Cross-Modal Matching of Rotated Stimuli by a Bottlenose Dolphin

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Abstract

A dolphin was trained to match shapes made from PVC pipes and fittings across the senses of echolocation and vision. In previous publications we have suggested the dolphin might perceive the shape of objects interrogated through its echolocation sense holistically and not just as a collection of features. To explore this hypothesis further, we conducted a cross-modal matching experiment where the dolphin had to match shapes that were rotated either clockwise or counterclockwise by 90 degree. The dolphin was tested on his ability to match the shapes either within a modality (pure visual or echoic matching) or across modalities (echolocation to vision or vision to echolocation).

Three different conditions were tested: the sample rotated by ± 90 degree while the alternatives remained unrotated, the sample unrotated and the alternatives rotated by ± 90 degree and both the sample and the alternatives rotated by ± 90 degree. The results of this experiment show that one of the important matching criteria for the dolphin was not just shape but also the orientation of the object. When the sample was rotated but the alternatives were not, then his performance dropped to chance levels for both within modality matching as well as across modality matching. When both the sample and the alternatives were rotated then his performance averaged at 85% (comparable to matching performance without rotation).

These results support the hypothesis that the dolphin perceives the objects holistically and not as a collection of features. If features alone would have been the deciding criteria for matching then his performance should have stayed equal to pre-rotation performance.

Introduction & Setup

This experiment investigated how rotation of either the sample or the alternative objects would affect the animal's performance during the matching in four different paradigms: Pure visual matching (VV), pure echoic matching (EE), echoic-to-visual matching (EV) and visual-to-echoic matching (VE). Is the animal able to recognize the shape of an object independent of its orientation? What type of rotation would be difficult for the dolphin? The simplest case is a rotation around the z axis (tested here) where the same features of the object are available to the animal. Would the animal treat the object as a different object or would try to match it to the best alternative? Several setups were tested in VV and EE first, then in both EV and VE:

- Sample is rotated and both alternatives are in their normal position. The dolphin would have to match to the upright alternative.(Figure 3, first row)
- Sample is upright and both alternatives are rotated (different alternatives). (Figure 3, second row)
- Both the sample and the alternatives are rotated by the same amount of degrees. (Figure 3, third row)

in total four different object that Ginsan was already familiar with from previous experiment (OP, DL, FF & SQ see Figure 1) were used. We wanted to test the immediate response that Ginsan would have to rotated objects rather then to teach him to match rotated stimuli by slowly increasing the degree of rotation (i.e. 0 degree, 10 degree, 20 degree etc.). For this purpose we rotated the objects by 90 degrees either clockwise or counterclockwise. Each of the conditions was tested for 3 sessions in each form of MTS and each of the 4 objects (OP, DL, SQ & FF) were used 4 times in each session as the sample stimulus. Trials were balanced so that each object appeared the same amount on left and on the right. Objects were only combined in their original pairings (Op with DL and SQ with FF) and not across pairings.

