78. Lilly, John C. 1962. "Vocal Behavior of the Bottlenose Dolphin." Proc. Am. Philos. Soc. Vol. 106. P. 520-529

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VOCAL BEHAVIOR OF THE BOTTLENOSE DOLPHIN

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(Read April 27, 1962)

IN THE literature of ancient Greece and Rome, there are many references to dolphins. It may be appropriate to raise the question of the relationships that may have existed between man and dolphin in ancient times. Of the many different kinds of relationship that may have existed, one of the most intriguing involves the vocal behavior of the dolphin. The representation of the dolphin as a messenger of the god Apollo, as an object of worship for various sects, as a subject for many stories of friendships with boys and rescuers of men, as a subject for at least one of Aesop's fables, representations on coins, statues, and mosaics, show a surprising concentration of interest of a special sort by the Minoans, the Greeks, and the Romans.

Aristophanes (448 to 380 B.C.) wrote in *The Frogs,* "(the dolphin) races here and oracles there." Aristotle (384 to 322 B.C.) wrote in *Historia Animalium,*

> the dolphin when taken out of the water, gives squeaks and moans in the air . . . for this creature has a voice (and can therefore utter vocal or vowel sounds), for it is furnished with a lung and a wind pipe: but its tongue is not loose, nor has it lips, so as to give utterance to an articulate sound (or a sound of a vowel and a consonant in combination).

Gaius Plinius Secundus (the Elder) (A.D. 23–79) wrote "pro voce gemitus humano similis" (for a voice [the dolphin] has a moaning or a wailing similar to that of the human).

Many scholars have labeled these and similar ancient writings as farfetched, mythical, legendary, imaginative, and apocryphal. Such deductions of these scholars in regard to the dolphin should be questioned in the light of the findings presented in this paper.

In brief it looks as though the ancients knew more about these animals than any of the subsequent scholars. We have succeeded in training dolphins to produce sounds which resemble spoken English. We have so taught them with only one piece of apparatus other than that available to the ancient Greeks. The modern apparatus is the magnetic tape recorder. This machine aided us in obtaining our first insights by allowing us to slow down the high speed and high-pitched productions of the dolphins and thus to recognize that they can produce "humanoid" sounds.

The ancient dolphin referred to by the above writers may have been the common dolphin, *Delphinus delphis,* of the Mediterranean; however, examination of the species of dolphins present in the Mediterranean and the Black Sea shows that the Greeks may have been acquainted with the same species that we are working with today.

The subject of this research is the bottlenose dolphin which has the proper name of *Tursiops truncatus* (Montagu) (fig. 1). He is a shoal-water dolphin, extensively distributed around the shores, bays, and sea near the coasts of the southeastern United States, Mexico, and the Caribbean Sea, and also is found far from this region, for example near the southern coast of England during the summer, the Mediterranean Sea, etc. This particular species of dolphin lives in small groups consisting of a bull and two to four cows with their offspring. Each group in shallow water seems to have a certain territory through which they cruise and hunt certain kinds of fish for food.

This is the animal that appears in the circus acts in the various marine aquaria in the United States. Sometimes this animal is called "porpoise"; it is not, scientifically speaking, a porpoise. The porpoises are smaller, have shorter jaws, and have differently shaped teeth and usually small body sizes. Both this animal and the true porpoises are mammals, members of the whale family, the Cetacea. (The game fish which is commonly called a dolphin was named a dolphin several centuries ago apparently because of its habit of rushing along the surface of the sea, spurting water upward on his blunt forehead, giving the appearance similar to the blowing of the proper dolphins.)

Aristotle knew the differences between the mammal porpoise and the mammal dolphin. He said, "some people are of the opinion that the porpoise of the Euxine is related to the dolphin." He was probably speaking of *Phoceana,* the porpoise of the Black Sea and *Delphinus,* the common dolphin (or even *Tursiops*).

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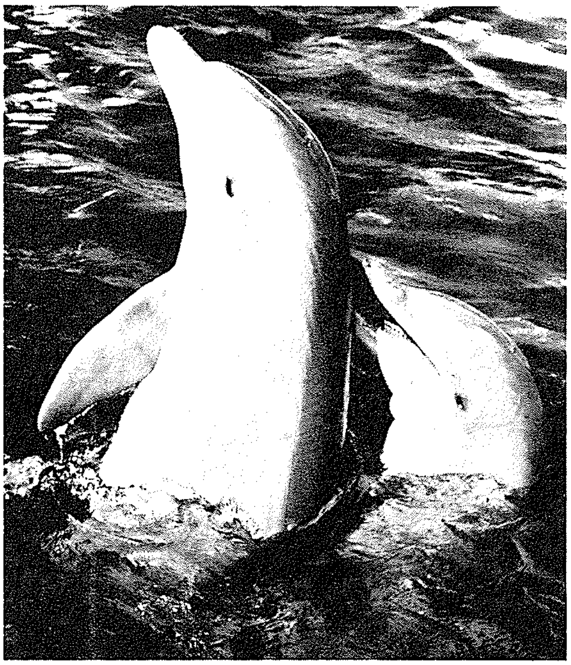

FIG. 1. Two bottlenose dolphins vocalizing in air. The open mouth of the one dolphin is not necessary for the vocalization. The sound escapes from the open blowhole. (From Lilly, John C., *Man and dolphin*. London, Victor Gollancz, 1962.)

