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How *Betta splendens* finds its way

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ABSTRACT

This study investigated the Siamese fighting fish *Betta splendens* performance in associating a stimulus with a specific cue when distractors are present. After trained to associate a specific color cue to a stimulus (conspecific) in a tank containing three colored distractors, the fish was challenged to locate the exact place where the stimulus fish was presented. With only color cues as guides, the Siamese fighting fish spent most of its time close to the color where the stimulus fish was previously presented, regardless of the distractors. However, fish trained to associate an empty place (no cues) to a stimulus fish, and then tested to localize the specific zone where the stimulus was shown, succeeded to locate the place even without any obvious cues/distractors for orientation. This study confirms that Siamese fighting fish show good conditioned learning and cannot be distracted by other stimuli. In addition, an unexpected good performance in the absence of cues may suggest the Betta's ability to orientate by using another sensorial modalities, as magnetic orientation. Collectively, the results of this study confirm Betta as a valid and reliable model for learning and memory tests, and suggest more studies should be developed for the better understanding of the fish's spatial orientation mechanisms.

1. Introduction

Finding the way is a widespread problem for all animal kind. Resources are usually found separated in space, and distances and directions need to be properly processed for successful orientation. After Tinbergen's (1951) pioneer study of digger wasps, many other reports approached the way animals encode information about the environment for spatial traveling and recall of relevant places.

Spatial orientation allows efficient travel between places because it requires encoding of the location of cues in a particular environment. Thus, animals use distal and local cues, and many other signals in a stimulus–response (S–R) association so as to navigate, learn new routes, and track known resource spots. While the natural environment offers many more spatial cues than an animal actually uses when guiding their way through, the majority of the studies on spatial learning use a single cue as the unconditioned stimulus (US) to be associated to a conditioned stimulus (CS) (Al-Imari and Gerlai, 2008; Braubach et al., 2009; Broglio et al., 2010; Karnik and Gerlai, 2012). This paper addresses US-CS using multiple cues as distractors with the purpose of testing the animal's ability to distinguish the US and ignore distractors.

A delayed matching to sample is usually observed when distractors are present (Wilkie, 1983; Fitzgeorge et al., 2011; Buckolz et al., 2014). Evidence suggests that animals exposed to a to-be-remembered stimulus hold it in memory and respond faster during a probe when no other stimuli are present (Wilkie, 1983; Shettleworth and Westwood, 2002). Thus, distractors affect the ability to learn and properly remember, since it inserts confusion to what was seen and where. According to Haworth et al. (2014), distractors that are always at the same location do not affect the animal's reaction as much as distractors placed in random locations. The presence of distractors was used to test learning and memory mainly in humans (Chun and Jiang, 1998; Zehetleitner and Müller, 2010; Schlagbauer et al., 2014) and birds (Wilkie, 1983; Shettleworth and Westwood, 2002; Haworth et al., 2014). However, it is still not clear whether spatial learning takes place with extraneous stimuli that are simply ignored or whether these extraneous stimuli can significantly affect orientation. This study addresses this issue in a freshwater aggressive species, the Siamese fighting fish *Betta splendens*.

The fish *B. splendens*, native from small turbid streams and lakes of Southeast Asia, need advanced spatial navigation to recognize places in order to obtain food, locate conspecifics (opponents and mates), and avoid predators (Braddock and Braddock, 1955; Roitblat et al., 1982; Verbeek et al., 2008). Such ecological and social features seem to have favored the selection of spatial skills in this species. Therefore, the fish *B. splendens* was used as a model to

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approach place learning based on single US-CS in which extraneous stimuli were used as distractors. By using a phylogenetically primitive animal, this study may assist to shed a light on the evolutionary mechanism of brain route formation for learning and memory.

