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Horizontal and Vertical Echoic Angular Resolution in the Bottlenose Dolphin (*Tursiops aduncus*)

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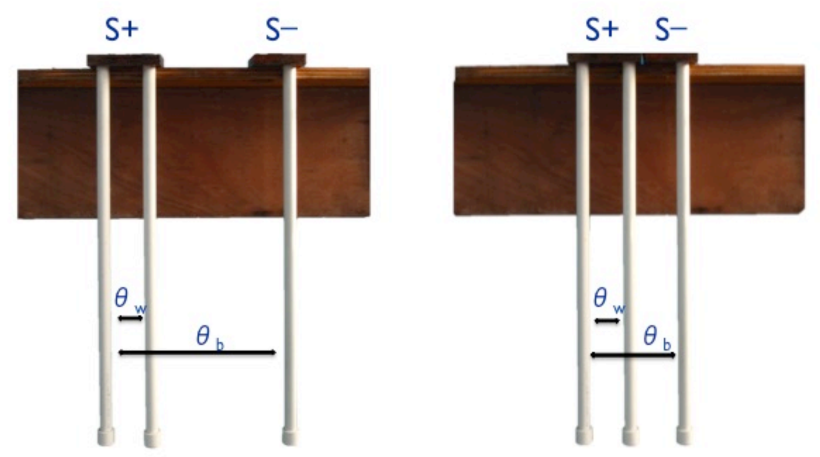
Introduction

Previous experiments have proved dolphins' ability to solve Two-Alternative-Forced-Choice-Task (2AFCT) in two horizontal discrimination experiments and resulted 75% correct threshold at 1.60 and 1.50 degrees angular separations (Branstetter et al 2003 and 2007). A dolphin's minimum audible angle (MAA) was obtained at 0.90 and 0.70 degrees in the horizontal and vertical planes respectively by passive listening tests (Renaud et al 1975). This study aimed to investigate and compare a bottlenose dolphin's angular resolution (AR) ability in both horizontal and vertical orientation in reference to the dolphin's ventral plane using 2AFCT.

Methods

The subject of this study was an eight-year-old, female Indo-pacific bottlenose dolphin (*Tursiops aduncus*), called Dumisa. Dumisa was required to wear eyecups and distinguish between two arrays of air-filled PVC rods using echolocation. The array consisted of a double rod (S+ stimulus) separated by constant 2 degrees (θ_w) and a single rod (S− stimulus). The separation between the S+ and S− arrays (θ_b) was varied resulting in angular differences ($\Delta\theta=\theta_b-\theta_w$) between 4.00 and 0.25 degrees (4.00, 3.00, 2.00, 1.75, 1.50, 1.25, 1.00, 0.75, 0.50 and 0.25 for the horizontal test, and 4.00, 3.00, 2.75, 2.50, 2.25, 2.00, 1.75, 1.50, 1.25, 1.00, 0.75, 0.5 and 0.25 for the vertical test) (Figure 1). The stimuli were positioned on the wooden arc, maintaining constant distance from the subject at all angular differences.



θ_w Angular separation between the rods, within the array

θ_b Angular separation between the arrays

$\Delta\theta=\theta_b-\theta_w= 6.00-2.00 = 4.00$ $\Delta\theta=\theta_b-\theta_w= 2.25-2.00 = 2.25$

Figure 1: Two different settings of the test stimuli, widest angular difference (4.00 degrees) and the smallest angular difference (0.25 degree) with the double rod (S+ stimulus) positioned on the left

Experimental Setup

The experimental setup consisted of a stimuli presenter device where the stimuli were placed and lowered in the water; a stationing platform and hoop with two response paddles, both helping the dolphin to maintain the correct position; a hydrophone array for acoustic recording; and two separator screens to prevent the trainer and the dolphin from seeing the stimuli (Figure 2). The experimental setup was the same for both orientations, except that the dolphin was trained to take her initial position with an axial rotation of 90 degrees for the vertical discrimination experiment (Figure 3 and 4).

