

Cognition in elasmobranch fishes, a likely possibility.

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Abstract

While evidence of cognition in a variety of fish species has been documented, it is widely considered that a class as ancient as the Chondrichthyes is not capable of cognition. We therefore provide a brief summary of the literature concerning learning in elasmobranch fishes, an example of the social organization shown by a colony of captive bonnethead sharks, and supportive observations of free-ranging blackfin reef sharks, all of which suggest cognitive capabilities, which we define as a process of sequential thinking, using mental references, as opposed to instinctive reactions to key stimuli. The evidence indicates that elasmobranchs readily learn, possess ecological intelligence, and refer to mental representations to make decisions. Finally, the proof needed to demonstrate cognition, in general, is discussed.

Keywords

Sharks - Cognition - Learning - Social Organization-Decision Making

Introduction

There is increasing recognition that when animals learn to perform new tasks, they think, consciously or unconsciously, about the problems they face and the solutions they attempt or achieve (Griffin 1992, 2001). It is commonly believed, however, that elasmobranch fishes (the sharks and their near relatives) are inferior to other vertebrates in the extent to which they modify behavior through learning processes. This is supposedly due to much smaller brains possessed by elasmobranchs. The direct comparison of relative brain sizes among vertebrates by Northcutt (1978), showed, however, that elasmobranchs possess brains equal in size or even larger than those possessed by many birds and mammals (Fig. 1).

This unfortunate, "small-brain" myth was the likely result of early workers, concentrating their studies only on readily available, small-brained species. There is also evidence that among other taxa, notably birds, the miniaturization of the brain has no evident effect upon the animal's cognitive faculties. (See: Barber 1993, Balda and Kamil, 1998, Pepperburg, 1999, Griffin 1992, 2001)

Learning

Excellent evidence exists that sharks not only readily learn operant responses, but readily learn, using the respondent conditioning paradigm as well. Clark (1959) trained an adult male and female lemon shark *Negaprion brevirostris* to press a submerged target, connected to a submerged bell, five days a week for seven weeks. By the end of the seventh week, both sharks were readily pressing the target almost immediately after submergence. After ten weeks of non-training, testing was begun again and the operant response was repeated immediately by both sharks.

Brightness-discrimination by a female nurse shark *Ginglymostoma cirratum* was also amply demonstrated by differentially pressing small, submerged targets (light vs dark) after operant training (Aronson et al. 1967). The discrimination was learned by day 5 after one session/day, lasting 7-16 minutes and was maintained, without decrement, for one month of testing. The shark's learning curve of the discrimination was compared to the mean learning curve by lab-mice *Mus musculus* and also the cichlid teleost *Tilapia macrocephala*, trained in comparable apparatus and similar programmatic techniques (Fig. 2). The great similarity among the curves does not equate learning by the members of the three species, but indicate that differences in learning must be examined by using more complex problems.

The next example demonstrated clear learning through use of the second major paradigm, i.e., the classical or respondent conditioning paradigm. Gruber and Schneiderman (1975) conditioned the nictitating eyelid-response (CR) of five immature lemon sharks *Negaprion brevirostris*, using a 1-3 v, electric shock (US) and a collimated, white light (CS) of 0.5 sec. duration with a CS-US interval of 0.4 sec. Testing ended after 7 days with 100 acquisition-trials/day. Equal numbers of subjects (n=5), in three groups, controlled for spontaneous blinking, sensitization, pseudo-conditioning and backward conditioning. The learning curves of the progress of the CR are shown during the first three days of acquisition (Fig. 3). By Day 2, two of the 5 sharks showed 100% response during the second block of ten trials and by Day 3, essentially 100% response was noted during all trials and this remained throughout the remaining 4 days. Six days of extinction sessions followed the seventh day of testing (Fig. 4). One can readily see spontaneous recovery occurring during the second day. Extinction of the CR was essentially complete by the sixth day.

These three-mentioned cases are only a few examples of learning being readily shown by elasmobranchs (see also Wright and Jackson 1964; Banner 1967; Gruber 1967; Nelson 1967; Kalmijn 1971, 1978; Gruber and Cohen 1978; Berg and Schulj 1983).

