# Buzz that Rod!
# Acoustic analysis and patterns of the echolocation signals of a blindfolded bottlenose dolphin performing a horizontal and vertical angular resolution task


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## Abstract


A bottlenose dolphin was tested on her ability to echoically discriminate between a set of two air-filled PVC rods and a single PVC rod with diminishing angular separations between the two sets. The first experiment measured her horizontal angular resolution and the second experiment measured her vertical angular resolution. The dolphin was able to distinguish between angular separations as low as 1.00 degrees in either experiment (both horizontal and vertical). During the experiment the echolocation signals that the dolphin used for the task were recorded with a 32-element planar hydrophone array at 500 ksamples/second/channel that was mounted perpendicular to the dolphin's body axis between the dolphin's head and the presentation position of the PVC rods. A synchronised 10-second recording was obtained after the dolphin had stationed in a hoop and the rods had been lowered into the water for interrogation through the animal. We present an acoustic analysis of the click type used through out the task, the pattern of interrogation with the changing angular separation and an overall comparison of the recordings obtained in the horizontal condition (PVC rods perpendicular to the ventral plane of the dolphin body) versus the vertical condition (PVC rods parallel to the dolphin ventral plane). The analysis shows that the beam shape can vary quite a bit throughout the task and the dolphin uses clicks of different frequency content. These results shed light on how the dolphin is using its echolocation ability to perform the task and to resolve small differences of objects it echolocates on.


## Methods

The general setup followed the experiment of Branstetter et al 2003 and is shown in Figure 1. The test apparatus consisted of a stationing hoop with response paddles and a screen to block the dolphin's view, a rod presentation device on which the stimuli were lowered into the water and a planar hydrophone array that was mounted perpendicular between the dolphin and the stimuli at about 90 cm distance from the tip of the rostrum of the animal. The dolphin was trained to wear a pair of opaque silicone eyecups for the duration of each trial. Further details of the setup are also shown in poster **Bay24.B.7** later at this conference.

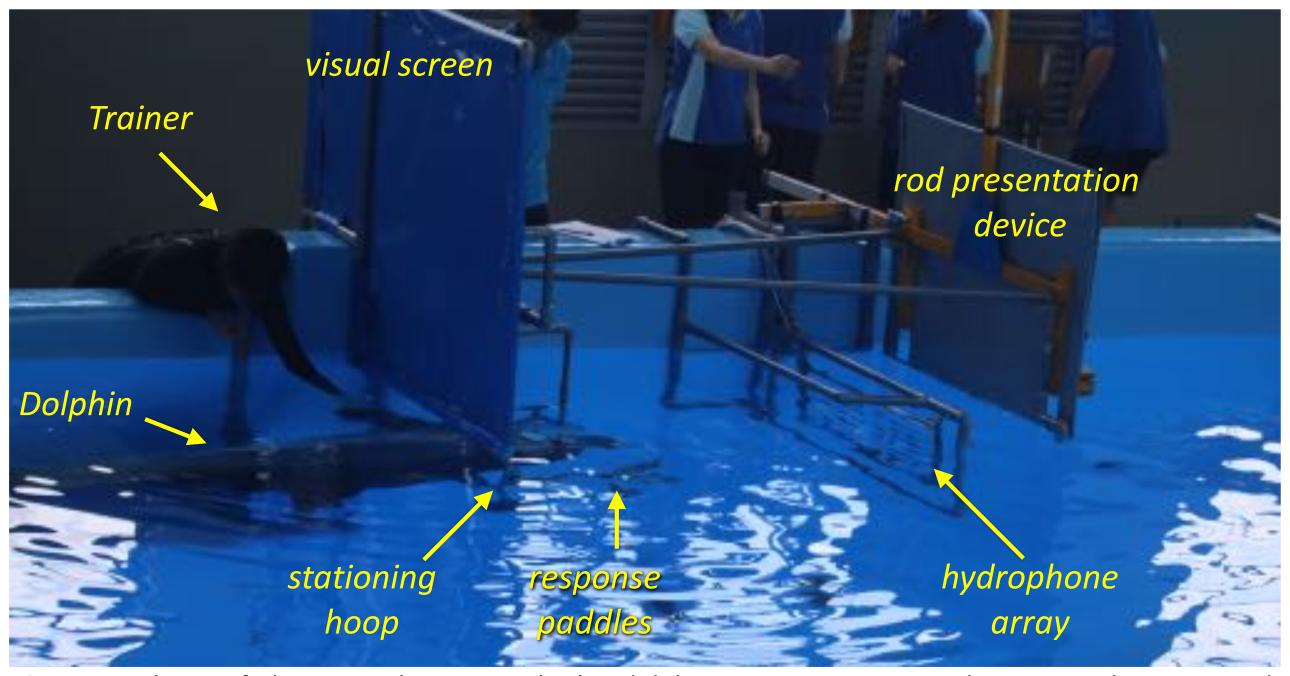


***Figure 1:*** Photo of the general setup with the dolphin, trainer, stationing hoop, visual screen, rod presentation device and hydrophone array.

