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Sounds Emitted by the Bottlenose Dolphin

The audible emissions of captive dolphins under water or in air are remarkably complex and varied.

John C. Lilly and Alice M. Miller

Some of the sonic (audible to human beings) emissions of the bottlenose dolphin of the east coast of the United States (*Tursiops truncatus* Montagu) have been described (*1*). One of the classes of emissions (the clicks) has been studied situationally in the limited context of their use in echo-location (*2–4*). Some of the supersonic components of these clicks have been measured (*2, 3*). In this article we present evidence that the dolphin's audible sonic emissions can be divided into at least three classes: (i) sine-wave type whistles; (ii) slow trains of clicks (buzzings); and (iii) a class of complex waves emitted in bursts (quacks, squawks, blats). It can be shown that these classes of sounds are emitted under different environmental conditions and states of need. It is shown that each animal probably has at least two sound-producing mechanisms available for simultaneous use. The dolphin's now well-known use of click trains (creaking, and so on) as "sonar" is not under discussion here and has been eliminated as far as possible in the experiments (*5*).

The methods of investigation were briefly as follows: A captive animal was restrained and confined in water 10 to 15 inches deep, in a space 15 inches wide and 7.5 feet long, with polyurethane foam 1 inch thick along one side of the water box to attenuate echoes somewhat. (The same animal was also observed and the emissions were checked under conditions in which the dolphin could swim more freely.) A hydrophone, with preamplifier (*6*), was placed beside the animal's beak (rostrum). The animal could not move its head more than 6 inches (one wavelength at 10 kilocycles per second in sea water) from its mean position relative to the hydrophone and walls. The output of the hydrophone was amplified and recorded on a magnetic tape recorder at 60 inches per second (*6*). The pass band of this configuration is determined by the hydrophone (upper limit, about 33 kcy/sec) and a high-pass filter (1 kcy/sec). For analytical purposes, the tape recording was played back (slowed down 8 to 16 times), analyzed electrically, and recorded with an ink writer or a mirror galvanometer oscillograph, or both (*6*).

The sounds recorded were those emitted (i) spontaneously in solitude, or (ii) on hearing sounds of another animal nearby in a similar water box, or (iii) in response to maneuvers on the part of the observer. Most of the findings reported here are based on observations of four animals studied intensively (every day for 3 to 6 months) and of ten others observed for periods of from 24 hours to 6 days.

In solitude an animal emits whistles and clicks and, very rarely, quacks or blats. In response to, and in exchange with, another dolphin at a distance, an animal emits whistles and trains of clicks (at a relatively slow repetition rate) and occasional quacks. In violent play, courtship, and intercourse, in close quarters, each may emit all three classes of sounds, with fairly frequent squawks, quacks, and blats.

The sounds that an observer can elicit from a restrained dolphin can be of any of the three classes, depending on the tactics of the observer. As described previously (*1–4*), placing a fish or any object in the box sets off trains of clicks of a particular kind (creakings). A loud whistle by the observer elicits whistles. Bodily manipulations (gentle to painful) can elicit whistles or quacks or blats. In the presence of an observer an animal can and does shift from emitting sounds under water to emitting sounds in the air, by raising its blowhole out of the water. The whistles in the air are faint and occur at the blowhole slit; they are accompanied by small bubbles, which are lacking in most underwater emissions. To make loud clicks, blats, squawks, and quacks (and other air-borne sounds not here described), the animal opens its blowhole and releases the internally produced sounds into the air.

