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# ______Non-Social Behavior in *Aurelia aurita*______

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**Abstract**

Non-social behavior is defined as actions or activities not oriented towards society or community and its interaction or relationships. This experiment demonstrates the way *Aurelia aurita*, otherwise known as moon jellyfish, conducts themselves towards other moon jellyfish in closed environments. The results of this experiment conclude that moon jellyfish demonstrate consistent non-social behavior towards other moon jellyfish in the same tank. This suggests that the moon jellyfish has sufficient cognition to recognize other jellyfish and intentionally distance themselves from others. This may be driven by different factors, such as anti-predation adaptation to a group escape response. The results of this study can contribute to future studies on the evolutionary reasons why this behavior is chosen and the cognitive rationale behind it, as well as the degree to which individuals will distance themselves.

## Introduction

Moon jellyfish, otherwise known as *Aurelia aurita*, have been at the center of discussion for animal psychologists and marine biologists for a long time. Being found in swarms throughout the world, they are without a doubt one of the most well-documented jellyfish that exist. Moon jellyfish have often been found in open and deep water, often in neritic and inlet environments, typically distributed between latitudes of 70º N and 40º S (Möller, 1980) and in regions like the North Atlantic and North Pacific (Möller, 1980), especially in coastal regions like the Mediterranean and Japan. They typically are found impeding fishing activities, power plant cooling, and local tourism on beaches, aquaculture, and marine biology studies (Möller, 1980; Purcell et al., 2007; Richardson et al., 2009). Their growth as a species is vast and can change drastically through their life, sometimes ending up with the size of their disk being 140 to 250mm wide, 50 to 90mm high (Mayer, 1910).

Despite the abundance of information on *Aurelia aurita,* including sexual and asexual reproduction as well as complete life cycle from larva to medusa (Kakinuma, 1975). Studies on *Aurelia aurita* typically focus on the population dynamics of the blooms and life cycle capabilities. Little has been written about the social behavior of individual moon jellyfish. In particular, a significant gap in social behavior remains to be explored in an individual laboratory setting.

This study attempts to discover the social nature of *Aurelia aurita* in a controlled environment and understand whether they can be social and recognize other jellyfish of the same species, but more importantly, whether or not they will go towards other jellyfish and perform prosocial behavior, or away to perform antisocial behavior. We aim to shed light on the innate social behaviors and capacity for social engagement of this widely distributed species.

## Literature Review

The first ever accepted recorded sighting of the *Aurelia aurita* dates back to 1758, written by Caroli Linnaeus in his book *Systema naturae per regina tria naturae,* where he first recorded the jellyfish as *Medusa aurita* (later changed to *Aurelia aurita*) to be found in the Baltic Sea. He briefly described the jellyfish as having a circular structure, a gelatinous form, and four central horseshoe rings that are central to the body. He is the first to have recorded it; however, he did no further research on it. This was also the same description of Péron F. and Lescuer C.A. in their book *Annales du Muséum national d'histoire naturelle de Paris* in 1810. Péron F. and Lescuer C.A. did not conduct any research on the jellyfish, but they did describe it more accurately than Linnaeus had in his book, and are also partly credited with the discovery of *Aurelia aurita*.

Not much has been said about the other parts of *Aurelia aurita,* including behavior or nervous system structure, until about 100 years later. George John Romanes, considered to be the father of comparative psychology, published *Further Observations on the Locomotor System of Medusae* in 1877. Romanes was the first to do notable research on the medusa and was the first as well to hypothesize on the capabilities of the neuron's electric distribution from the jellyfish's core neuron clusters. He discussed the contraction of the muscular structure in the jellyfish and that the contraction occurred in an omnidirectional movement under the bell, but could not yet prove it. He further demonstrated the transmission through nerve fibres was possible with help from Edward A. Schäfer in 1878, guided by Romanes' suggestions a year earlier. Schäfer discovered the presence of both bipolar and tripolar nerve cells in the jellyfish, and Emil Bozler in 1929 confirmed this through nerve staining and further discovered more complex multipolar cells within the jellyfish.