Free swimming blackfin reef sharks, *Carcharhinus melanopterus*, learned to recognize the second author during her long-term study (Porcher 2005) after 3 to 5 encounters. They showed their familiarity by approaching from in front, while unfamiliar sharks either remained at a distance or approached from behind, apparently to avoid being seen. As well as demonstrating learning, the sharks' behaviour indicates awareness of frontal images. They consistently responded to slight changes in movement or posture while attending to the researcher, as well (Porcher, own data). Other ethologists have noted comparable phenomena in studies of predation in terrestrial animals. (For example: Elgar 1989)

Social organization

Relatively complex social interactions are also evident among sharks. One such case involves a group of bonnethead sharks *Sphryna tiburo* (Myrberg and Gruber 1974). Ten adult members of the species were closely observed for approximately two hours, almost daily, for seven months in a large (40 x 60 m) channel, about 7 m in width. Interactions seldom occurred. However, one interaction invariably took place whenever two individuals approached one another head-on: one shark actively avoided the other by changing course. This resulted in what was termed "Give-way" (Fig. 5). The shark that Gave-way was operationally termed as subordinate and the other individual, dominant. Analysis of give-ways amongst all members of the group resulted in several noteworthy facts. First of all, a clear straight-line, size-dependent, social hierarchy existed among all members of the group. Additionally, it was apparent that females shied away from the three largest males (the latter were not the largest members of the group). But, why? Severe biting of females by males occurs during the reproductive season of elasmobranchs and even gender-segregation exists among numerous species. Results from the bonnetheads indicated that females are aware of a potential threat faced when near adult males. Also, since individuals approached one another head-on and at the same depth in the channel during Give-way, it is not unreasonable to consider that the size of a given individual was extremely difficult, if not impossible, to assess and yet the hierarchy showed clear, absolute size dependency. This suggested that bonnethead sharks individually recognize companions.

A similar social organization is also known in another species of shark, the smooth dogfish *Mustelus canis* (Allee and Dickinson 1954), and the second author repeatedly saw the same individuals visiting together from a distant home range. These companions sometimes appeared during the same month, year after year, in the same lunar phase, yet at no other time, indicating that they knew each other as distinct from all other sharks (Porcher, unpublished data). Recognition of other individuals has been demonstrated in many species of fish, notably at cleaning stations (Bshary, Wickler and Fricke, 2002).

Decision Making

Cognition is best demonstrated when an animal must make a decision between two alternatives. Evidence of decision making is a strong indicator that the animal referred to one or more mental representations before acting. Many examples of decision making have been found in fish, one of the most exceptional being the yellowhead jawfishes *Opistognathus aurifrons*, of the western Atlantic, who choose rocks of the appropriate size and shape to build their nests (Colin 1972). Their ability is often given as evidence for cognition in teleost fishes (Bshary, Wickler and Fricke 2002). Blackfin and white-tipped reef sharks, (*Triaenodon obesus*), sometimes flip on their backs to wriggle in the sand, presumably to scratch or to free themselves of a remora. The substrate in the study area is made up of sand interspersed with

reef flats, and the sharks were observed to choose only sandy places for such maneuvers. They had made a decision with respect to the use of available parts of the environment to serve their purposes.

A more striking example of sharks making a decision occurred when two blackfin left a "spawning dome" (Myrberg 1988) where they were hunting, to follow the second author to a feeding site they had not visited before, though they had not seen her for 8 months. Leaving the visible prey and scent-filled area to follow her required making reference to an old memory that she had sometimes supplied food, and granting the mental representation greater importance than the present-time stimulation of the spawning dome.

