



Clicks, whistles and pulses: Passive and active signal use in dolphin communication



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ABSTRACT

The search for signals out of noise is a problem not only with radio signals from the sky but in the study of animal communication. Dolphins use multiple modalities to communicate including body postures, touch, vision, and most elaborately sound. Like SETI radio signal searches, dolphin sound analysis includes the detection, recognition, analysis, and interpretation of signals. Dolphins use both passive listening and active production to communicate. Dolphins use three main types of acoustic signals: frequency modulated whistles (narrowband with harmonics), echolocation (broadband clicks) and burst pulsed sounds (packets of closely spaced broadband clicks). Dolphin sound analysis has focused on frequency-modulated whistles, yet the most commonly used signals are burst-pulsed sounds which, due to their graded and overlapping nature and bimodal inter-click interval (ICI) rates are hard to categorize. We will look at: 1) the mechanism of sound production and categories of sound types, 2) sound analysis techniques and information content, and 3) examples of lessons learned in the study of dolphin acoustics. The goal of this paper is to provide perspective on how animal communication studies might provide insight to both passive and active SETI in the larger context of searching for life signatures.

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1. Introduction

Dolphin communication is both complex and contextual [1]. Dolphins communicate using both vocal and non-vocal signals including visual, tactile, kinesthetic, and chemoreceptive [2] including cross-modal abilities [3]. Because of the highly developed acoustic sense in dolphins, researchers have emphasized the recording and analysis of vocalizations [4]. Dolphin sound production and reception are highly directional in both frequency and intensity [5]. Dolphins produce two sounds simultaneously producing clicks on the right side and whistles on the left side [6]. Dolphins are also capable of internal sound pointing by reshaping their sound focusing organ

(the melon) and parameters including frequency, intensity, and duration can all be modulated independently, providing opportunity for detailed encoding of information [7]. The directional nature of dolphin sound adds a complication to many studies and requires triangulation involving multiple hydrophones or separation of individuals during recording.

Dolphin sounds are divided into three primary categories: Whistles, clicks, and burst pulsed sounds. All sounds can be used socially while echolocation is thought to be primarily for navigation and hunting. Spectrally distinct sound types include 1) Whistles – primarily social communication including *frequency-modulated whistles*, *amplitude modulated whistles* and *whistle squawks*, 2) Clicks – navigation and orientation including *echolocation click trains*, and *buzzes* and 3) Burst pulsed sounds – primarily social sounds including *squawks*, *barks* and *pops*. Recently discovered

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synchronized vocalizations include *squawks*, *screams*, and *brays*, and show prosodic elements to dolphin communication. Dolphins also make in-air vocalizations including *chuffs*, *raspberries*, and non-vocal impulse sounds including *jaw-claps*, *tail cavitation*, *tail slaps*, and *bubbles* [8].

Dolphins are both predator (on fish, squid) and prey (sharks, orcas) and use both passive and active sonar. Hearing sensitivity is excellent and many species produce signals with a bi-modal frequency bands around 40–50 kHz and 130–140 kHz [9]. But when do dolphins listen passively and when do they actively search? Passive acoustic vigilance and “eavesdropping” on neighbors allows for information sharing from one individual to another without cost, while active vigilance via echolocation is used for final targeting of prey or clarification of information already passively detected. However, the costs of active vigilance may have a cost as it does for other species [10].

The need for stealth is best exemplified by the use of crypticity by killer whales (*Orcinus orca*). Resident killer whales in the Pacific Northwest eat fish and use regularly spaced clicks when hunting their prey, primarily fish that do not hear high frequencies. Transient killer whales, that eat small dolphins and porpoise who hear high frequencies, use irregularly spaced click patterns that are hidden in the background noise [11].

2. Measurement techniques and information content

Historically, whistles are the most studied dolphin vocalization because of their ease in measurement. The majority of literature on whistles report qualitative comparative visual assessments of frequency contours made by human judges while quantitative techniques (Discriminant Function Analysis, Principal Component Analysis) have been occasionally attempted [12]. Neural networks (NN) have been used to quantify whistles, although NN analysis requires *a priori* data to train a computer [13]. Since many datasets may have a low N of whistles this is not a practical technique for many studies. NNs have also been primarily developed for tracking whistles contours, which eliminates the measurement of other important social signals such as burst-pulsed sounds.

