# INVESTIGATION ON THE ABILITY OF *TURSIOPS TRUNCATUS* TO DISCRIMINATE, RECOGNISE AND CLASSIFY GEOMETRIC SHAPES USING VISUAL AND/OR ACOUSTIC PERCEPTION

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**INTRODUCTION** This paper presents the results of three experiments in which a dolphin, free swimming and using both visual and echolocation perceptions, was requested to discriminate (first experiment), to recognise (second experiment) and to classify (third experiment) differently shaped objects. Visual and echolocation perceptions rely on different phenomenologies to detect/recognise objects (sonar is capable of transmitting and receiving from objects sound energy with a variety of waveforms, sight is capable of receiving light energy reflected from the objects). Thus the scene perceived by the two senses concerns two different domains, with an overlapping area. Let us assume, for example (Fig. 1a), that the set of targets present in the detection space is: {A, B, C}. One sense can perceive only the subset {A, B} and the other sense only the subset {B, C}, depending on the phenomenology used to detect targets. In the overlapping area the two senses interact and the level of evidence is increased. The domains of echolocation and sight can be represented by Venn diagrams, that depend on the distance of the dolphin from the objects (the area of overlapping increases with decreasing range), on the background and noise. For the objects used in these experiments the potential detection space of sight and echolocation of a dolphin is shown in Figure 1. Moreover, the two senses may have different confidence levels: dolphins may rely more on acoustic than visual perception or vice versa, depending on their distance from the objects, on environmental conditions, and on their physiological state.

Acoustic and visual processing is quite complex and involves many issues. This work addresses the problem of the levels (automatic, selective, cognitive) at which a dolphin is able to process visual and/or acoustic perception.

a) In the first experiment, (automatic-level processing) the dolphin was requested to discriminate an object, identical to the sample and translucent to light (detectable acoustically), from other two alternative objects opaque to both light and sound (detectable visually and acoustically) (Fig. 1b). Most of this task can be performed automatically, comparing the gross characteristics of the objects, generated from the visual and echolocation phenomenologies, without necessarily implying objects recognition.

b) In the second block of experiments (selective – level processing) the dolphin was requested to discriminate two objects-translucent to light from another alternative object opaque to both light and sound (Fig. 1c) and to recognise in the total information received from the two translucent objects, differing only in shape, the specific features of the object that matched the sample. This task involves, besides capacity to discriminate, an ability to select the echo features of specific targets to recall them from memory and the ability to compare the present sonar echoes with those already stored in memory (Au, 1992 and 1993). However, this task can be performed without necessarily implicating the ability to represent objects symbolically.

c) In the third block of experiments (cognitive – level processing) the dolphin was requested to discriminate two objects translucent to light from an object opaque to light and sound, as above, and to recognise between them the object that matched the shape of the sample but differed in size from it (Fig. 1d). This task deals with cognitive symbols, rather than with echo features. It implies the ability of fusing the similarities (edges, lines, angles, symmetry), abstracting the differences produced by the change of size, and comparing the spatial relations between the sample and the objects.

These experiments give us ways of "looking into" the dolphin's knowledge of the world.

**METHODS Subject.** The subject was an adult female bottlenose dolphin (*Tursiops truncatus*) named Alpha. She was born free in the Caribbean Sea and was about 18 years old at the time of study (February 1997- March 1998). Alpha had no previous experience in any type of experiment.

**Materials.** A set of spheres ($S_i$), cylinders ($C_i$) and rectangular prisms ($P_i$) were used as targets/samples (see Tab. 1 for details). They were made of Plexiglas (PMMA), a material which is translucent to light (optical reflectivity 8%) but with a good acoustic reflectivity (37%). A set of alternative objects ($O_i$) was casually chosen (a green plate, a red skittle, a buoy, a plastic clothes-hook etc.) and used for training and experiments. They were well detectable both echoically and visually (optical and acoustic reflectivity > 50%).