NATURALLY OCCURRING SOUNDS

In the natural setting, the dolphin produces sounds mostly under water. However, when an animal is removed from water or is found stranded, faint sounds can be heard coming from the blowhole; and at sea a rare dolphin may challenge fishermen with louder sounds from the open blowhole.

The descriptions in the scientific literature of the naturally occurring sounds of the dolphins up to 1961 are verbal and tend to onomatopoeic. Observers used only descriptive words in order to define these sounds.[1, 2] The sounds can be divided into several classes. Each of the previous writers agreed that dolphins emit extremely *high pitched whistles or squeaks*; they also agreed that they emit *clicks and buzzings*. These two classes we shall call whistles and clicks. Beyond these, previous authors did not show much agreement. Some of the sounds are called barking, jaw snapping, jaw claps, mewing, moanings, wailings, and several descriptions using analogies to the sounds produced by other animals. Such verbal descriptions have performed a useful function of indicating that the sounds produced by the dolphins are myriad and complex. They suffer from the shortcomings that one does not know anything quantitative about the sounds thus described, nor does one know truly how they sound to one's self. This deficiency of verbal descriptions is difficult to overcome in the usual published literature; one should publish tape recordings. By several methods of portrayal of the sounds these deficiencies are being slowly repaired. We published amplitude oscillographic tracings and sonic spectrographic patterns (fig. 2) of various of these sounds.[3, 4]

An animal can whistle and click, and as we first demonstrated, can do so simultaneously.[3] Quite recently we have discovered that such emissions come from the two separate phonation mechanisms in their nasal sacs (first best described by Lawrence and Schevill [5]), one in the right nasal passage and the other in the left nasal passage.[6] One of

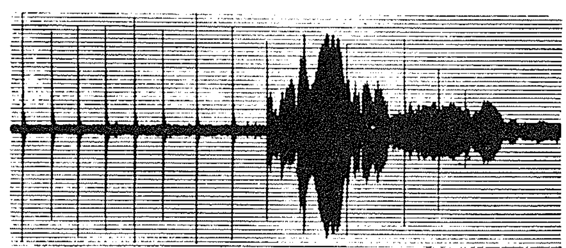

FIG. 2. Amplitude record of a simultaneous train of clicks and a whistle from a single dolphin. The sounds are underwater ones picked up with a hydrophone and recorded with a high speed tape recorder (60 inches per second). The hydrophone was within 6 inches of the head of the animal. (Lilly, John C., and Alice M. Miller, *Science* **133**: 3465, 1689, 93, May 26, 1961.)

[1] McBride, Arthur F., and D. O. Hebb, Behaviour of the captive bottlenose dolphin, *Tursiops truncatus*, *Comp. & Phys. Psychol.* **41**: 2, 111–123, April, 1948.

[2] Wood, F. G., Jr., Underwater sound production and concurrent behaviour of captive porpoises, *Tursiops truncatus* and *Stenella plagiodon*, *Bull. Mar. Sci. Gulf and Caribbean* **3**(2): 120–133, 1954.

[3] Lilly, John C., and Alice M. Miller, Sounds emitted by the bottlenose dolphin—the audible emissions underwater or in the air of captive dolphins are remarkably complex and varied, *Science*, **133**(3465): 1689–1693, May 26, 1961.

[4] Lilly, John C., and Alice M. Miller, Vocal exchanges between dolphins, *Science* **134**(3493): 1873–1876, December 8, 1961.

[5] Lawrence, Barbara, and William E. Schevill, The functional anatomy of the delphinid nose, *Bull. Mus. of Comp. Zool.* (Harvard Col.) **114**: 4, February, 1956.

[6] Lilly, John C., *Man and dolphin*, Garden City, N. Y., Doubleday, 1961; and London, England, Victor Gollancz, 1962.

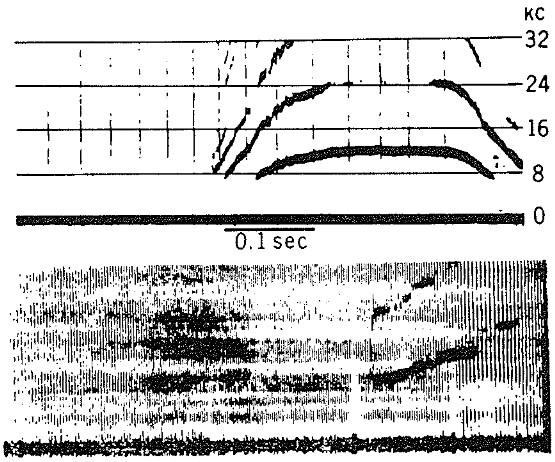

FIG. 3. *Upper*: Sound spectrograph analysis of a whistle and concurrent train of clicks (sonic and supersonic components). The frequencies of the sounds emitted in this sequence extend from about 6 to at least 64 kcy/sec. This figure shows the fundamental, first, and second harmonics, some of the third, and a bit of the fourth up to 32 kcy/sec. The high frequencies have been emphasized in the sonograph. Without such emphasis it can be shown that most of the energy of the whistle lies between 6 and 20 kcy/sec, in the fundamental and first and second harmonics. Similar presentation of other sequences shows peaks for the clicks corresponding to those for the whistles. *Lower*: A sonic spectrogram of a simultaneous squawk and whistle from a bottlenose dolphin. Frequency and time scales are the same as in figure 3 upper. The squawk consists of a series of clicks whose repetition rate is varied by the animal from 400 per second down to 220 per second. The animals are capable of emitting clicks up to the order of 1,200 per second and down to 1 per minute. This figure also shows the bands of frequencies whose intensities are under the control of the animal. Apparently they modulate frequencies selectively by changing the size of their air cavities in their nose. In the vicinity of the whistle record the control of the frequency bands is particularly obvious. (Lilly, John C., and Alice M. Miller, *Science* 133: 3465, 1689–93, May 26, 1961.)

our animals tends to click only on the left side and whistle only on the right side and can do so on both sides simultaneously or separately (fig. 8).