Simultaneous Clicks and Whistles

Here we present analyses of only the underwater sounds and the underwater sonic components of the air-borne sounds. Figure 1 is a graphic amplitude record (*6*) of simultaneous underwater emission of a slow train of clicks and a whistle. The clicks occurred at a rate

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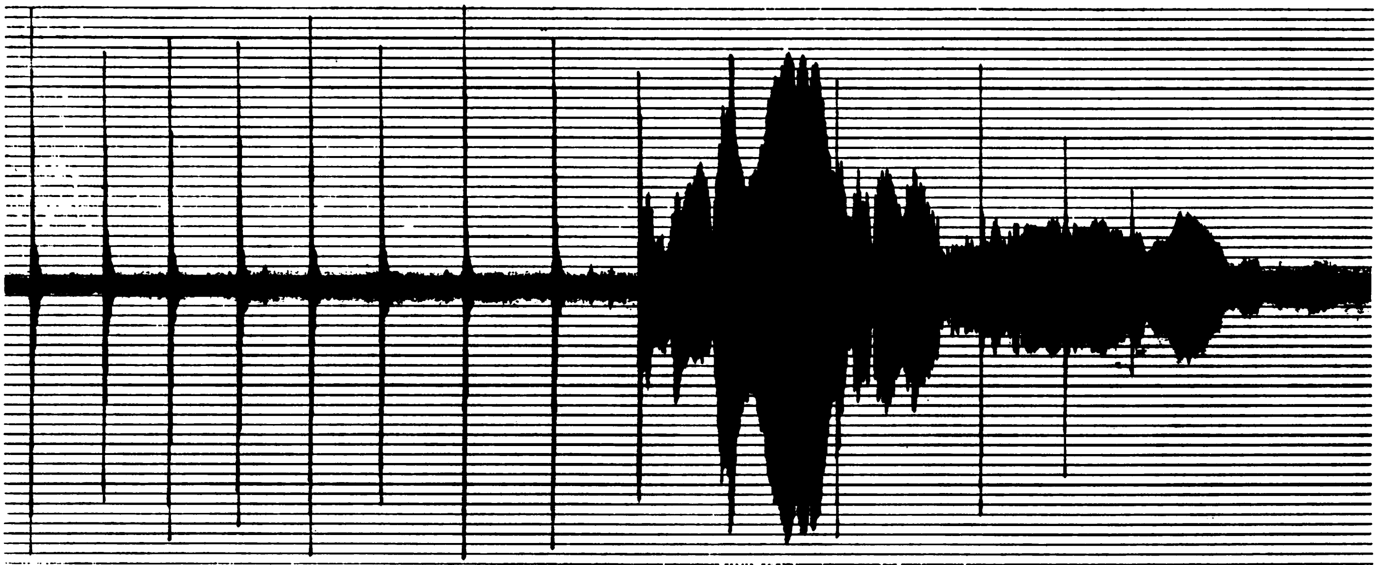

Fig. 1. Amplitude record of a train of clicks and a whistle. Mirror galvanometer (4800 cy/sec) record from a slowed tape recording (1/16 original speed) from an AN/PQM hydrophone set. This record shows the rapid changes in amplitude of the whistle emission and the simultaneous production of clicks during whistling (see Fig. 2, *1A* and *1B*). Records such as this, made with a paper speed ten times that used in making this record, were used in calibrating and standardizing the amplitudes and frequencies, in the preparation of Fig. 2.

of about 30 per second; the whistle lasted 0.3 second. At least five clicks occurred during the whistle. The train of clicks ended during the whistle (in other emissions a train of clicks has been found to start in, to continue beyond, or to stop during a whistle). Notice the rapid changes in amplitude of the whistle. The patterns of such changes are extremely complex, varying markedly from one emission to another; however, in most cases the amplitude (Fig. 2) quickly reaches peak and falls during the rest of the emission. [Some of the quick variations are undoubtedly caused by echoes, standing waves, and interference phenomena in the restraint box, but not by changes in the distance of the head from the hydrophone (*3*)]. Whistle emissions (in a solitary dolphin or in a pair) usually occur in groups of one to four whistles, rarely in groups of five, six, seven, eight, or nine. In a series of 1000 whistles, groupings of two or three whistle emissions were most frequent. Within a group of whistles, each emission is separated from the others by intervals of silence (in a group of eight animals) or by a low-frequency, low-amplitude sound (in the case of a single animal). Each emission lasts from 0.1 to 0.4 second; the most frequent duration is 0.25 second; an emission of 0.1 second is rare. The frequency-time curves for the emissions in a group of whistles resemble one another closely; between one group and another there are larger differences in pattern.