**Procedures.** The training and three different experiments, (292 trials) took place between February 1997 and March 1998 in the Rimini Delphinarium (Fig. 2a). During the training the dolphin was familiarised with the Delayed Matching-To-Sample procedure (DMTS) (Roitblat *et al.*, 1990), which was carried out with the alternative objects ($O_i$) only. Each trial began at a start station with the dolphin facing out of the pool towards the trainer, who presented her the sample, suspended on a string about 1 m underwater. A few seconds before the sample was removed, a frame with a set of three objects (including a copy of the sample), suspended on strings and randomly ordered, was gently lowered into the water at a depth of 2m and about 20 m away from the station. Upon a sign of the trainer, Alfa swam towards the scene and could use as much time as she liked to examine it. She indicated her choice by touching the object with her rostrum and standing in front of it for at least 5 seconds. If the answer was correct, she was called back with a whistle and rewarded with fish. If the choice was incorrect she was called back with a low frequency signal and the trial was not repeated. The number of trials was limited (10-20) to prevent the dolphin from learning through the reward mechanism.

**Experiments.** Experiment 1 concerned the discrimination task. Experiment 2, formed by two blocks 2a and 2b, concerned the recognition task and experiment 3, formed by two blocks 3a and 3b, concerned the classification task.

In the experiments 1, 2a and 3a the sample was exposed both to vision and echolocation, while in the experiments 2b and 3b it was presented to the dolphin only echoically. For this purpose the sample together with an hydrophone Brüel & Kjær 8105 was hidden inside a hollow fiberglass sphere (Ø 40 cm) almost transparent to ultrasounds (Fig. 2b). The clicks of the dolphin were monitored and recorded respectively on a HP Digital Oscilloscope 54520 and a Wide Band Recorder (10 Hz-300 kHz). The recorded sonar pulses were processed using MATLAB m-file language and the procedure described in Azzali *et al.* (1998).

In the experiments 3a and 3b the sample presented to the dolphin by the trainer differed in size (but not in material and shape) from the match, that the dolphin had to choose.

Measurements on acoustic characteristics (longitudinal and transversal velocity) of the Plexiglas, on the scattered radiation patterns and the acoustic images of the targets were carried out in laboratory at a frequency of 200 kHz to check if it were possible to recognise shapes using up-to-date sonar systems.

**RESULTS** The results of all the experiments are reported in Table 2 and in Figure 3.

In the six sessions (73 trials) of experiment 1 Alpha's choice accuracy was significantly higher (correct responses ranged between 90% and 100%) than a random choice (G>25, df=1, P<0.001, G Test) for all the three samples ($S_1$, $C_1$, $P_1$).

In the six sessions (85 trials) of experiment 2a the dolphin's performance was statistically significant for the sphere and the cylinder (G>12, df=1, P<0.001) but not for the prism (G=0.04, df=1, P=NS). The comparison between her choice accuracy in these two experiments didn't result significant for the sphere and the cylinder (G=2.05 and G=2.69, df=1, P=NS respectively) but was significant for the prism (G=17.96, df=1, P<0.001) because she didn't recognise it although she was able to discriminate it. Her choice accuracy didn't change in function of the higher level of difficulty. In experiment 2b (44 trials) the visual perception of the sample was precluded and Alfa's recognition performance was significantly higher than a random choice for all the three geometric shapes (including the prism) (G=5.59, df=1, 0.01<P<0.02 for sphere and prism; G=18.74, df=1, P<0.001 for cylinder). However Alpha chose the "negation" instead of "affirmation" to indicate the prism (she could easily identify it, but she touched the other target). A similar behaviour has been reported in literature (Helweg *et al*., 1996). The analysis of the clicks used by Alpha in this experiment shows that the signals employed to recognize the cylinder and the sphere are similar to each other but distant from the ones used for the prism (Fig. 4a).