A sonic spectrographic analysis of the clicks [3] shows separate dominant frequencies for each click (fig. 3). In the case of the whistle, one can see the fundamental $1 \times F$, and at least $2 \times F$, $3 \times F$ and at least $4 \times F$. The animals can produce the first, second and up to the seventh harmonic of the lowest frequency emitted. $1 \times F$ is usually, though not necessarily, continuous and shows the dominant "frequency modulated" nature of the lowest frequency groupings.

The third class of underwater sounds is very large and includes variously called barks, buzzings, mewings, and so forth.[3] In our experience such sounds can be as short as three or four extremely loud clicks which are probably the so-called jaw-snappings or jaw-clapping, or they can be prolonged for a few tenths of a second or even a few seconds. When they are prolonged to these longer values, in the middle range, one begins to call them *barks*, and when they are prolonged over longer periods of time or when several animals are emitting them, they are called mewings or even *wailings* (fig. 4).

The so-called jaw-claps are literally extremely short barks. In all of our experience with the animals closing their jaws very rapidly, the sound from the jaws is a very low frequency "thud."

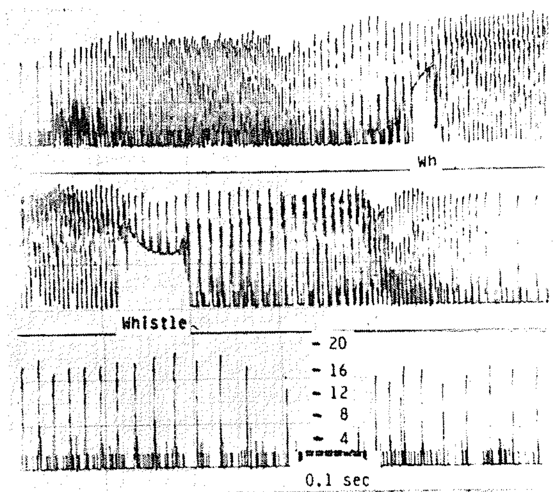

FIG. 4. Record of a squawk emitted underwater during stimulation by a human being. The squawk was preceded and followed by a train of clicks at a low rate of repetition (25 to 40 clicks per second). Two whistles occurred during this squawk, one (top trace) at 0.7 and one (middle trace) at 0.95 second after the beginning of the squawk. The frequency calibration (in kilocycles per second) is given, with the time scale (real time), on the bottom trace. A record of frequencies versus time on the sonograph of this same tape shows all of these frequencies, plus others up to at least 64 kcy/sec. Clicks of repetition rates of 140 to 400 per second occurred, in this particular squawk, about 0.82 second after the beginning of the squawk (beginning of middle trace). In other squawks, clicks at rates up to 800 per second have been sustained for as much as 0.5 second. A loud squawk was heard from the open blowhole in air simultaneously with emission of this squawk under water. (Lilly, John C., and Alice M. Miller, *Science* 133: 3465, 1689–1693, May 26, 1961.)

Since their teeth interdigitate so well and go into soft tissue rather than colliding end on with one another that there seems to be no way that the jaws themselves or the teeth could give a "clap" or a "snap." We have found, however, when an animal emits a very short sharp series of loud clicks (fig. 5), that he tends to open and close his mouth very rapidly. (This gesture acts as a threat.) We have seen other animals move rapidly away from such a gesturing and vocalizing animal and we ourselves pull our hand or arm or leg rapidly away from such an animal. Such a gesture combined with the loud short click train probably gave rise to the mistaken notion of a "jaw clap."

Several authors have described a special kind of clicking which using the analogue of the creaking rusty hinge has been dubbed "creakings." This seems usually to be associated with food finding and food recognition and is thought to be evidence of the activity of these animals excellent "sonar" operations, described so well by Scheville, Norris, Kellogg, and others.[7, 8, 9, 10, 11, 12, 13]

Some of our recent studies throw doubt on the necessary and sufficient *sonic creakings* as the source of the sonar pulses. In our experience there are *ultrasonic pulses* quite separately emitted from the *sonic pulses*.[4] If one listens with a radio receiver connected to a hydrophone at about 100 kilocycles every so often one can hear a stream of pulses being emitted straight ahead from the given animal. Such ultrasounds can be dissociated with any sonic output whatsoever. The ultrasonic pulses can be locked in or not locked in with sonic pulses. When the sonic pulses are associated with the ultrasonic, they are apparently being used to communicate the sonar information to the nearby animal by means of the lower communication (sonic) band of frequencies.

