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Reprogramming of the Sonic Output of the Dolphin: Sonic Burst Count Matching

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The sound-producing mechanisms in the bottlenose dolphin (*Tursiops truncatus*) operate naturally underwater with a closed blowhole. In these experiments, Tt's reprogrammability in the vocal airborne mode and in vocal-acoustic interlock with another species is demonstrated. Human-speech (Hs) output programs were constructed from randomized vowel-consonant (VC) and consonant-vowel (CV) lists and simple English words and phrases. The analysis of the dolphin's sonic vocal output in response to these Hs vocal programs demonstrates Tt's reprogramming: in matching number of and trains of bursts, interburst silences, and latencies; ability to differentiate between Hs stimuli and other Hs comments or corrections, and ability to program from natural delphinic sounds to "humanoid" emissions.

INTRODUCTION

SOME physical analysis of the sonic and ultrasonic emissions of bottlenose dolphins (*Tursiops truncatus*) underwater has been previously reported in the literature by us and by others.¹⁻¹² The frequency bands covered by these underwater emissions extend as follows: from approximately 5 to 25 kHz for the fundamental frequencies and to at least 120 kHz for the harmonics of the whistles ("squeaks"), and from approximately 800 Hz to 170 kHz (fundamentals and harmonics) for click trains (pulses). The adult *Tursiops* usually emit sounds without losing air either from the lungs or from the sound-producing mechanisms. Thus the normal predominant mode of vocal signaling behavior of the bottlenose dolphin is by means of sounds produced inside the body, underwater. (A less frequently observed event is the loss of air from the closed

blowhole slit during whistling or clicking. This air loss is observed frequently in sucklings and youngsters, and in adults under stress situations.)

Under special circumstances, the dolphin exposes the blowhole to air, opens it, and emits loud sounds in air; some of these sounds that resemble human speech sounds we call "humanoid vocalizations."^{3,4,6,13,14a} The present account is a description of experiments on the programming of this vocal behavior.

I. APPARATUS, MATERIALS, AND TECHNIQUES

For picking up and transmitting the airborne voice output of the dolphin and the speech output of the human, either two Shure model 545 Unidyne II microphones were used or a model 545 plus a Lavalier model 560. The outputs of these microphones were recorded on a Wollensak 3M model 1580 tape recorder (*Tursiops* No. 11) and on a Sony model 262D tape-recorder deck with its recording amplifier SRA-2 (*Tursiops* No. 26). The useful frequency characteristics of this equipment extended from 100 Hz to 10 kHz. A satisfactory recorded amplitude range of approximately 35 dB was found.

Sonic analyses of these materials were made on a sonic spectrum recorder (12-kHz range, Kay Electric Co. Sona-Graph model 662-A). A mirror galvanometer oscillograph (Honeywell-Heiland model 906B) was

¹ J. C. Lilly and A. M. Miller, *Science* **133**, 1689-1693 (1961).

² J. C. Lilly and A. M. Miller, *Science* **134**, 1873-1876 (1961).

³ J. C. Lilly, *Man and Dolphin* (Doubleday & Co., Inc., Garden City, N. Y., 1961), p. 312.

⁴ J. C. Lilly, *Proc. Am. Phil. Soc.* **106**, 520-529 (1962).

⁵ J. C. Lilly, *Science* **139**, 116-118 (1963).

⁶ J. C. Lilly, *The Mind of the Dolphin (a nonhuman intelligence)* (Doubleday & Co., Inc., Garden City, N. Y., 1967), p. 310.

⁷ W. N. Kellogg and R. Kohler, *Science* **116**, 250-252 (1952).

⁸ W. N. Kellogg, R. Kohler, and H. N. Morris, *Science* **117**, 239-243 (1953).

⁹ W. N. Kellogg, *Porpoises and Sonar* (University of Chicago Press, Chicago, Ill., 1961), p. 177.

¹⁰ J. J. Dreher, *J. Acoust. Soc. Am.* **33**, 1-2 (1961).

¹¹ W. E. Evans and J. H. Prescott, *Zoologica* **47**, 121-128 (1962).

¹² T. G. Lang and H. A. P. Smith, *Science* **150**, 1839-1844 (1965).

¹³ J. C. Lilly, *Arch. Gen. Psychiat.* **8**, 111-116 (1963).

¹⁴ (a) J. C. Lilly, *Science* **147**, 300-301 (1965). (b) J. C. Lilly and A. M. Miller, *J. Comp. Physiol. Psych.* **55**, 73-79 (1962).

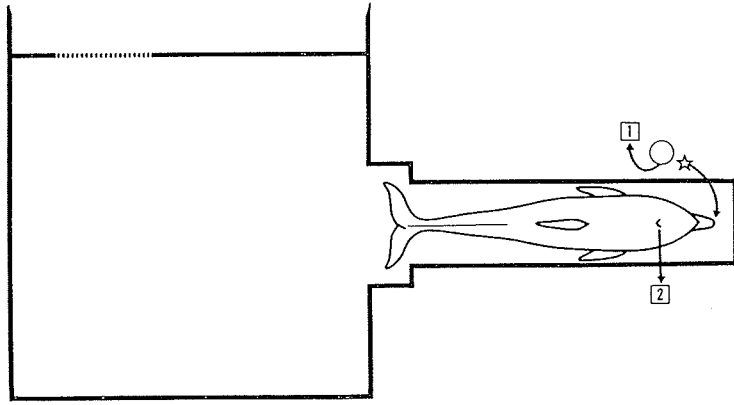


FIG. 1. Schema of experimental configuration. The dolphin (Tt) is in the recording position in the side arm. The programmer (O) is standing beside the side arm reading from the program developed from Table I and displayed in Table II. The Hs voice program is recorded through Microphone No. 1 and Tape Channel No. 1. ("Tape" is indicated by □.) The Tt voice outputs are recorded through Microphone No. 2 and Tape Channel No. 2. When a food reward ("fish"*) is used, it is either manually given to Tt or dispensed by means of a mechanical feeder triggered outside the tank room. The Fibreglas tank (2.5×2.5 m) has a door (⋯⋯) opening into the other tanks. The transparent side arm is ~2.5 m long by 0.5 m wide by 0.5 m deep.

used for envelope and fundamental-frequency recording. The mirror galvanometers are linear to 4800 Hz. An inkwriter oscillograph (Grass polygraph model 8, 12 channels) was used for envelope recording and continuous-frequency analyses in isolated passbands with a limit of 45 Hz for rectified and integrated envelopes. A storage oscilloscope (Tektronix model 564) was used for checking analyses of waveforms, burst count, burst timing, and train latencies. A 29-channel narrow-band (135-Hz) analog spectrum analyzer (Kay Electric model 30 modified) at the input to a LINC computer was used to give a quantitative measure of the frequency of occurrence of use of each narrow band in the range 135–8000 Hz (in two steps of 29 channels each).

Two male bottlenose dolphins (*Tursiops truncatus*) cooperated in these experiments. With *Tursiops* No. 11, the experiments were carried out after the dolphin had been in close vocal and physical contact with investigators for a period of 4 yr. This dolphin was estimated to be 2 yr old at the time of his first intensive interspecies programming. *Tursiops* No. 26 was placed in the laboratory at an estimated age of 2 yr; these experiments were carried out after 3 yr of contact with the investigators.

In the experiments with Dolphin No. 11, a special tank with a side arm (Fig. 1) was used. The dolphin was free to go from his home tank into the side arm at any time. The tank room had sound-absorbing carpets on walls and ceiling. The investigator entered the room, stood beside the side arm with a bucket of fish, put on his own microphone, and adjusted the microphone for the dolphin. He held his list of stimulus cues in the left hand and fed the dolphin with the right hand. If not already positioned, the dolphin was induced to enter the shallow (25 cm deep) water in the side arm placing the blowhole in air near the microphone.

In the second set of experiments with Dolphin No. 26, the investigator entered a flooded room (13 m×7 m, 45 cm water depth). The dolphin was free to swim into or out of this room from a flooded balcony (5 m×7 m). An experimental area within the room was sound-proofed (carpet on walls and ceiling). Both the *Tur-*

siops and the human moved freely in the room, most frequently between two microphones suspended from the ceiling.

With Dolphin No. 11, a male's human voice was used as the stimulating source; with Dolphin No. 26, the voice of a female human was used.