In experiment 3a (48 trials) the classification performance of the dolphin was statistically significant for the sphere and the prism (G>20, df=1, P<0.001), even if again Alfa chose the "negation" to indicate the sphere. However the dolphin was unable to classify the cylinder (G=0.22, df=1, P=NS). In experiment 3b (46 trials) the classification accuracy of Alfa, impeded from seeing the sample, didn't differ significantly from experiment 3a (G=1.11, df=1, P=NS for spheres; G=0.02, df=1, P=NS for cylinders; G=0.95, df=1, P=NS for prisms). Again the dolphin was unable to classify the cylinder (G=0.06, df=1, P=NS), but differently from the previous case, she significantly confused it with the prism only (P=0.035, df=1, Binomial Test). The results of clicks' analysis show that sonar pulses used to insonify prisms and cylinders are more similar than the ones used for the spheres (Fig. 4b).

Laboratory experiments on the targets presented to Alfa indicated that the scattered radiation patterns contain too little information to recognise the shapes while the acoustic images contain information too complex for humans to process it in detail (Ruggini, 1998).

**CONCLUSIONS** The results of the three experiments can be summarised as follows:

1. The performance of Alpha in discriminating the objects was excellent (experiment 1).
2. Alpha showed difficulty in recognising the prism when the sample was exposed to both echolocation and sight (experiment 2a). However, when the sample was exposed only to echolocation, the dolphin's capability in recognising prisms, besides cylinders and spheres, was good (experiment 2b). Perhaps dolphin relied more on sight than on echolocation in experiment 2a.
3. There are several ways to classify the shapes, that can be separated in two or more categories depending on which shape property one looks for. Alpha was able to classify the spheres (a smooth shape) and the prisms (an edged shape), abstracting the differences produced by the changes in size. However she showed great difficulties in classifying cylinders (a smooth shape but with contours), that she confused in experiment 3a sometimes with spheres and sometimes with prisms, but in the acoustic experiment 3b significantly with prisms only.

4. It seems that the dolphin classifies the shapes in two categories: smooth surfaces versus edged surfaces and has difficulties in classifying shapes intermediate between them.
5. Alpha seems to change the features of her sonar pulses as a function of the stimulus object and/or of the difficulty to perform the task.
6. Alpha's choice accuracy in the trials in which the sample was exposed only to her echolocation was equal or better (experiment 2) than in the trials in which it was exposed to both her vision and echolocation. This result seems to contrast with previous studies (Pack *et al.*, 1995; Harley *et al.*, 1996). However the material translucent to light used for targets allowed the two senses to interact and to participate in the decision only when the dolphin was very close to the scene. It seems that Alpha, dealing with this type of material, was most successful when she could rely only on the acoustic perception to select the features of the sample.

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**Table 1.** Stimulus objects characteristics

**(a)**

| | **SPHERE** | **CYLINDER** | **PRISM** |
|---|---|---|---|
| DIMENSIONS (mm) | S1 (∅58)<br>S2 (∅72) | C1 (∅50x50)<br>C2 (∅50x100)<br>C3 (∅50x200)<br>C4 (∅70x220) | P1 (40x40x60)<br>P2 (40x40x122)<br>P3 (40x40x245)<br>P4 (40x40x163.5) |
| EDGES | 0 | 2 | 12 |
| VERTICES | 0 | 0 | 8 |
| HORIZONTAL SYMMETRY PLANS | 1 | 1 | 1 |
| VERTICAL SYMMETRY PLANS | $\infty$ | $\infty$ | 4 |

**(b)**

| | **P1, C1, S1** | **P2, C2, S2** | **P3, P4, C3** | **C4** |
|---|---|---|---|---|
| VOLUME ($mm^3$) | 9.700 ca | 196.000 ca | 392.000 ca | 846.000 ca |

**(c)**

| | **REFLECTIVITY** | | **DENSITY** | **SOUND VELOCITY** ($10^3$ m/s) | | **ACOUSTIC IMPEDANCE** ($\rho = 10^6$ $Kg/m^2 * s$) | |
|---|---|---|---|---|---|---|---|
| | **ACOUSTIC** | **OPTICAL** | ($\rho = 10^3$ $Kg/m^3$) | **Vl** | **Vt** | **$\rho$ x Vl** | **$\rho$ x Vt** |
| PLEXIGLASS (PMMA) | 37% | 8% | 1.18 - 1.19 | 2.73 | 1.43 | 3.2 | 1.7 |