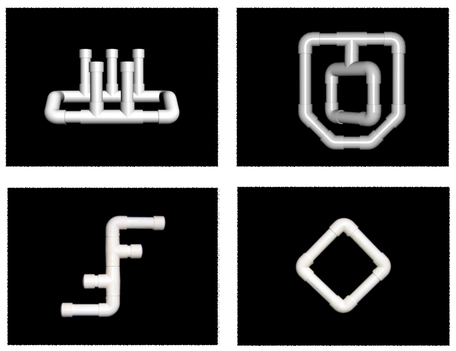

Figure 1: The four objects used in the experiment

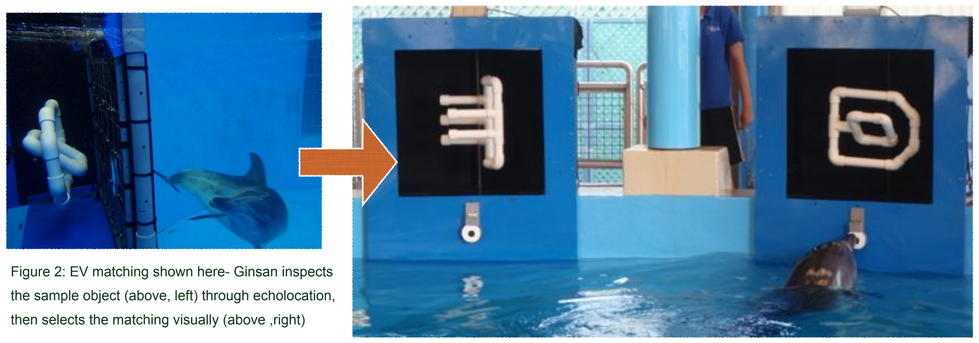

Figure 2: EV matching shown here- Ginsan inspects the sample object (above, left) through echolocation, then selects the matching visually (above ,right)

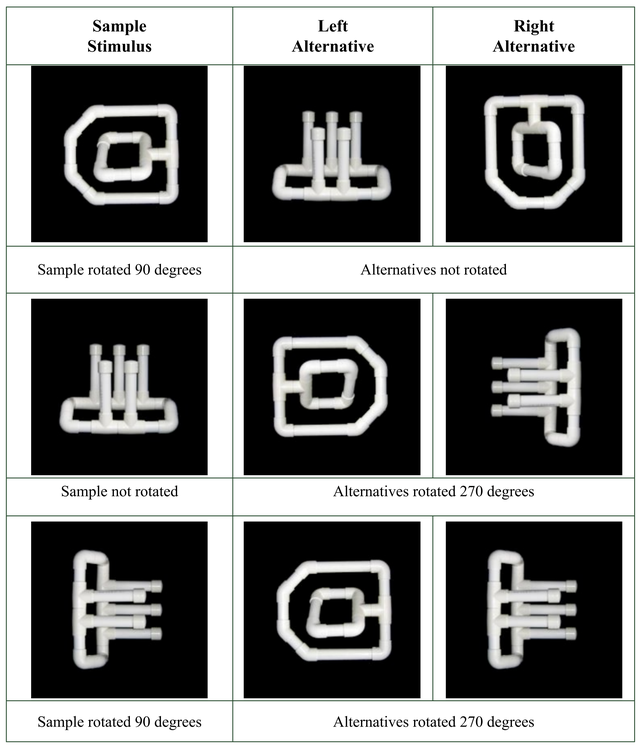

Figure 3: some examples of the three conditions used

VV results

Table 1 shows the results of visual-to-visual matching. The total correct numbers (right most column) show that Ginsan basically treated the rotated sample (first block) as a "new" object rather then a rotated form of the objects that he knew. Thus he choose to select one object in a pair (DL in the first and SQ in the second) that he selected most of the time – thus indicating that his definition of matching also included rotation, i.e. if the orientation was not matched as well he would just choose one of the objects (independent of the sample). When the alternatives were rotated but not the sample (second block) he showed the same strategy – selecting one of the pair over the other (significantly) but not matching it to the sample object (which had remained unrotated). This showed that he was clearly able to differentiate between the rotated alternatives (he selected DL 20 out of 24 times, and SQ 21 out of 24 times) but for him there was no connection to the sample object. In contrast though when both the sample and the alternatives were rotated he was able to match all of the objects successfully (see last block, right column). This was clear evidence that Ginsan's definition of matching also included the orientation of the object and that if there was no match in orientation as well as in shape that he chose the strategy to select one object within a pair (which ensured that he was still about 50% correct and was rewarded for that). Besides choosing one alternative object of the other within a pair he also showed a second strategy by staying on one side if his definition of matching had no solution – in the sample only rotation he showed a significant bias towards the left side (he went left 30 out of 47 times, p=0.02). In the alternatives rotated condition he showed a significant bias towards the right side (he went 29 times out of 48 trials to the right, p = 0.04). As Ginsan matched correctly on 46 out of 48 total trials in the third condition (both samples and alternatives rotated) he showed no side bias here. The switch in side biases from condition one to condition 2 shows that he was probably testing different strategies and trying to see which one worked best given that fact that for him the orientation of objects was part of the matching process.