Figure 2 is the record of a group of two emissions. Their graphical amplitudes (*A*) and frequencies (*B*), versus time, as recorded simultaneously from a slowed tape are shown. (The original recording was made at a rate of 60 inches per second; during playback and analysis the recording was slowed to 3¾ inches per second—a 16-fold

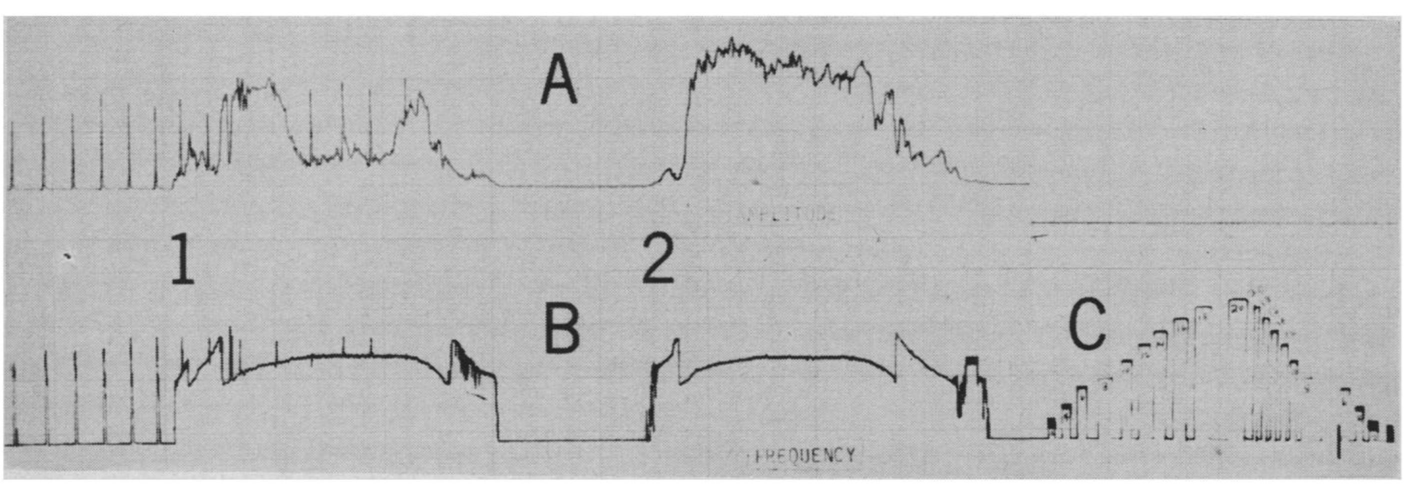

Fig. 2. Records of a train of clicks and two whistle emissions. Trace *A*, amplitude of underwater sound versus time; trace *B*, frequency analyses versus time. *1*, first emission; *2*, second emission; *C*, frequency calibration in steps as follows: 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20 kcy/sec. The duration of each emission is about 0.3 second. Notice that the patterns of amplitudes are quite different for emissions *1* and *2*, even though the patterns of frequencies are similar for the two emissions. Notice also that the first whistle emission (*1*, *A* and *B*) starts and continues during a train of clicks.

reduction in speed). There is some compression of the highest amplitudes of emission No. 2. The time-frequency patterns of these two emissions are more similar to one another than either is to patterns of previous or subsequent groups in this series. It is to be noted that, except for the clicks and for instrumental artifacts when the whistle amplitude is low, these whistles are sine-type waves with integral harmonics ($1f$, $2f$, $3f$, and so on) and with usually smooth and sometimes abrupt frequency changes of a monotonic nature. The frequencies in one emission can range from 4 to 18 kilocycles per second; the usual emission has frequencies between 9 and 12 kilocycles per second throughout most of its time course. Despite great differences in amplitude (differences at times as great as 100 decibels), the frequency patterns in a long series are surprisingly stable. In a solitary dolphin the emissions become less frequent and quite stereotyped; with pairs of dolphins, the emissions are frequent and quite complex, with alternation between emissions from each animal and with rare overlaps or rare simultaneous emissions (duets).