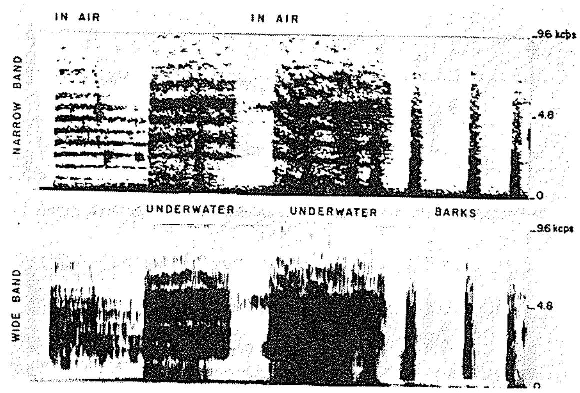

FIG. 5. Sonic spectrogram of sounds produced in air and underwater alternately by a bottlenose dolphin. The upper sonogram is recorded with a narrow band 45 cycles per second filter. The bottom sonogram is recorded with a wide band of 300 cycles per second filter. The first group of sounds produced are reported by listeners to resemble those of a stringed musical instrument resembling a banjo. The second group of sounds resemble barks. The wide-band record shows that the sounds consist of short sharp pulses of sound in which the repetition rate is varied by the animal. The narrow band shows that the pitch in the first group of sounds is 740 per second, in the second group is 1,050 cps, in the fourth group it starts at 1,280 cps and falls to 960 cps during the sound.

This record is 1.2 seconds long. The modulation and selection of various bands of frequencies by the animal is well illustrated by the first, second, and third sounds. In the third sound the animal has selected the fifth partial alone for enhancement in contrast to the first sound in which the animal has selectively dropped out the first partial and enhanced the third, fourth, fifth, sixth and seventh. In the second sound the second through the sixth partials are enhanced as the first partial is dropped out towards the end of the emission. Each one of the barks on the original record can be shown to be a small number of clicks ranging from 5 to 12 (see text).

Thus a more up-to-date catalogue of sounds produced by dolphins would include at least five classes: (1) whistles, (2) sonic clicks, (3) ultrasonic clicks, (4) rapid click trains with various characteristics, and (5) a class of sounds ("humanoid") which we discuss at more length in the latter part of this paper.

NATURALLY OCCURRING VOCAL EXCHANGES BETWEEN DOLPHINS

During the course of our studies on the bottlenose dolphin, we found definitive evidence that

[7] Schevill, W., and B. Lawrence, High-frequency auditory response of a bottlenosed porpoise (*Tursiops truncatus*), *Jour. Exptl. Zool.* **124**: 147, 1953.

[8] Schevill, W., and B. Lawrence, Food finding by a captive porpoise, *Breviora* **53**: 1, 1956.

[9] Kellogg, W. N., R. Kohler, H. N. Norris, Porpoise sounds as sonar signals, *Science* **117**: 239, 1953.

[10] Kellogg, W. N., R. Kohler, H. N. Norris, Echo ranging in the porpoise, *Science* **128**: 982, 1958.

[11] Kellogg, W. N., R. Kohler, H. N. Norris, Auditory perception of submerged objects by porpoises, *Jour. Acoust. Soc. Amer.* **31**: 1, 1959.

[12] McBride, A., quoted by W. Schevill, Evidence for echolocation by cetaceans, *Deep-Sea Research* **3**: 153, 1956.

[13] Norris, Kenneth S., John H. Prescott, Paul V. Asa-Dorian and Paul Perkins, An experimental demonstration of echo-location behaviour in the porpoise, *Tursiops truncatus* (Montagu), *Biol. Bull.* **120**(2): 163–176, April, 1961.

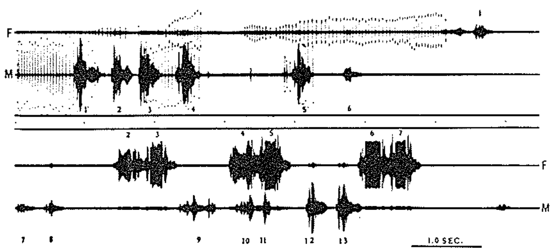

Fig. 6. A graphic record of a vocal exchange between two dolphins. (Top trace in each pair) emissions of the female (F): (bottom trace in each pair) emissions of the male (M). The upper pair of traces shows a click-and-whistle exchange; the lower pair, a continuation of the same record without the clicks. (Dots between pairs of traces) seconds of elapsed time; elapsed time for the whole record, 15 seconds. For reproduction, the peaks of the clicks of the female were marked with black dashes; the tips of those of the male, with black dots. Whistles are numbered in sequence for each animal. Other disturbances in the base line are, in most cases, water noises. (Lilly, John C., and Alice M. Miller, *Science*, **134** (3493): 1873–1876, December 8, 1961.)

they do exchange some of the above sounds in appropriate fashions.[4]

Each animal waits until the other animal is either silent, in the case of the whistles, or there is an opportunity to alternate within the train in the case of clicks (fig. 6). One can hear click exchanges going on between two animals with little overlap. A close study of the overlap shows that they alternate their clicks during the period of overlap. The whistles are very "politely" exchanged except for one case called a "duet." Each animal whistles simultaneously; they match frequencies so well that one can hear beats between the two emissions. (This seems to be analogous to the rather irritating habit that some people have of saying a word simultaneously with one's self.)