EE-results

We next tested Ginsan in echoic-to-echoic matching with the same three conditions as in the pure visual matching. Table 2 shows the results of that part of the experiment. In the first condition (sample rotation) Ginsan showed no significant performance on any of the parings as in the visual matching but he did not show a selection of one object within a pairing over the other rather he now had a clear side bias towards the left object, regardless of what that object was (he went left on 40 out of 48 trials, p=0.001).

In the second condition where the alternatives were rotated he also was not matching significantly any of the samples presented and again he showed a side bias and went left 46 out of 48 times- thus not showing any object selection again.

In the last condition with both sample and alternatives rotated he showed some interesting results: he was able to match correctly the paring of SQ/FF but not OP/DL. These results suggest that the differences in echolocation for OP and DL were not strong enough to make a match – which might be a condition of the rotation as he had been able to match the pair correctly if no rotation was implemented. This could mean in particular that certain parts of the objects which he used to define the object were not "visible" when rotated (i.e. a feature like a horizontal pipe might not reflect enough acoustic energy back to him when rotated 90 degrees).

On the other hand with the paring of SQ/FF he had no problems matching in this condition, which meant that all the necessary features to perform a match must have been available to his sense of echolocation. In the last condition he showed again a significant side bias towards the left (he went left 33 times out of 48 trials) following the same strategy as before by just choosing a side (left) in when he did not know what the match was.

EV results

In the next set the same three conditions were tested in echoic-to-visual matching. Now Ginsan displayed some interesting results: in contrast to the previous two experiments (VV and EE condition 1, sample rotated) he now was able to match correctly on both pairs (although with lower performance on SQ/FF). No significant side bias could be detected (he went left 28 times out of 48 trials, p= 0.06). Continuing these results in the second condition (alternatives rotated) he also was able to correctly match the pair of SQ/FF but he had difficulties in matching OP/DL correctly (although is was significantly above chance - 18 out of 24 correct). He showed an object bias in that pair for DL selecting it 16 out of 24 trials and a side bias (he went right on 30 of 48 trials, p = 0.03). This meant that even tough both objects were rotated he was able to discriminate between them echoically. In the third condition (sample and alternatives rotated) he was again significant on all pairs and this time showed no significant side bias (he went right on 27 of 48 trials, p = 0.08).

VE results

In the final experiment the three conditions were tested in visual-to-echoic matching (see Table 4). In the first condition (sample rotated) he successfully matched both parings (18 out of 24 correct on OP/DL and 23 out of 24 correct on SQ/FF). In the second condition (alternatives rotated) he did not correctly match above chance for OP/DL but he was able to distinguish between SQ and FF. he had a side bias towards the left and selected that side 31 out of 48 trials. In the third condition (sample and alternatives rotated) he could not match OP/DL but successfully matched SQ/FF.

These results are comparable to the results in EE matching – where the rotation of the alternatives posed a problem for Ginsan and similarly some parts of the object that he used in identifying the object might not reflect back to him when rotated by 90 degrees. A further performance degrading reason might be the fact that Ginsan had a lot more practice in EV matching then in VE as a lot of the training and work was using EV matching and he did not have as much experience in that paradigm.

Conclusions

Overall Ginsan seemed to treat objects that were rotated by 90 degrees as different objects. For him the orientation of the object was a integral part of his matching rules which meant that only if the orientation of the sample object and of the alternatives matched, his conditions were fulfilled and was able to match correctly. In the pure echoic condition some features appeared not be accessible to him - thus causing more errors when both sample and alternatives were rotated. Further analysis of the echolocation recordings that were obtained while he was interrogating the stimuli could shine more light on what features were accessible to him and which ones were not.

A gradual increase in rotational difference (i.e. 22.5 degree, 45 degree and 67.5 degree) could also explore if the dolphin could learn to change his matching rules and match stimuli successfully within and across modalities even when the sample object was rotated by a different degree then the alternatives.

References:

[1] Hoffmann-Kuhnt, M., Chitre, M. A., Potter, J. R. and Cai, C. "What do dolphins see in sound? - a simulation of the backscattered sound field from an object insonified by an echolocation click," in 17th Biennial conference on the biology of marine mammals, Cape Town, South Africa, P. Best and M. Bester, Eds., 2007.