These studies and conclusions were the foundation for Adrian Horriage in 1956, who was the first to study behavior in jellyfish by looking at the nervous system and fibres in the jellyfish and making the connection to swimming and movement behavior. This was evident through his use of silver staining of the nerves to examine the individual endings and connections to come to the conclusion of how jellyfish were able to move in the water and how they can rotate their body through control of the tensing and relaxation of muscles. There are further studies stemming from groundwork laid down by Horriage to discuss motor function, swimming capabilities, and spatial rotation, but none to describe social behavior. Though he did not discuss any form of social behavior, he did still talk about the use of neural nets within the jellyfish, as well as the biological makeup of the jellyfish, later giving precedence to more research being conducted on the life cycle and genetic makeup of the jellyfish. He is one of the main reasons why researchers today consider *Aurelia aurita* to be one of the most researched jellyfish.

In 1962, Henri Thiel, a Dutch professor, was the first to talk about jellyfish with regard to behavior. Roughly 200 years after its discovery by Linnaeus, he established two important traits of the *Aurelia aurita* that would begin to give us insight into how they behave. The first being the behavior of strobilation, the process of asexual reproduction of the jellyfish in which a jellyfish breaks off a piece of its body to form a genetically identical jellyfish. The second was the movement of populations in and around the Baltic Sea. He went on to study jellyfish and is the first notable figure to deeply research their asexual behavior concerning strobilation in detail and write about their movement as a group. He did not, however, talk about the sexual behavior or any courtship behavior that was later discovered by researchers, but rather the life cycle stages known in the order of: Gamete, Planula, Primary Polyp, Immortal Polyp Colony, Juvenile Medusa, Mature Medusa (Cunningham, 2024).

This is where the modern-day researchers of population dynamics base the foundation of their research. Henri Thiel's work on jellyfish has been expounded upon by people like Henry Tiemann in 2009, who proceeded to speculate that *P. periphylla* (otherwise known as the "Helmet Jellyfish") migrating to the surface would increase mate encounters when moving from 3 to 2 dimensions. He hypothesized that jellyfish were able to find each other for mating purposes and could locate other fertile jellyfish of the opposite sex to mate with. He did this by recording the depth at which juvenile males stayed at, then the depth that aggregate adults rose to during the night to mate with each other. He then proved how this species of jellyfish is capable of not only social behavior but also courtship behavior. Unfortunately, he lacked particular samples of sperm and egg to biologically prove this, but was able to justify this claim through behavioral observation and recording.

Then, in 2015, Stein Kaartvedt discussed the movement of *P. periphylla*. In his study, he followed the movement of groups of jellyfish using a remotely operated vehicle (ROV) and discovered how group movement worked. He found that both in the evening and at night, *P. periphylla* are able to locate other jellyfish with high accuracy and get close enough to unintentionally entangle their tentacles with each other. The results on the social behavior of *P. periphylla* added to the emerging pattern that jellyfish are not simply passive drifters but rather display active and varied behavioral repertoires of adaptive significance. Yet, he was unable to mention why on a biological level this was possible, but on a behavioral level, he was able to come to this conclusion through his work. He refuted the claims made by Tiemann et al., due to the idea that *P. periphylla* are social hunters because of the way krill move asperatically on the water's surface. He hypothesized that the reason jellyfish move together on the surface of the water is actually due to the possibility of more jellyfish tentacles being present, causing the jellyfish to catch more fish.

While these studies were done on the jellyfish *P. periphylla*. There is still a chance of overlap as both *Aurelia aurita* and *Periphylla periphylla* come from the same class called Scyphozoa. Sharing an unknown evolutionary estimated split off from each other, between 100 million years ago and 635 million years ago (Van Iten et al., 2014; Mizrahi et al., 2021).

This is where we start for the basis of the current study. We are aware of some similar jellyfish's abilities to travel in blooms and become social because of this established research. We know that some related jellyfish are capable of locating the same species of jellyfish with good accuracy, as well as having good reason to conclude they are capable of replicating this behavior within open populations. However, we have yet to determine if the individual jellyfish itself is a social animal on its own accord. It seems like this is the case due to the traveling pattern established by researchers. However, we cannot be certain until we prove this in a controlled environment. We want to know if there is no incentive, like mating or feeding, will there still be an incentive to stay together or stay away from each other?