Sonic spectrographic analysis of this kind of exchange shows some of the real complexities of these whistles (fig. 7). The fundamental frequency is usually continuous. The first, second, third, fourth, and higher harmonics are usually discontinuous. We have found that some of the harmonics of these whistles can still be detected as high as 150 kilocycles. The harmonics appear and disappear in complex ways.[4]

Each dolphin's voice differs very much from each other voice. For example, some animals fill in between emissions with low frequency whistling (somewhat the way some people say "aah" between words).

Analysis of the sounds called a bark or a mewing or a wailing depending upon its duration, show each to be a fast series of clicks. (Some of these are asymmetrical clicks, i.e., there are short pulses not balanced out by other short pulses on the other side of the base line (fig. 2). In other words, the emitter in the dolphin's head is a nonlinear biological device, not a linear one.)

Such sounds seem common only during intense emotional excitement on the part of the animal, either sexually aroused, angry, or in similar intense states. (One can elicit such sounds (with training) under nonemotional conditions.)

These sounds are used naturally in what one might call *emotional exchanges*.[6] If one dolphin is irritated with the behavior of another one or of a human observer, he emits such a rapid series of clicks at great intensity and at the same time makes gestures such as rapid head movements, either vertically or horizontally, with the mouth either open or closed. Such movements and sounds signify in no uncertain terms that the animal is emotionally upset. For example, if an observer puts a leg into the tank and the dolphin does not want him to enter the tank at that point, such a sound may be emitted just before the animal begins to bang on the leg with the side of its jaw in rapid oscillating movements. They will treat one another in similar fashion though some-

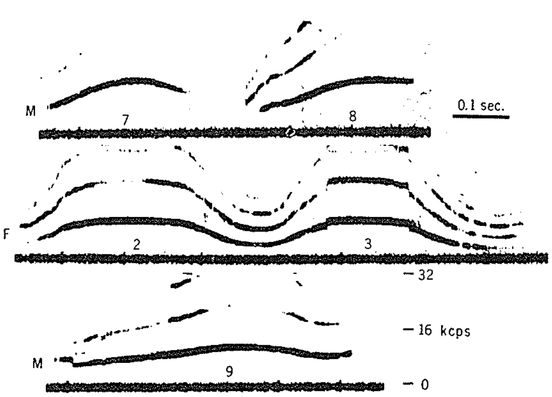

Fig. 7. Sonograms of a portion of an exchange between two dolphins. (M) Emissions of the male; (F), of the female. Emissions are numbered to correspond to the numbering of the amplitude trace in fig. 6. The fundamental (f) and the first two overtones ($2f$ and $3f$) may be seen on these sonograms. Additional sonograms with twice this frequency scale show that energy in the 3rd, 4th and 5th overtones decreases rapidly as compared to that of the fundamental and the first two overtones. There was some enhancement of the higher frequencies in recording the sonograms. (Lilly, John C., and Alice M. Miller, *Science* **134** (3493): 1873–1876, December 8, 1961.)

times even more violently than they treat the humans. After several weeks in captivity dolphins apparently learn that humans do not hear these sounds emitted under water very easily, and they begin to express their state by emitting such sounds in air above water aimed at the particular human involved (fig. 5).

THE PRODUCTION OF SOUNDS BY DOLPHINS IN CONTACT WITH MAN

Certain sounds of the dolphins tend to be emitted in air after they have been in close contact with man for several weeks.[6] At first they tend to emit their naturally occurring sounds described above and merely transfer them from under water into air. The first sounds heard in air emitted by a newly captured dolphin are usually whistles and clicks.

In the case of baby dolphins, there is a stream of bubbles associated with their production of whistles under water. If the head is moved into the air one can hear the whistles very faintly in air being emitted at the exit to the blowhole slit. This is the extent of the known naturally occurring airborne sounds of the dolphin.

As the animals remain in captivity for longer and longer periods, they open their blowholes and emit extremely loud clicks and whistles (fig. 8). For a person standing five or ten feet away from such an animal, the intensity of the sound can be so high that it is definitely uncomfortable. The clicks sound like very loud hand clapping by a human: the whistles sound as loud as the maximum intensity of those by an expert human whistler, but are of a higher frequency.[6]

After several weeks of such noises one begins to notice a changing pattern of the airborne sounds to more complex sounds involving longer emissions, greater richness of selection of frequencies and harmonics. In our experience such changes occur if and only if people have been talking to the animals directly and very loudly individually (fig. 5). Slowly but surely these sounds become more and more like those of human speech[6] (figs. 9 and 10).

When I first discovered this effect in 1957 it was in a series of experiments designed for totally different purposes than studying the vocalizations.[14] The effects occurred during a study on

[14] Lilly, John C., and Alice M. Miller, Operant conditioning of the bottlenose dolphin with electrical stimulation of the brain, *Jour. Comp. & Physiol. Psychol.* **55**: 1, 73–79, February, 1962.

