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Who is whistling? Localizing and identifying phonating dolphins in captivity

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ABSTRACT

Acoustic communication through whistles is well developed in dolphins. However, little is known on how dolphins are using whistles because localizing the sound source is not an easy task. In the present study, the hyperbola method was used to localize the sound source using a two-hydrophone array. A combined visual and acoustic method was used to determine the identity of the whistling dolphin. In an aquarium in Mexico City where two adult bottlenose dolphins were housed we recorded 946 whistles during 22 days. We found that a dolphin was located along the calculated hyperbola for 72.9% of the whistles, but only for 60.3% of the whistles could we determine the identity of the whistling dolphin. However, sometimes it was possible to use other cues to identify the whistling dolphin. It could be the animal that performed a behavior named "observation" at the time whistling occurred or, when a whistle was only recorded on one channel, the whistling dolphin could be the animal located closest to the hydrophone that captured the whistle. Using these cues, 15.4% of the whistles were further ascribed to either dolphin to obtain an overall identification efficiency of 75.7%. Our results show that a very simple and inexpensive acoustic setup can lead to a reasonable number of identifications of the captive whistling dolphin: this is the first study to report such a high rate of whistles identified to the free swimming, captive dolphin that produced them. Therefore, we have a data set with which we can investigate how dolphins are using whistles. This method can be applied in other aquaria where a small number of dolphins is housed; though, the actual efficiency of this method will depend on how often dolphins spend time next to each other and on the reverberation conditions of the pool.

1. Introduction

Acoustic communication through whistles is well developed in dolphins because sound is the best way in which energy is transmitted through water [1,2]. However, little is known on how dolphins are using whistles among themselves because identifying the sound source is not an easy task [3,4]. It is essential to determine which individual dolphin is producing each sound to obtain an adequate whistle data set that could be used to assess whistle usage.

In terrestrial species like mammals and birds (e.g., sea lions [5]; foxes [6]; penguins [7]), directional and omnidirectional microphones are easily used to determine which is the phonating animal because individuals can usually be seen vocalizing and/or tend to be static. In water, identifying the sound source is more complicated because sound propagates almost five times faster in water than in air and the phonating animal moves in a 3-D environment without giving clear cues that it is vocalizing. Additionally, having visual contact with each individual depends on water visibility.

To cope with these problems, previous studies worked with free swimming [8] or temporarily restrained [9] isolated captive dolphins. However, their results represented the isolation situation of dolphins and not a more natural scene of free swimming, socializing animals [10]. Other researchers have used tags to identify the whistling individual, such as an optical telemetry device or vocalight placed on the dolphin's forehead [3] or a datalogger placed on the dolphin's dorso [11]. They had mixed results because they could not always determine which was the phonating dolphin; the tag would either light [3] or record [11] when another dolphin than the one carrying the device whistled. In addition, dolphins changed their behavior when they carried the device [11], making it difficult to investigate how dolphins were using whistles.

The simultaneous emission of sounds and bubbles in free swimming captive dolphins [12] has also been used. This method had the disadvantage that not all whistles are produced simultaneously with bubbles [3,13], therefore, an array of hydrophones combined with visual data has recently been used to calculate the sound source and to identify the free swimming whistling dolphin in captive [4] and wild [14] environments. This approach was useful in determining a set of several, possible whistling dolphins [4,14], but as dolphins swim next to each other, they could not identify the phonating individual.

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We suggest that the approach of using an array of hydrophones combined with visual data is viable to identify the whistling dolphin in captive situations where a small number of dolphins are swimming together. Therefore, in the present study, the hyperbola method, a simple technique based only on time differences of arrival of the same sound to different receptors [15,16] was used to localize the sound source of whistles from two dolphins swimming freely in captivity. A combined visual and acoustic method (e.g., [17,4]) was used to determine the identity of the whistling dolphin.

2. Materials and methods

This research was performed for 22 days from October 2006 through October 2007 in an aquarium in Mexico City where two adult bottlenose dolphins were housed in two different pools. For 15 days, dolphins were held in an oval pool with 28 m major axis, 20 m minor axis, 4 m depth in the periphery, and 5 m depth in the center (Figs. 1 and 2), and for 7 days in a rectangular pool with 17 m length, 8 m width, and 4 m depth. The walls and bottom of both pools were concrete painted light blue, with little algae growing on them. Water temperature averaged 20.5 ± 2.7 °C, water salinity averaged 29.2 ± 2.9 ppt, and water clarity was always good (i.e., always seeing the bottom of the pool).

A two-hydrophone array using EDO 8200 transducers (−198 ± 1 dB re 1 V/μPa from 3 Hz to 100 kHz) was placed in the center of one side of the pool at a depth of 2 m (Fig. 1). A two-hydrophone array was used because this makes the system affordable and accessible to many researchers that are only able to acquire two-channel or stereo recorders. Two distances between elements were used in the two pools where dolphins were housed because the pool dimension was changed by the aquarium staff when a divider was added. When dolphins were in the oval pool, a distance between elements of 20 and 10 m was used during 14 and 1 days, respectively. In the rectangular pool, a distance between elements of 17 m was used during 3 days, and of 12 m during 4 days.