2. Material and methods

2.1. Animals

Twenty seven Siamese fighting fish males, *B. splendens* Regan, 1910 were used as experimental fish for this study. Other six *B. splendens* were used as unconditioned stimulus. All fish were adult males (6–8 months) obtained from an Ornamental fish farm in Natal, RN, Brazil, and held in high-density racks. Water quality at the housing racks was maintained by filtration (mechanical, biological, carbon filter). Fish were housed individually in 1 L acrylic tanks, allowing water circulation between fish. Water temperature was kept at 28 °C and photoperiod set 12L:12D cycle. Fish were fed flake food (38% protein, 4% lipid, Nutricom Pet) and *Artemia salina*.

2.2. Experimental lab and maze

The laboratory used for the tests was an 18 × 10 m room with all walls painted in white. Windows were closed and covered with white polystyrene. Six 2 × 2.6 m white dividers were placed in the middle of room forming a barrier that restricted the experimental area to an 18 × 5 m space. In this space, three tanks were arranged in line, each one 5 m away from the other. The ceiling of the room was also painted in white and fluorescent tubes (1.5 m long) organized in lines illuminated the room.

The tank used was a squared (100 × 100 cm) open-field glass tank with 4 small tanks (20 × 10 cm) lying at the center of each wall and equidistant from the corners. The open-field tank had all walls covered with black sheet to prevent the fish from seeing outside. A start box (10 cm diameter) was placed in the middle of the tank and each experimental fish was released by removing the start box with a hook at the beginning of each trial. The tank and the smaller aquaria were filled with system water (same water from the holding racks) for a depth of 15 cm and it was changed everyday to ensure water quality. The learning test was divided in three phases: (1) habituation, (2) training, and (3) probe.

2.3. Spatial learning

In the habituation phase (1), 15 fish were individually allowed to explore the testing tank for 5 days. On the first and second days, fish were placed in the start box for 1 min and after release, fish could swim for 1 h. The same procedure was performed on the other days, but fish were allowed to explore the tank for 20 min on the third and fourth days and 5 min on the fifth day. After each trial, fish were moved back to their holding tank. For each habituation period, fish were rotated throughout a tank positioned in a different place inside the lab.

After habituation, the training phase (2) took place. For that, each small tank inside the open-field received a color card (20 × 10 cm) attached to the back wall, each one in a different color: blue, green, yellow and red. A stimulus fish (*B. splendens*) was placed in one of the four small tanks in order to serve as an unconditioned stimulus while the card color served as a conditioned stimulus. From the 15 experimental fish, each 5 fish were trained to find the stimulus fish in a different color tank, thus, 5 fish received the stimulus associated with the green background, while another 5 fish found the stimulus in the yellow tank, and the other 5 fish within the red tank. The other color cards were randomly distributed to the other 3 small tanks and served as distractors. The experimental fish experienced 4 trials of 5 min per day during 5 days (total of 20 trials). Three open-fields with a different color arrangement were used, thus every trial, fish were introduced in one of the open-fields and experienced a different display of the color tanks. By rotating the experimental fish through the 3 open-fields, association with cues other than the color could be avoided. All the behavioral tests were video-recorded from an overhead camera (SONY® DCR-SX45).

The probe (3) for the associative learning took place 24 h after the last training section. All procedures and conditions were the same as in the training phase, except that no stimulus fish was presented and the experimental fish was allowed to explore the open-field for only 5 min after released from the start box. The exploring period (5 min) was recorded for learning analysis. This group was expected to spend time checking the color cards (distractors) before finding the correct card previously associated to the stimulus fish.

As a control group, 12 fish were submitted to the same procedure above cited, but no color cards were added to the experimental tank. For this group, the habituation phase (1) followed the exact same procedure described for the spatial learning task (see above). After that, experimental fish underwent the training phase (2). For that, one small tank inside the open field received the stimulus fish; no color cues were used. From the 12 experimental fish, each 4 fish were trained to find the stimulus fish in a different place: 4 fish received the stimulus at the north tank, another 4 fish found the stimulus at the south and the other 4 fish found it at the west tank. Three open-field tanks were used for the tests and every trial, fish were introduced in a different tank. By rotating the fish through different open-fields, possible external cues could not be used as guides, although the stimulus was always in the same coordinate position (north, south or west). The experimental fish was subjected to 4 trials of 5 min per day for 5 days (total of 20 trials). All the behavior was recorded from an overhead camera. The probe (3) was recorded on the day after the last training section, and no stimulus fish was presented. The experimental fish could explore the tank for 5 min during which recording was performed for later analysis. This group was expected not to find the correct position where the stimulus fish was present due to the total absence of cues that could guide the fish.