The hydrophone array consisted of 32 Reson TC4013 hydrophones arranged in a planar array as shown in Figure 2. The signals were amplified by a set of four 8-channel custom-built amplifiers and then acquired through a National Instruments data acquisition system at a frequency of 500kHz per channel. Each recording had a 2 second pre-trigger time, and an 8-12 second post trigger time that was recorded. Furthermore the system had both an in-air and an underwater LED that lit up when the recording was trigged. This allowed for the synchronisation of two cameras – one in air mounted in the ceiling above the complete setup and one underwater camera that was placed in line with the center of the stationing hoop approximately two meter behind the rod presentation device. The hydrophones were arranged at distances of 10 cm from each other on a PVC frame with monofilament lines to hold them in the same location every trial of every session.

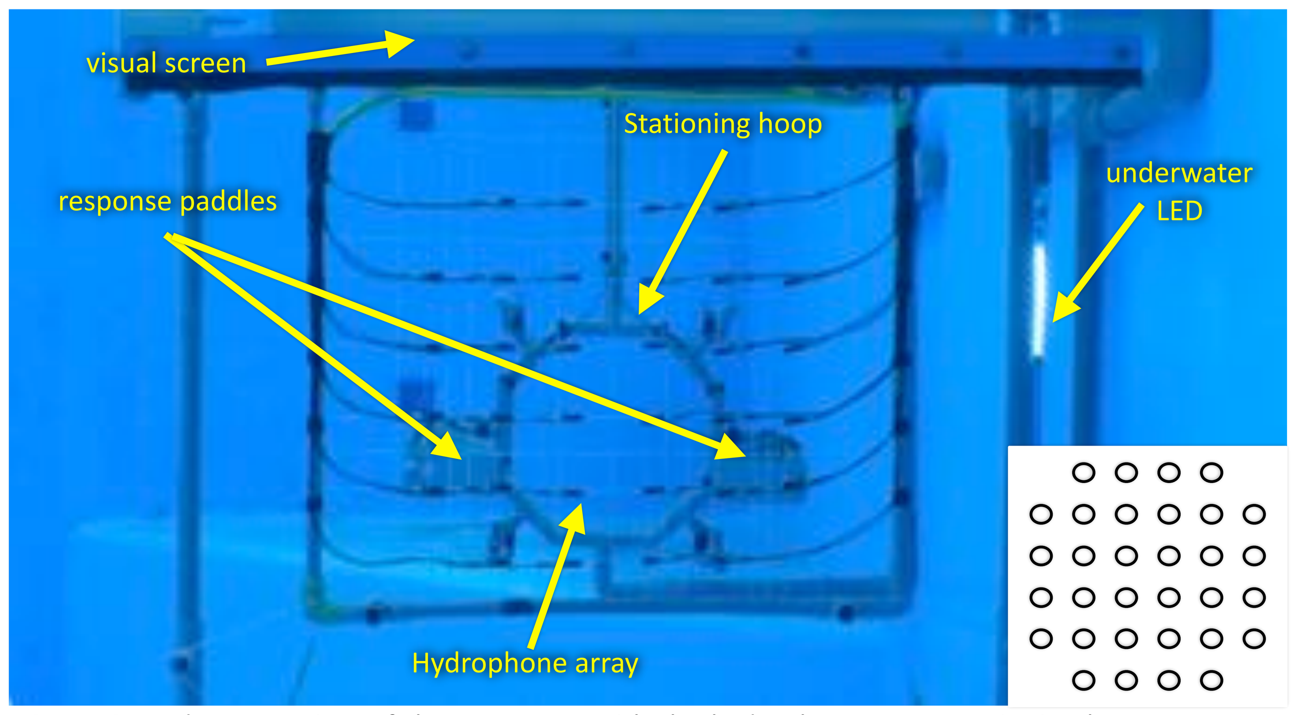


***Figure 2:*** Underwater view of the test setup with the hydrophone array, stationing hoop, response paddles, LED and visual screen; a schematic of the array configuration shown on the right bottom side.