Such whistles, when played back at one-eighth the original speed, sound something like an air-raid or police siren whose tone shifts or warbles. In general, in the first half of the emission the tone rises; in the second half it may go on rising, level off, fall, or warble in a complex fashion. In a continuous series, each group of two or

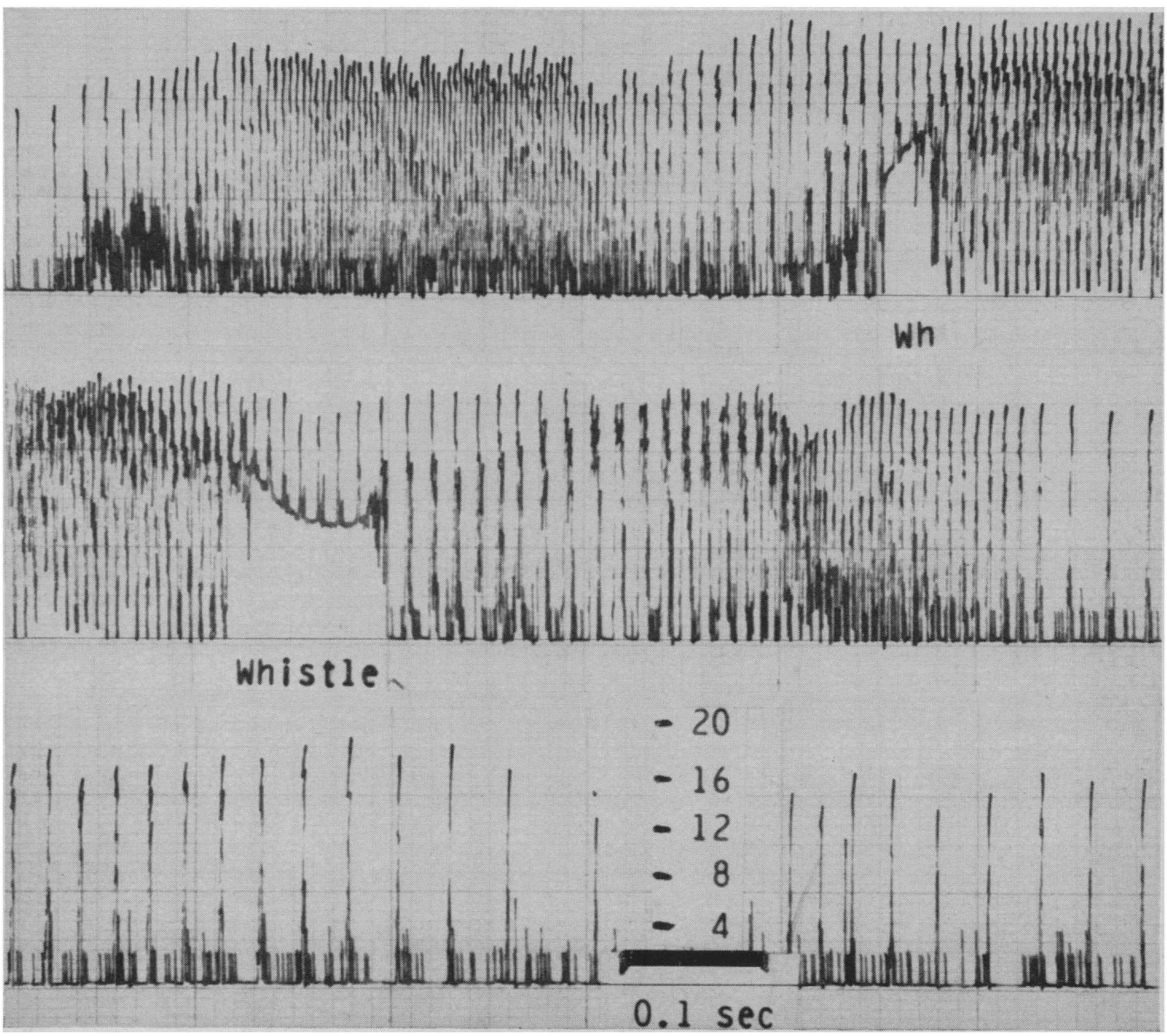

Fig. 3. Record of a squawk emitted under water during stimulation by a human being. The squawk was preceded and followed by a train of clicks at a low rate of repetition (25 to 40 clicks per second). Two whistles occurred during this squawk, one (top trace) at 0.7 and one (middle trace) at 0.95 second 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 (see