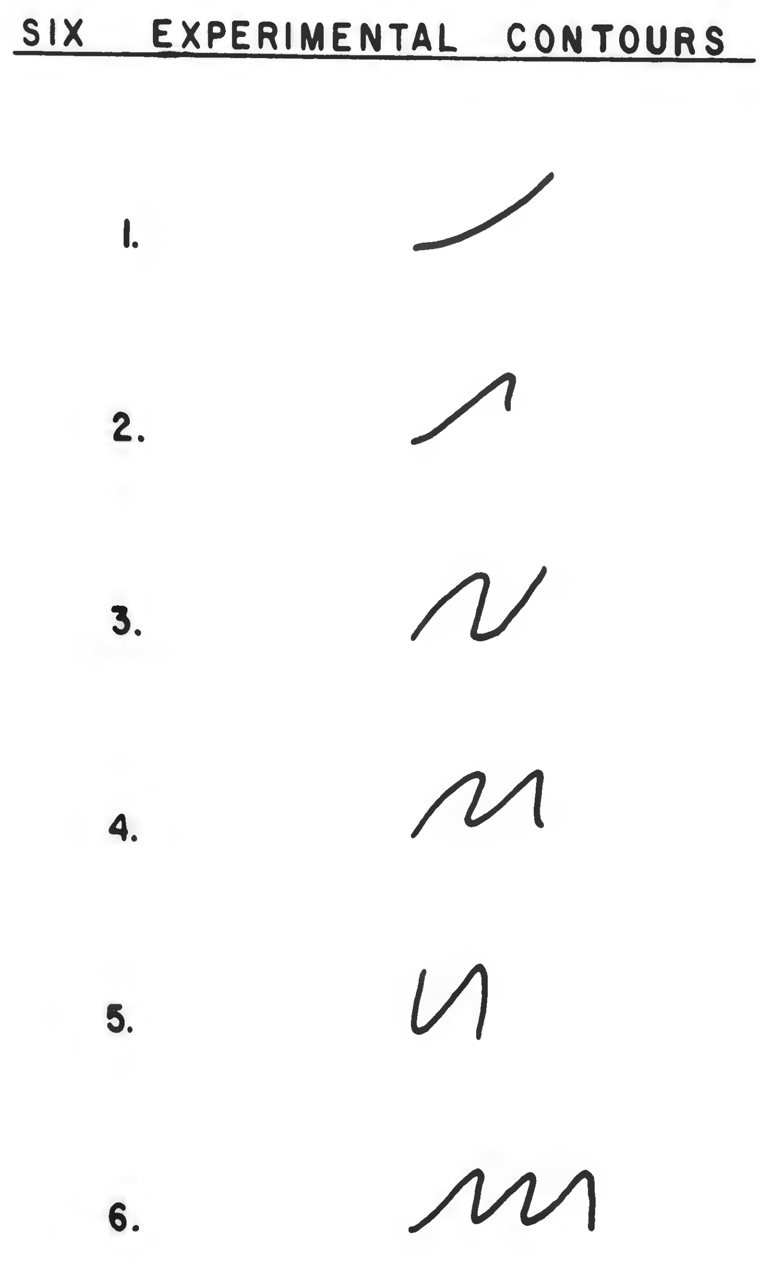

Fig. 3 - Test Stimuli

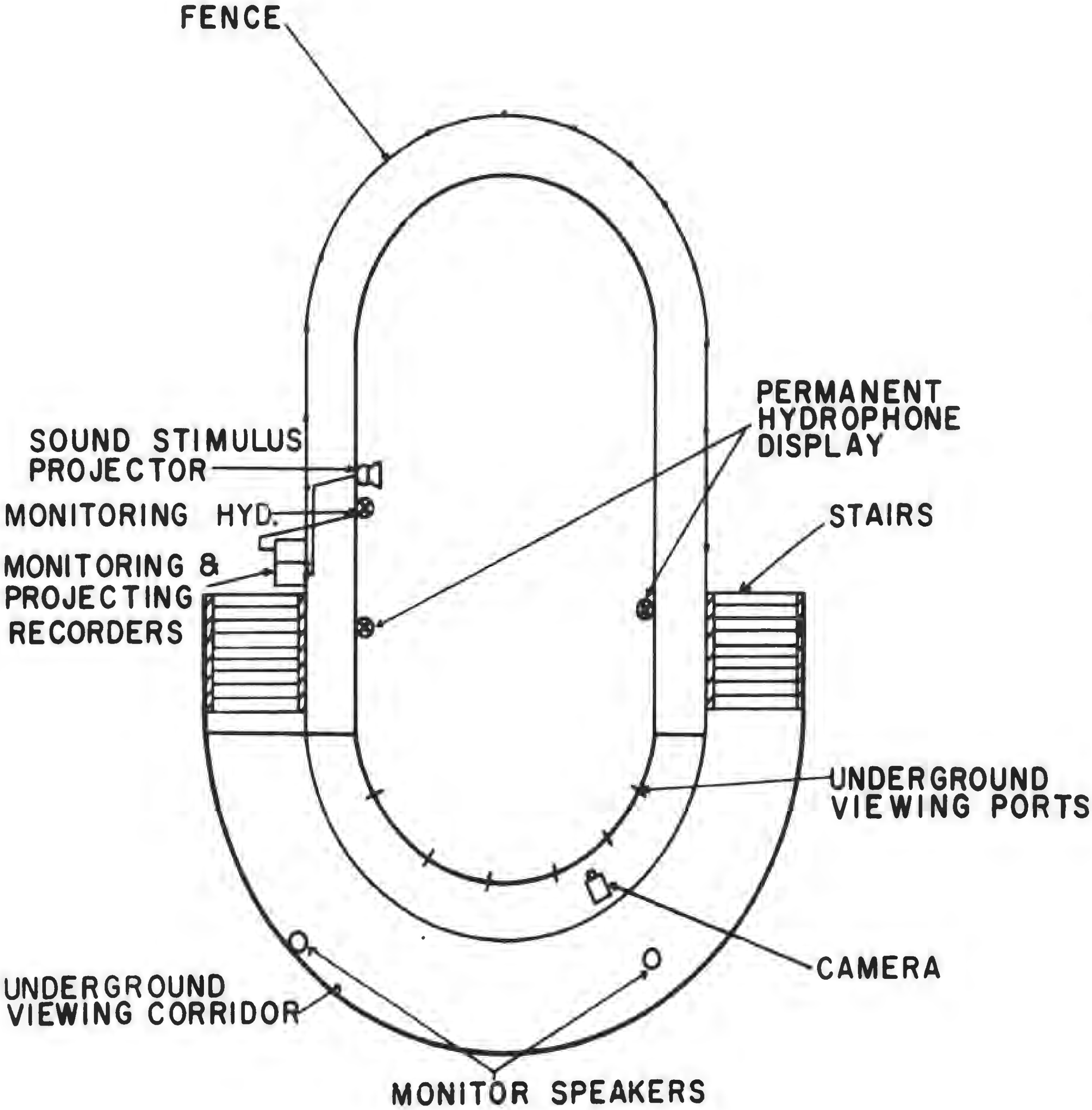

Fig. 4 - Communication Experiment Setup.