**Table 2.** FIVE EXPERIMENTS RESULTS ($S_i$= sphere; $C_i$= cylinder; $P_i$= prism; $O_i$= alternative object; V=visual perception; E=echolocation).

| | **SPHERE** | | | | **CYLINDER** | | | | **PRISM** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Scene** | **Trials** | **Correct Responeses (%)** | **Statistical Significance** | **Scene** | **Trials** | **Correct Responeses (%)** | **Statistical Significance** | **Scene** | **Trials** | **Correct Responeses (%)** | **Statistical Significance** |
| **EXPERIMENT 1**<br>**- DISCRIMINATION -**<br>(V/E - V/E) | $S1 \rightarrow S1 \wedge O1 \wedge O2$ | 10 | 90 | N=25<br>df=1<br>G=25.745<br>$P<0.001$<br>(G test) | $C1 \rightarrow C1 \wedge O1 \wedge O2$ | 11 | 91 | N=26<br>df=1<br>G=27.046<br>$P<0.001$<br>(G test) | $P1 \rightarrow P1 \wedge O1 \wedge O2$ | 10 | 100 | N=22<br>df=1<br>G=29.821<br>$P<0.001$<br>(G test) |
| | $S1 \rightarrow S1 \wedge O1 \wedge O2$ | 15 | 100 | | $C1 \rightarrow C1 \wedge O1 \wedge O2$ | 15 | 100 | | $P1 \rightarrow P1 \wedge O1 \wedge O2$ | 12 | 100 | |
| **EXPERIMENT 2a**<br>**- RECOGNITION -**<br>(V/E - V/E) | $S1 \rightarrow S1 \wedge P2 \wedge O$ | 12 | 100 | N=32<br>df=1<br>G=16.368<br>$P<0.001$<br>(G test) | $C2 \rightarrow C2 \wedge (S2 \vee P2) \wedge O$ | 13 | 85 | N=28<br>df=1<br>G=12.320<br>$P<0.001$<br>(G test) | $P2 \rightarrow P2 \wedge (S1 \vee C2) \wedge O$ | 9 | 33 | N=25<br>df=1<br>G=0.039<br>P=NS<br>(G test) |
| | $S1 \rightarrow S1 \wedge (P1 \vee C1 \vee C2) \wedge O$ | 20 | 75 | | $C2 \rightarrow C2 \wedge (S1 \vee P2) \wedge O$ | 15 | 100 | | $P2 \rightarrow P2 \wedge C2 \wedge O$ | 16 | 62.5 | |
| **EXPERIMENT 2b**<br>**- RECOGNITION -**<br>(E - V/E) | $S1 \rightarrow S1 \wedge (C1 \vee P1) \wedge O$ | 15 | 80 | N=15<br>df=1<br>G=5.596<br>$0.01<P<0.02$<br>(G test) | $C1 \rightarrow C1 \wedge (S1 \vee P1) \wedge O$ | 14 | 100 | N=14<br>df=1<br>G=18.739<br>$P<0.001$<br>(G test) | $P1 \rightarrow P1 \wedge (S1 \vee C1) \wedge O$ | 15 | 20 | N=15<br>df=1<br>G=5.596<br>$0.01<P<0.02$<br>(G test) |
| **EXPERIMENT 3a**<br>**- CLASSIFICATION -**<br>(V/E - V/E) | $S1 \rightarrow S \wedge (C2 \vee P2) \wedge O$ | 15 | 0 | N=15<br>df=1<br>G=20.124<br>$P<0.001$<br>(G test) | $C2 \rightarrow C \wedge (S1 \vee P2) \wedge O$ | 18 | 44 | N=18<br>df=1<br>G=0.217<br>P=NS<br>(G test) | $P2 \rightarrow P \wedge (S1 \vee C2) \wedge O$ | 15 | 93 | N=15<br>df=1<br>G=24.521<br>$P<0.001$<br>(G test) |
| **EXPERIMENT 3b**<br>**- CLASSIFICATION -**<br>(E - V/E) | $S1 \rightarrow S \wedge (C2 \vee P2) \wedge O$ | 12 | 8 | N=12<br>df=1<br>G=9.361<br>$0.001<P<0.01$<br>(G test) | $C2 \rightarrow C \wedge (S2 \vee P2) \wedge O$ | 15 | 47 | N=15<br>df=1<br>G=0.065<br>P=NS<br>(G test) | $P2 \rightarrow P \wedge (S1 \vee C2) \wedge O$ | 15 | 100 | N=15<br>df=1<br>G=20.124<br>$P<0.001$<br>(G test) |