text). Clicks of maximum repetition rates (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 emitted from the open blowhole in air simultaneously with emission of this squawk under water.

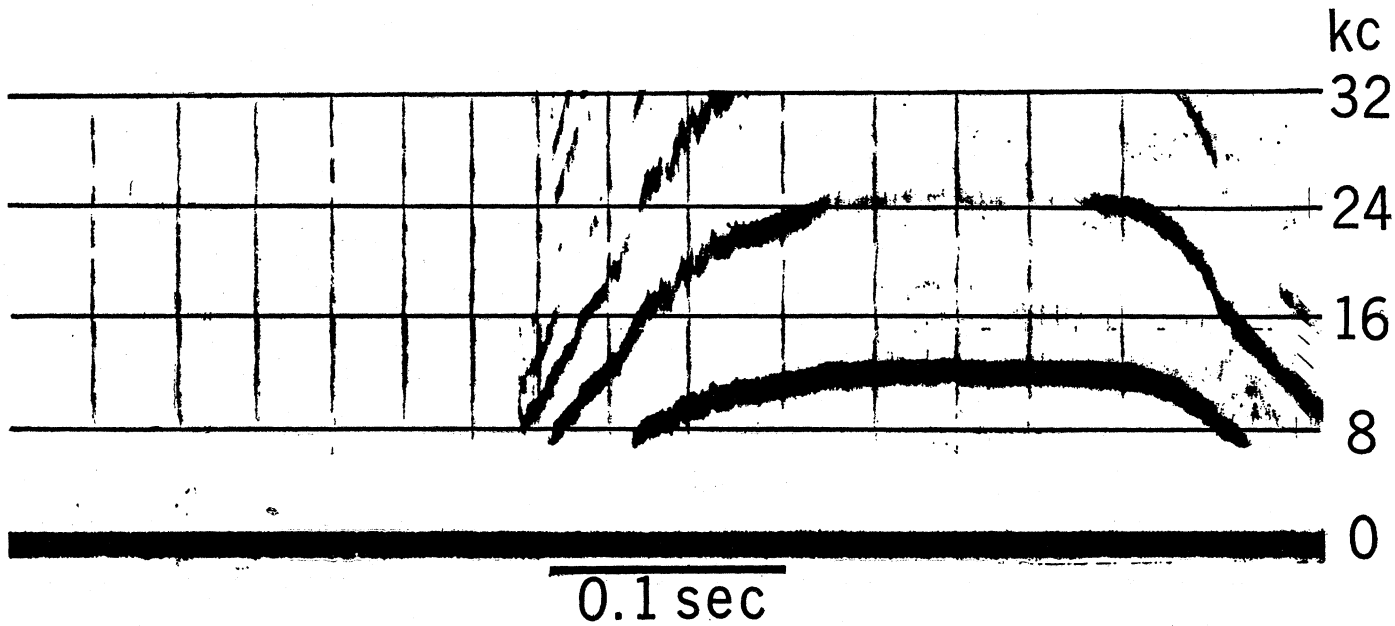

Fig. 4. Sound spectrograph analysis of a whistle and concurrent train of clicks (sonic and supersonic components). The frequencies of the sounds emitted in this sequence extend from about 6 to at least 64 kcy/sec. This figure shows the fundamental, first, and second harmonics, some of the third, and 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 kyc/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.

three whistles may differ from the group just before or just after it, with the following notable exception.