PRETEST

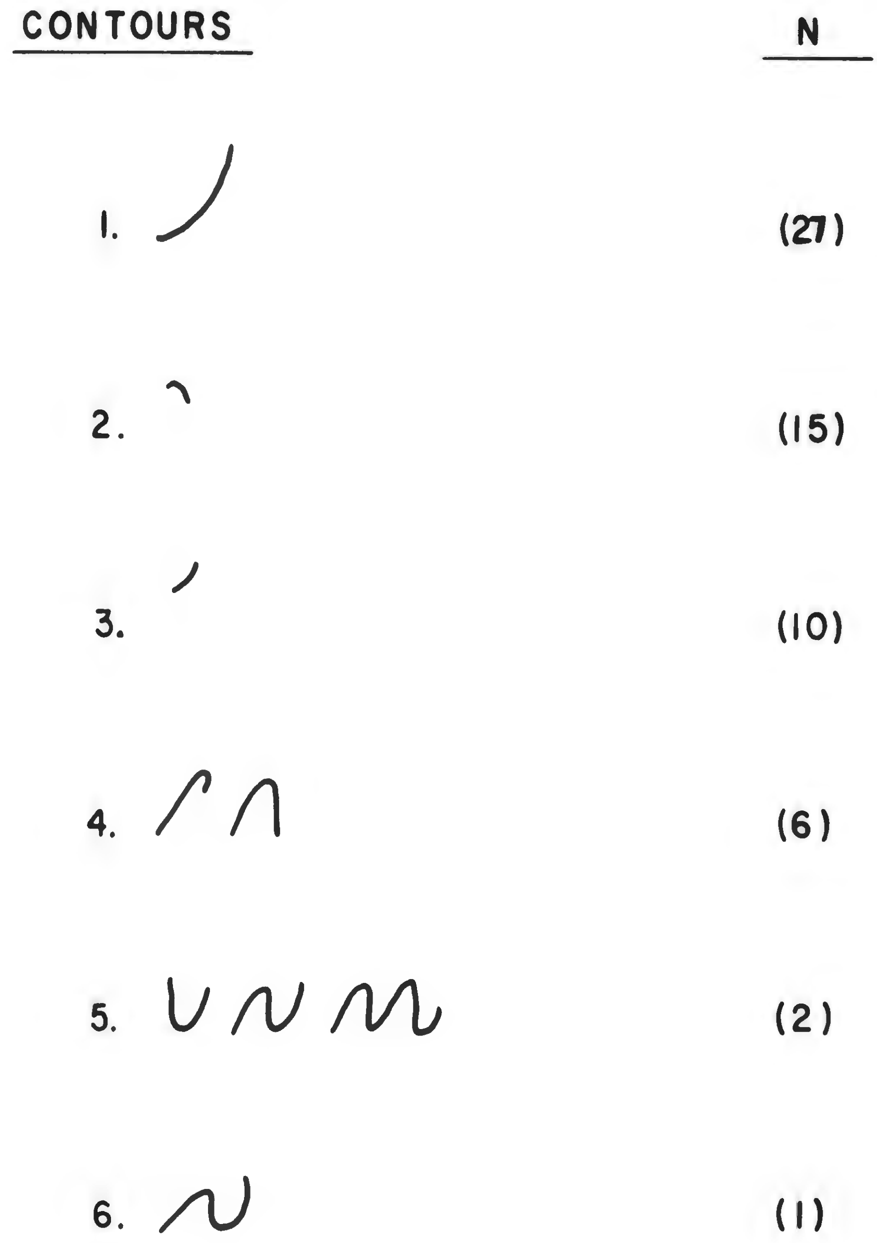

Fig. 4a - Experimental Contours

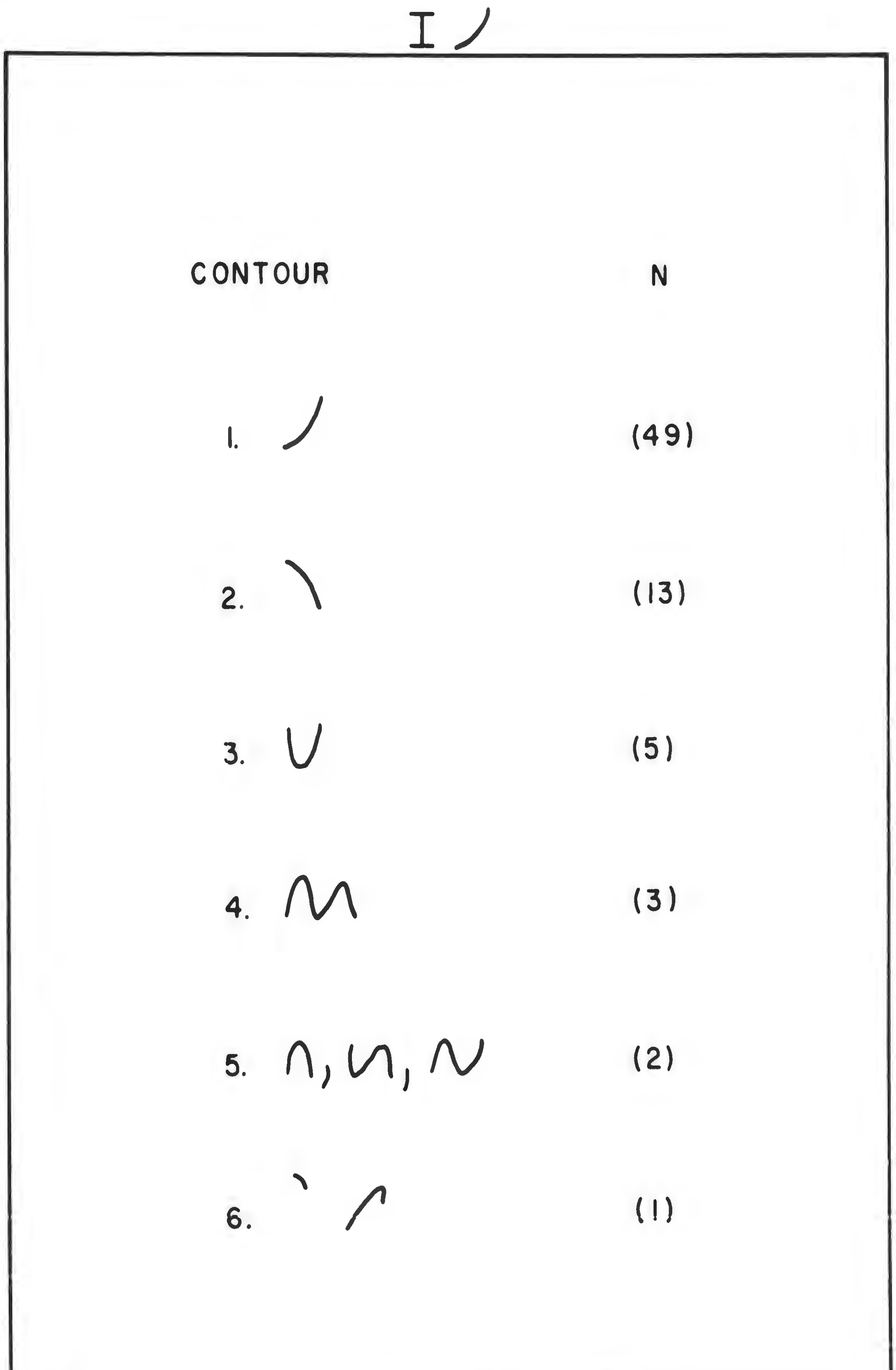

Fig. 5 - Responses to Contour I.