[2] Pack, A. A, Herman, L. M., Hoffman-Kuhnt, M., and Brandstetter, B., The object behind the echo: Dolphins (Tursiops truncatus) perceive object shape globally through echolocation. Behavioural Processes 58, 1-26, 2002

[3] Pack, A. A., Herman, L. M., and Hoffman-Kuhnt, M., Dolphin Echolocation Shape Perception: From Sound to Object. In J. Thomas, C. Moss, & M. Vater (Eds.). Advances in the study of echolocation in bats and dolphins. University of Chicago Press, Chicago, 2004

[4] Hoffmann-Kuhnt, M., Chitre, M. A., Lee, W. J. and Potter, J. R., Seeing Through the Clutter – Acoustic Imaging in Dolphins. Biannual Conference on the Biology of Marine Mammals 2005, San Diego, Dec 2005

[5] Hoffmann-Kuhnt, M. Chitre, M. A., Seekings, P. and Abel, G. "Acoustics of shape recognition by a dolphin in a cross-modal matching-to-sample paradigm," in ASA-EAA Joint Conference Acoustics'08, Paris, France, vol. 123, 2008, p. 3361

Table 1: Results of VV matching

	Sample object	rotated 90 degree	rotated 270 degree	Total correct
Sample rotated	OP	0 / 5	1 / 7	1 / 12
	DL	6 / 7	5 / 5	11 / 12
	SQ	5 / 5	6 / 6	11 / 11
	FF	2 / 6	3 / 6	5 / 12
Alternatives rotated	OP	2 / 6	1 / 6	3 / 12
	DL	5 / 6	6 / 6	11 / 12
	SQ	6 / 6	6 / 6	12 / 12
	FF	2 / 6	1 / 6	3 / 12
Sample and Alternatives rotated	OP	5/6	6/6	11/12
	DL	6/6	5/6	11/12
	SQ	5/5	7/7	12/12
	FF	6/6	6/6	12/12

Table 2: Results of EE matching

	Sample object	rotated 90 degree	rotated 270 degree	Total correct
Sample rotated	OP	4/6	4/6	8/12
	DL	3/6	3/6	6/12
	SQ	5/6	6/6	11/12
	FF	3/6	3/6	6/12
Alternatives rotated	OP	2/5	4/7	6/12
	DL	3/6	3/6	6/12
	SQ	5/6	3/6	8/12
	FF	4/7	3/5	7/12
Sample and Alternatives rotated	OP	4/6	5/6	9/12
	DL	2/5	4/7	6/12
	SQ	6/6	6/6	12/12
	FF	7/7	5/5	12/12

Table 3: Results of EV matching

	Sample object	rotated 90 degree	rotated 270 degree	Total correct
Sample rotated	OP	5/6	6/6	11/12
	DL	6/6	6/6	12/12
	SQ	6/6	6/6	12/12
	FF	4/6	5/6	9/12
Alternatives rotated	OP	4/6	3/6	7/12
	DL	5/6	6/6	11/12
	SQ	6/6	6/6	12/12
	FF	6/6	6/6	12/12
Sample and Alternatives rotated	OP	4/6	6/6	10/12
	DL	4/5	5/7	9/12
	SQ	6/6	6/6	12/12
	FF	7/7	5/5	12/12

Table 4: Results of VE matching

	Sample object	rotated 90 degree	rotated 270 degree	Total correct
Sample rotated	OP	7/7	3/5	10/12
	DL	3/6	5/6	8/12
	SQ	6/6	6/6	12/12
	FF	5/5	6/7	11/12
Alternatives rotated	OP	4/6	5/6	9/12
	DL	2/5	3/7	5/12
	SQ	6/6	6/6	12/12
	FF	2/7	3/5	5/12
Sample and Alternatives rotated	OP	6/6	4/6	10/12
	DL	1/5	3/7	4/12
	SQ	6/6	6/6	12/12
	FF	6/7	3/5	9/12