## Methods

### *Subjects*

A total of 16 adult individuals of *Aurelia aurita* were tested. The sex of the subjects was not determined. Subjects were housed at the laboratory of Comparative Psychology at the University of Padova in two identical stock tanks specifically devoted to maintaining jellyfish (O16 Jellyfish aquarium from https://petjellyfish.co.uk), eight subjects in each tank. The tank is 38 cm tall, 20 cm deep, and includes 16.8 litres. Salt water (salinity: 32 ppt; NO3 level: 20–25 mg/L) was maintained at a constant temperature of 22° ± 2°C. The tank was circular to prevent the jellyfish from getting tangled in the corners. Additionally, there was a constant clockwise water flow that facilitated the jellyfish's swimming. The tank is equipped with built-in filtration and multi-LED lighting on the top (10 watts) and a remote control. Two hours before the experiment, moon jellyfish were fed to satiation with brine shrimps (*Artemia salina*). A 14-hour light/10-hour dark (L/D) photoperiod was used.

*Apparatus and Procedure*

The experimental apparatus (length x height x width, 20 x 15 x 14 cm) was divided into five equal-sized sections. At each end of the tank, there were two stimulus areas (length x width, 4 x 14 cm), where the stimuli were presented as shown in Figure 1. These stimulus areas were separated by two choice areas (4 x 14 cm) by a green mesh (0.5 x 0.5 cm), which allowed the transfer of visual and chemical cues between the areas. The central area (4 x 14 cm) was located in the middle of the apparatus, where the jellyfish began the observation period. The walls and floor of the tank were covered with white plastic material. The apparatus was lit by one fluorescent lamp (6.5 watts). The water level in the apparatus was set to 9 cm. Unlike the stock tank, no pump was inserted to avoid the water flow, which might have affected the subjects' direction of swimming.

Stimulus females were introduced 5 min prior to the test; the subject was gently introduced by a jellyfish net into the middle of the tank into a transparent cylinder (6 cm diameter). After 2 minutes of acclimatization, the cylinder was raised, and the jellyfish's position in the three areas (two choice areas and the central area) was recorded for 20 minutes. In half of the tests, the social stimuli were on the left; in half of the cases, it was on the right.

We calculated the time spent by the subjects swimming in the two choice areas. The dependent variable was the proportion of time (calculated in seconds) spent near the stimulus jellyfish, given by the following formula: [time spent near the stimuli / (time spent near the stimuli + time spent near the empty compartment)].

## Results

Statistical tests were carried out using SPSS 29.0.2.0. Data were normally distributed (Shapiro-Wilk, p = 0.240); accordingly, we used parametric analyses. First of all, we analyzed whether jellyfish preference changes over time and whether there was any side bias in the apparatus by a repeated-measures ANOVA with Time (five intervals of four minutes) as a within-subjects factor and side of the stimuli (left / right) as between between-subjects factor. Then, a one-sample t-test (0.50 as chance level) was used to assess the overall preference of jellyfish to swim in the two choice areas.

The repeated measure ANOVA showed that the proportion of time close to the social stimuli did not significantly change as a function of time (Time, $F(4, 52) = 0.121$, $p = 0.975$, partial eta squared $\eta^2_p = 0.009$). The side of the stimuli (left vs. right) did not affect jellyfish choice ($F(1, 13) = 2.536$, $p = 0.135$, $\eta^2_p = 0.163$). No interaction between Time and Side was found ($F(4, 52) = 1.823$, $p = 0.138$, $\eta^2_p = 0.123$).

Overall, jellyfish did 13.81 ± 7.97 (mean ± std. dev.) movements across the three areas during the observation time and spent significantly more time near the empty compartment ($t(15) = -2.541$, $p = 0.023$; Cohen's $d = -0.635$).