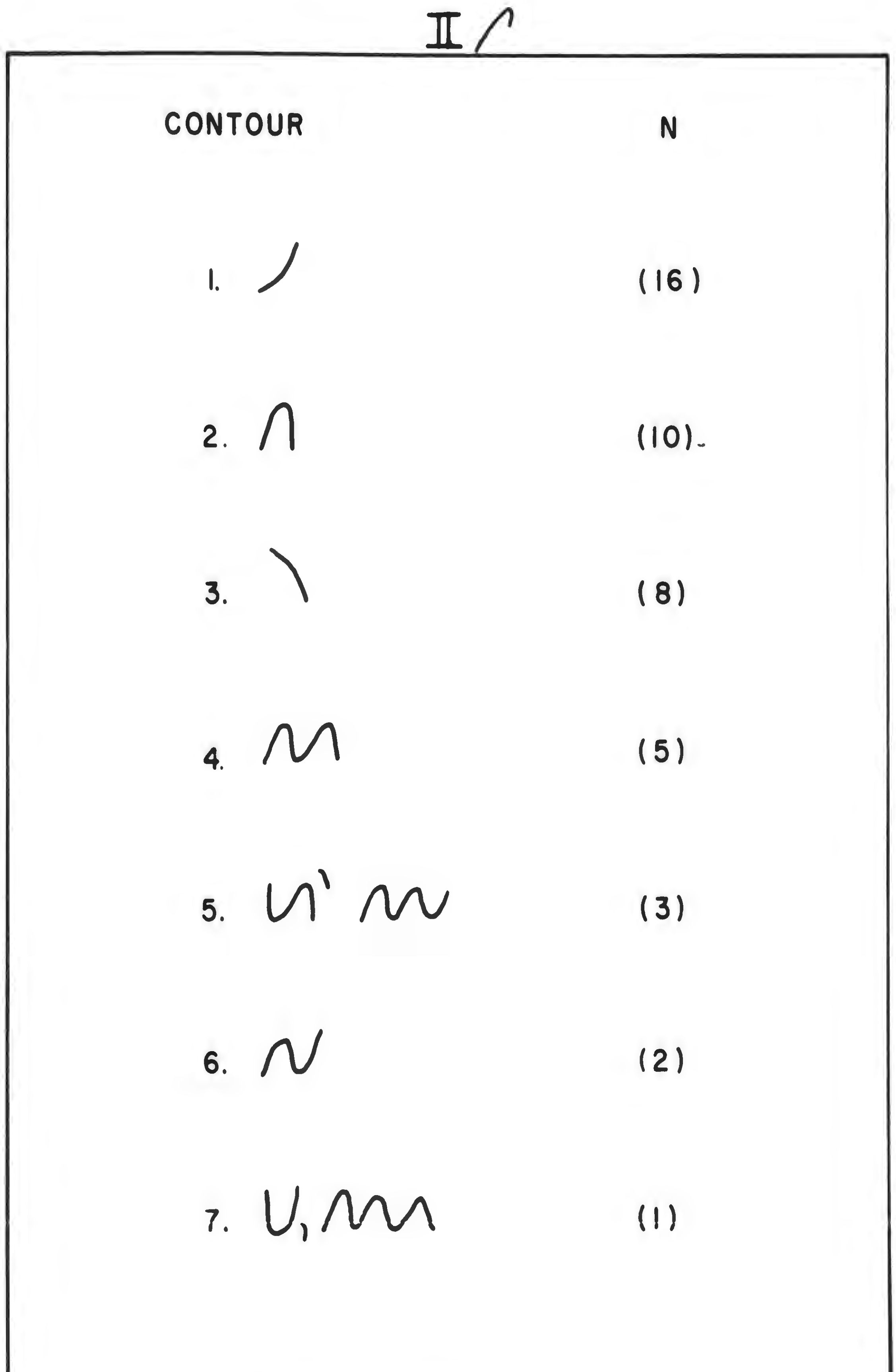

Fig. 6 - Responses to Contour II.