On the few occasions in which the second author brought a second person to the study area, the sharks responded by swiftly approaching her, then vanishing into the veiling light. After several minutes, the same sharks reappeared in long files and went directly to the stranger. This initial disappearance never happened when the normal routine was followed. The sharks' actions provide evidence that they recognize sudden changes in their environment and make consistent and rapid decisions to stay or leave, corresponding to events that are expected versus unexpected. (Porcher, unpublished data)

Eventual proof of cognition in sharks

Fig. 7 shows the hearing thresholds of lemon sharks *Negaprion brevirostris* that were obtained by two different means. The lower graph is an audiogram, based on behavioral responses noted by Nelson (1967), while the upper graph shows compound action potentials, recorded at threshold, from seven lemon sharks, obtained from the CNS (8th cranial nerve) by Corwin (1981) at the same audio frequencies. The two curves show remarkable similarity to the same sensory stimuli by both neural and behavioral actions. Proof of cognitive abilities in animals await precisely such correlates. But, rather than sensory events, such a correlate must occur between neural and mental events such as emotions and thoughts. Such a correlate will not be easy to establish. But if it were, there would probably be little interest in doing it (Griffin 1992). Until then, we must continue to seek justification for cognitive abilities by animals through an ever-increasing abundance of evidence for such abilities. We consider this report on elasmobranch fishes as adding to that evidence.

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Figures

Fig. 1.

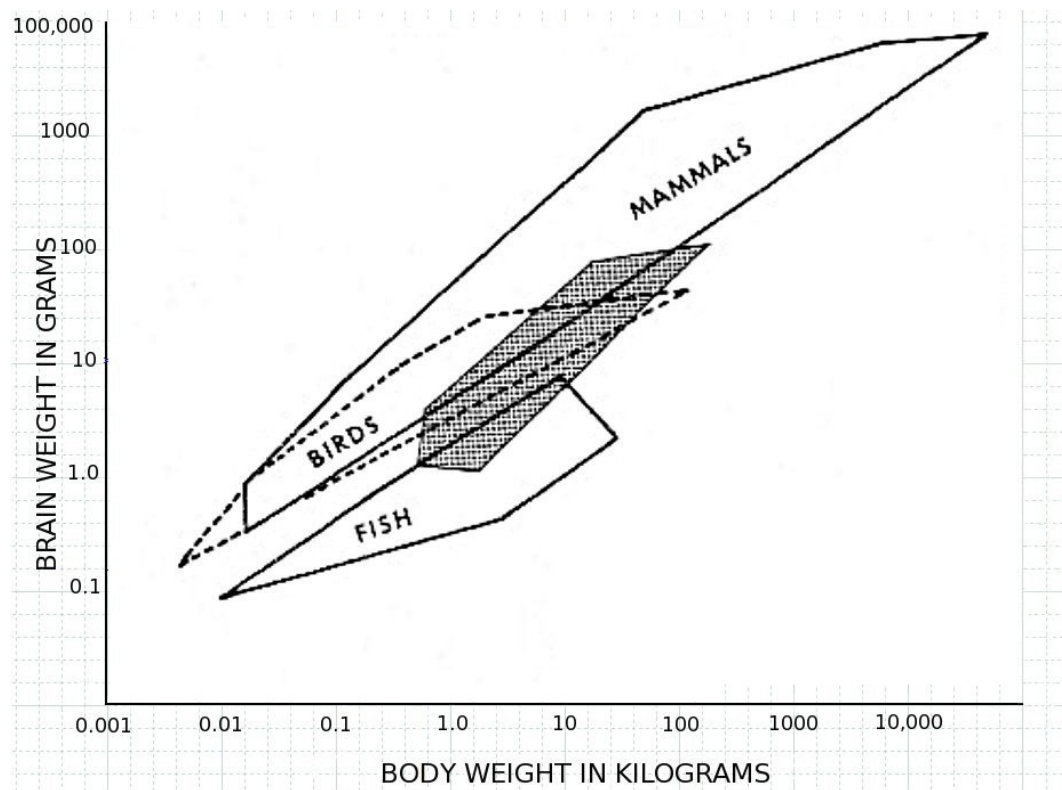


Fig. 1. Brain and body weights for four vertebrate classes expressed as minimum convex polygons, after Jerison (1973). Stippled polygon encloses elasmobranch brain-to-body ratios and overlaps polygons for bony fishes, birds, and mammals (Northcutt (1978).