Recently passive acoustics have become a popular technique in the field, along with some real-time acoustic tools [14]. Although passive acoustics allows the presence or absence of a species to be detected over large periods of time, it does not address the detailed social or cognition questions posed about dolphins and whales. To compensate for this issue, researchers have used information theory to assess the complexity of dolphin whistles [15,16] although other social signals have not been analyzed using this technique. Little work has been done on analyzing sequences of sound types to look for spatial, prosodic, motif, or rhythmic information although newly emerging literature would suggest that this is an important aspect of dolphin communication [17,18].

Increased understanding of mechanistic and perceptual classification is needed to determine the natural boundaries of signal units and classification by delphinids, as it

has been for other taxa [19–23]. Recently analysis of dolphin signature whistles using standard techniques indicate that the separation of fundamental units in whistles may help in the identification of caller ID and the process of communication [24].

Both the presence of referential calls or a graded system of communication, or both, is still unspecified for dolphins. Although some researchers argue that the signature whistle meets the criterion for a reference identifying an individual, the identification and isolation of other fundamental units of sound, potentially referential, within the dolphin signal repertoire, has only recently been attempted using cutting-edge computer techniques [25,26].

Complex syntax, semantics and referential signal use has been found in many species. Studies of alarm calls in wild vervet monkeys [27], ground squirrels [28] and prairie dogs [29] have revealed elements of symbolic referential communication and competence. Similarly, laboratory studies of intra and interspecies referential communication and competence have revealed both semantic and syntactic understanding in common and pygmy chimpanzees [30] and bottlenose dolphins [31]. Dolphins, a non-terrestrial and most alien of social mammals, have the second largest encephalization quotient and complex cognitive abilities [32,33] and have a variety of mechanisms of information transfer [34] and teaching mechanisms [35], and would be likely candidates for such complexity.

Information content has also been explored in the context of interspecies interactions of delphinids. What is the mechanism or process by which two disparate species understand each other? Cross-species communication is also both passive and active. Some species take advantage of their neighbors monitoring abilities and learn the meaning of appropriate alarm calls (birds, primates). Two examples in the dolphin world illustrate the creation of shared/mutual calls during interaction. Resident killer whale pods in the Pacific Northwest have pod dialects. However, when interacting with other pods, they have a small repertoire of shared calls for use with the other group [36]. Recently, the complex dynamics of vocalization used between two species of sympatric dolphins in Costa Rica has been reported, suggesting that they also share types of calls when together and revert back to their own species calls when separate [37]. Both these examples suggest that it is more efficient to create a new communication system with another species than to learn the intricacies of the other's communication signals. Ironically this has been the approach of necessity in human/animal cognitive interfaces due to the lack of understanding of nonhuman animal communication systems. In fact this technique has proven successful for bonobo chimpanzees [30], African grey parrots [38] and, to a limited degree, dolphins [39,40,41]. The question of whether there are universal features of communication across all species, as described for birds and mammals [42], or avenues of sensory system overlap, remains largely unexplored.

When studying other species we often learn of our own biases and assumptions regarding the world around us. The following are four specific examples of lessons we have learned through the field of dolphin acoustics and

communication research that are particularly relevant to SETI.