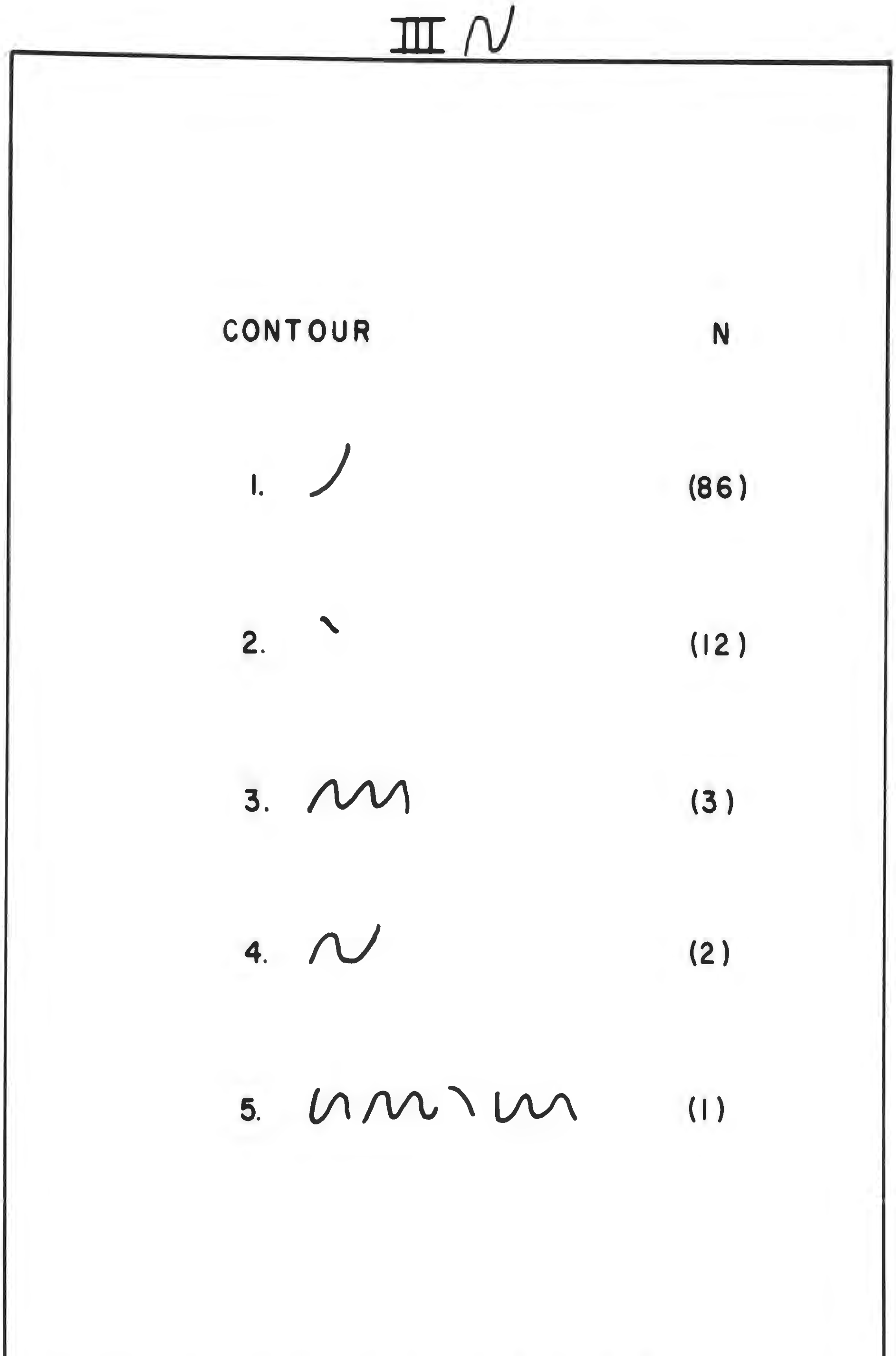

Fig. 7 - Responses to Contour III.