II. DEFINITION OF TERMS USED

A *program* is defined as a set of detailed instructions (expressed or implicit) transmitted by one biocomputer and received by another and/or used by both in interlock relationships. A program includes guidelines as to expected recordable and analyzable behavioral performances, vocal and nonvocal. A program defines values of time intervals between events, their amplitude, phases, durations, frequency ranges and modes of transmission, conduction, and reception. When possible, an attempt to measure the accuracy of the transmission and reception of a given program is made.

In a program, a "*burst*" is defined as a physical entity: a continuous series of pressure variations in a gas, liquid, or solid, the amplitude of which remains above an arbitrarily chosen threshold value for a minimum period of time, and of which the waveform frequencies and group repetition rates remain above a given value for the same period of time (Fig. 2). For the purposes

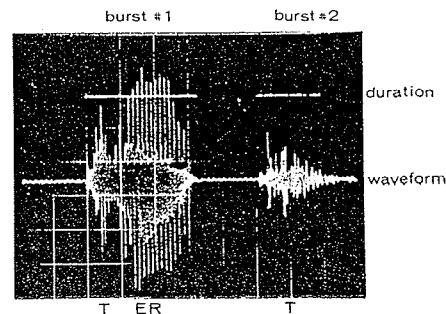


FIG. 2. The term *burst* is a sonic physical term. An oscilloscope display from a Tektronic model 564 storage cathode-ray oscilloscope of two bursts as defined in this program. The upper trace shows the duration of each burst (50 msec/cm), and the lower trace is the waveform of each burst using a wide-band filter (SKL 302). The word *tert* contains two bursts with a silence of 100 msec between "er" and the final "t".

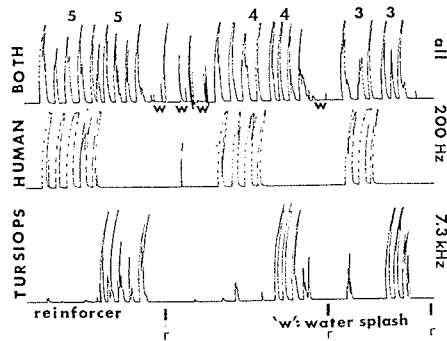


FIG. 3. Three typical Hs stimulus trains and the Tt voice output responses to each train. Analysis and graphic presentation of a portion of a magnetic-tape recording of Expt. 5 without cutting or editing (real time, continuous). The Hs voice program consists of three stimulus trains: the first has five bursts (mI i k iz te zi); the second has four bursts (II va ol nI); and the third has three bursts (aIz i ot). To cover the wide amplitude range (40 dB), an automatic gain control circuit was applied to the combined signals, and the resulting signal is displayed on the uppermost trace (Hs train precedes each Tt response train). In the middle and bottom traces, the two voices are separated for graphic purposes by two narrow-band filters (SKL 302) and displayed separately. Food reinforcement was used at times indicated by r; w indicates water splashes.

of this discussion, the *burst source* is either a dolphin or a human. For psychophysical experiments, the chosen amplitude, repetition rates, and minimum time durations are a function of the source's previous programming, hearing curve, frequency difference limens, and time functions (man, woman, or dolphin).

The determinants of the "burst" for physical recordings and displays are a function of the instrumental modifications of the original waveforms (the over-all instrumental transforms) of the sequence of the original pressure variations. Such variables as frequency passbands, impulse responses, differential phase shifts, intermodulation, rectification, and time transforms determine part of the definition of the burst in the program.

In the sequence of such bursts, the period of time between the instant of the end of one burst (below threshold instant) and the beginning instant of the next (above threshold instant) is defined as the "interburst silent interval" or "*interburst silence*." The duration of the interburst silent interval is the time measured from the "below-threshold instant" of burst one to the "above-threshold instant" of the next burst in sequence (Fig. 2).

A *train of bursts* is defined as a sequence of bursts in time in which the burst repetition rate and interburst silence maximum durations are programmatically (i.e., by the imposed program and/or given programs in the man or the dolphin) defined within a certain range of values and within a certain frequency-of-occurrence distribution (Fig. 3).

The time interval between individual separate trains is defined either in the program, or is to be determined experimentally.

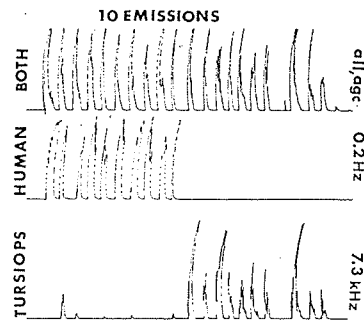


FIG. 4. A train of 10 bursts, man-dolphin. An oscillographic presentation in real time and continuous of a portion of the magnetic tape recording of Expt. 1. The stimuli train of 10 bursts (oIn ot laI tFu kI tFi aIn ki oIl tI) by the human programmer is number matched in the dolphin's vocal output response. In the middle and bottom traces the Hs (middle trace) and Tt (bottom trace) outputs are separately displayed for graphic purposes by two narrow-band filters (Spencer-Kennedy). To cover the wide amplitude range (40 dB), an automatic gain-control circuit was applied to the combined signals and the resulting signal is displayed in the uppermost trace.

In dolphin-human experiments, the human programming is specified by programs arbitrarily assigned to the operator, by those already existing below levels of awareness in the operator, and by those developed between the operator and the dolphin in the experiments. In the case of the dolphin, similar programming exists. Some human and some dolphin programs are already present, others can be created and certain behavioral parts of both recorded experimentally by objective methods. A limited set of these programs are found and described in this paper (the experiments, the results, and the analyses).

III. PROGRAMMING SUBROUTINES

The two dolphins were each separately exposed to human-speech transmissions delivered underwater or in air, formally and informally, several times a day. Between experiments, the feeders spoke loudly in air to the immersed dolphins during feeding, two times per day. At no time was food deprivation a part of the program. The weight of the consumed fish was measured at every feeding for each *Tursiops*. Normal daily food intake was maintained, when needed, by supplementary feedings.

Initially food (fish) was used as a behavior-starting reinforcer. As the program developed, the time of application of this reinforcer was manipulated. In some experiments, the dolphin was fed to satiation prior to the session; later, in other experiments, fish giving (by operator or by machine) was eliminated completely.

For descriptive purposes, the imposed programming techniques are divided into arbitrarily chosen subroutines. In the real situation, these subroutines were used simultaneously or in overlapping sequences.

The first subroutine was designed to increase the incidence of airborne vocalizations and to inhibit the dolphins' natural waterborne emissions. At each

feeding period, the dolphin was given a fish for each airborne sound produced (no matter the type); spontaneous airborne vocalizations were rewarded. Within a few sessions, each dolphin learned to use the airborne mode as a vocal operant.^{14b} All approaches and contacts by the investigators outside of the normal feeding sessions reinforced this behavior.

The second subroutine was designed to select and reinforce the production of only certain kinds of sounds and to extinguish others. Quick extinction of airborne whistles was achieved. In this process, slow and rapid click trains that occurred were rewarded.

The third subroutine selected only the rapid (greater than approximately 100 pulses per second) click trains. The slow clicks were not reinforced and became extinguished to a rare-occurrence level.

The fourth subroutine further selected only those rapid clickings that approached the range of parameters of the human voice. During this programming, the dolphins were exposed to the human voice, speaking very loudly. It was found that gradually the dolphin emitted the desired sounds within the limits of his programs, of the low-frequency end of his hearing spectrum, and the low-frequency end of the spectrum of his sonic output.^{3,4,5,9,15-17} (See also Discussion, below.)

The fifth subroutine selected only those sounds that occurred in response to the immediately preceding voice stimulus—i.e., he was rewarded for producing sounds only after a human voice utterance.

In the sixth subroutine, the sounds emitted were shaped further. The rapid click trains were found to resemble some physical aspects of human speech—e.g., vowel sounds, timing, and intonations of the preceding human utterance.

During Subroutine VII, the human used a paired-syllable list and the number of the dolphin's bursts were programmed to be two for a speech output of two human syllables in each train. For those human syllables that contain more than one burst ("it" for example), the program called for the dolphin to give one burst.

Subroutine VIII called for the dolphin to match a number of syllables (1 to 10) with an equal number of bursts: For the actual performances, see Results.

IV. CHOICE OF VOCAL PROGRAM

In the experiment with Dolphin No. 11, the human-speech output program is constructed from a list of nine vowels and 11 consonants,¹⁸⁻²⁰ arranged in vowel-

TABLE I. The human speech output program is constructed from this list of nine vowels (first vertical column) and 11 consonants (first line of the table) arranged in a vowel-consonant (VC) and consonant-vowel (CV) list. Only the easily pronounceable combinations of these VC and CV "nonsense syllables" were used (187 combinations out of the possible 198 items). This program was utilized for many experiments. From this program a randomized list was developed (see Table II) for the programs used in this paper.

