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Visual discrimination abilities in the gray bamboo shark (*Chiloscyllium griseum*)

Theodora Fuss*, Horst Bleckmann, Vera Schluessel

Department of Comparative Sensory Biology and Neurobiology, Institute of Zoology, University of Bonn, Meckenheimer Allee 169, 53115 Bonn, Germany

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ABSTRACT

This study assessed visual discrimination abilities in bamboo sharks (*Chiloscyllium griseum*). In a visual discrimination task using two-dimensional (2D) geometric stimuli, sharks learned to distinguish between a square, being the positive (rewarded) stimulus, and several negative stimuli, such as two differently sized triangles, a circle, a rhomboid and a cross. Although the amount of sessions to reach the learning criterion and the average trial time needed to solve each new task did not vary significantly, the number of correct choices per session increased significantly with on-going experiments. The results indicate that the sharks did not simply remember the positive stimulus throughout the different training phases. Instead, individuals also seemed to learn each negative symbol and possibly had to "relearn" at least some aspects of the positive stimulus during each training phase. The sharks were able to distinguish between the 2D stimulus pairs at a learning rate corresponding to that found in teleosts. As expected, it took the sharks longer to learn a reversal task (with the positive stimulus now being the negative one) than to discriminate between the other stimulus pairs. Nevertheless, the present results suggest that bamboo sharks can learn visual discrimination tasks, succeed in a reversal task and probably retain (some) information about a previously learned task when progressing to a new one.

1. Introduction

Organisms use the perception and discrimination of color, shape and size for many different tasks. The ability to discriminate visually between different objects with regard to shape and size has already been tested in a wide range of vertebrates (e.g., chickens: Jones and Osorio, 2003; sea lions: Schustermann and Thomas, 1966; Mauck and Dehnhardt, 1997; monkeys: Nitsch and Jarosch, 1972; Tanaka, 2000; Vonk and MacDonald, 2002; rodents: Zoccolan et al., 2009; humans: Hoffmann and Logothetis, 2009) and invertebrates (octopus: Schaller, 1926; Grasso and Basil, 2009; bees: Schnetter, 1968; Giurfa et al., 1996; Campan and Lehrer, 2002; Srinivasan, 2010).

There is a variety of studies on the learning and memory abilities of teleosts available, testing the discrimination of colors, line orientations, shapes and sizes as well as object categorization skills. Herter (1929, 1930) and Meesters (1940) showed that several teleosts were able to recognize black and white patterns even when color schemes were reversed (Meesters, 1940), which was confirmed by Schluessel et al. (2012) in experiments on Malawi cichlids (*Pseudotropheus* sp.). Results on cichlids were complemented by another study which concluded that *Pseudotropheus* sp. could distinguish images from their vertical mirror image counterparts (Gierszewski et al., 2013). Discrimination of color and line orientation were successfully tested in zebrafish (*Danio rerio*; Arthur and Levin, 2001; Colwill et al., 2005) and weakly electric elephant-nose fish (*Gnathonemus petersii*; Schuster and Amtsfeld, 2002), while differentiation of color was successfully shown in goldfish (*Carassius auratus*; e.g. Neumeyer, 1986, 1992). Additionally, goldfish (Douglas et al., 1988; Frech et al., 2012) and Cypriniformes (*Phoxinus phoxinus*, Sutherland, 1962) were shown to recognize size constancy, while form constancy was recently shown to be recognized by cichlids (*Pseudotropheus* sp., Schluessel et al., 2013), providing evidence for advanced visual discrimination abilities in teleosts. Schluessel et al. (2012) also showed that Malawi cichlids not only perceived, remembered and discriminated selected visual stimuli, but also distinguished between two mental categories (representative objects in two mental categories: "fish" and "snail"). As predators, prey, habitat types or con-specifics may vary in size, shape and even coloring, using general features (gross similarities) provides fish with a certain degree of flexibility to react appropriately (Schluessel et al., 2012). Ambon damselfish (*Pomacentrus amboinensis*) even used visual stimuli as predictors for the availability of food at a certain time and place (anticipatory behavior; Siebeck et al., 2009).

Although several teleosts from different habitats featuring different lifestyles and behaviors have been tested, these studies are far from reflecting the actual biological breadth of currently over 30,000 extant fish species. Sharks, rays and chimeras belong to the

* Corresponding author. Tel.: +49 228735488.
E-mail address: thfuss@uni-bonn.de (T. Fuss).