2.4. Statistical analysis

The behaviour of the experimental fish was analyzed using the Any-Maze® video tracking software. The open field tank was divided in areas: 4 equal areas located around each small aquarium (1050 cm^2 each) plus the central and corner areas (5000 cm^2). The time the fish spent in each area was calculated for the training phase, both for the associative learning and spatial learning. The time spent in the central and corners areas were calculated as a unique area because these areas could not be associated to any stimuli or cues. The percentage of time spent in the tank areas were compared by Friedman ANOVA test, since data showed dependence and non normal and homoscedastic distribution (according to Shapiro–Wilk and Levene tests respectively). A probability level of $p < 0.05$ was used as an index of statistical significance.

3. Results

Fig. 1a shows the performance of the fish on the training phase, in which fish were allowed to explore an open field tank where four smaller aquaria were placed, each one in a different color and one of them presenting a stimulus fish to attract the attention of the experimental fish. The time spent at the area where the stimulus fish was presented was higher than any other area and above any random chance (Friedman ANOVA day 1: $\chi^2 = 29.98$, $p < 0.001$; day 2: $\chi^2 = 17.52$, $p < 0.001$; day 3: $\chi^2 = 14.73$, $p = 0.002$;

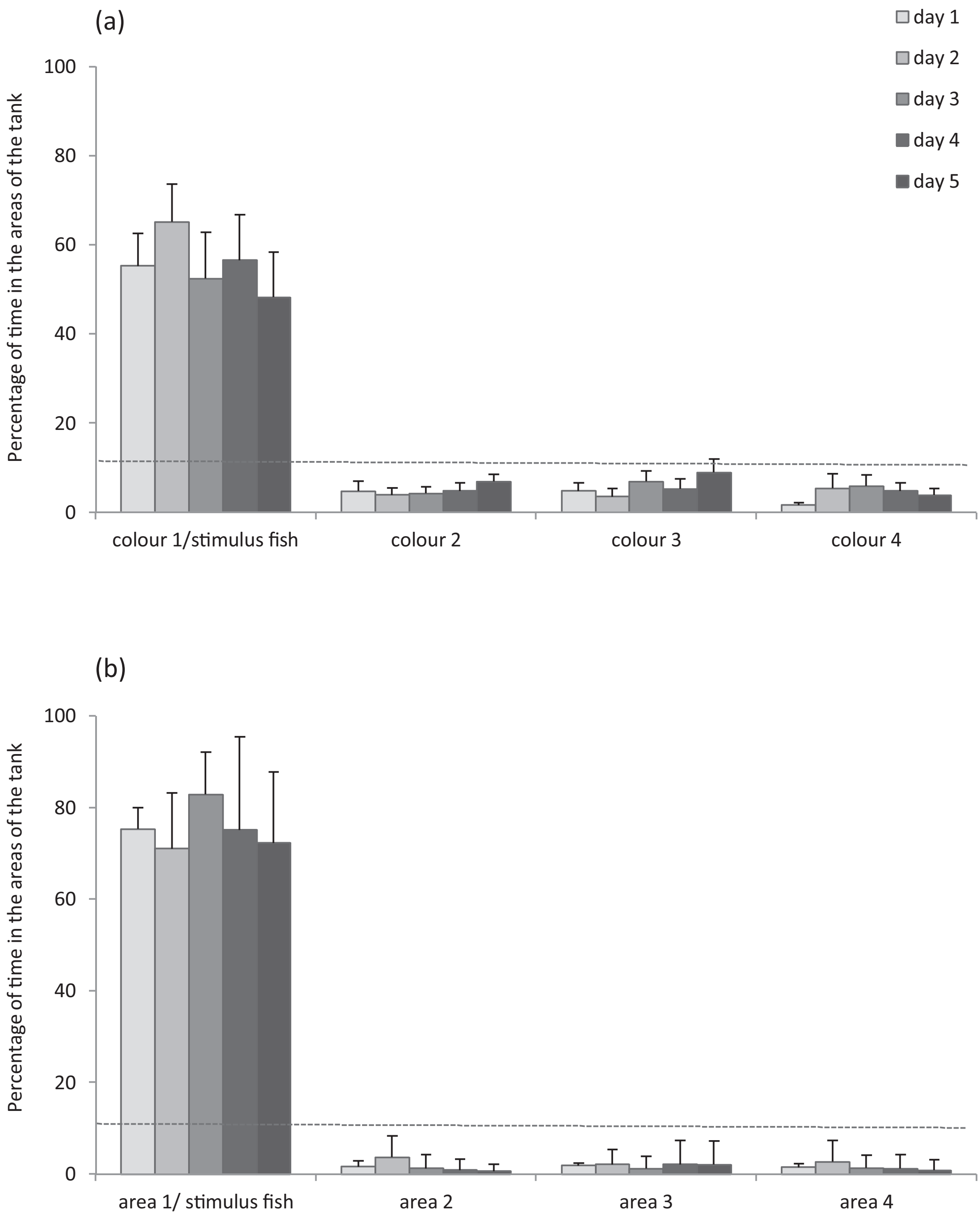

Fig. 1. *Betta splendens* training for (a) associative learning task and (b) spatial learning task. The data (mean ± SD) shows the percentage of time spent in each area of the tank. (a) each area of the tank showed a different color and one of them also presented the stimulus