		CONSONANTS										
		r	l	z	v	lʃ	w	m	n	t	k	s
VOWELS OR DIPHTHONGS	i	ir	il	iz	iv	ilʃ	wi	im	in	it	ik	is
		ri	li	zi	vi	lʃi	wi	mi	ni	ti	ki	si
	ɪ	ɪr	ɪl	ɪz	ɪv	ɪlʃ	wɪ	ɪm	ɪn	ɪt	ɪk	ɪs
		rɪ	lɪ	zɪ	vɪ	lʃɪ	wɪ	mɪ	nɪ	tɪ	kɪ	sɪ
	e	er	el	ez	ev	eɪʃ	wɛ	em	en	et	ek	es
		re	le	ze	ve	lʃe	wɛ	me	ne	te	ke	se
	ɛ	ɛr	ɛl	ɛz	ɛv	ɛɪʃ	wɛ	ɛm	ɛn	ɛt	ɛk	ɛs
		rɛ	lɛ	zɛ	vɛ	lʃɛ	wɛ	mɛ	nɛ	tɛ	kɛ	sɛ
	a	ar	al	az	av	aɪʃ	wɑ	am	an	at	ak	as
		ra	la	za	va	lʃɑ	wɑ	mɑ	nɑ	tɑ	kɑ	sɑ
	o	or	ol	oz	ov	oɪʃ	wɔ	om	on	ot	ok	os
		ro	lo	zo	vo	lʃo	wɔ	mo	no	to	ko	so
	u	ur	ul	uz	uv	uɪʃ	wu	um	un	ut	uk	us
		ru	lu	zu	vu	lʃu	wu	mu	nu	tu	ku	su
	ai	air	aɪl	aɪz	aɪv	aɪlʃ	wɑɪ	aɪm	aɪn	aɪt	aɪk	aɪs
		rai	lai	zai	vai	lʃai	wɑɪ	mai	nai	tai	kai	sai
	oi	oir	oil	oiz	oiv	oilʃ	wɔɪ	oɪm	oɪn	oɪt	oɪk	oɪs
		roi	loi	zoi	voi	lʃoi	wɔɪ	moi	noi	toi	koi	soi

consonant (VC) and consonant-vowel (CV) pairs (Table I). Only the easily pronounceable combinations in General American language are used (187 out of 198 items). Two sets of this population of "nonsense syllables" are arranged.

The first list gives the CV and VC pairs in a systematic order (Table I). The second list was constructed from a randomized arrangement of the CV and of the VC syllables. This randomized set was divided up into subsets of syllables containing from 1 to 10 syllables. The order of these subsets was randomized (Table II).

The investigator read the first list to the *Tursiops* in a loud, natural voice. (Later, a tape recording of the reading voice was used.) Initially, the rate of the presentation of syllables in the human-speech output during each train was paced by a small light flashing once every 0.7 sec within the visual field of the reader.

In the first experimental series, the list of Table I was used, with Subroutines V-VII. The programming called for extinction of other sounds by withholding reward. When the production of whistles and slow pulsing trains was reduced to a small fraction of the number of the humanoid sounds produced, no further extinction was demanded.

Once the dolphin followed the "two-bursts-for-two-syllables" rule (Subroutine VII), he was programmed with Subroutine VIII with the second list (Table II). If, in the judgment of the phonetically untrained human operator, the dolphin failed to match burst number to syllable number, Subroutine VII was reinstated briefly before returning to Subroutine VIII.

¹⁵ W. N. Kellogg, *J. Comp. Physiol. Psych.* 46, 446-450 (1953).
¹⁶ W. E. Schevill and B. Lawrence, *J. Exptl. Zool.* 124, 147-165 (1953).
¹⁷ C. S. Johnson, *NOTS TP* 4178, 1-27 (1966).
¹⁸ G. A. Miller, *Language and Communication* (McGraw-Hill Book Co., New York, 1951) p. 298.
¹⁹ R. K. Potter, G. A. Kopp, and H. C. Green, *Visible Speech* (D. Van Nostrand Co., Inc., New York, 1947), p. 433.
²⁰ H. Fletcher, *Speech and Hearing in Communication* (D. Van Nostrand Co., Inc., New York, 1953), p. 461.

TABLE II. Example of human program and phonetic output analysis (Session 5). The first line of each numbered group is the syllable read by the operator. The second line is the IPA symbols for the items of the first line. The third line is the transcribed version of the recorded output of the operator. The human-speech output program for Expt. 5 is composed of 38 stimulus trains. The number of bursts in each train varies from 1 to 10. This randomized list was developed from the VC and CV list shown in Table I. Each stimulus train has been numbered in the order of presentation. The second line is the Hs stimulus program. These IPA symbols were transcribed (Line 1) for the Hs operator's convenience to facilitate reading from list. Line 3 is the Hs speech output program transcribed from the magnetic-tape recording of the experiment.

1.	in ɪn ɪn	oal ul ul	oom um um							
2.	at ət ət	ree ri ri								
3.	oyn oɪn oɪn	oat ot ot	lye lɪɪ lɪɪ	chew tʃu tʃu	kih kɪ kɪ	chee tʃi tʃi	ine aɪn aɪn	key ki ki	oil oɪl oɪl	tih tɪ tɪ
4.	en en en	ane en en	eat it it	ayer er er	noo nu nu	we wi wi	ate et et	chay tʃe tʃe	moe mo mo	
5.	ta tə tə	rah rə rə								
6.	oh o o	lee li li	vay ve ve	coy koɪ koɪ	aim em em					
7.	woe wo wo	moo mu mu	itch itʃ itʃ	wye waɪ waɪ	wih wi wi	moy moɪ moɪ	ehh e e			
8.	oys oɪs oɪz	air aɪ ɹ	eem im im	sey se se						
9.	ett et et	ighch aɪtʃ ɹɪtʃ	ace es es	eel il il	ah ə ə					
10.	oot ut ut									
11.	roy roɪ roɪ	kah kə kə	ovv av av	kehk ke ke	oyv oɪv oɪv	noy noɪ noɪ	rye raɪ raɪ	nigh naɪ naɪ	ootch utʃ utʃ	
12.	mih mi mi	eek ik ik	ease iz iz	tay te te	zee zi zi					
13.	lih lɪ lɪ	və və və	ole ol ol	ni ni ni						
14.	eyes aɪz aɪz	ee i i	otch otʃ otʃ							
15.	ah ə ə	ass as as	oyer oɪr oɪr	oy oɪ oɪ						
16.	kay ke ke	lieu liu liu	ick ɪk ɪk	so so so	etch etʃ etʃ					
17.	teh tɛ tɛ	nitch etʃ etʃ	l've aɪv aɪv	zi zɪ zɪ	cha tʃə tʃə	me mi mi	choy tʃoɪ tʃoɪ	oo u u		
18.	oak ok ok	i ɪ ɪ	loy loɪ loɪ	vio vaɪ vaɪ	see si si	chi tʃɪ tʃɪ	rih rɪ rɪ	ose os oz		
19.	toy toɪ toɪ									

continued on p. 1417

For each number-matching response, the dolphin was rewarded with a fish. The number of seconds of time delay between the end of the dolphin's reply and the presentation of the fish were randomized. [This instruction avoided the use of this event as a "stop signal" by the dolphin—i.e., as a signal to terminate the dolphin's series of sonic bursts (see Discussion).]

The experiments reported here are those using the syllable subsets in randomized orders (Table II). Various control procedures to avoid the transmission of information to the dolphin other than by the vocal mode were done. Elimination of the food reward was achieved. The investigator was removed from the room; tape-recorded human speech outputs and a mechanical

fish dispenser were substituted for the operator. Thus, undesired sonic, visual, and tactile sources of guides for starts, rates, durations, and stops were eliminated (cf. Ref. 21).

The experiments with Dolphin No. 26 were carried out with simple English words and phrases. Intensive sessions were carried out over a period of 2 yr. After the initial contacts and interlock were established, no food reward was used. The vocal output in air of the

²¹ O. Pfungst, *Clever Hans (The horse of Mr. Von Osten). A Contribution to Experimental Animal and Human Psychology*, C. L. Rahn, Translator (Henry Holt and Co., New York, 1911). Also O. Pfungst, *Clever Hans*, R. Rosenthal, Ed., *The Horse of Mr. von Osten* (Holt, Rinehart and Winston, Inc., New York, 1965).