2.1. Experimental work or unnatural environments that restrict animal movement or natural behavior can give false information about a process. Follow the data and observe the animals in a natural habitat to understand a natural law or system

Decades ago scientists used information from dolphin echolocation signals to develop a SONAR theory. Sound is four and a half times faster in water than air so dolphins have fast processing abilities. From traditional tests on captive dolphins, whose heads were temporarily immobilized in a headrest, scientists noted that click production followed a “Two Way Travel Time” rule (TWTT). This rule stated that Click A goes out and comes back to a dolphin to be processed before another Click goes out. Thus temporal space between the click production and reception was typically large (> 20 msec). After observations in the wild [43] showed a bimodal distribution of clicks intervals (< 19 msec and > 19 msec,), and some studies in captivity that showed when dolphins were close to their target their clicks were tightly packed, scientists acknowledged that dolphins were breaking the TWTT Rule. Once the military started measuring echolocation used by actively moving dolphins, SONAR theory was adjusted to incorporate this natural use of clicks by dolphins. SONAR theory also did not explain other observations of dolphins in the wild. For example, dolphins have the ability to scan from ten meters above into the sand and identify a fish buried in the sand [17]. Sonar theory did not explain how the dolphins were able to penetrate the sediment at such great distances to detect objects, yet dolphins were doing this in the wild.

The natural abilities of dolphins to manipulate water was also misunderstood and distorted from artificial observations. In captivity, dolphins also make bubble rings and use them as toys, manipulating, pushing, and biting them for fun. However, in the wild, dolphins use bubble rings as an aggressive signal, showing their natural use of these bubble ring in the wild [17]. During foraging, dolphins can also create vortices of water that move along the bottom and hover over low pressure gradient fish holes, essentially marking a spot for digging [44], and suggesting that dolphins are able to create a tool as well as use tools.

2.2. Know the sensory abilities of your species and do not assume human perceptual parallels

What does a dolphin really hear? Previous audiograms of dolphins and porpoise showed that many species have a maximum sensitivity between about 30–40 kHz, and between 80–100 kHz [5]. After that sensitivity is dropped off. Researchers traditionally process and display dolphin vocalizations relative to human hearing sensitivity, suggesting that the fundamental frequency is the most important component of a dolphin whistle. However, [43] dolphin whistles adjusted for the hearing sensitivity of a dolphin show maximum sensitivity to the second harmonic, not the fundamental frequency as suggested by past work.

2.3. Signal to noise ratio: Make sure you know what noise is before you ignore it

The most commonly studied dolphin vocalization is the frequency modulated whistle because it is easy to measure. However, researchers [43] showed that other whistles that appear messy and are not easy to measure in contour extraction programs, can carry other types of modulated information, previously considered noise. In most cases, researchers ignored or threw out these difficult-to-measure amplitude modulated (AM) whistles thinking they were “noise”. Instead, these signals were eventually found to be common AM signals in the repertoire of many dolphin species and not an artifact of distorted anatomy or environmental factor. The field of epigenetics (the study “junk” DNA, previously thought to be useless) emerged after scientists realized that the non-DNA matter found in DNA strands functioned differently, but significantly, in biologically meaningful ways.

2.4. If a framework or method is not illuminating a process try a new one rather than giving up on studying the process

Scientists have a long history of exploring two way communication interfaces with other species. For decades scientists explored the abilities of apes or dolphins using human language without recognizing the limitations of vocal anatomy of each species. Subsequently an old framework reemerged (social-rivalry) from work with an African grey parrot [38], providing a new, and productive methodological framework for many species including bonobo and common chimpanzees [30] and dolphins [41]. Techniques to bridge the sensory gap between species, including technological interfaces, have been used for cognitive interfaces even with an alien species like a dolphin [40].

3. Conclusions

Scientists face the daunting task of trying to understand and decode animal signals by applying previous research techniques used with other taxa or human subjects. Human perceptual abilities and human-biases continue to challenge our research techniques when assessing other species. This paper discussed multiple examples of mistakes (and corrections) made in dolphin research over decades, including constraining animals to assess their natural abilities, misunderstanding sensory systems, missing important information in “noise”, and using antiquated experimental frameworks. These mistakes provide insight and suggest ways to correct our course to prevent similar mistakes during future SETI searches and astrobiology exploration. Key to this process is the upfront acknowledgment of different sensory, perceptual, and social systems when ascertaining or measuring aspects of non-human life or complex signals. The implications for astrobiology include the ability to understand natural systems off-world and complex properties and communication systems of unknown species. Many animal communication studies can likely inform and contribute new insight to astrobiology and SETI during the search for life signatures.

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