fish ($n = 15$) and (b) each area of the tank was represented by an empty small aquarium and one of them also presented the stimulus fish ($n = 12$). The dashed horizontal line indicates random choice at $y = 11\%$ $(5000 + (4 \times 1050)\ \mathrm{cm}^2)$. Fish was allowed to explore the tank for 20 min per day. *Betta splendens* showed strong preference for the area where the stimulus was shown during all the five training days (Friedman ANOVA, $p < 0.001$).

day 4: $\chi^2 = 19.05$, $p < 0.001$; day 5: $\chi^2 = 14.05$, $p = 0.003$). The experimental fish showed aggressive behavior against the stimulus fish during all trials. Since this fish is known as a fighting fish, it was motivated to stay close to the stimulus fish and show agonistic displays.

Fig. 2a shows the percentage of time fish remained close to each color area on the probe day, in which the stimulus fish was not present. The experimental fish spent more time close to the color area where stimulus was presented than close to any other area (Friedman ANOVA: $\chi^2 = 14.98$, $p = 0.002$). It is also remarkable that fish were able to make the association irrespective of which color cue they were trained with (each 5 fish were trained with a different color), and the presence of other colous as distractors.

Fig. 1b presents the training period of *B. splendens* in an open-field tank where there were 4 smaller aquaria, one of them with a stimulus fish. The experimental fish spent most of the time at the area where the stimulus fish was placed (Friedman ANOVA day 1: $\chi^2 = 18.45$, $p < 0.001$; day 2: $\chi^2 = 14.20$, $p = 0.003$; day 3: $\chi^2 = 16.69$, $p < 0.001$; day 4: $\chi^2 = 18.39$, $p < 0.001$; day 5: $\chi^2 = 9.00$, $p = 0.03$).