SONIC-BURST COUNT MATCHING IN DOLPHIN

TABLE II—(continued)

20.	<i>aze</i> øz øz	<i>coo</i> ku ku	<i>ees</i> is iz	<i>ir</i> ɪr ɪr	<i>eve</i> iv iv	<i>oll</i> əl əl	<i>l'm</i> aɪm aɪm			
21.	<i>it</i> ɪt ɪt									
22a.	<i>may</i> me me	<i>own</i> on on	<i>im</i> ɪm əm	"correction"						
22.	<i>may</i> me me	<i>own</i> on on	<i>im</i> ɪm ɪm	<i>wah</i> wɑ wɑ	<i>an</i> ən ən	<i>toe</i> to to	<i>kie</i> kaɪ kaɪ	<i>meh</i> me me	<i>ai</i> aɪ aɪ	<i>ray</i> re re
23.	<i>ees</i> is iz	<i>ooze</i> uz uz	<i>or</i> or or							
24.	<i>zeh</i> ze ze	<i>iss</i> ɪs ɪz								
25.	<i>knee</i> ni ni	<i>are</i> ɑr ɑr	<i>ite</i> aɪt aɪt	<i>reh</i> re re	<i>row</i> ro ro	<i>ove</i> ov ov				
26.	<i>ma</i> mɑ mɑ	<i>is</i> ɪz ɪz	<i>too</i> tu tu	<i>zoo</i> zu zu	<i>een</i> in in					
27.	<i>eer</i> ir ɪr	<i>ev</i> ev ev	<i>oyt</i> oɪt oɪt	<i>veh</i> ve ve	<i>la</i> lə lə	<i>no</i> no no				
28.	<i>ice</i> aɪs aɪs	<i>sa</i> sɑ sɑ	<i>ek</i> ek ek							
29.	<i>vee</i> vi vi	<i>ire</i> aɪr aɪr	<i>each</i> iɪʃ iɪʃ	<i>zye</i> zɑɪ zɑɪ	<i>voy</i> voɪ voɪ	<i>vous</i> vu vu	<i>atch</i> ætʃ ætʃ			
30.	<i>oove</i> uv uv	<i>soy</i> soɪ soɪ	<i>iv</i> ɪv ɪv	<i>choe</i> tʃo tʃo	<i>ack</i> æk æk	<i>zah</i> zɑ zɑ	<i>sue</i> su su	<i>si</i> sɪ sɑɪ		
31.	<i>oon</i> un un	<i>oyk</i> oɪk oɪk	<i>leh</i> le le	<i>rue</i> ru ru	<i>tie</i> taɪ taɪ	<i>chie</i> tʃaɪ tʃaɪ	<i>my</i> maɪ maɪ			
32.	<i>cheh</i> tʃe tʃe	<i>ohm</i> əm əm								
33.	<i>nay</i> ne ne	<i>la</i> lə lə	<i>lay</i> le le	<i>omm</i> əm əm	<i>ache</i> ek ek	<i>ika</i> aɪk aɪk	<i>ale</i> el el	<i>isle</i> aɪl aɪl	<i>ell</i> el el	<i>zoe</i> zo zo
34.	<i>oze</i> oz oz	<i>way</i> we we	<i>oyz</i> oɪz oɪz	<i>av</i> əv əv	<i>vih</i> vɪ vɪ	<i>voe</i> vo vo	<i>woy</i> woɪ woɪ	<i>as</i> ɑs ɑs	<i>em</i> em em	
35.	<i>nah</i> nɑ nɑ									
36.	<i>oos</i> us uz	<i>neh</i> ne ne	<i>tea</i> ti ti	<i>woo</i> wu wu	<i>zay</i> ze ze	<i>oym</i> oɪm oɪm				
37.	<i>sigh</i> saɪ saɪ	<i>oych</i> oɪʃ oɪʃ	<i>seh</i> se se	<i>oake</i> uk uk						
38.	<i>ill</i> ɪl ɪl	<i>zah</i> zɑ zɑ	<i>oor</i> ur ur	<i>ezz</i> ez ez	<i>koe</i> ko ko	<i>weh</i> we we				

dolphin was shaped to a closer approximation of the human-speech output. The operator raised her pitch near the magnitude to which he had lowered his formantlike frequencies and pitch. Overlap of the pitch and of the formants of the female human-speech output and the male dolphin output were achieved (see Results).

V. RESULTS

The tape-recorded materials of the Hs (human) and Tt (dolphin) outputs from the two sets of experiments were analyzed by various methods for number of bursts per train, burst timing, frequency spectrum, and pulsing rates.

The first analyses were generated by an acoustic monitoring of the taped sessions. The number of bursts in the Hs train and the number of bursts in the Tt

response train were counted. Several observers counted what they heard with the tapes played back at either normal speed or at slowed down speeds (2X to 32X). Independent counts were made from oscillographic recordings of the rectified and integrated envelopes of bursts, with the full passband and with bands isolated with various high-pass and low-pass filters. Counts were also made from spectral records (sonagrams). The primary recorded waveforms displayed on a storage cathode-ray oscilloscope were also used to count bursts.

Figure 3 shows a typical oscillographic recording of part of Expt. 5 of the Hs bursts and the Tt bursts. Each separate envelope is defined by its ends (below 30 dB from peak). The man emits five bursts and the dolphin emits five; the man emits four and the dolphin emits four; the man emits three and the dolphin emits

three. In Fig. 4 is shown another part of the same experiment, a train of 10 bursts by the man, and a train of 10 bursts in the response of the dolphin.

Figure 5 shows an oscillographic record of Expt. 5, in which the dolphin matches number of bursts with few errors. Thirty-eight Hs trains and 38 Tt trains were recorded. (Table II gives the nonsense-syllable

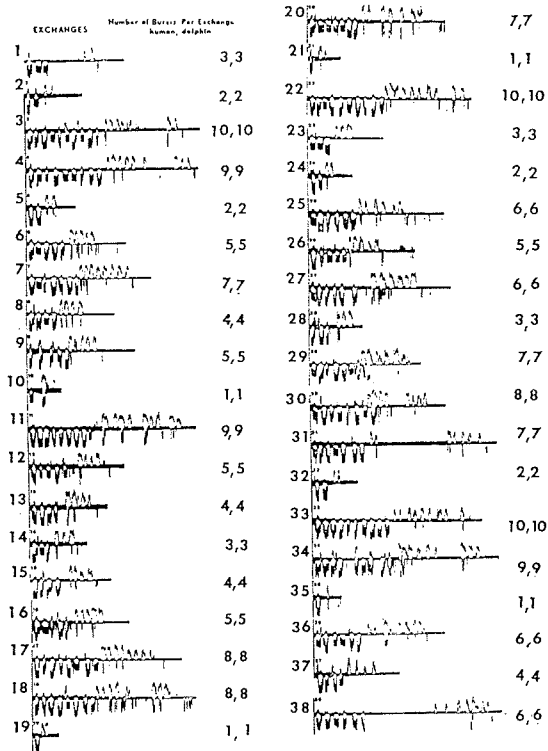


FIG. 5. An oscillographic record of a train of 38 human (Hs) vocal output stimuli trains and 38 dolphin (Tt) vocal-train responses from the magnetic-tape recording of Expt. 5 developed in real time. The Hs and Tt outputs have been separated for graphic purposes by narrow-passband filters and their rectified signal (General Radio model GR1142A) output displayed. The Hs output was filtered using an Allison model 2DR set between 300 Hz L.P. 30 dB/oct and 780 Hz H.P. at 30 dB/oct. The Tt output signal was filtered using an SKL 302 set at 5 kHz H.P. at 18 dB/oct and 5 kHz L.P. at 18 dB/oct. The Hs output generally appears in the downward galvanometer deflection at the beginning of each trace (presentation of each train of stimuli which varies in numbers of bursts from 1-10) and the Tt output in the upward deflection of each trace sequential to the Hs train (except in those instances of Tt overlap and in those instances when the energy distribution of peak partials and frequencies in an Hs or Tt burst are such that they also appear in the other channel). The specific vocal program utilized in this experiment is displayed in Table II. (See also Fig. 17.) The numbers after each trace refers to the burst count by a phonetician: for the human (first number) and for the dolphin (second number). In Presentations 7, 19, 36, and 38, an untrained observer counting nonsense syllables instead of bursts gave a score of one less than the correct value for the human, thus generating "dolphin errors" artificially. In certain instances in the above graphic recording, some of the dolphin's responses that are audibly detectable above the noise level of the tape, do not give large enough responses to be seen on the photographically reproducible record—e.g., in Presentation 3, a listener counts 10 bursts in the dolphin's vocal output. An additional source of error in the graphical presentation is that extraneous noises such as water splashes caused deflects that must be eliminated in the burst counts.