Fig. 2.

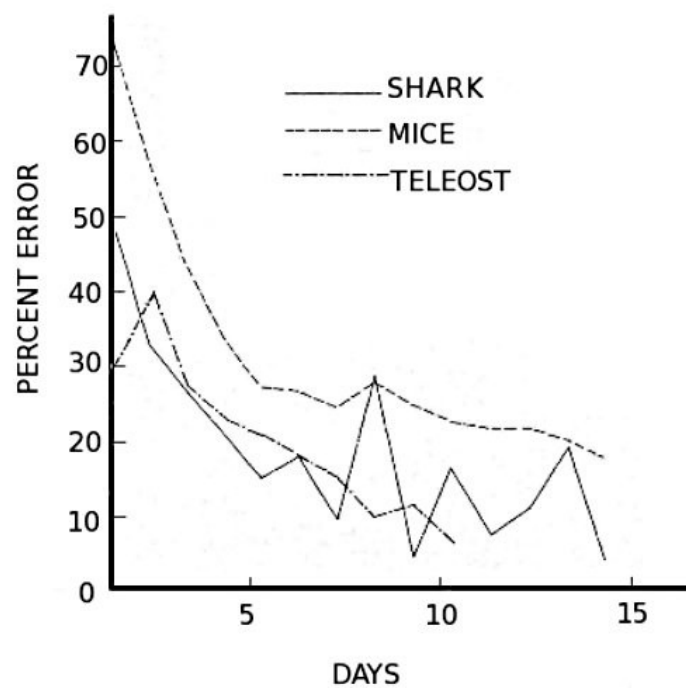


Fig. 2 Learning curve for shark in the light-dark discrimination problem. The average learning curve for 8 mice trained in a similar conditioning paradigm and the average curve for 5 *teleosts* *Tilapia* in a related problem, involving visual discrimination are provided (see text: from Aronson et al. 1967).