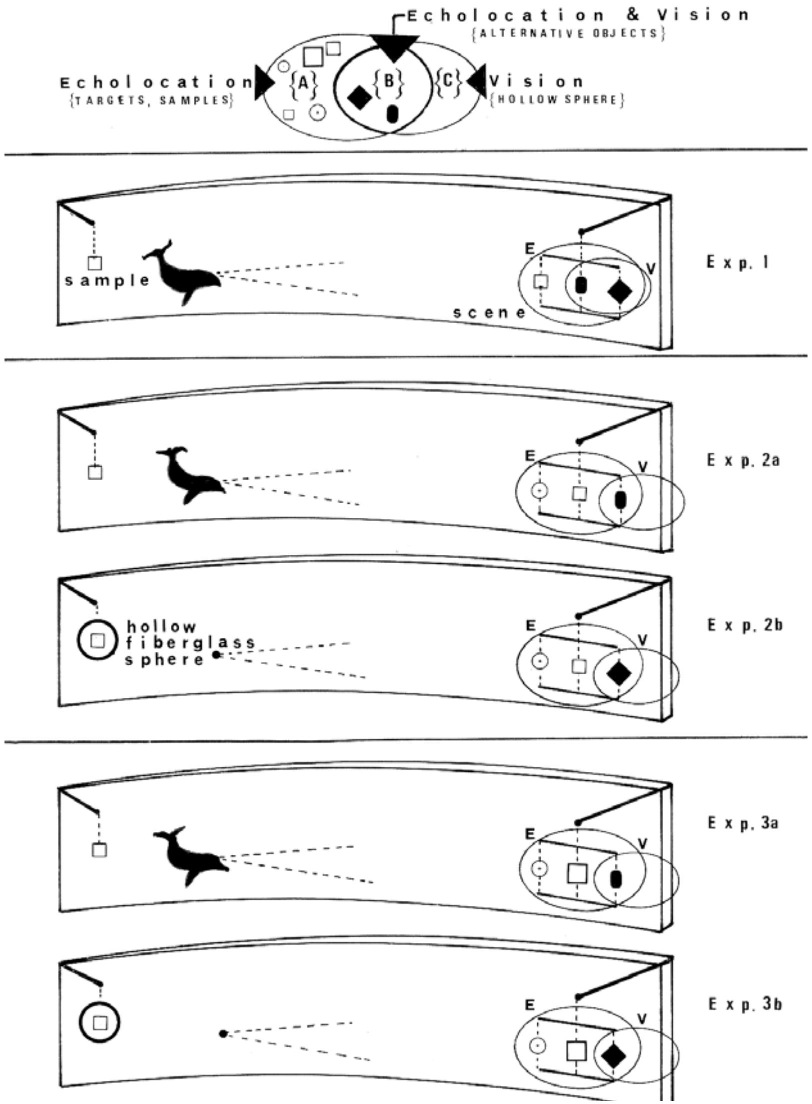


**Fig.1** Representation of the objects used in the experiments by Venn diagrams (**a**), and of the experiments carried out in the Rimini dolphinarium (**b**), (**c**), (**d**).