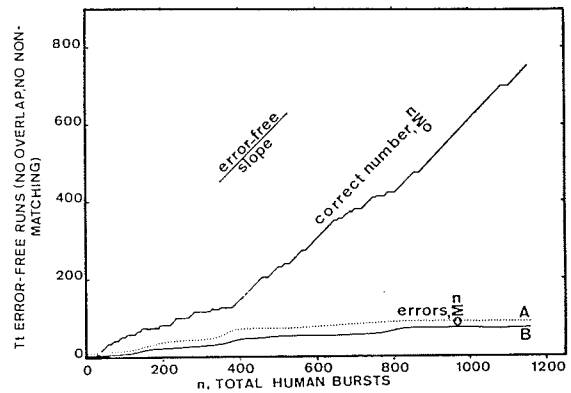


FIG. 6. The results of analysis of the dolphin's ability to match number of bursts are summated over six experiments using a vocal program developed from Table I and represented by Expt. 5 in Table II. Curves A and B are represented 10 times enlarged on the vertical scale in Fig. 7. Error-free number of burst matching increases with exposure to the program. Each successful response is plotted as a quantum jump on the Y axis and the X axis. When an error is made on the main curve, it is stepped one on the X axis and zero on the Y axis. The error curves (A and B) are stepped zero on the Y axis when there is no error, and for each response train with an error is stepped one on the Y axis and on the X axis. \sum_0^n is the summation from response train₀ to the response train_n.

list used as stimuli). (Figure 17 shows some detail of Train 22 not shown here; see Sec. VI).

Figure 6 shows the time course for six such experiments of the acquisition of the ability to match number of bursts. It is to be noticed that the error-free runs increase in duration with further exposure to the program.

Figure 7 shows the dolphin's errors on a vertical scale enlarged 10 times over that of the previous figure.

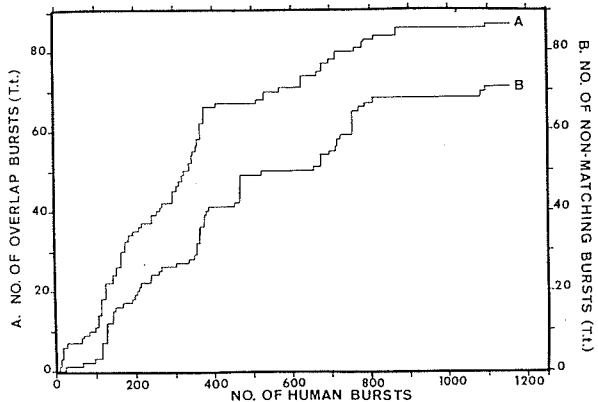


FIG. 7. The results of analysis of the dolphin's errors are summated over six experiments using a vocal program developed from Table I and represented by Expt. 5 in Table II. Two kinds of errors are plotted: Curve A represents Tt's vocal output response as events when they overlap the Hs vocal output train of stimuli either during a burst or an interburst silence; Curve B represents Tt's mismatch in response to every burst of each Hs stimulus train. Error Curves A and B demonstrate that initially the dolphin has a random distribution of errors; later runs show an alternation in type of error; there are error-free runs first of one kind, then for the other, and finally for both. (See also Fig. 6 where these two error curves are represented on a vertical scale one-tenth this size.) Curve A represents a total "overlap" burst error of 7.16% and Curve B a 6.21% "nonmatching" burst error.

SONIC-BURST COUNT MATCHING IN DOLPHIN

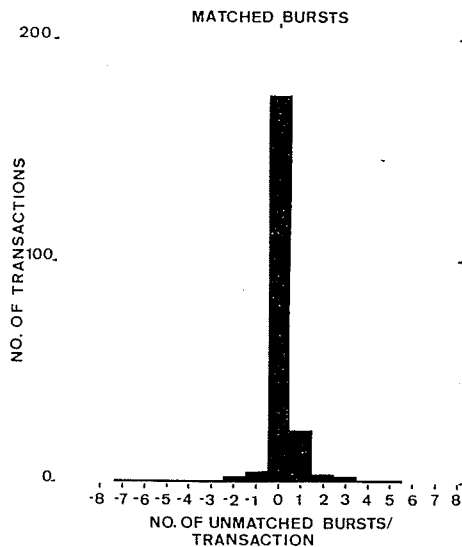


FIG. 8. Dolphin's success-error distribution curve by naive listening tests for six experiments on one dolphin using a vocal program developed from Table I and represented in Table II. *Abscissa*: zero position is the correct number of bursts per train of stimuli; plus numbers represent numbers of bursts above those in stimulus train; minus numbers represent deficiency in number of bursts by the dolphin in response to Hs stimulus train. Analysis by naive observers who count "nonsense syllables" rather than objective bursts. This important source of error was corrected by a phonetician, and by coordinated CRO observations (storage scope) and listening tests (Fig. 9).

Two kinds of errors are plotted. Error A is the overlapping of the human delivery time by the dolphin—i.e., putting bursts in the interburst intervals during the time the human is speaking. Error B is mismatch of number of Hs bursts and Tt number of bursts. From these two figures, it can be seen that the dolphin at the beginning has a more-or-less random distribution of errors. Later runs show alternation in type of error; there are error-free runs first for one kind of error, then for the other, and finally for both.

Figures 8 and 9 show a summated success-error distribution curve for six experiments as measured by objective methods and by listening tests.

During these experiments, normal nonprogrammed Tt outputs (such as slow clickings and whistlings) were not included in the statistical data.

Further analyses of the dolphin's sounds and of the human speech include sonic spectrograms prepared on both voices covering 85-Hz to 8-kHz ranges, both narrow and wide band (45 and 300 Hz). Figures 10(a) and 10(b) show a sample sonic spectrogram of the human voice and of the dolphin's reply.

These spectrograms plus sections at chosen times were then analyzed for (1) pulsing rate (45- and 300-Hz analyzing filters) and (2) peak partials of the fundamental that showed maximum amplitudes (formants and formantlike occurrences). The instants of time for the analyses were chosen during vowel production by

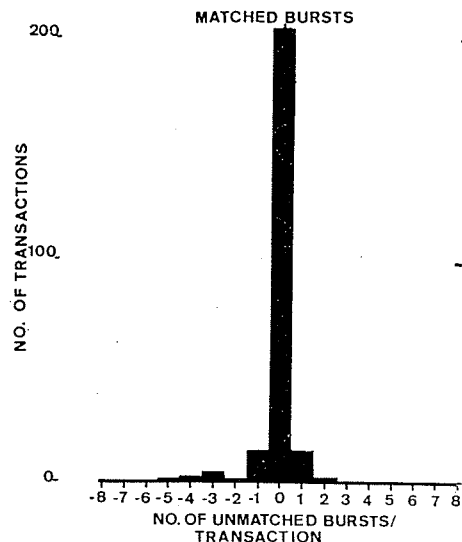


FIG. 9. Dolphin's (Tt) success-error distribution curve by objective and by listening tests for six experiments using a vocal program developed from Table I and represented in Table II. Analysis by listening tests by trained observers who count bursts rather than nonsense syllables and by objective methods. (See also Fig. 8.)

the human and during corresponding periods of relatively steady-state activity in the dolphin's record.

These measurements are plotted as shown in Fig. 11. The source pulsing-rate values (in the human case, laryngeal pulsing, or pitch) are plotted along the X axis (log scale). Log frequency is plotted on the Y axis, showing the frequency of each of the partials above the fundamental for varying values of the fundamentals. The maximum amplitude partials (peak partials) were selected at a given instant of time and are represented by dots (human) or rectangles (dolphin) plotted at the location of each peak partial on the log-log plot.