Distress Signal

If an animal is placed in a distressing situation it will emit two particular dissimilar whistles again and again, as a pair, until relieved by another animal or an observer. The first whistle of the pair is a simple crescendo throughout. The second is a simple decrescendo throughout the emission. The distress signal silences all other dolphins who immediately search for its source. They push an animal which has emitted it to the surface of the water and subsequently carry on complex whistle exchanges with it.

Particular trains of clicks, or "sonar," emitted in echo-location, ranging, recognition, and navigation situations have been described by others (*2–4*). In addition, we find that pairs of animals produce trains of clicks, similar but not identical, under the conditions that evoke whistling and with some of the characteristics of the whistling (Figs. 1 and 2). Sometimes one of the pair puts out a "solo" train, sometimes the two alternate clicks, and rarely they emit clicks simultaneously. When the clicks are slowed down and played back, one can hear that the tones are modified in a systematic fashion not connected with relative movements of the animal. Our recordings include trains of clicks of from 1 to 800 clicks per second. The trains in the slow group (1 to 30 clicks per second) occurred with no need for, or production of, creakings (sonar).

Sounds of class iii (quacks and so on) may possibly be modified trains of clicks at a higher repetition rate, modified with considerable modulation of the middle- and lower-frequency components (components with a range equal to or lower than that of the whistles). Samples of such sounds have been recorded which had constant and also variable click repetition rates from about 50 to about 800 clicks per second, with some constant and some variable frequency components, and with train durations from 0.1 second to 3 or more seconds. The durations are not as predictable as those of the whistles. These sounds, also, occurred without any need for creakings.

It has been observed that whistles can be emitted while class iii sounds are being made (Fig. 3). Such observations demonstrate that the bottlenose dolphin has at least two separately controllable sonic emitters, one for the production of clicks and one for the production of whistles. Study of frequency-time graphs for several hundreds of whistles, individual clicks, and high- and low-speed trains of clicks reveals evidence of some degree of acoustic coupling between these two systems. The sonic [not supersonic (see *3*)] frequency analysis of a click shows it to be a complex wave form with several frequency components, as discussed for sounds of class iii. Figure 2 (*A1*) shows several clicks superimposed on the whistle amplitude record. The frequency curve (*B1*) shows that these clicks contain high-frequency components of frequencies very near those of the whistle and of its first and second harmonics (as determined by other analytic methods), and also that a frequency component in the train of clicks was modulated prior to and during emission of the whistle. It can be shown, by means of the sonograph (*6*) (Fig. 4), that other components, with frequencies up to at least 64 kilocycles per second, are of fixed frequency and vary in intensity with time.

Mechanism

One probable mechanism to explain these results, and similar ones shown in Fig. 3, is that the clicks "shock-excite" the resonant frequencies and harmonics of the air-containing cavities (variable sacs, fixed sinuses, fixed nasal passages, and so on) in the head. One or more of these sacs is used to produce whistling and can be made to click-resonate briefly during whistling as well as during nonwhistling periods. Because some of the sacs change size and shape through movements of muscles in their walls, the frequencies of the whistle or of the click-excited resonances, or of both, change. The fixed cavities emit their characteristic click-excited frequencies as the coupling and the internal air path are varied. Records on the sonograph (Fig. 4) show these fixed bands better than they can be seen from Figs. 2 and 3. Figure 3 shows the variable components at middle frequencies (less than 22 and more than 2 kcy/sec) better than the sonograph does. During a rapid train of clicks such changes can be detected on the plot of frequency versus time, as shown in Fig. 3.