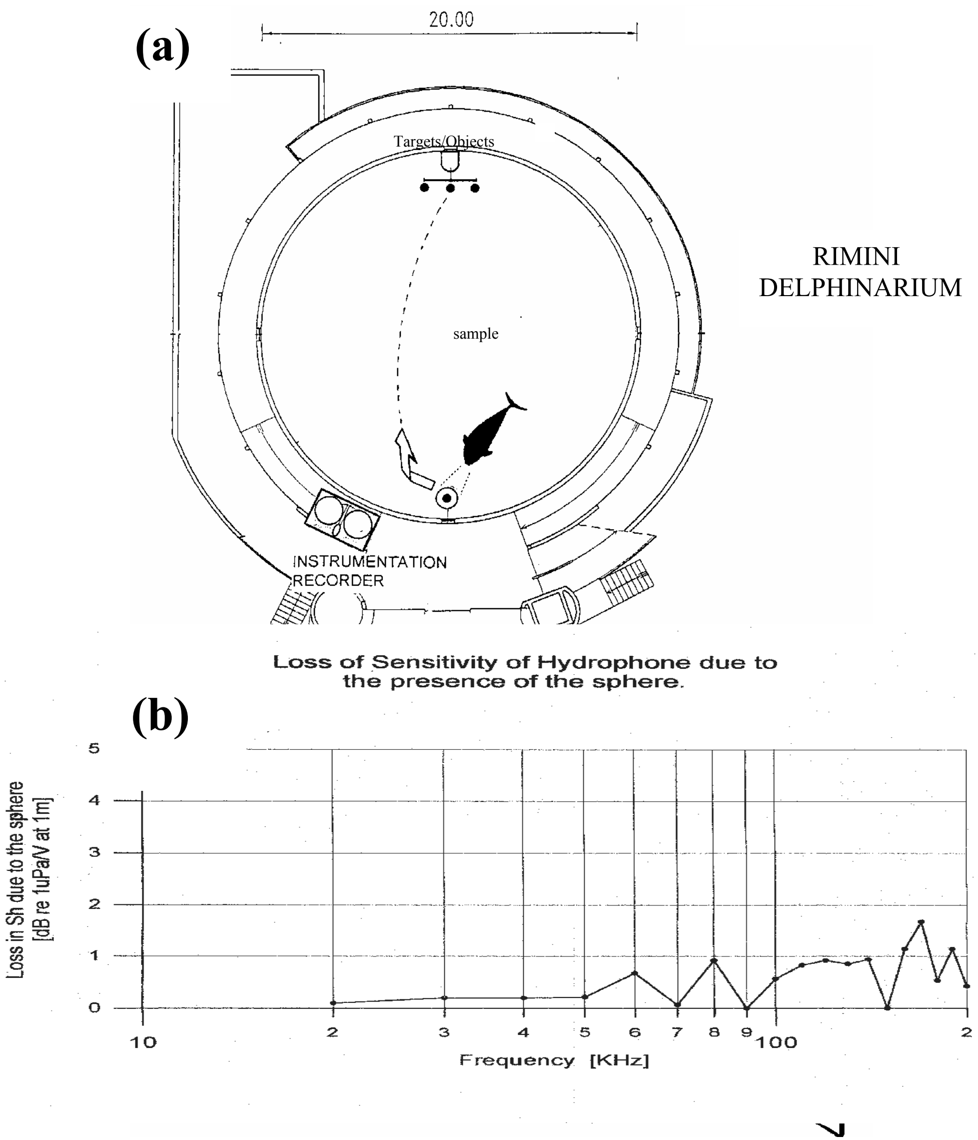