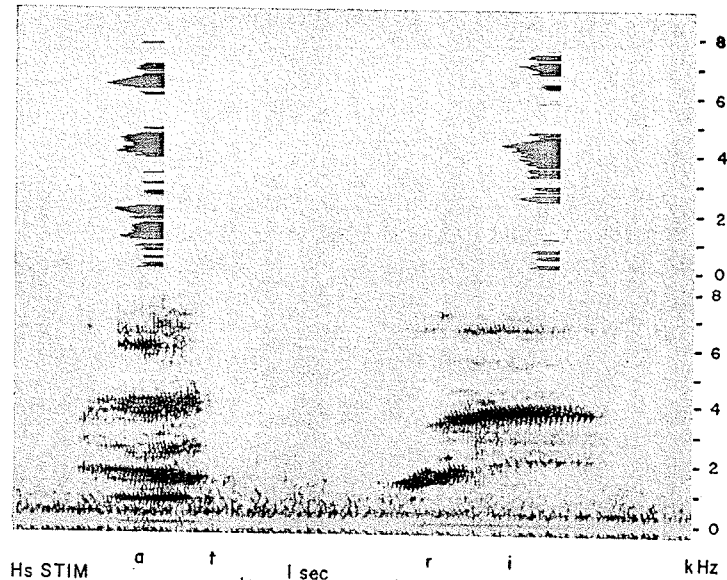
Figure 11 shows the Tt's output to occur at higher values of pulsing rate and higher frequencies of the peak partials ("resonance") as compared with that of the Hs outputs.

Figure 12 shows a population of 120 corresponding human male and dolphin male sounds taken late in the programming sequence. The period of the experiments chosen is that in which the dolphin was giving correct numbers of bursts matching the numbers of human bursts, and is chosen from corresponding human and dolphin trains.

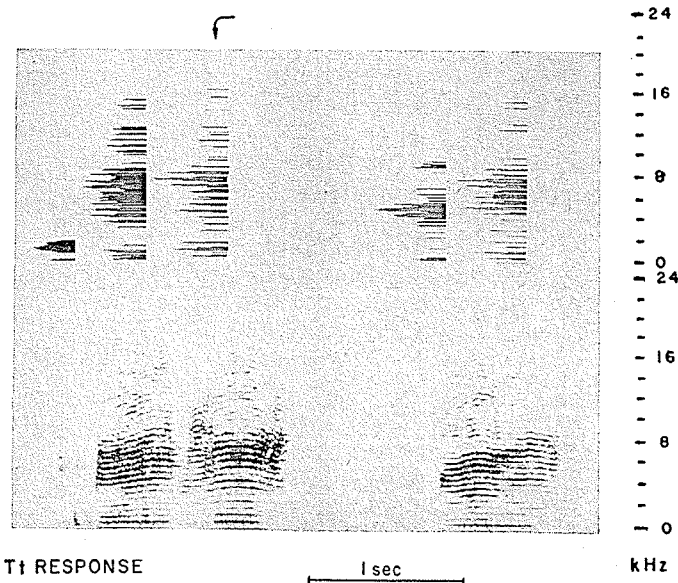
Figure 12^{22,23} thus shows the corresponding parametric regions of the human vowel sounds and the sounds emitted by the dolphin. Notice the separation of the parametric regions of the two voices.

²² G. Fant, "Acoustic Analysis and Synthesis of Speech with Applications to Swedish. Ericsson Technics No. 1. p. 108 (1959).

²³ H. M. Truby, "Acoustical-Cineradiographic Analysis Considerations" *Acta Radiol. Suppl.* 182, 199, Fig. 2-64 (1959).



(a)



(b)

FIG. 10. Sample of technique for sound spectrographic and sectioner display of two syllables "at ri" here defined as two bursts of the Hs stimulus train [the Tt response is portrayed in Fig. 10(b)]. The sonic analysis was prepared from the magnetic-tape record of Expt. 5 in real time using the narrow-band (45-Hz) analyzing filters covering the ranges from 85 Hz to 8 kHz. The sectioner (amplitude) display [upper portion of Fig. 10(a)] covers the same ranges. Six peak partials are visible in "at"; there are three in "ri." For the analysis plotted in Fig. 11, additional sections were made and the peaks counted (not shown). (b). Sound-spectrographic and sectioner display of two Tt bursts, the dolphin's voice output response to the Hs stimulus train "at ri" [see Fig. 10(a)]. The sonic analysis was prepared from the magnetic-tape record of Expt. 5 at a speed 2X slowed (using the narrow-band 45-Hz analyzing filter) covering the ranges from 85 Hz to 12 kHz (170 Hz to 24 kHz from the record). The sectioner (amplitude) display [upper portion of the Fig. 10(b)] covers the same ranges. The symbol close to the center at the top of the Figure indicates a displacement of this amplitude spectrogram to the left when relating it to the spectrogram in the lower portion of the Figure. The numbers of peak partials shown for each section from left to right are 2, 19, 10, 7 and 10. Other sections (not shown) were used for Fig. 11.

As a consequence of these measurements, a program was instituted to use the female human voice in vocal interlock with another dolphin (No. 26). The rationale employed was that the human female voice is higher pitched (has a higher fundamental source pulse rate) and has somewhat higher peak partials (formant frequencies) than the male human voice. Figure 13 shows some of the results after 2 yr of programming. It was found that the human female moved her voice up toward the pulsing rate and peak-partial frequency regions of the programmed dolphin.

VI. DISCUSSION

A. Channel Limits

Figure 14 summarizes the communication channels used in these experiments. The human (1) and the dolphin (5) are information transmitters and receivers with quite different characteristic ranges of hearing (4, 8) and of sonic outputs (2, 6). The human operator transmits bands of frequencies (2) only some of which he is aware (8, 1) and hence controlled by his own hearing feedback (1, 2, 8). The dolphin receives some of these bands, modified by the physical means of

SONIC-BURST COUNT MATCHING IN DOLPHIN

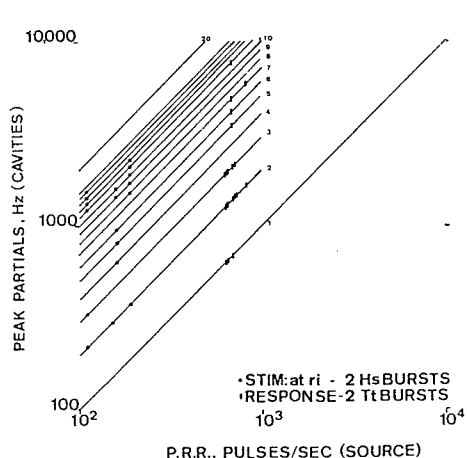


FIG. 11. Parametric analysis of the source pulsing-rate values are plotted along the X axis (log scale) and the log frequency is plotted along the Y axis showing the frequency of each partial (peak partials) varying fundamental frequencies (cavity resonances). The Hs speech output program is a stimulus train consisting of two syllables (bursts) "at ri." The sonic analysis of the vowels are represented by the black dots. Tt No. 11 voice response train with its two bursts is represented by the black rectangles. The distinctly isolated regions between the Hs (male) programmer's pitch and the Tt's response is readily apparent; no overlap is evident.

transmission (3), and his own hearing ranges (4). The dolphin (5) computes on the basis of this modified input, and transmits a sonic output (6) controlled by his own hearing feedback from that output (6, 4, 5). This output (6) then passes through the physical modifiers (7). The human operator (1) hears this output (6, 7) with modifications through his hearing-range limits (8), through his hearing- and pattern-recognition programs (1, 8). These multiple-feedback loops through the human and dolphin biocomputers (Ref. 24) established the limits for the results observed in these experiments.

Figures 15 and 16 illustrate quantitatively some of the physical and psychophysical limits on these feedback loops. The human-speech output covers a much higher range of frequencies than the hearing detects. The dolphin's hearing detects the higher human output frequencies, but probably not the lower ones (Refs. 17, 25-28, and Lilly, unpublished data).

The dolphin's sonic output covers a range as large as (if not larger than) his hearing. The very high frequencies in the dolphin's output are not detected by the human hearing. The loop-shared regions are shown in Fig. 16, as well as the regions that are only human

²⁴ J. C. Lilly, "The Human Biocomputer. Theories of Programming and Metaprogramming," CRI Scientific Rept. No. CRI-0167 (1967).

²⁵ J. F. Corso, *J. Acoust. Soc. Am.* 35, 1738-1743 (1963).

²⁶ J. Zwillocki, *J. Acoust. Soc. Am.* 29, 795-804 (1957).

²⁷ W. E. Montague and J. F. Strickland, *J. Acoust. Soc. Am.* 33, 1376-1381 (1961).

²⁸ J. C. R. Licklider, "Basic Correlates of the Auditory Stimulus," in *Handbook of Experimental Psychology*, S. S. Stevens, Ed. (John Wiley & Sons, Inc., New York, 1951).