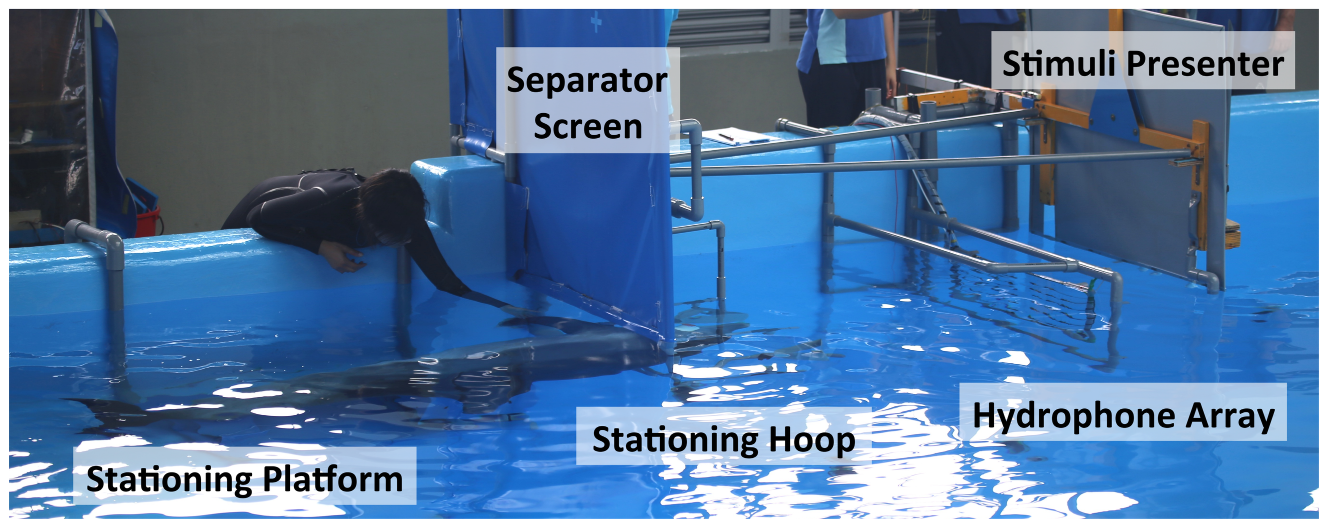


Figure 2: Complete experimental setup with the dolphin stationing in the hoop waiting for the presentation of the stimuli

Procedure

During the trials Dumisa stationed in the hoop at a distance of 2 m from the stimuli and located the position of the double rod (left or right side for the horizontal and dorsal or ventral for the vertical orientation). Dumisa indicated her choice by pressing the response paddle on the respective side of the stationing hoop (right or left for Horizontal AR, while dorsal or ventral position for the Vertical AR experiment).

Each test session consisted of 24 trials and had three phases: 'warm-up' trials, two sets of test trials and 'cool-down' trials. The initial six 'warm-up' trials were conducted with the two biggest angular separation differences (3.00 or 4.00 degrees). If Dumisa made more than one mistake, the session was aborted. The two sets of test trials were presented in a staircase procedure with diminishing angular differences. The position of the S+ was assigned pseudo-randomly (left and right for Horizontal and dorsal or ventral for Vertical AR) and balanced over the two test sets. Finally the sessions were finished with the 'cool-down' trials (3.00 or 4.00 degrees) to end on a positive note.

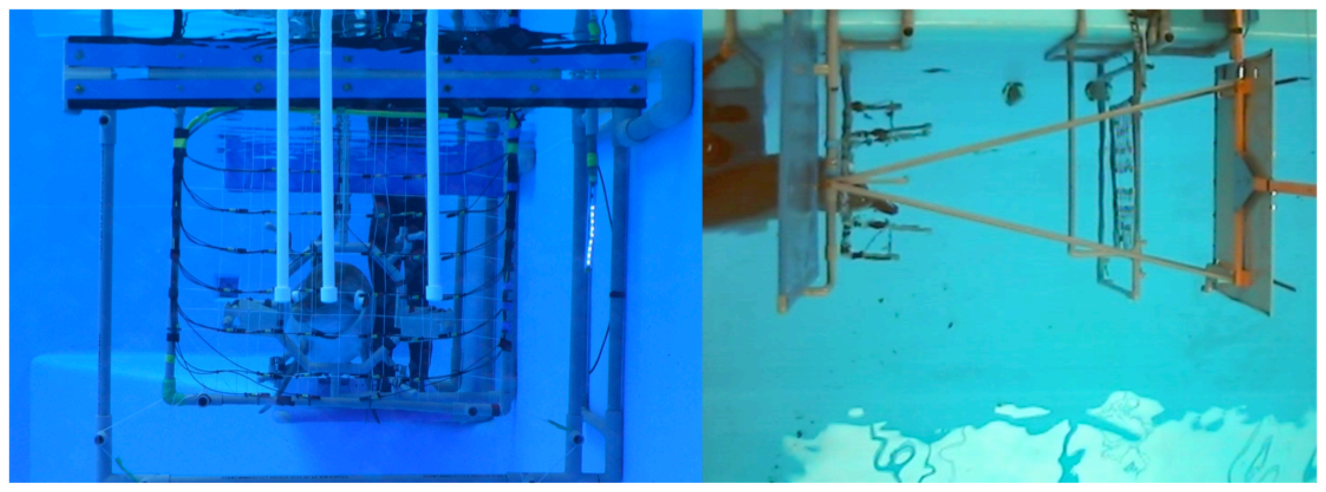


Figure 3: Underwater, front view (left) and overhead view (right) of a Horizontal Angular Resolution trial, Dumisa choosing correctly the right side