## Test Procedure

For a trial the blindfolded dolphin stationed in the hoop and on a command by the experimenter the set of rods for a particular trial were lowered into the water. The rod assembly also contained a magnetic switch that was automatically closed when the rods were completely lowered into the water. This switch then triggered an automated recording on the data acquisition system. The dolphin echolocated on the array of rods and indicated her choice by either pressing the left or the right response paddle. The dolphin the returned to the trainer to be reinforced for a correct choice and wait for the the next trial.

## Data Analysis

The collected acoustic data were processed the following way: First, the trigger time was determined through the trigger channel. Figure 3 shows a typical time series of one of the channels. Then all channels were processed with a Fast Fourier Transformation (FFT) and the channel with the highest energy across the entire frequency band was selected as the reference channel. Based on the location of a click in the time series of the reference channel the location of the same click in all other channels were determined.

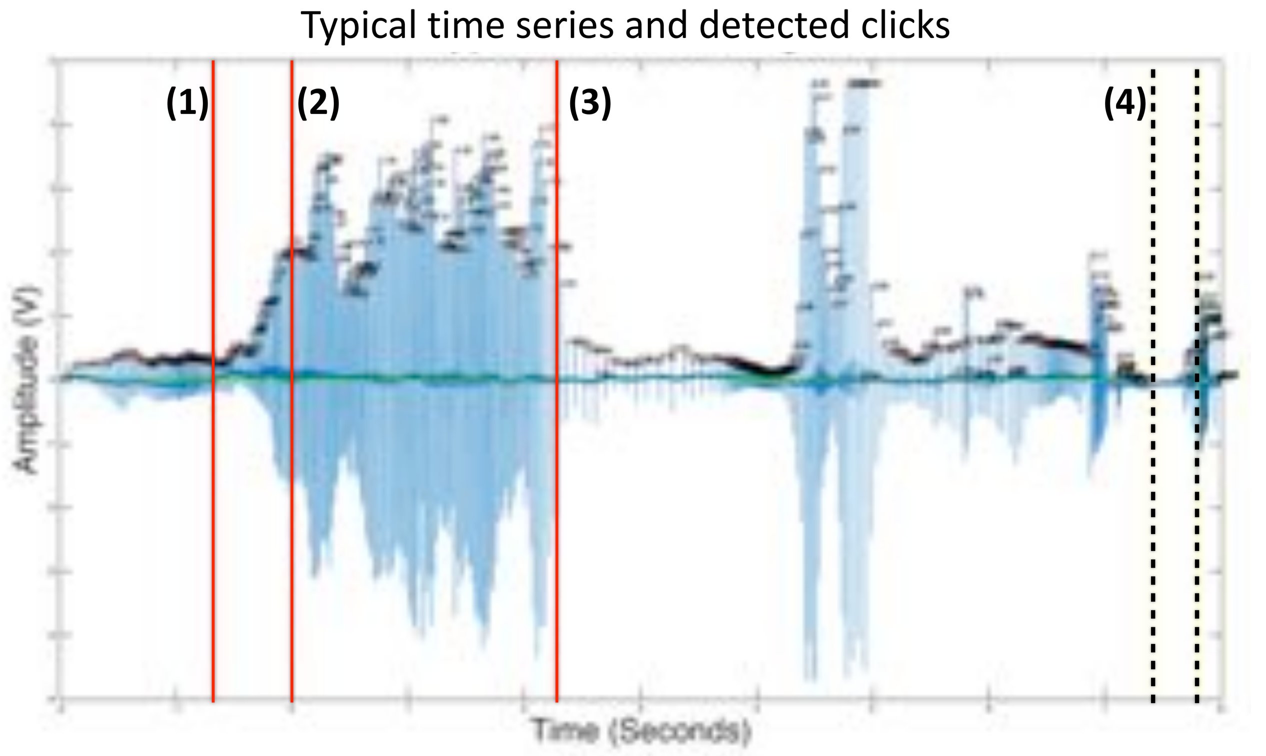


***Figure 3:*** Typical time series from one of the hydrophones. (1) rods start dropping, (2) rods are fully dropped and recording is triggered, (3) the dolphin's head passes the PVC bar and presses the paddle. (4) quiet section used to determine the average noise floor for the threshold.

After a high-pass filter and a Hilbert transform a threshold was set at 6 times the ambient noise floor for the detection of clicks. The individual clicks were then extracted and the energy was interpolated for the location of each hydrophone. Next, the clicks emitted by the dolphin and the reflections from the rods are extracted. The locations for the same clicks are determined for all channels within a time window.