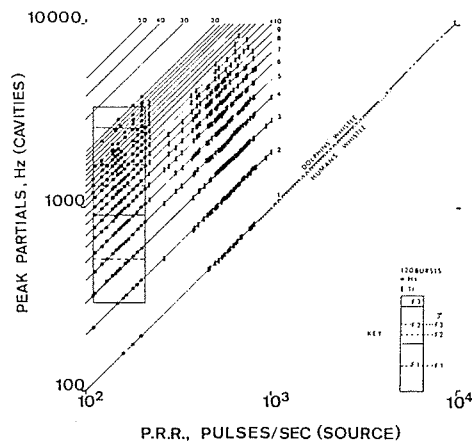


FIG. 12. The Hs speech-output program for this display was selected at random from the experiments developed from Table II. The 120 bursts selected (Hs and Tt No. 11) for analysis were extracted from matching trains (stimulus and response) in the experiment. (●) represents the Hs vowel output and (■) the Tt voice responses. (See Fig. 11 for parameters.) Key in lower right shows the human speech-formant regions for the first, second, and third. (Key—see Refs. 22 and 23.)

detected, only dolphin detected, and not detected by either.

B. Reprogramming Mode of Transmission

The sound-producing mechanisms in the dolphin operate naturally underwater with a closed blowhole. In these experiments, the dolphin's ability to open the blowhole and make airborne sounds is selectively programmed and thus forces the phonatory apparatus to function in another mode in vocal-acoustic interlock with another organism. That the dolphin adapts to

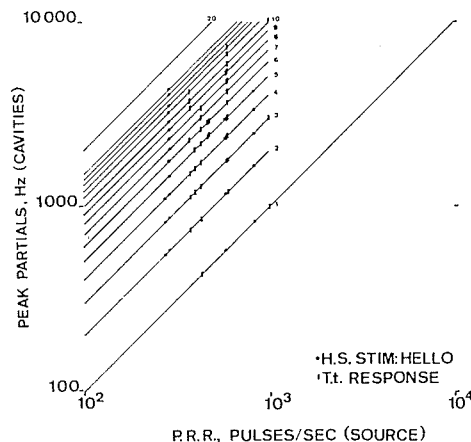


FIG. 13. The Hs speech-output program stimulus train analysis was "hello" (●) and (■) is the analysis of Tt No. 26's voice output response. In this program analysis, it is demonstrated (compare with Figs. 11 and 12) that the Hs (●) output (pitch) and the Tt response overlap in the frequency ranges. In this experiment, the pitch of the Hs (female) voice output has been raised and overlaps the dolphin's. In a sense, the dolphin's high-pitch reprogrammed the Hs female voice to unusually high values (up to 800 Hz). (See Fig. 11 for parameters.)

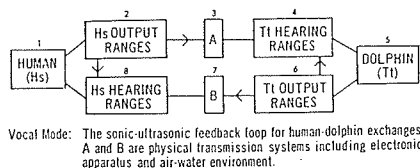


FIG. 14. Vocal-mode flow diagram for (Hs) and dolphin (Tt) vocal programming. Hs and Tt are both confined on the input and output side by (3) and (7)—the physical transmission systems including electronic apparatus and the air-water environment. The Hs programmer (1) has specific vocal output ranges (2) and vocal-input ranges (dependent upon his hearing curve) that effect the programming of Tt (5). Tt, on the other hand, is restricted by the effects of his hearing curve on the input side and his vocal-output ranges. Cognizance of this interlock system in the programming is essential in the analysis-interpretation of every experiment. (See Fig. 15 for hearing curves, and Fig. 16 for vocal-output curves.)

this mode of signaling with man is shown in these experiments. It is also shown that the dolphin can be programmed (within determinable limits) to reproduce some physical aspects of the human-speech output. In spite of the natural use of a band of frequencies approximately ten to twenty times that normally utilized in the human voice range, the dolphin can shape up the transmissions in the lower end of his output frequency spectrum. His hearing curve (and probably his frequency-differentiation threshold) extend into the upper portion of the human-speech frequency spectrum; therefore probably in a limited way he can hear human speech (Figs. 15 and 16).

C. Start and Stop Signals

What guides does the *Tursiops* use to initiate the vocal response at the correct time? Latencies between the end of the Hs train and the beginning of the dolphin response were measured.

The values of these latencies fall within the distribution curve of the values of the interburst silent intervals in the human presentation. On the average, the dolphin

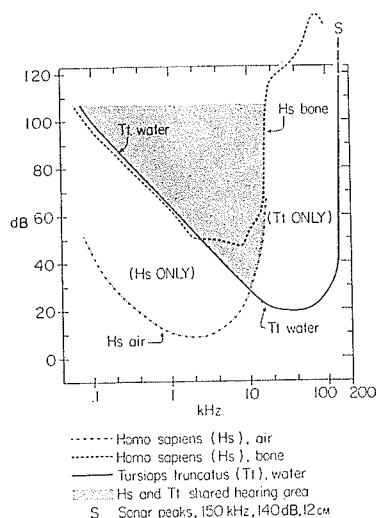


FIG. 15. Comparison of the human (Hs) sonic and dolphin (Tt) sonic and ultrasonic hearing curves in air and in water plotted from the data developed by Lilly, Corso, Zwislocki, Johnson, and Montague (see Refs. 17, 25-28). Only a limited narrow band of frequencies is shared and consequently defines some limits of (2) through (8) in the vocal-mode flow diagram (Fig. 14) (decibels re 0.0002 dyn-cm² peak pressure).

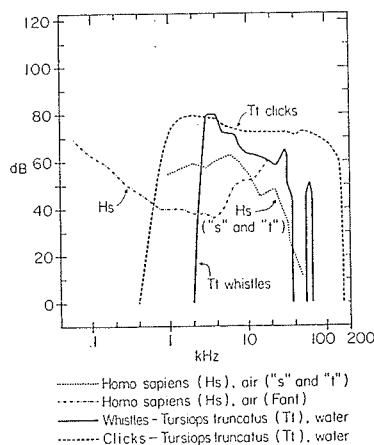


FIG. 16. Comparison of the sonic and ultrasonic vocal output curves of the human (Hs) in air and the dolphin (Tt) in water. The Hs curve (....) represents sonic-ultrasonic high-frequency energy for the consonants "s" and "t". The Hs curve (-.-.-) represents Fant's vowel and consonant 40-phon equal-loudness contour curve (Ref. 22) (decibels re 0.0002 dyn/cm² peak pressure).

tended to start his replies with a latency approximately the same as that of the interburst intervals in the human trains (Figs. 3, 4, and 5). How he is able to do this is not clear. It is probable that the dolphin picks up clues from some special modifications of the human voice for the last items in a train. No effort was made to control the voicing of the human reading from the list—i.e., the male investigator gave the usual list-reading-intonation to this presentation. For example, he often used a falling pitch on the last item of each train. It is probable that the dolphin developed a pattern-recognition program for this change (and possibly for others).

As in the case of the counting horse (Clever Hans, Ref. 21), the investigator may have been giving visual or adventitious sonic clues to the dolphin for matching the given number of bursts in a train. As in the case of the horse, a "start signal" for the repetitive trains of bursts and a "stop signal" to finish at the correct number may have been transmitted by the investigator below his threshold for awareness. As a control on these possibilities, the material was recorded on magnetic tape and the investigator was moved out of the visual and acoustic detection environment of the dolphin. The experiment programmed from the tape gave results similar to the ones reported above. It was found that no detectable clues other than those given by the taped voice were necessary for the dolphin's accurate performance.