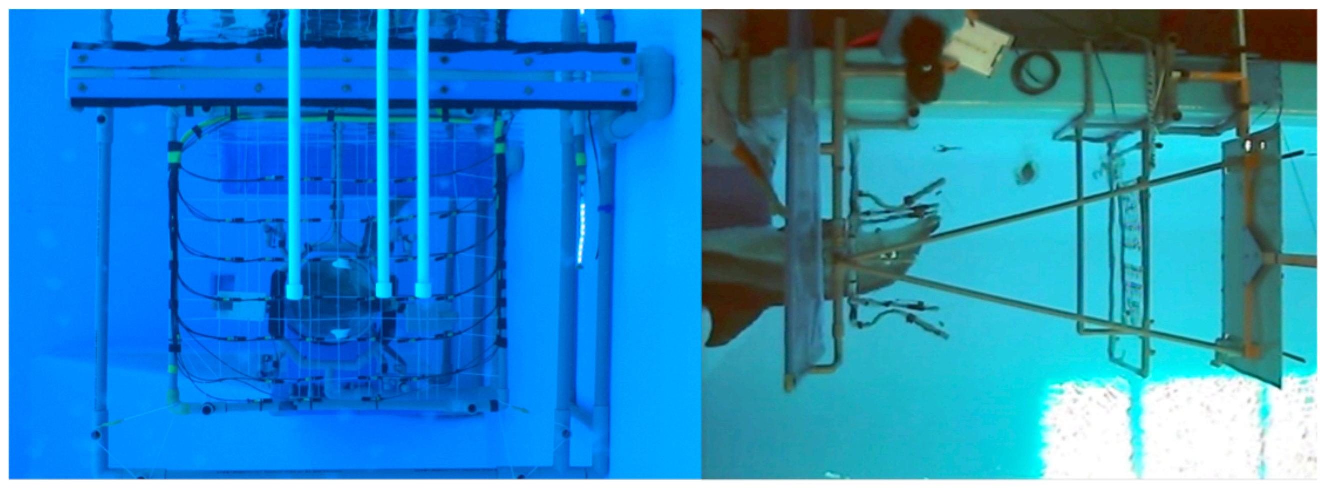


Figure 4: Underwater, front view (left) and overhead view (right) of a Vertical Angular Resolution trial, Dumisa choosing correctly the ventral side

Results

Altogether 13 different angular separation degrees were tested in a course of four experiments, two Horizontal (HAR I and II) and two Vertical AR (VAR I and II) (Table 1). Each degree was tested 60 times during 780 test trials. The dolphin's correct performance showed the same trend for both Horizontal and Vertical AR, gradually decreased with the separation difference (Figure 5). As the task became more difficult Dumisa favoured the right side to the left (incorrect choice right: 146, left: 53) and the dorsal side to the ventral (incorrect choice dorsal: 84, ventral: 38).

Table 1: Summary of Dumisa's performance (%) on the 13 angular separation degrees during the Horizontal (HAR I and II) and Vertical (VAR I and II) angular resolution experiments

	4.00	3.00	2.75	2.50	2.25	2.00	1.75	1.50	1.25	1.00	0.75	0.50	0.25
HAR I	93.33	96.67				90.00				71.67	73.33	58.33	61.67
HAR II						91.67	86.67	88.33	78.33	75.00	70.00	68.33	63.33
VAR I	95.00	96.67		86.67		96.67	91.67	91.67	88.33				
VAR II			93.33		90		83.33			86.67	71.67	70	55

1. Horizontal Angular Resolution

Dumisa was tested on 10 different angular separation degrees. The first Horizontal AR test (blue) involved the range of 4.00 to 0.25 degrees, resulting 75% correct threshold between 2.00 and 1.00 degree. The second experiment (green) was designed to determine the threshold level more accurately involving three additional angular differences (1.75, 1.50 and 1.25 degrees). As it is shown in Figure 3 the dolphin's correct performance was exactly 75% (45/60) at 1.00 degree angular separation.