Fig. 3

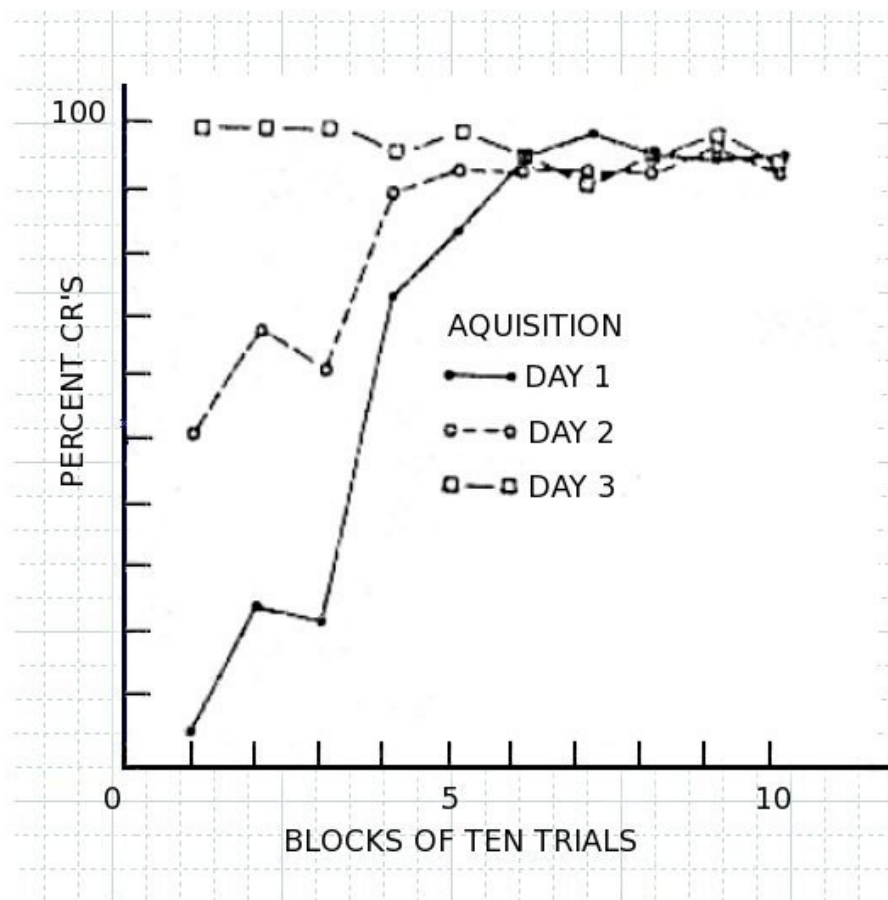


Fig. 3. Percentage of nictitating membrane CRs in the experimental group during successive blocks of trials in the first three acquisitions sessions (Gruber and Schneiderman 1975 @Psychonomic Soc., Inc.)

Fig. 4

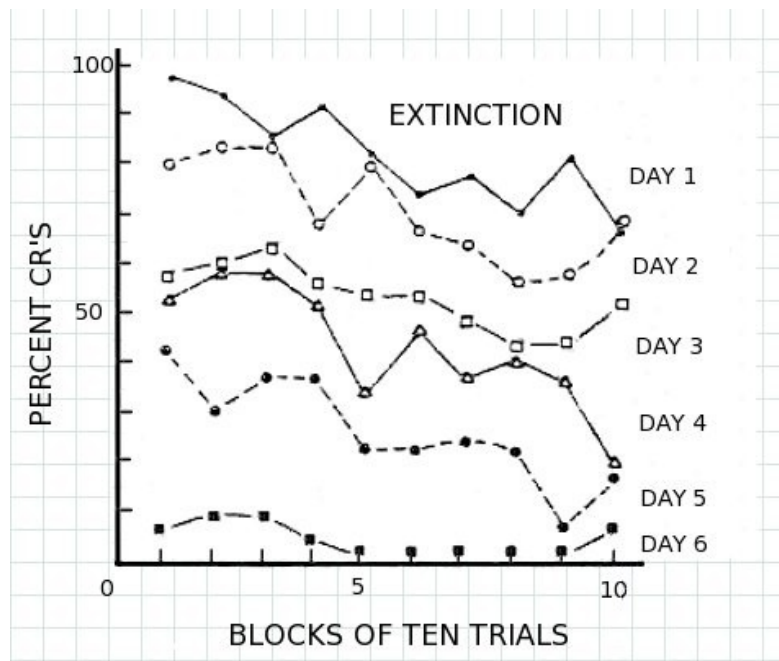


Fig. 4. Percentage of nictitating membrane CRs in the experimental group during successive blocks of trials in each extinction session (Gruber and Schneiderman 1975 @Psychonomic Soc., Inc.).