**Figure 1**

*Jellyfish Tank Used In Experiment*

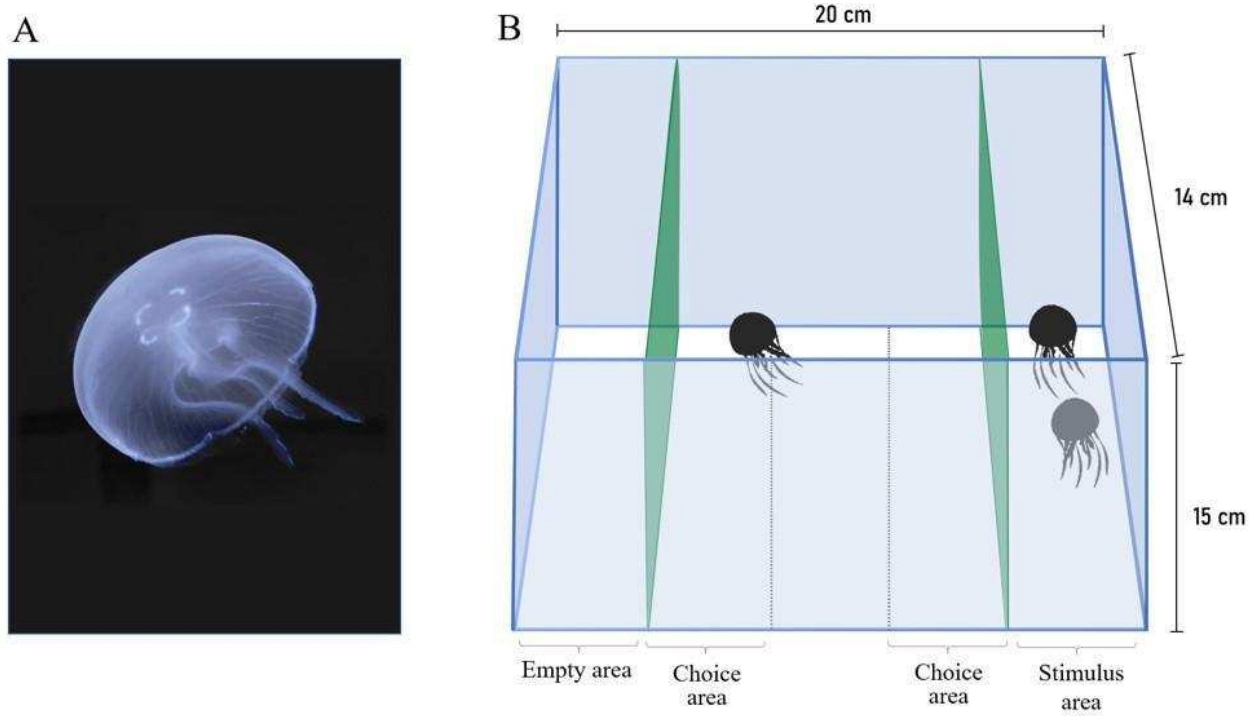
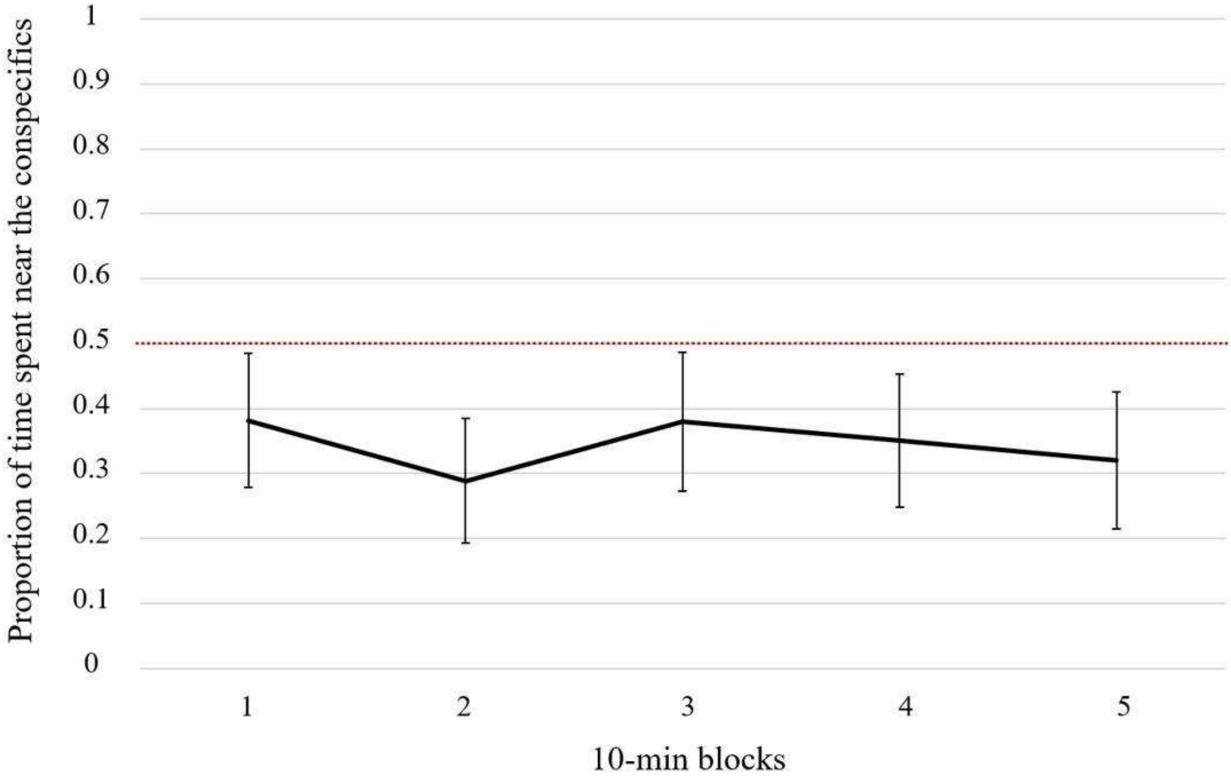