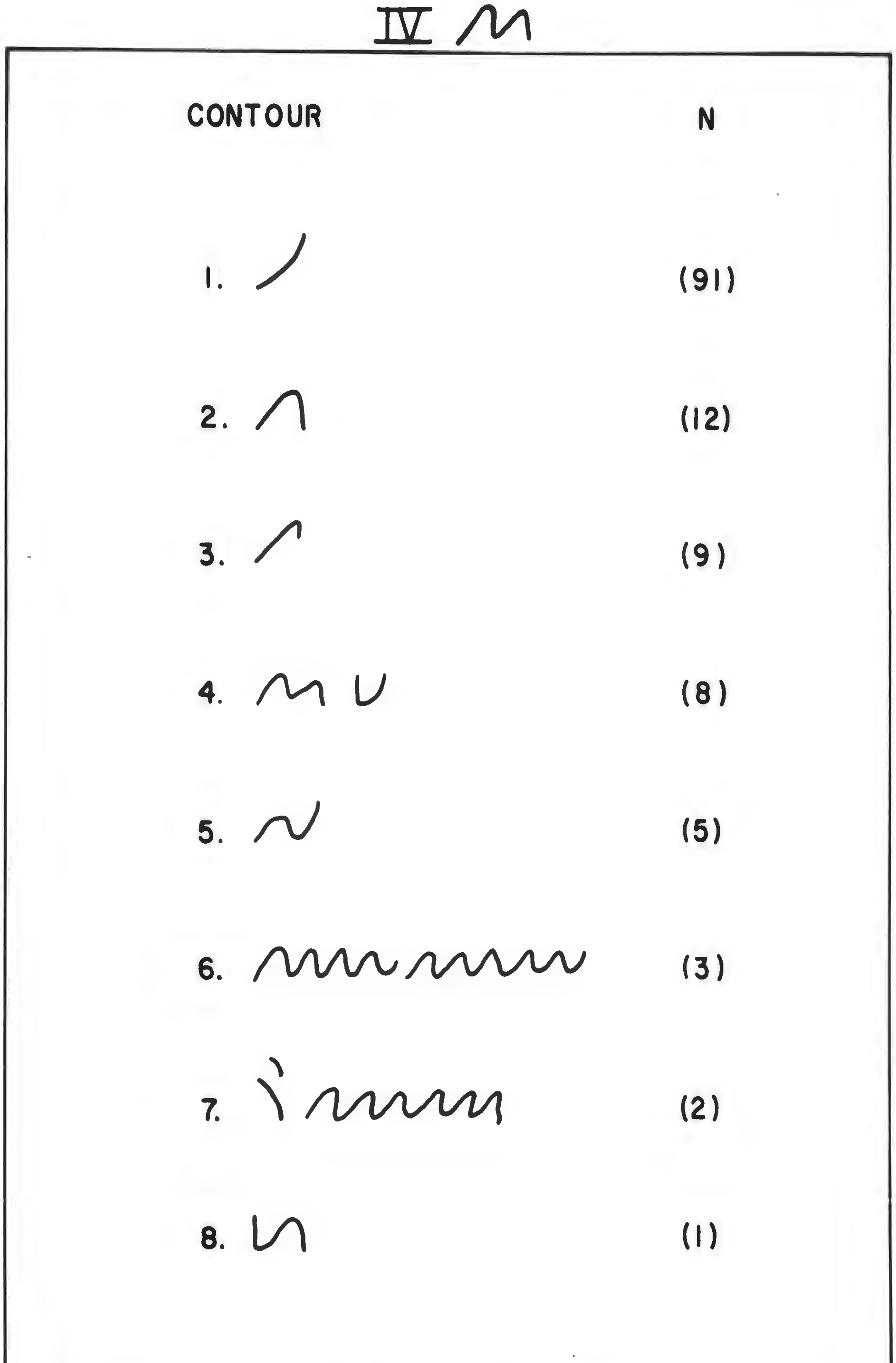

Fig. 8 - Responses to Contour IV.