2. Vertical Angular Resolution

In the absence of any preliminary data the first Vertical AR experiment (red) involved the higher range of angular differences, 4.00 to 1.25 degrees only. The result of the first Vertical AR experiment suggested that the threshold of 75% correct performance would be lower than 1.25 degrees angular separation. Thus a second Vertical AR resolution experiment (orange) was designed including smaller angular separations (1.00, 0.75, 0.50 and 0.25 degree). Altogether 13 different angular separation degrees were tested. The lowest angular separation with at least 75% correct performance was at 1.00 degree (Figure 5).

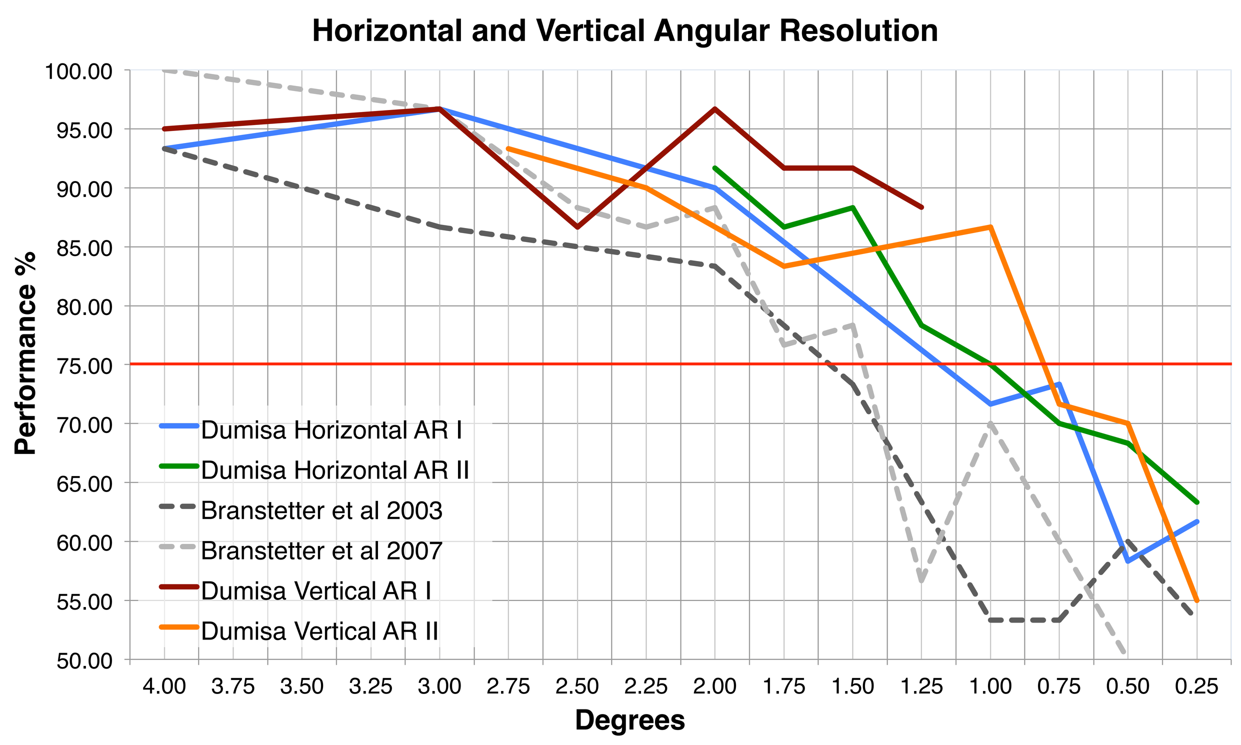


Figure 5: Comparison chart of the results obtained from both Horizontal and Vertical Angular Resolution experiments with Dumisa and previous Horizontal AR experiments (Branstetter et al 2003 and 2007) with the threshold level of 75% correct performance

Conclusion

The dolphin was able to discriminate separations as low as 1.00 degree horizontally and 1.00 degree vertically. Both experiments provided a psychometric function for the dolphin's echoic resolution in the horizontal and vertical dimension. These results agree with previously obtained localisation abilities of both echolocating (Branstetter et al 2003 and 2007) and passive listening dolphins (Renaud et al 1975). In comparison to Renaud's findings that suggested moderately better localisation abilities on the vertical plane, Dumisa's performance on 1.00 degree separation also showed a higher number of correct trials during Vertical AR. These results support evidence that the dolphin can recognize shapes through echolocation alone (echo-imaging).

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