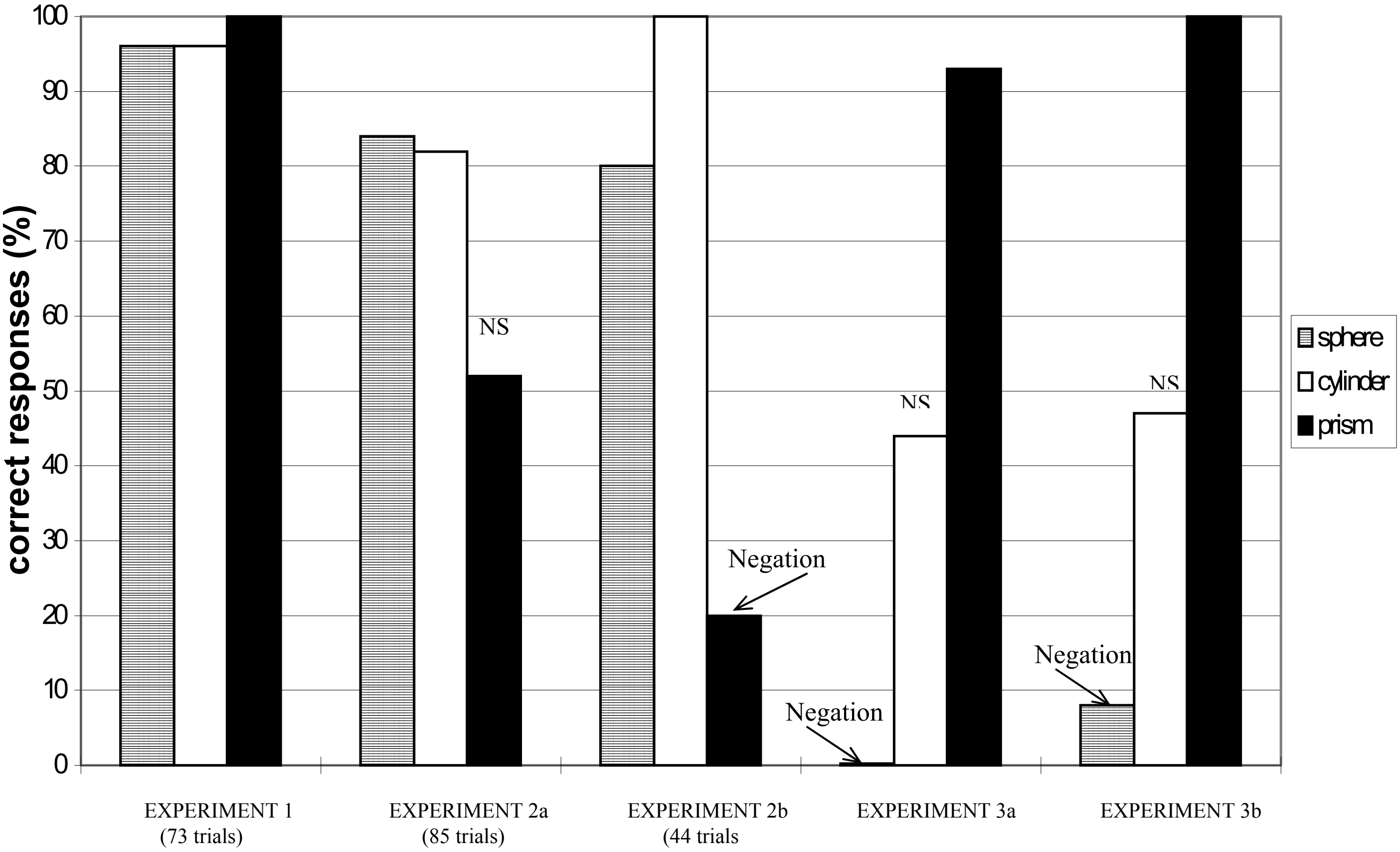