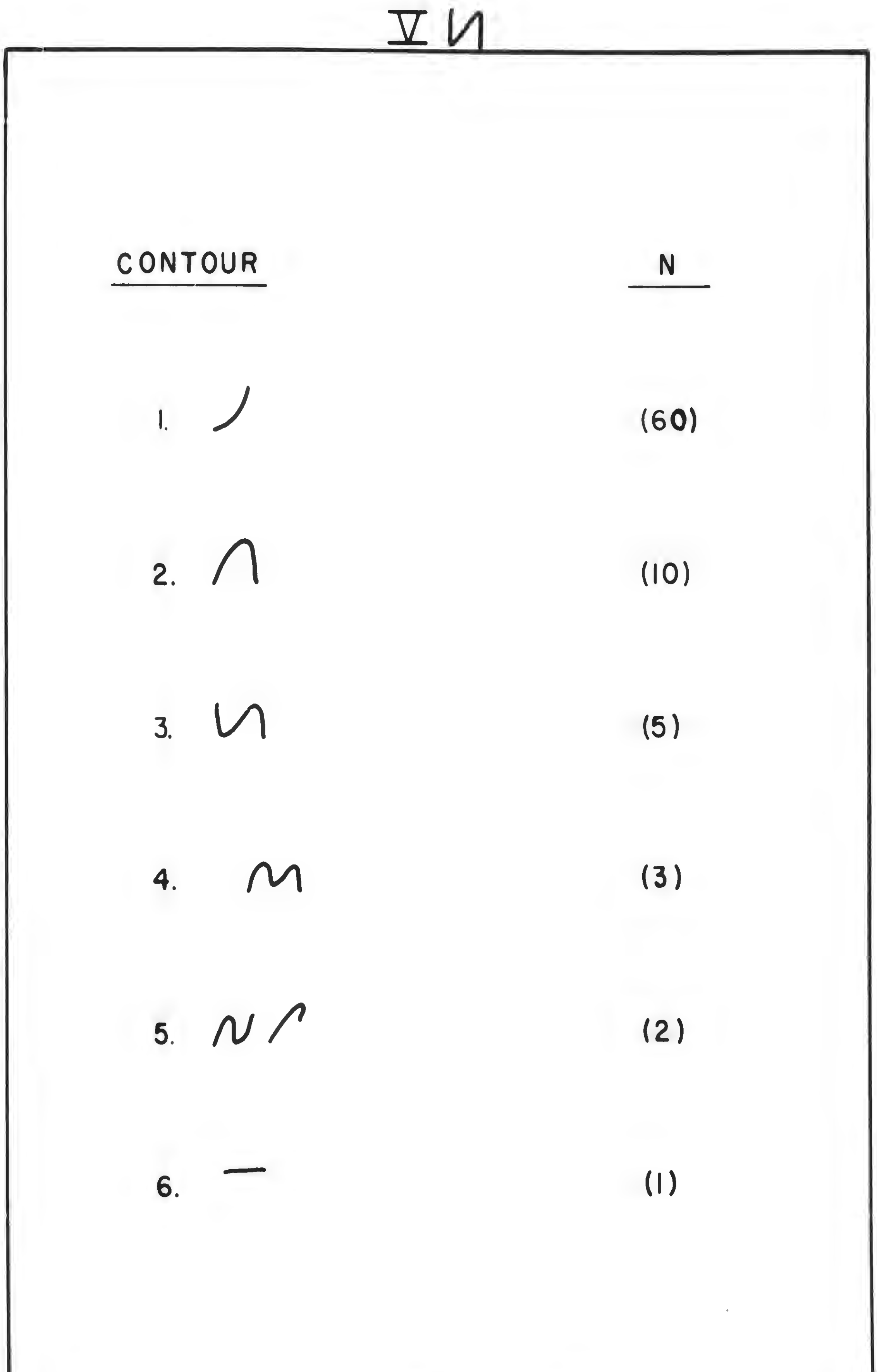

Fig. 9 - Responses to Contour V.