The following information was stored for each click:

- A small section of the original time series
- The exact location of the click in the time series
- An interpolation of the signal power

For the analysis the clicks were grouped the following way: 1) Clicks before the rods are dropped, 2) Clicks when the rods were dropped but were not lowered completely and 3) Clicks emitted from the time when the rods were in their final position (trigger time) to when the dolphin had made her choice.

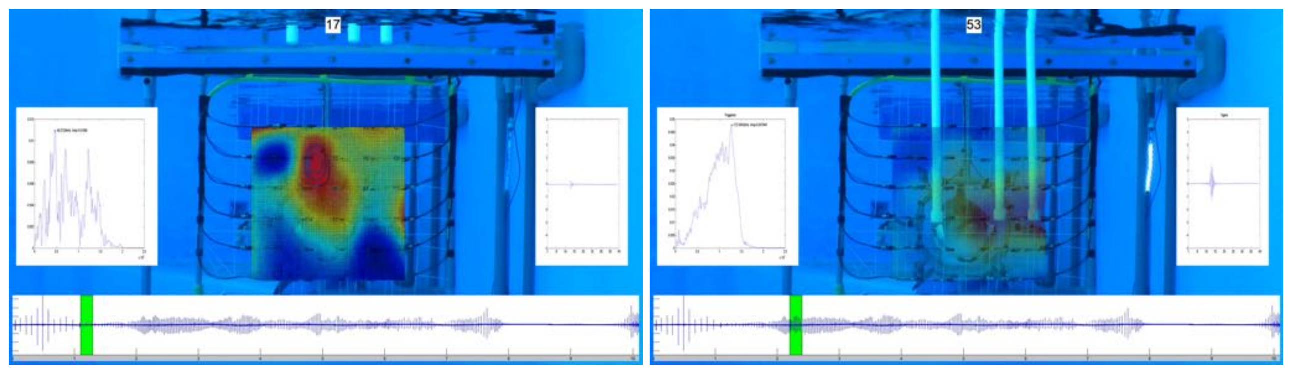

***Figure 4:*** Composite overlay of the energy of Dumisa's echolocation beam for a video frame when the rods are not yet dropped and for a frame when the rods are dropped completely. On the left is click no 17 detected in the sequence and on the right click number 53. Superimposed over the video frame is the power spectral density (left), the interpolated energy as recorded on the array (middle) and the time series of the click (right).

## Results

Figure 5 shows a histogram of the location of the peak energy of the dolphin's echolocation beam across all trials in reference to the array. Clicks recorded before the rods are dropped are shown in green, clicks during the lowering of the rods are in blue and clicks after the rods a dropped completely are in red.

Dumisa seemed to focus most of the time on the upper left corner (green bars) when the rods were not dropped yet - but then once the rods were in their final position she seems to focus on two lobes (red bars) that correspond with the approximate locations of the rods.