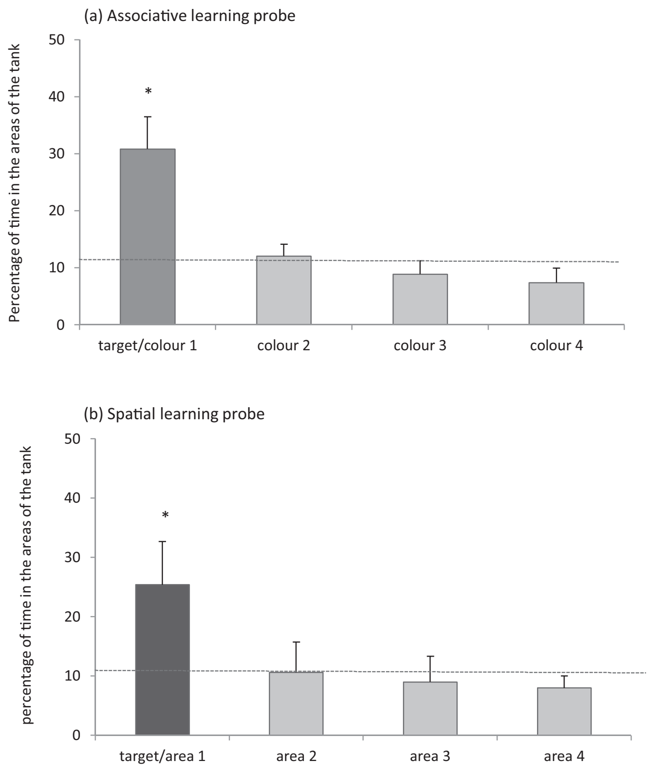

Fig. 2. Time *Betta splendens* spent in each area of the tank when (a) only cue color cards were presented (no stimulus fish) and (b) no cues were available. The data are expressed as mean ± SD, sample size (*n*) equal 15 fish for each task. The dashed horizontal line represents random chance at $y = 11\%$ $(5000 + (4 \times 1050)\ cm^2)$. Asterisk indicates significance value (Friedman ANOVA, $p < 0.05$). (a) Fish showed preference for the color card area where stimulus fish was previously presented (on the training phase) and (b) fish localized and showed preference for area 1, where stimulus fish was previously found.

Again, the experimental fish presented agonistic displays during all encounters, indicating its motivation.

Fig. 2b illustrates the spatial distribution of the fish when only empty aquaria were presented. Fish spent time in close proximity to the place where stimulus fish was previously found (Friedman ANOVA: $\chi^2 = 12.60$, $p = 0.006$), which showed that it could identify where to expect the stimulus even without cues for navigation.

4. Discussion

This study shows that the Siamese fighting fish is able to associate the presence of a stimulus fish with a color cue but, contrary to the presented hypothesis, the presence of distractors does not affect learning and recall. Fish spent the most time in close proximity to the color cue alone on the testing day, confirming the fish's ability to perform conditioned learning tasks (Bronstein, 1989). Even more impressive, fish also showed robust preference to the place of the stimulus fish when no associative cues were present. This finding means that *B. splendens* are not only able to perform associative learning regardless of the presence of distractors, but also achieve direction by some other guide, possibly by using magnetic orientation.

During the training of both groups (color cues and control), the experimental fish spent most of the time close to the stimulus (Fig. 1a and b) and showed many agonistic displays against it. This behavior is a male Siamese fighting fish intrinsic feature that could be used as motivation for the animal to seek out the stimulus fish when inside the open-field tank. According to Bertolini (2003), the Osphronemidae family presents varied levels of aggressive behavior, with the *B. splendens* being the most aggressive of the group. Some studies indicate benefits of the aggressive display for the animal emitter; for instance, the most aggressive fishes acquire the most food (Adams et al., 1998; Tamilselvan, 2010), obtain greater mating success (Berglund and Rosenqvist, 2003; Weir et al., 2004), and experience increases in the release of serotonin and dopamine in brain structures related to motivation (Kania et al., 2012). This study succeeded in using a conspecific as the unconditioned stimulus, since the experimental fish showed learning as indicated by its seeking behavior for the stimulus fish.