**Fig.2 (a)** Experimental set-up showing the dimension of the pool, the position of the targets/objects and of the sample, hidden inside a hollow sphere transparent to ultrasounds. **(b)** Transparence of the sphere to ultrasounds.

**(a)**

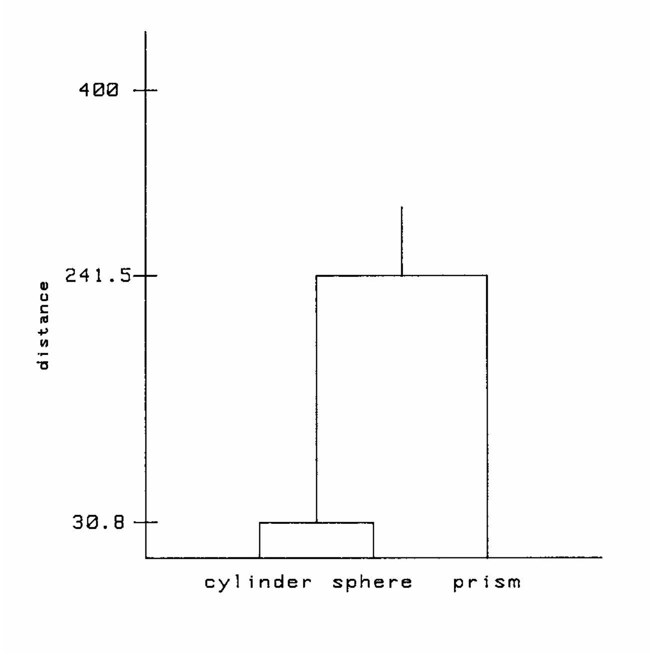


**(b)**

| | SPHERE | CYLINDER | PRISM |
|---|---|---|---|
| **EXP. 1 versus EXP. 2a** | N = 57, df = 1<br>G = 2.049, P = NS<br>(G test) | N = 54, df = 1<br>G = 2.692, P = NS<br>(G test) | N = 47, df = 1<br>G = 17.966, P < 0.001<br>(G test) |
| **EXP. 2a versus EXP. 2b** | N = 47, df = 1<br>G =0.126, P = NS<br>(G test) | N = 42, df = 1<br>G =3.921, 0.02 < P < 0.05<br>(G test) | N = 40 df = 1<br>G =4.037, 0.02 < P < 0.05<br>(G test) |
| **EXP. 3a versus EXP. 3b** | N = 27, df = 1<br>G =1.107, P = NS<br>(G test) | N = 33, df = 1<br>G =0.016, P = NS<br>(G test) | N = 30, df = 1<br>G =0.947, P = NS<br>(G test) |

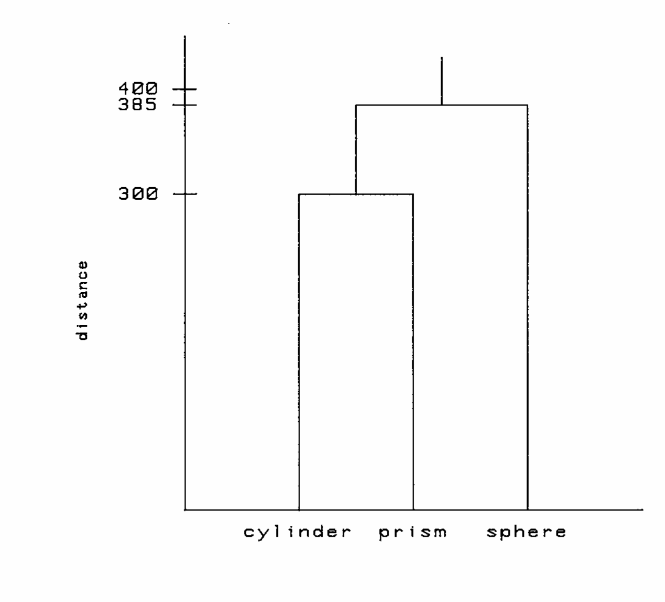
**Fig. 3 (a)** Proportion of correct responses in percentage (**a**), and comparison of choice accuracy in the five experiments (**b**).

(a)



| | Sphere | Cylinder | Prism |
|---|---|---|---|
| **Sphere** | 0 | 1172 | 385.5 |
| **Cylinder** | | 0 | 300.8 |
| **Prism** | | | 0 |

(b)



| | Sphere | Cylinder | Prism |
|---|---|---|---|
| **Sphere** | 0 | 30.8 | 241.5 |
| **Cylinder** | | 0 | 249.1 |
| **Prism** | | | 0 |

**Fig.4** Inter-target similarity distances (matrices and dendrograms) of the sonar pulses used by Alpha (**a**) in the experiment 2b, and (**b**) in the experiment 3b.