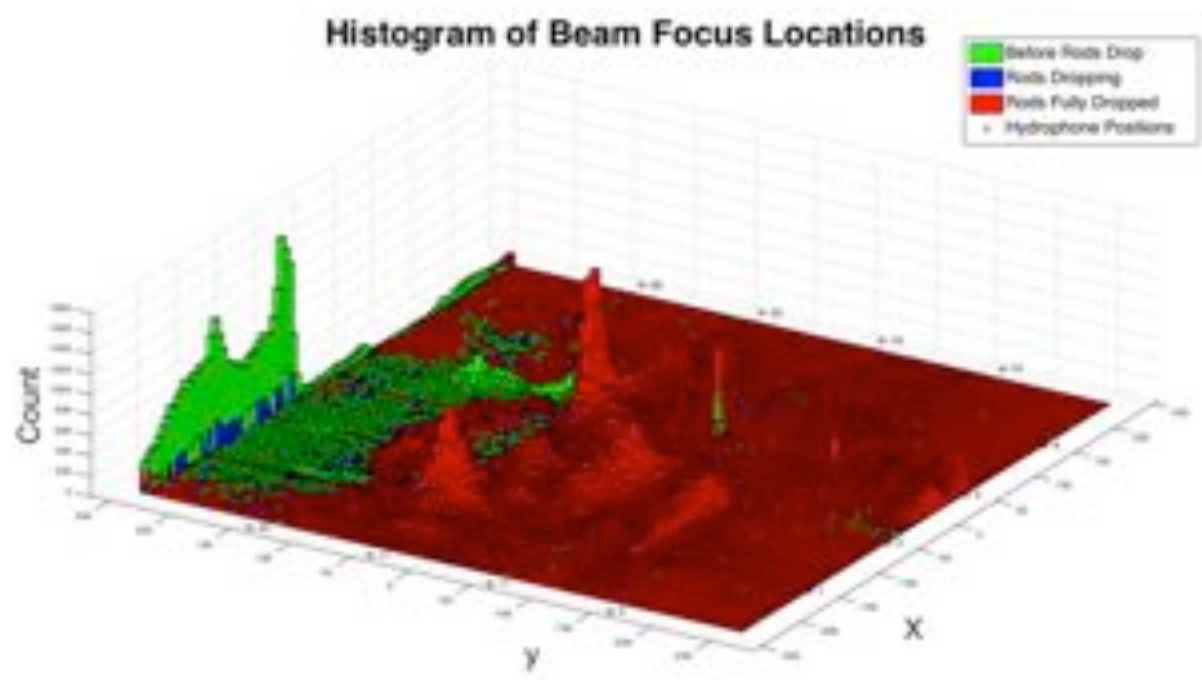


***Figure 5:*** Histogram of the echolocation beam focus location in reference to the hydrophone array.

**Number of clicks vs angular separation:**

The statistical analysis showed that after taking the mean number of clicks per trial for each angle of separation a linear regressive relationship can be found between the number of clicks and the angular separation (Figure 6). This means when the task was more difficult Dumisa used more clicks in her attempts to solve the problem. This agrees with Au & Penner 1981 and Au and Turl 1983.

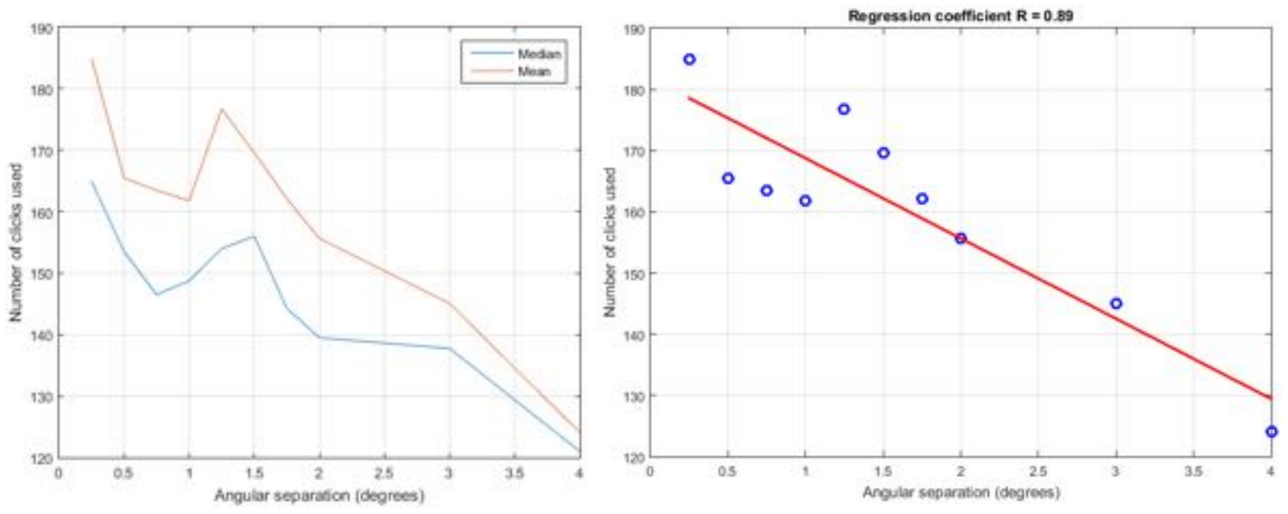

***Figure 6***: Mean and median number of clicks versus the angular separation.

An analysis of the frequency content of of the clicks showed some variation but so far no clear trend (i.e. higher frequency content in the clicks with an decrease in the angular resolution). Further analysis of all collected data is pending to investigate changes in frequency content further.

What we could observe through was an increase in energy within the series of clicks (from when the rods were completely lowered to when Dumisa moved her head to press the response paddle).

Overall there was no detectable difference between trials measuring the horizontal angular resolution and trials from the vertical angular resolution task. In both tasks Dumisa seemed to use more clicks when the task was more difficult but no other differences were observed. this seems to fit with the overall psychophysical results that showed that she was able to resolve the same angular differences (as low as 1.00 degree) in both the horizontal and the vertical orientation.

## Conclusion

In conclusion, the acoustic recordings there were obtained within the experimental setup were the first time such recordings were done covering the entire area of the dolphin echolocation beam with a large array of hydrophones. It provided a first insight into what strategies the dolphin might use when faced with that task and how she might adapt her echolocation signal to gather the most detailed information. it also provided more information into how the dolphin might be able to recognize shapes through echolocation and what the limitations of that ability might be.

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