Fig. 5

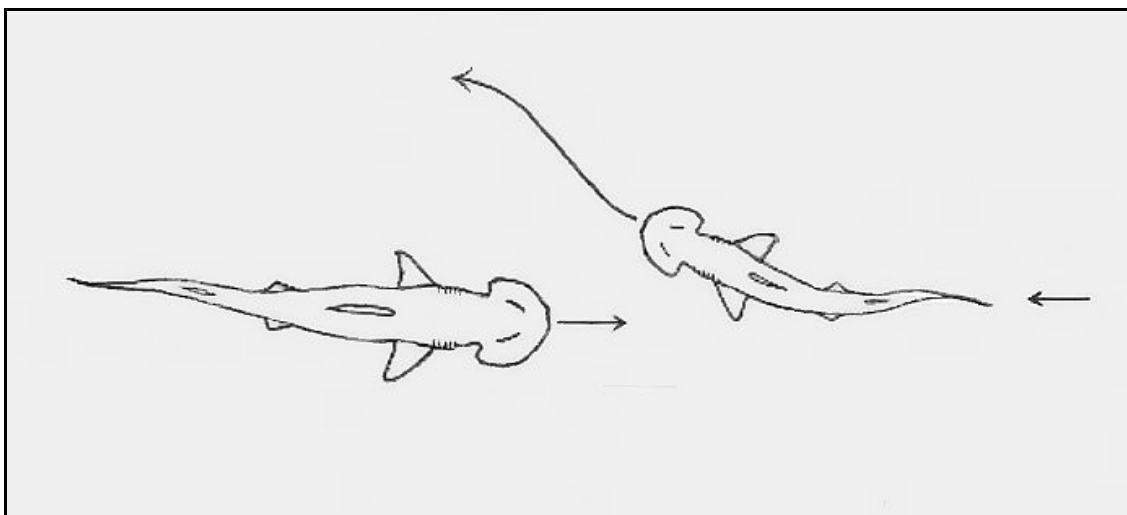


Fig. 5. Shark on the left Giving-way to the shark on the right (Myrberg and Gruber 1974).

Fig. 6



Fig. 6. Fig. 6. *Carcharhinus melanopterus* (photo by I F Porcher),

Fig. 7

Behavioral and Neural Thresholds

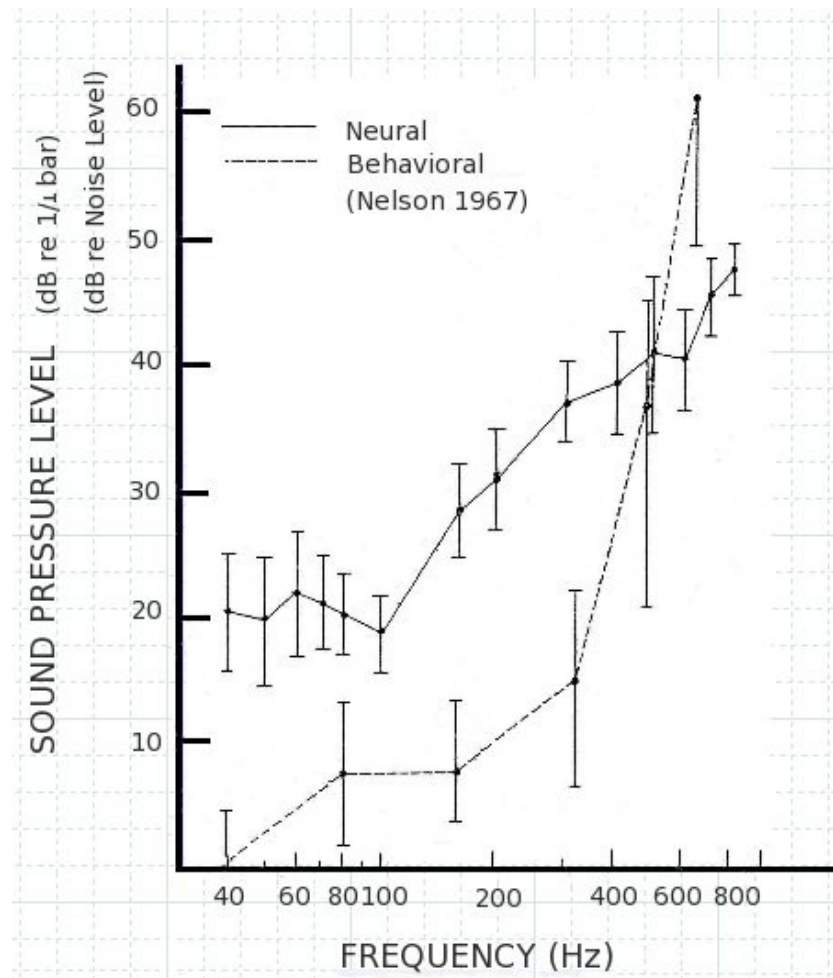


Fig. 7. Behavioral and neural frequency threshold curves for *Negaprion brevirostris*. The solid curve is a mean threshold for 7 lemon shark ears in dB re 1 μ bar. Dashed curve is from Nelson's (1967) operant conditioning study of sound thresholds for the same species. Direct comparisons between the curves are not possible since the values for the dashed curve are referenced to filtered noise level around each frequency. However, a low frequency plateau of best sensitivity below 200 Hz and a gradual threshold increase above that frequency are evident in both curves (Corwin (1981).

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