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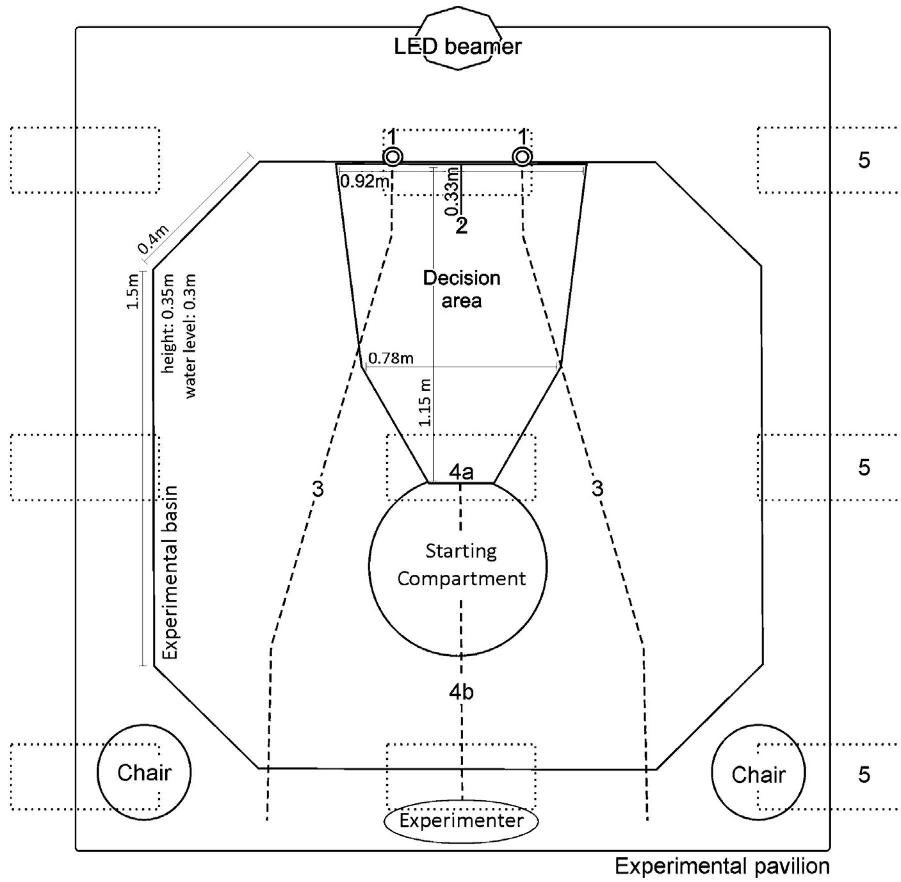

Fig. 1. The experimental setup within the experimental basin inside a white pavilion. The keyhole-shaped setup consists of a starting compartment (SC), a decision area and a frosted screen for projection with a divider to allow the projection of two 2D objects at a time and to provoke a clear, unambiguous choice (left or right). For projection, an LED beamer is used. Sharks are placed within the SC at the start of each trial. 1 = feeders, 2 = frosted screen for projection, 3 = cable pulls to release food from the feeders, 4a = guillotine door, 4b = cable pull to open guillotine door, 5 = ceiling-mounted fluorescent tubes (above the pavilion roof).

cartilaginous fishes and represent the oldest extant jawed vertebrate group. They have been extremely successful over the past 450 million years and inhabit almost every marine and freshwater environment (Compagno, 1999). Sharks still suffer from a negative public image and so far, few studies have been conducted to refute this prejudice, but the ones that have investigated selected cognitive abilities in sharks and rays indicate that they are as sophisticated as those of many other vertebrates. Graeber and Ebbesson (1972) and Graeber et al. (1973) successfully trained intact, telencephalon- or tectum-ablated nurse sharks (*Ginglymostoma cirratum*) to distinguish between colored and black and white striped discs. Freshwater stingrays (*Potamotrygon motoro*) also distinguished successfully between black and black and white striped discs (Schluessel, unpublished data). Aronson et al. (1967) compared the learning rates of nurse sharks (*G. cirratum*) in visual discrimination experiments (using illuminated transparent rectangles) to the learning rates of teleosts and mice and found them to be similar. Moreover, sharks and stingrays also used visual abilities to solve spatial tasks (Schluessel and Bleckmann, 2005, 2012; Fuss et al., 2013a,b). Van-Eyk et al. (2011) showed that giant shovelnose rays (*Glaucostegus typus*) discriminated colored (rewarded) stimuli from other colored (unrewarded) distractor stimuli of variable brightness. Juvenile blacktip sharks (*Carcharhinus melanopterus*) and gray sharks (*C. menisorrah*) solved visual discrimination tasks successfully with regard to stimulus orientation, form, differential brightness, and color (Tester and Kato, 1963). Electric shocks were used for negative reinforcement, but rigorous testing was lacking. The sharks were not subjected to a standardized training schedule; they were given different numbers of tasks, received different amounts of electric shocks and participated in different numbers of sessions per day before training was terminated. Reversal training – as performed in the present study – has not been previously tested on any shark.

Considering the various vertebrates and invertebrates which are able to distinguish visual stimuli, this ability must provide individuals with a distinct advantage with regard to recognizing and classifying different organisms (e.g., prey, predators or conspecifics) and objects (e.g., shelter or landmarks for orientation). As elasmobranchs hold a key phylogenetic position in the evolution of the brain of jawed vertebrates, information on their cognitive functions, even basic ones, such as simple visual discrimination abilities, will provide interesting insights from a biological as well as an evolutionary standpoint.

Bamboo sharks (*Chiloscyllium* spp.) belong to the family Hemiscyllidae (order Orectolobiformes; Compagno, 1999) and are small benthic sharks which inhabit small territories in primarily shallow waters, such as lagoons and inshore environments, sea grass meadows, rocky and coral reef environments (Compagno et al., 2005). The present study aimed to investigate visual discrimination abilities in the gray bamboo shark (*Chiloscyllium griseum*) with regard to five two-dimensional (2D) stimuli and subsequent reversal learning. To facilitate comparison with previous studies performed on teleosts, similar 2D objects were used for the present study. Minnows (*Phoxinus laevis*), sunfish (*Xenotis megalotis*), cichlids (*Pseudotropheus* sp.), sticklebacks (*Gasterosteus aculeatus*), damselfish (*Pomacentrus amboinensis*) and goldfish have already been