**Figure 2**

*Proportion of Time Spent Near Conspecifics Over Time*



## Discussion

Our experimental study indicates that individual jellyfish prefer to stay apart from each other rather than together as a group. This indicates that although they travel in large blooms across the globe, as individuals, jellyfish intentionally stay away from other jellyfish. This is an important discovery, because it tells us that there are other factors as to why a jellyfish would form these large groups and persist in these large groups for long periods.

If we can identify these factors, then we can likely better predict the global movement patterns of the *Aurelia aurita* and begin to mitigate the impact of the invasive species that causes issues like interfering with fishing, aquaculture, marine biology, and tourism worldwide.

Further research is recommended to explore whether there are any possible abilities in grasping, reaching, and recognition of food. This is to determine if they come across their food merely by chance or if they exhibit intentional reaching and traveling towards the food. If the latter is true, we can then better understand the jellyfish's movement across regions of the ocean, not by tracking them, but by monitoring their prey. On the contrary, if their behavior is purely reflexive, a different approach may be necessary.

Additionally, region-specific studies should be done to determine jellyfish bloom movement with regard to the ocean currents and temperature. This could reveal whether such environmental factors contribute to group formation, suggesting blooms occur more due to environmental influences than by social preference. These studies have been done for other Jellyfish like *P. periphylla,* but not for the *Aurelia aurita*.

Some limitations that were present during the study were the sexual dysfunction that the jellyfish had due to the tank's living conditions. This was because the jellyfish tank lacked native bacteria that jellyfish are typically exposed to in their native environment, which can alter their movement speed or use of tentacles (Cunningham, 2024). This is much more difficult to control for however, as there are over sixty different kinds of bacteria found within the native environment of the *Aurelia aurita*. The majority of bacteria found within the native environment were α-Protobacteria, γ-Protobacteria, and Bacteroida (Jensen et al, 2023). This makes it difficult to regulate the ratio of necessary bacteria to mimic the native environment.

Another limitation is that we had not examined for fertility or age of the subjects, and anti-social behavior could likely change if they were younger and fertile, controlling for age and sex, as mentioned earlier by Henry Tienmann's findings of sexually mature jellyfish coming together to mate. It is unclear whether or not these subjects were in fact male or female. In this study, it was observed and theorized based on knowledge that they were likely older and more infertile jellyfish.

It is worth noting that our experimental apparatus differed from those commonly used in fish studies. In such studies, the stimulus area is often located in a separate but adjacent tank, allowing only visual cues to reach the test subjects. Moon jellyfish are known to respond to light (Hamner et al., 1994; Arai, 1997), but their visual system is primitive, and there is no evidence that they can visually recognize objects or conspecifics. For this reason, we set up an apparatus that allowed both visual and chemical communication between the stimulus and the subject jellyfish. We cannot exclude the possibility that the stimulus jellyfish released alarm-related chemical cues, leading the test subject to avoid that area. For instance, if moon jellyfish are not highly social in such contexts, the stimuli individuals may have experienced stress due to the enforced proximity of conspecifics, possibly triggering the release of aversive chemical signals.

## Conclusion

In conclusion, we have found that *Aurelia aurita*, in a controlled environment, has the capacity for social behavior and can recognize other jellyfish of the same species, but actively chooses to perform antisocial behavior. We initially did not expect this conclusion to occur, but it gives us insight into the jellyfish's behavior and cognition, which can be further expanded upon in the future. However, this is only the beginning of the discovery of the capabilities of the *Aurelia aurita*, and further studies must be conducted to establish its sensory, reflex, identification, and regional movement competencies. This finding helps add to prior work done to describe the moon jellyfish's known qualities as a species.

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