Analyses of the sounds produced by a pair of severely restrained animals suggest that the whistles are a form of communication, just as some of the slow trains of clicks may be. Rapid trains of clicks (squawks, quacks, and so on) occur most frequently as a result of human intervention, during intense emotional situations such as in courtship and violent play, and during electrical brain stimulation in reward (start) systems but not in punishment (stop) systems (*7*). Thus it appears that trains of clicks express (at least) intense pleasure in various forms, or possibly anger (at times).

That the dolphin has precise and accurate control of these emissions is no longer in doubt. These sounds are classified as vocalizations used for communication. What information is communicated is yet to be determined.

Summary

The sonic emissions of the bottlenose dolphin are remarkably complex. Three classes of these sounds are discussed and presented graphically. The sine-type wave whistles range in frequency from about 4000 to 18,000 cycles per second. The clicks contain components of this same frequency range plus some components of higher frequencies. Complex waves of high amplitude and of many frequencies are also emitted in water or in air. Situations in which sounds of one or more of these classes can be elicited simultaneously from one and from two restrained animals are described. The necessity for, and occurrence of, creakings for purpose of navigation, ranging, and recognition (sonar) have been eliminated in the experiments under discussion.

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6. We wish to thank J. C. Steinburg and Roger Dann of the University of Miami for the use of an AN/PQM hydrophone set; Herbert Gentry (Precision Instrument Co.) for the use of a tape recorder; William Murphy (Cordis, Inc.) for the use of a Massa graphic recorder; and F. G. Walton Smith (Marine Laboratory, University of Miami) for past use of laboratory space. The frequency analyzer used in this study was devised by one of us (J.C.L.). We wish to thank K. N. Stevens (Massachusetts Institute of Technology) for his help and for the use of a sonograph (Kay Electric Co., Pinebrook, N.J.). The mirror galvanometer oscillograph is a Minneapolis-Honeywell Heiland Model 906-B with M-8000 galvanometers. We also wish to thank William Rolleston and F. G. Wood, Jr., for supplying dolphins in the early stages of the work.
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Science in the News

In the Senate: The Debate on Education; The Internal Security Committee Studies Disarmament

The Senate has been involved in an elaborate debate over the school bill since Tuesday of last week (16 May) and will probably still be at it when this appears. Senator Morse, the floor manager for the bill, made it clear that he felt he had enough votes to defeat any amendment opposed by the Administration. If anything, this encouraged the amenders, who could then propose whatever came to mind without having to worry about its consequences, since there was no chance of its being adopted.

Senator Blakely, a very conservative Texas Democrat, suggested simply rebating to each state 5 percent of all the income taxes collected within each state, a proposal that would cost the federal government about $3 billion a year, something over 3 times as much as the Administration bill. Senator Cotton, a conservative Republican of New Hampshire, suggested granting the states 3 cents for each pack of cigarettes sold within the state. Senator Proxmire, a liberal Democrat of Wisconsin, wanted to eliminate the words "federal grants" from the bill and substitute "income tax sharing." Senator Bush, of Connecticut, offered a Powell-type amendment, prohibiting aid to segregated schools, and Senator Thurmond, of South Carolina, offered a Powell-type amendment in reverse, prohibiting the Administration from holding up aid to segregated schools. Cooper, of Kentucky, and Javits, of New York, liberal Republicans, asked for changes in the formula for allocating the grants among the richer and poorer states.

The first week of the debate was occupied with these proposals, all of which were easily defeated, and of which only the Cooper-Javits amendment seemed to be taken very seriously. Senator Goldwater, who voted against loans for private schools last year, then proposed loans for private schools. Senator Talmadge offered a more generally worded version of Senator Thurmond's counter-Powell amendment. Senator Dirksen, with the martyr-like air that has been coming over him lately, proposed cutting the bill back to construction grants only, although he assured the Senate