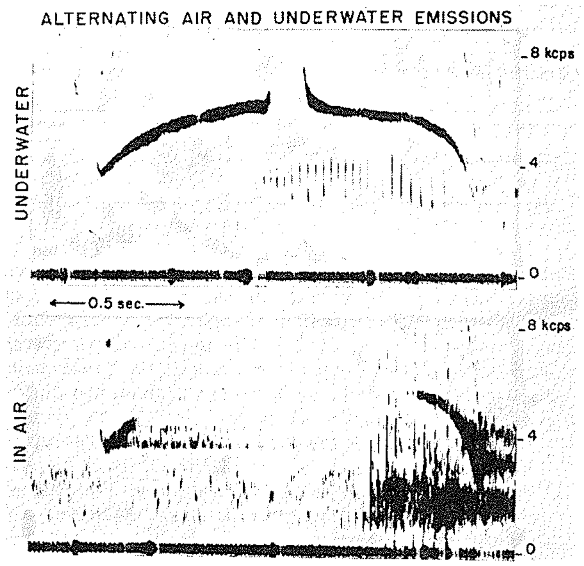

FIG. 8. A dolphin emitting whistles and clicks simultaneously alternating between air and underwater emissions. This animal is whistling with her right nasal passage and sacs and clicking with her left nasal passage and sacs. At the beginning of the recording the right half of the blowhole is open as she begins her whistle. At 0.12 second after the beginning of the whistle (upper and lower trace)—she closes the right half of her blowhole shutting off the emission of sound in air (lower trace) and enhancing the underwater whistle (upper trace). The whistle rises in frequency from the initial value of 3.5 kc to 6.3 kc followed by a silent break. The whistle starts again at 7.8 kc, and falls to 1 kc (see below). Just before the silence, underwater clicks are started (upper trace) which are not detected by the air microphone (lower trace, 0.6 second after the beginning of the whistle). After the emission of 15 clicks underwater the left blowhole is opened and clicks in air are detectable (lower trace, one second after the beginning of the whistle). The next eight clicks are detectable in both the underwater and air channels. She stopped clicking before the end of the whistle. At 1.38 seconds from the beginning of the whistle the right half of the blowhole is once again opened and the whistle appears in air (lower trace). In air the whistle can be seen to continue beyond the 4 kilocycles at which it disappears in the underwater trace.

In the original recording the whistle can be traced down to 1 kilocycle 1.42 seconds after the beginning of the whistle. The above whistle recording is considered to be two whistle emissions separated by a short silence. This pair closely resembles the two special whistles of the bottlenose dolphin's distress call. Only the fundamental frequencies are shown in this display. The first and second harmonics are 12–30 decibels below the intensity of the fundamental. The air record shows many room echos between the ceiling and the water.

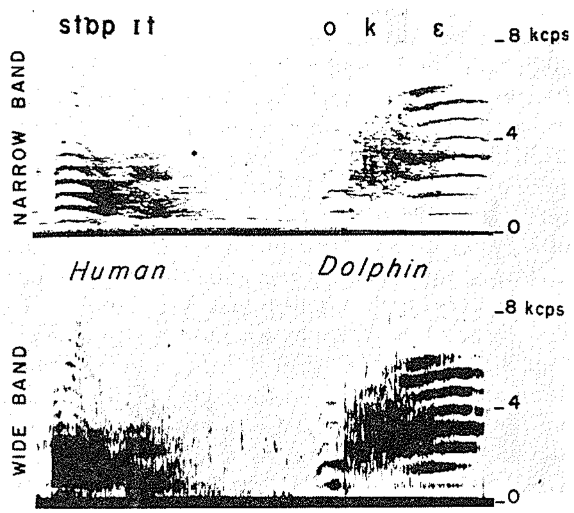

FIG. 9. Part of a vocal exchange between a human and a dolphin. As in previous figures the upper trace is narrow band and the lower trace is wide band. The whole trace is 2.4 seconds long. The human says "stop it." There is a pause, and the dolphin makes a sound which closely resembles a small child saying "okay." The fundamental pitch of the dolphin's "o" starts at 500 cps and rises to 800 just before the sound of the "k." The pitch of the terminating "ɛ" sound starts at 950 cps and falls to 800 cps. It is to be noticed however that the dolphin enhances various partials selectively so that during the "o" the first two partials contain the high energy and during the "ɛ" sound the energy starts in the third and fourth partials and broadens out to include the second through the eighth partial. During the rather noisy "k" sound the maximal energy emitted is intermediate between that of the "o" sound and that of the "ɛ" sound. The overall maximal energy band lies between 1 kilocycle and 6. In contrast to the dolphin, the human's maximal energy is between 200 cps and 3.50 kcps. This record illustrates that a dolphin in exchanges with a human can emit sounds resembling a word other than that spoken by the human.

the brain of the first animal; we need not go into the details of the other experiment here.[14] During the course of these experiments under certain conditions, the animal was emitting very peculiar sounds that we had not heard from any other dolphin. Later in retrospective analysis of the tapes on which we were recording our information, we heard unmistakable resemblances to the human voice in these emissions from this dolphin. Further analysis and further study gave us a totally unexpected and surprising correlation between parts of what I had said in dictating information to the tape and the subsequent emissions by the dolphin. Because of the well-known, facile nature of the human ear which can supply missing parts of messages, we did not quite trust this evidence.

It was many months before we were able to believe this evidence. From November, 1957, until May, 1958, we studied the accumulated information from three animals; in May a preliminary announcement of our findings was made.[15] These findings were met with total disbelief on the part of others who had worked with the dolphins. (In some quarters this disbelief exists even today.) However, we also found there were many people whose interest was immediately aroused and many of our "loyal skeptics" encouraged us to continue. Since then we have accumulated much corroborative evidence, not only bearing out these early findings, but extending the observations into new areas of experience.