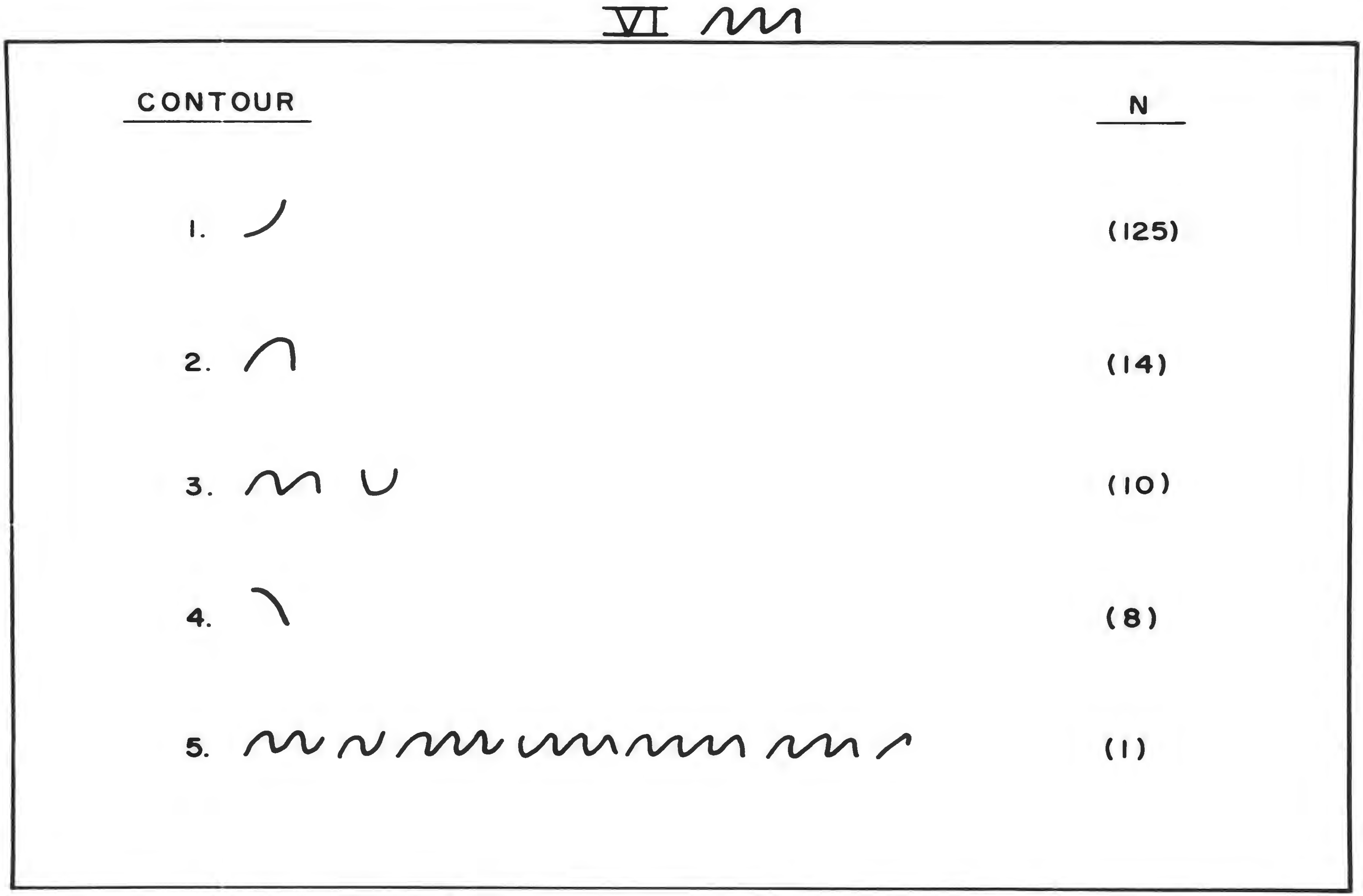

Fig. 10 - Responses to Contour VI.