To estimate the influence of the presentation of the fish as a start, stop, or timing signal, and to eliminate the fish as a physiological reward, experiments were carried out immediately after the dolphin was fed to satiation. During these experiments, when presented with a fish the dolphin accepted it, allowed it to drop to the bottom of the side arm, and thus accumulated a pile of fish during the session. (At this stage, the fish giving and receiving were still part of the program.) When the dolphin wished to terminate the experiment, he lifted a fish on the end of his upper jaw and either threw it out of the side arm or moved it toward the investigator. Random reinforcement schedules were

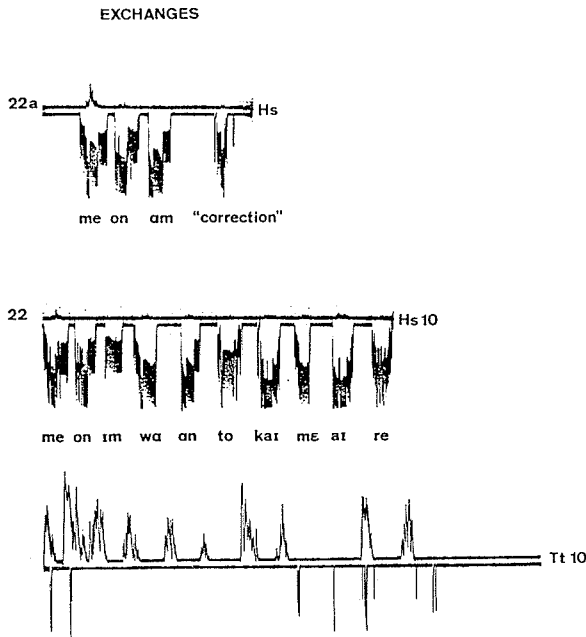


FIG. 17. An oscillographic record from the magnetic-tape recording of Expt. 5. There has been no editing or cutting from the onset of 22A to the end of 22 except for display purposes. In Fig. 5, the graphic display of stimulus-train 22 (10 Hs bursts) and Tt's voice output (10 Tt bursts) responses have been included, whereas trace 22A was not. This example illustrates the dolphin's acoustic-storage and pattern-recognition ability that enabled him to respond only to the correct Hs stimulus train with the correct number of matching bursts. (See Fig. 5 for parameters used to develop graphic display.)

successful. Complete elimination of the giving and receiving of fish was also successful, thus the reinforcing and cueing possibilities of the fish were eliminated.

D. Counting or Recent Acoustic Memory?

Several working hypotheses were developed during these experiments. Of all of the processes the dolphin may be using to respond with the correct number of bursts there are at least three of importance: conditioned programs, "counting," or straight readout from recent acoustic storage. The concept of conditioned programs can be analyzed further and shown to be equivalent to one or both of the others or is a name for unknown processes at present unanalyzable.

The dolphin may "count" the number of bursts heard and put out an equal number. One way that the dolphin could indicate that he knows that the experimenter expects an equal number of bursts would be for him to give back an equal number of bursts of simple sonic structure—i.e., even to the point of making each of his bursts in the train very similar. If this were the case, one might expect all of his sounds to be similar, if not identical. However, the dolphin's bursts in a number-matching train are distinguishably different in pitch contours, durations, interburst silences, and com-

plexity of patterning. The last burst of each of his trains has a characteristic patterning. These variations favor the recent-acoustic-memory playback hypothesis over the counting one. To count bursts, a very brief acoustic memory span is needed with a quick registration of the count for the summed total; in the playback hypothesis, there is a longer memory span; there is storage of the whole train (up to 10 items) and subsequent playback of the output equivalent of the stored acoustic image of the whole train. The latter process makes possible a more complex patterned output than a repetitive reproduction of a train of, say, clicks, of the same number as in the human train. In addition, on listening tests it has been found that there are resemblances when comparing *corresponding bursts* in the human train and the dolphin's response train despite differences within the train. At times, there are resemblances (though in different frequency and pitch regions) between the patternings of the human and the dolphin. Further work needs to be done in this area to determine what parameters the dolphin is mimicking.

Additional complex behavior occurred during many of these experiments. For example, in the session with Tt No. 11, it was noted that if the human corrected his output after he made an error that the dolphin matched only the corrected version of the output. Figure 17 shows an example of such an occurrence. (In Fig. 5, the rest of the session is shown with Line 22a of Fig. 17 left out.) The programmer (Hs) says (Line 22a) "me, on, am," hesitates and says "correction" and starts over, giving "me on Im wa an to kaI me aI er," i.e., a train of 10 nonsense syllables (Line 22 of Fig. 5). The dolphin (Tt) replies with only 10 bursts, the total number in the train of the corrected version, with no reply to the previous three bursts ("me on am") or the word *correction*. Similar events are frequent enough to lead to the hypothesis that the dolphin has learned (at the very least) to recognize that pattern that is to be matched (stimulus) and that which is to be ignored (instructions, corrections, deletions). What clues Tt uses for this selection are at present obscure.

The dolphin (No. 26) working with the female human programmer learned to reproduce only the Hs output given in an emphatic loud voice and did not match asides, instructions, laughter, etc.

One aspect of these experiments that is considered to be important is the initiation and termination of a session by the behavior of the dolphin. If, at the beginning of the experiment, the dolphin did not swim into the side arm he was left alone in isolation (visual and tactile), solitude, and confinement for a few minutes. A second attempt was then made, and if he did not come into the side arm at that point, he was isolated further for an hour or more. All the above experimental runs were made when the dolphin was ready to start.

Similarly, each experiment was terminated by the dolphin. During a given run, the dolphin may stop vocalizing and back out of the side arm into his home

tank. If this happened, the investigator waited for a short period (5 min); if the dolphin did not return in that time, the investigator (in a loud voice) said that the experiment was over and left the room. With this technique, three experiments were scheduled each day.

Signs of fatigue in the dolphin during an experiment were shown by decreased amplitudes of the Tt output. At times, by using proper shaping-up techniques, the amplitude could be restored. At other times, a rest period sufficed to restore the amplitude.

Anatomical, biophysical, and physiological studies were done on the sound-producing mechanisms in the head of the dolphin. The results of these analyses are reported elsewhere, important results for purposes of explication of parts of these experiments are given here.

In the natural state, emitting underwater sounds, the dolphin employs two mechanisms located below and on each side of the blowhole. Some of the anatomy of these systems have been described (Ref. 29). In this state, this system operates as a closed set of membranes, tubes, and sacs. During the sound production in air, these mechanisms function as a resonating system with one end open in the air, thus changing its resonance and other characteristics.

In several experiments, the airborne vocal outputs of the dolphin were picked up with an air microphone and simultaneously the underwater outputs were recorded through a hydrophone in separate channels on a tape recorder (Crown 800 series). When the blowhole was open in air, most of the sonic energy was recorded from the microphone; there was a radical reduction of the amount of energy recorded in the water. With the blowhole closed and most of the head underwater, most of the voice energy was recorded underwater through the hydrophones (Ref. 4). In the natural immersed state (underwater sounds), the monitoring of his own sounds through his ears is easily accomplished. With the blowhole open in air and the ears underwater, the dolphin probably has difficulties hearing the sounds he is releasing in the air itself (Fig. 14). The direct transmission in his head of the sounds produced is probably the only clue that he has as to what he is producing.

His underwater hearing of the voice of the human in air has a large reduction in amplitude owing to the air-water interface (reflection of most of the sonic energy). Thus the interspecies feedback in the sonic-ultrasonic

²⁹ B. Lawrence and W. E. Schevill, *Bull. Mus. Comp. Zool.* 114, 103-152 (1956).

sphere introduces a new set of conditions for which the dolphin must adaptively program. That the dolphin does so reprogram reproducibly and accurately to these artificial conditions shows a flexibility and a plasticity of vocal reprogramming of a high order.

Bastian's experiments³⁰ with *Tursiops truncatus* illustrate further the dolphin's reprogrammability. Using arbitrarily assigned environmental changes (visual) and operant controls (levers), two dolphins were induced to communicate with natural underwater sounds in order to solve a problem requiring cooperative efforts. The dolphins succeeded in these tasks (at a high level of confidence) by using short bursts of clicks (one to the other) at the crucial time in the program sequence to indicate which of two levers to press. These results imply an already known (or else an acquired) meaning for the click sequence—a meaning shared by at least two dolphins.

In these experiments in which a food reward (fish) or "physiological reinforcer" was eliminated, it is not obvious what the reinforcers are (what motivates the dolphin). As a working hypothesis, we assume that *Tursiops truncatus*, like *Homo sapiens*, has a sufficiently large and complex brain to have (or to develop) programs that motivate performances and hence act as "reinforcing programs" or "symbolic reinforcers" in the absence of explicitly humanly programmed rewards (such as fish giving). Presumably such hypothesized reinforcing programs include pattern-recognition and "success-failure" criteria with storage of the performance record as it develops. Such high-level programming does not seem to exist in the smaller-brained mammals (rat, cat, or monkey), nor in the "talking birds (parrot or mynah).

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³⁰ J. Bastian, *NOTS TP 4117*, 1-42 (Jan. 1967), and also in *Les Systemes Sonars Animaux, Biologie et Bionique*, R. G. Busnel, Ed. (Laboratoire de Physiologie Acoustique, Inra Cnrz-Jouy-en-Josas, France, 1967).