The first copies of the human voice by the dolphin (in 1957 and 1958) were at a relatively low

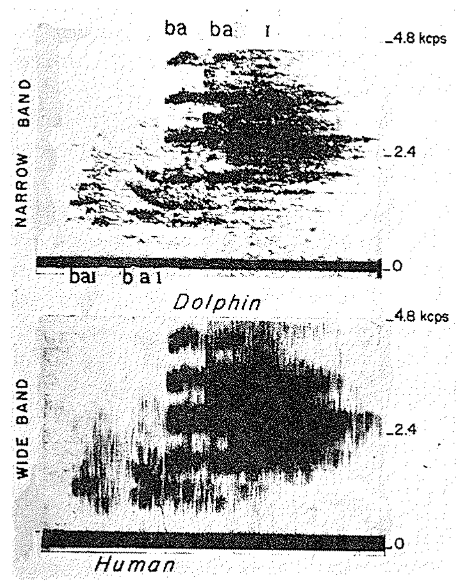

FIG. 10. A human dolphin exchange. The human says "bye-bye" and the dolphin says something which resembles "ba-byee" before the human has finished the last portion of her emission. This record is 1.2 seconds long. The frequency range shown is 4.8 kilocycles which is the band used by humans to transmit meaning in speech. The lowest frequency reached by the dolphin is 200 cycles towards the end of his emission. The selective enhancement of the partials above 1,000 cycles is illustrated in the upper trace. In general the human articulates with energies from 400 cycles to 3,000, whereas the dolphin uses a band from about 1,000 to 8,000. This record illustrates the extremely rapid responses of a cooperating dolphin.

[15] Lilly, John C., Some considerations regarding basic mechanisms of positive and negative types of motivations, *Amer. Jour. Psychiatry* **115**: 498–504, December, 1958.

amplitude. The most recent ones on the part of our three current animals are sometimes painfully loud for the human observer. The development of these sounds by a given dolphin is as follows:

Our longest observations have been of an animal by the name of Elvar who joined us on the fifth of July, 1960. Quite early in captivity Elvar was in intraspecies solitude but in constant daily contact with human observers from that day to this (25 months). Instructions to the human observers are to talk to him using words appropriate to the tasks at hand. In fact, they are asked to speak loudly to him in order to penetrate the surface of the water with the sound. For a long time each person in the laboratory was quite skeptical of the results to be obtained by this method. Each one felt a little foolish in attempting to elicit copies of human words from a small whale. However, by persistent efforts, in September, 1961, we were able to determine that Elvar was quite capable of the production of sounds like those of human speech. We began to encourage him to shape definite and distinctive words (figs. 9 and 10).

During his first year in captivity he had gradually developed air-borne sounds analogous to those that we use in our speech including the vowel sounds, plosives, hissings, and similar noises that we employ in communication with one another. However he was emitting these sounds in frequencies well above those which the normal adult human male or female emits. They were more comparable to those emitted by a very small child as it begins to emit these sounds in a very high-pitched falsetto. Spectrographic sonic analyses showed that the lowest frequencies that he was employing at that time were of the order of 1,000 to 2,000 cycles per second (fig. 5). Resemblances to human speech were heard by slowing the tapes down by a factor of two or four. By September, 1961, Elvar had accomplished the first task which we set him, i.e. emitting sequences of sounds bearing a high pitched resemblance to the sounds that human beings employ in their speech activities. He had not yet formed any words which we could recognize; these sounds were more like the babbling of a baby before the words are acquired.

In September we decided that he was ready for step 2, the formation of understandable words. A typical experience is that of Miss Alice Miller on the tenth of September. She entered the tank room and started speaking to Elvar at the edge of his tank. In his usual fashion he filled his mouth full of water and squirted it all over her. She hit the side of the tank and said "stop it." He squirted her again, she hit the side of the tank again and said loudly, "stop it." At about the fourth "stop it" said by Alice, Elvar started emitting very short sharp sounds in air very loudly with his blowhole open. On playback of the resulting tape at normal speed, this sounds like a very high pitched "wee." Immediately after the fifth "stop it" by Alice he said something which at normal tape speed is recognizable as a two-part sound, very high pitched and very short. By slowing the tape down by a factor of two, one can hear a very definite "stop it" produced by Elvar; there are many echoes in the room because of the high intensity. From the beginning it was found that if he is cooperating he follows the human's words very rapidly. For example his "bye-bye"-like sound follows immediately after her "bye-bye" (fig. 10).

From that episode onward, we began to elicit many more words from Elvar and found the following order of events.

When Elvar emits a sound in response to a sound repeated by a human again and again, in general he tends to break it down into its component parts, and emit one of these components after each production by the human. A typical session is that of October 23 in which Alice says "more Elvar" and Elvar comes back with "more var," a very high-pitched shortened "morelvar" all run together and then finally in a clear high-pitched Donald Duck voice with a delphinic accent says "more Elvar," in a clearly humanlike understandable manner.[16]

From the productions of September through those of October he had lowered his lowest frequency so that one could see from spectrographic analyses that he had moved his lowest partial well down in the region which is produced by Miss Miller, i.e., from about 1,000 cycles he had moved down to about 450 cycles.

Any time that he wishes he can raise his pitch and the frequencies emitted back up into a proper delphinic region at two to four times the normal upper human frequency region and decrease the time during which he puts out the emission (with the proper delphinic duration). Thus one finds in the productions of October, November, and December extremely short and high-pitched sounds mixed in with those that resemble human

[16] Lilly, John C., and Alice M. Miller, Production of humanoid speech sounds by the bottlenose dolphin, Manuscript, 1962.

words at normal speed. Several of these very high-pitched short sounds can be shown to be very short high-pitched compressed reproductions of human words by playing them back slowed down, somewhat in the fashion of the 1957 results and the "stop it" of September.