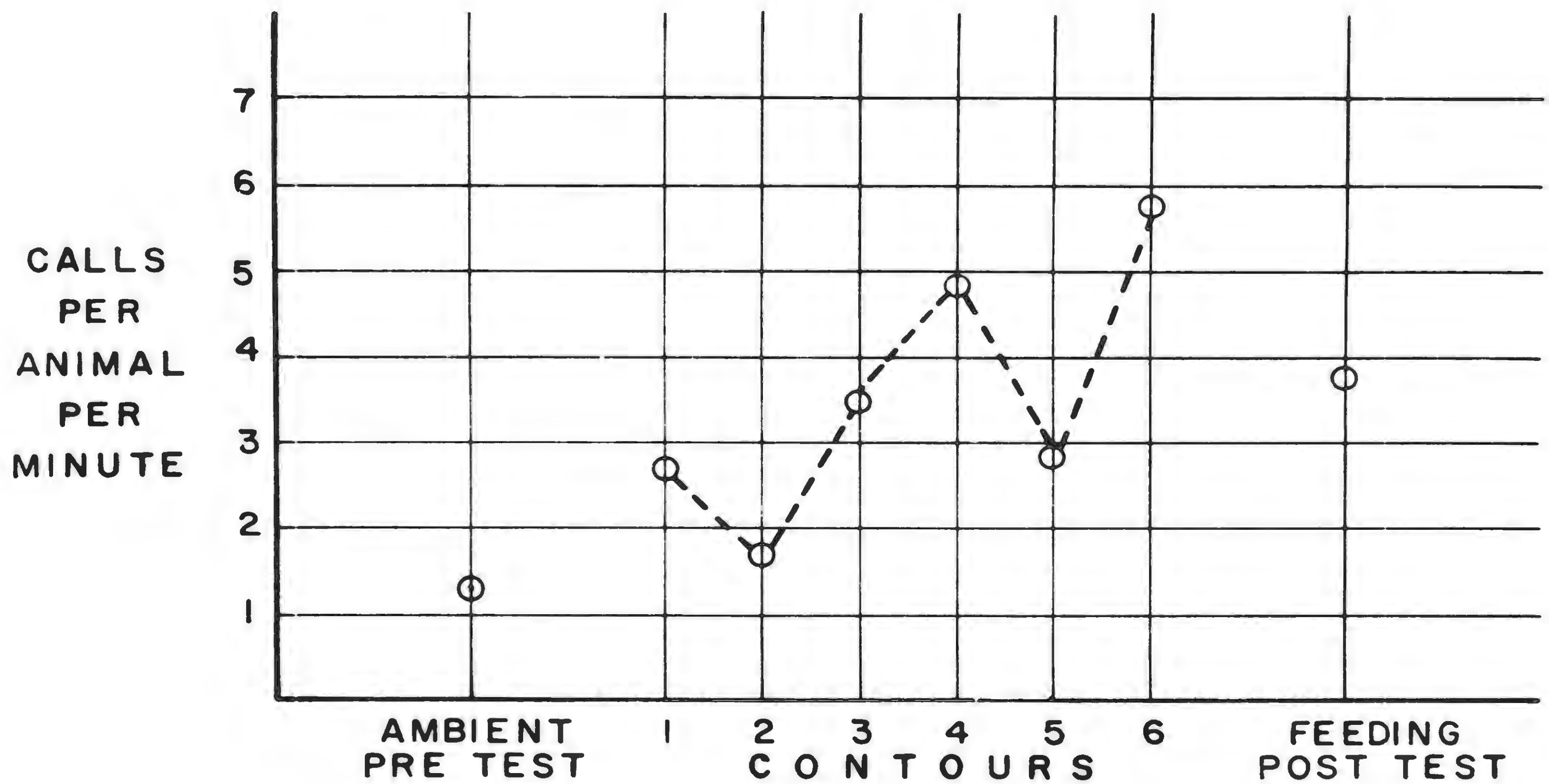

Fig. 11 - CALL DENSITIES OF SIX T. TRUNCATUS IN COMMUNICATIONS TEST.

$$H(X) = \log_2 N - \frac{1}{N}\sum_{i=1}^{r} n(x_i) \log n(x_i)$$

(GENERAL CASE, FREQUENCIES KNOWN)
PRESENTED INFORMATION

Fig. 12 - Information Formula Applied to Animal Signal Frequencies.