A two-channel M-Audio Microtrack© 24/96 recorder digitally sampled sounds for both hydrophones simultaneously at 88 or 96 kHz sampling rate with 16 bits, and a flat frequency response from 20 Hz to 41 kHz at 88 kHz sampling rate and from 20 Hz to 45 kHz at 96 kHz sampling rate. The digitized sounds were saved into CompactFlash® cards and later transferred to the hard disk of a desktop computer using a USB port. Therefore, the array-recorder system had the flat frequency response of the digital recorder.

Two video recorders (VR) were used (Fig. 2A): VR1 was a JVC GR-D395U video camera located 17 m from the edge of the oval pool (the furthest and highest possible position) to obtain a far range view of the whole pool where both dolphins were in view at most times (Fig. 2B); VR2 was a Panasonic NV-GS180 video camera located 5 m from the edge of the oval pool to obtain a close range view of the pool in order to capture the identity of each dolphin (Fig. 2C). VR2 had the audio input of a hydrophone located in between those used for acoustic localization. To aid in identifying the whistling dolphin, the position of both dolphins when a whistle was heard was also noted on paper.

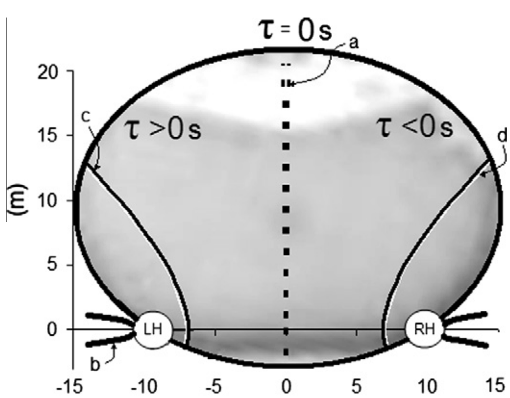

Fig. 1. Schematic of the oval pool depicting several hyperbolas where the sound source could be located. When $\tau > 0$ s, the source is located on the left half hyperbola, when $\tau < 0$ s, the source is located on the right half hyperbola, and when $\tau = 0$ s, the source is located along the center of the pool. LH = left hydrophone, RH = right hydrophone. The dashed hyperbola "a" corresponds to the smallest time difference of arrival (0 s < τ < 0.010 ms). The thick hyperbola "b" corresponds to the largest time difference of arrival for the oval pool (τ_{max} = 13.333 ms). The black and white hyperbolas "c" and "d" in between both hydrophones correspond to a time difference of arrival of τ = 9.004 ms and τ = 9.092 ms, respectively (depicting a time difference of 0.088 ms, which is the resolution of one of the programs, Canary©, used to compute the time difference of arrival).

3. Theory/calculation

To identify the sound source we first needed to determine its position. In water, to determine the position of the sound source several acoustic receptors or hydrophones in different array configurations and utilizing different signal processing methods are used [16]. All of them presume that each sound produced by the source is received by a sufficient number of elements of the array at different times and with different amplitudes.

The two-channel sound files were used to perform the localization of the sound source using the hyperbola method [15,16] with a custom excel program:

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1, \quad \text{for } a = \frac{\tau \cdot c}{2} \text{ and } b = \sqrt{d_h^2 - a^2}$$

where d_h = 10 m, 8.5 m, 6 m or 5 m, τ = time difference of arrival, and c = sound propagation speed.

The time difference of arrival (TDOA or τ) was calculated by cross-correlating the whistles of the two-channel sound file using Canary© 1.2 [18] and Raven© 1.3 [19] softwares with and without a filter. With Canary© 1.2, the resolution in computing τ was of 0.088 ms, whereas for Raven© 1.3, a resolution of 0.052 ms was observed. This resolution represents a distance between hyperbolas smaller than the size of a dolphin (Fig. 1); therefore, it did not present a problem in determining the position of the sound source. Only complete whistles that did not overlap with other sounds were used to compute the cross-correlation. When overlapped whistles were cross-correlated, a $\tau > \tau_{max}$ = 13.333 ms was computed, obtaining an imaginary hyperbola and a non reasonable result.

Sound propagation speed, c was calculated with measurements of surface water temperature and salinity taken *in situ* at the time when recordings were done, using the following formula [20]:

$$c(T,S,z) = 1449.2 + 4.6T + 0.055T^2 + 0.00029\,T^3 + (1.34 - 0.01T)(S - 35) + 0.016z$$

where T = water temperature in °C, S = water salinity in parts per thousand, and z = 2 m.

The hyperbola was traced over a photograph of the pool to localize the sound source (Fig. 1). The sound source was located in the space along the calculated hyperbola at any depth because only two hydrophones were used. If $\tau > 0$ s, then the source was located on the left half hyperbola; if $\tau < 0$ s, then the source was located on the right half hyperbola; and if $\tau = 0$ s, then the source was located along the center of the pool. We did not consider this a 3-D problem because pool depth was 4–5 m, dolphin's length was about 3 m, and dolphins seldom swam one over the other.

Once it was determined the space in which the sound source should be located, the phonating dolphin was identified using