In the CS-US associative learning probe with distractors, in which the conditioned stimulus and other color cards (distractors) were presented, fish remained a greater amount of time closer to the cue than the distractors. This response indicates that fish could associate the specific color to the presence of the stimulus fish (Fig. 2a) and other color stimuli in the ambient did not disrupt the fish's attention. Studies addressing single cue associative learning in other fish species (Salas et al., 1996; Pradel et al., 1999; Al-Imari and Gerlai, 2008; Braubach et al., 2009; Broglio et al., 2010; Karnik and Gerlai, 2012; Luchiari and Chacon, 2013) and also in *B. splendens* (Thompson, 1963; Thompson and Sturm, 1965; Hogan, 1967; Bronstein, 1989) have shown these animals' ability of classical conditioning. The present study corroborates the results of previous studies showing conditioned responses in fish, and extends this knowledge by showing that *B. splendens* do not show a divided attention effect for distractor stimuli. According to Sutton and Roberts (1998) and Shettleworth and Westwood (2002), these results suggest that "abstract" features (such as colors) and space information are processed in parallel.

Although the present data suggest that associative memory in the fish *B. splendens* cannot be affected by distractor stimuli, fish were trained with both the target and distractors, which may have helped them to get used to the distractors (distractors were not new). During the training phase, if both relevant (target) and irrelevant (distractor) stimuli are shown, they are processed as a connected unit (Fox and De Fockert, 1998), and thus, it facilitates the target to be distinguished during the probe. Therefore, new tests using distractors presented only on the probe and also mismatching the identity of the distractors (instead of colors, using different shapes for every training) are needed in order to improve our knowledge on the ability of fishes to divide attention during learning.

Nevertheless, a surprising result was observed from the control group; even in the absence of any obvious cue and rotating fish through different tanks (see Section 2.3), fish could identify the area where the stimulus was presented (Fig. 2b). From this result, it can be suggested that *B. splendens* are able to orientate and localize elements in the environment by some other type of sensor. Since it is not know the exact perceptual abilities of fishes for assimilating or ignoring stimuli, creating a completely controlled testing ambient becomes a huge challenge. The results shown here indicate that the fish recognize the target site, demonstrating assimilation and a remarkable ability to perceive the environment. A possible explanation as to how *Betta* fish could find its way may rely on magnetic orientation.

Many taxonomically diverse animals are able to perceive and respond to the Earth's magnetic field (Phillips, 1986; Tesch, 1974; Chew and Brown, 1989; Formicki et al., 2004; Wiltschko and Wiltschko, 2002; Schlegel, 2007; Burda et al., 2009; Vácha et al., 2010; Begall et al., 2012). While it is well established for birds (Wiltschko and Wiltschko, 2005), this is a widespread phenomenon that deserves more research. The magnetosensation in fish has been suggested by some observed behavior, such as the number of fish that were caught by nets containing ferrite magnets in contrast to control nets (Formicki et al., 2004), magnetic conditioning using punishment in Mozambique tilapia and zebrafish (Shcherbakov et al., 2005), spontaneous alignment in the holding tank following a certain magnetic direction in common carps (Hart et al., 2012), responsiveness to a particular direction based on magnetic field in zebrafish (Takebe et al., 2012), and also the presence of iron-rich crystals that respond to the magnetic field changes in the olfactory epithelium cells of rainbow trout (Eder et al., 2012). These and other studies have suggested that magnetic field perception may contribute to the fishes' ability to navigate, shoal, or simply learn about the environment. Although we could not rule out other unknown sense of orientation (e.g., lateral line), and at the present it is still speculative to suggest that the Siamese fighting fish may have the ability to orientate by magnetoreception, the results shown in this study certainly point towards the fish's ability to learn more complex spatial relationships.

In summary, the present study reinforces the idea that fish can learn varied relationships between arbitrary stimuli, and are not misguided by distractor cues. In addition, an unexpected good performance in the absence of cues may suggest the fish's ability to orientate by using another type of sense, such as perceiving magnetic fields. Although more detailed studies are essential for a thorough understanding of the fish's spatial navigation and to confirm their potential magnetic perception, this study contributes to this area of research by demonstrating, through the use of simple experimental protocol, that fish use complex forms of learning.

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