In several experiments with different human observers and different human voices, it is shown that Elvar tends to examine each new human voice and attempts to reproduce the novel characteristics of that voice compared to the previous one. A typical example is my voice working with him on the second of December, 1961. I ran him through a vocabulary that Alice had been helping him perfect which included such words as "speak, up, louder, more, etc." He knew the word "squirt" fairly well. I repeated the word "squirt" in order to induce him to squirt water and at the same time to say "squirt." He went through the various parts of the word "squirt" and finally said it clearly enough for that particular day. I then went on to work with him with a new word "water" in the phrase "squirt water." [16]

Elvar practiced "wa" separately from "ter" and then finally came out in the clear with a fairly

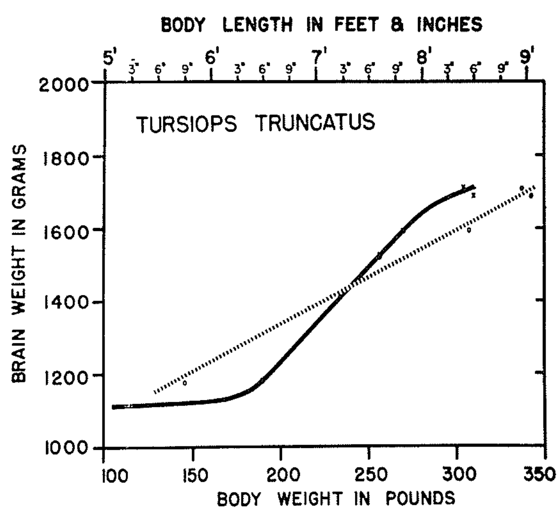

FIG. 11. Relations between brain weight, body length, and body weight of the bottlenose dolphin. The normal human brain weights lie in the lower portion of this graph. The critical threshold brain weight for the development of speech in the human child lies just below this graph (800–1,000 grams). The smallest bottlenose dolphin brain found by us was 1,150 grams. Presumably the dolphin's brain may be large enough and complex enough for the development of speech processes analogous to those of the human. (Lilly, John C., and Alice M. Miller, *Jour. Comp. & Physiol. Psychol.,* February, 1962.)

good copy of my word "water" emphasizing my "r." In contrast to Miss Miller's melodious "r" sound, my "r" is a very rattley, buzzy one. He copied this "r" with a loud fast sequence of clicks. He brought his lowest pitch down to about 200 cycles during this rendition, a new low for his lowest frequencies.[16]

We are still working on stage 2, i.e., perfecting individual words in English, with three animals, Elvar, Chee Chee, and Sissy. Slowly but surely we are moving over to stage 3 in which we are insisting on the animals using the words in the appropriate situations and contexts. We are also exploring the beginnings of stage 4, the ability of the animal to abstract information and to transmit it appropriately by means of words. The analyses of these latter studies are not far enough along to report at the present time.

In summary, the bottlenose dolphin is able to emit under water a series of sounds in his natural state which run from whistles and clicks to buzzings, mewings, and barkings, and several unclassified series of sounds. In captivity, the naturally occurring sounds continue and can be shown to be used in formal polite alternating exchanges between the individuals of pairs of animals. The whistles and clicks apparently are used to exchange information of a nonemotional nature. The barks are used in emotional situations to influence other animals and humans.

In addition to the naturally occurring underwater sounds, air-borne sounds are emitted in great profusion after a period of captivity. Dolphins can be, by appropriate techniques, induced to form sounds resembling those of human speech. After a period of emitting such humanoid sounds, the animals can be induced to begin to form relatively clear words very loudly or very softly in air.

These results illustrate that the very large brain of *Tursiops truncatus* (20 to 40 per cent larger than that of the average human) (fig. 11) may have within its complex structure speech capabilities, if not realized, at least potential, similar to those of the human.[14]

SUMMARY

It can be shown that the bottlenose dolphin (*Tursiops truncatus* Montagu) emits several different classes of complex sounds. Some of these sounds are encountered in the natural state, others are acquired during long periods of captivity in close contact with scientific investigators. Some

of these sounds are emitted under water without loss of air, others are emitted in air with the open blowhole above the water.

The naturally occurring underwater sounds consist of several classes including whistles, clicks, barks, creakings, etc. All of these sounds are relatively high pitched compared to those of the human voice and extend from 2 kcps to approximately 150 kcps. It can be demonstrated that, when a dolphin opens its blowhole and emits these sounds, the characteristic frequencies heard are lower than those heard simultaneously under water. A dolphin can be induced by various means to emit another class of sounds in air. Because of their resemblance to the sounds of human speech we have named these sounds "humanoid emissions." Analysis by means of the sound spectrograph and oscillographic methods demonstrates that these sounds are basically white noise-hissings and/or high-pitched buzzings, modulated in selective frequency bands by the efforts of the animal. Some of these emissions appear to be attempts on the part of the animal to reproduce words spoken by the investigators. Such mimetic activities are at times surprisingly clear and clean-cut. Tests of the capability of these animals of using such "words" appropriately are in progress.

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