Cephalopod Connection to Consciousness: A Literature Review

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ABSTRACT

This literature review explores the survival skills of octopuses and examines their connection to levels of consciousness. Octopuses are creatures known to have higher levels of intelligence, and behaviors under this category demonstrate consciousness through the ability to interpret one's surroundings and act accordingly. The ability to camouflage and the act of sleeping both demonstrate a higher level of consciousness. Camouflage necessitates a detailed self-awareness, while purposefully altering one's state of consciousness through sleep inherently exemplifies consciousness. Moreover, the mysteries of octopus arms, with their remarkable innovations—such as nerve regeneration that even surpasses human capabilities—strongly suggest a connection to some form of consciousness. Finally, while octopus reproductive patterns don't seem to be linked to consciousness, further research is needed to confirm this.

INTRODUCTION

Cephalopods exist as one of the great mysteries of biological sciences. Despite being invertebrates, which are known to have lower levels of cognition, the shell-less molluscs are, for the most part, cognitively advanced with complex forms of consciousness (Amodio et al). Encompassed in the cephalopod class are cuttlefish, squid, and octopuses, the latter of which this paper will focus on.

With three hearts, eight arms, and technically 2 brains, octopus anatomy is very unique. In terms of their nervous system, they have the largest out of any invertebrate, and it's made up of their brains, optic lobes, and arms (Schnell, et al). The first brain is their central brain, which controls basic motor function and conducts most of the decisions and choices. The second brain, or the brachial plexus – a network formed at the connection of axial nerve cords in every arm, encompasses all of the octopus' arms. Octopus arms are anatomically identical and make up the majority of the Peripheral Nervous System (PNS) as they have a certain degree of local cognition. A ring of fibers called the interbranchial commissure is what connects the arms to each other, as well as to the central brain. Inside each arm is the axial nerve cord, which contains two rows of sucker ganglia that have millions of sensory receptors and motor neurons, that then send information to the four intramuscular nerve cords (Carls-Diamante).

With multiple ways to perceive their environment, octopuses must have at least some form of consciousness, even if it's base-level. However, it's difficult to state for sure as there isn't yet an actual scientific agreement on what it means to be conscious, meaning the definition and criteria needed to be labeled as a 'conscious' organism have some gray area. However, there are a few guidelines to help determine whether or not an organism is conscious. In 2018, Sanna Ahvenharju, Matti Minkkinen, and Fanny Lalot constructed a model called the Five Dimensions of Future Consciousness. According to the model, an organism should have at least one of the following dimensions of consciousness in order to be considered conscious at a basic level: perceptive richness, evaluative richness, integration at a time, integration across a time, and self-consciousness (Ahvenharju et al). Perceptive richness, or P-richness, is the idea that an organism is actively aware of their surroundings. Evaluative richness, or E-richness, is the notion that an organism can have affective or emotional responses that then produce a positive

or negative valence, depending on the emotion. Integration at a time is the idea of 'mental time travel' – being able to remember the past or think about the future. Lastly, self-consciousness is the concept of 'self vs other', or the ability to make inferences for other animals based on one animal's past experiences (Godfrey-Smith).

RESEARCH PURPOSE

This paper aims to demonstrate which factors sensory consciousness and evolved intelligence in cephalopods, specifically in octopuses, determine their survival skills. For the future, this information could lead scientists to a better understanding of Disorders of Consciousness (DOC) patients' brains, as their brain structure shifts prompt the idea of a new "standard" of a healthy brain. Additionally, this information could help with understanding other nonverbal organisms and their levels of consciousness.

This paper will first establish why octopuses are the topic of inquiry by providing background on the connection between octopuses and humans. It will then provide an in-depth summary of the survival skills of octopuses, and continue on by discussing each skill's respective connection to higher levels of sensory consciousness or evolved intelligence. The connections to consciousness will be presented in the discussion, as well as any remaining questions or concerns, and what this information can mean for our future.

LITERATURE REVIEW

WHY OCTOPUSES

Octopuses as a species have very little in common with humans – the last known common ancestor was a microscopic worm, millions of years ago. Further, octopuses can't be classified as vertebrates, apes, primates, mammals, or warm-blooded, all of which are human traits. They are often stereotyped into having an extremely basic social life and to be solitary creatures – however that's not always the case. New information shows that some octopuses have bursts of social activity, sharing dens and displaying no signs of cannibalism (Mason et al). Even more so, scientists off the coast of Australia have found multiple scallop beds that act as grounds for octopuses to interact with each other (including mating, fighting, and exploring). This new connection doesn't just apply to octopuses, however; octopuses have recently been forming more interspecies connections – whether forming "cooperative hunting parties with fish" (Mason et al), or simply interacting with humans.

Biology in general has issues with definitive criteria for social capability – for example, the social capability of an insect is completely different than that of a monkey, but both animals can still be social. Therefore, scientists have hypothesized that where there are larger clusters of food and less shelter, social tolerance in octopuses specifically tends to be higher than those living more secluded lives, ultimately due to the forced proximity. However, although this is relatively accurate, it doesn't mean that all species of an environment will be social – there are varying degrees of sociability inside each environment (Mason et al).

SURVIVAL SKILLS

INTELLIGENCE

One of the most well-known characteristics of an octopus is their intelligence. They are capable of solving complex puzzles, using tools, and demonstrating long-term memory. They demonstrated behaviors such as escaping from tanks, opening jars, and even using coconut shells as shelters. This extraordinary intelligence is not just a result of instinct or behavior, but it stems from their complex brain structure. To better understand how they think, we need to explore the anatomy of the octopus's nervous system.

The octopus brain consists of three main lobes; the vertical lobe, optic lobes, and inferior frontal lobe. The vertical lobe is used for learning and retaining memories, and it's similar to the mammalian cortex. The optic lobes (of which there are two: large nervous structures outside the cartilage capsule of the brain and connected to the retinae) play a large role in the computation of visual input. Lastly, the inferior frontal lobe exists as a system to help process chemo tactile information, as well as motor programs (Amodio et al). It is important to note, however, that motor and sensory input does not only rely on the central brain.

One of the ways that octopuses are able to display their high levels of intelligence is through their problem-solving skills. Not only do octopuses have flexible tool use – that is, they will solve problems in multiple different ways, and on the chance that an attempted solution doesn't work, they will change tactics and try again – but they also have advanced problem-solving skills in their natural environment with artificial tasks. For example, they can remove lids from jars and receive food containers from small crevices, both with and without visual input (Amodio et al).

Furthermore, their ability to adapt to new environments and new interactions with humans also support claims of higher levels of intelligence. An experiment in 2010 concluded that octopuses can tell humans apart, despite wearing identical uniforms. Biologist Robert C. Anderson directed the study – he had two staff members at the Seattle Aquarium treat one of the octopuses differently: one member fed the octopus while the other poked it with a brush. They continued the behaviors for two weeks, and afterwards there was a noticeable difference in how the octopus would react upon seeing either member of staff. Additionally, at the University of Otago in New Zealand, the octopuses began to shoot jets of water at the lights, effectively short-circuiting the power and turning off the lights (Godfrey-Smith).

CAMOUFLAGE

Octopuses use their ability to camouflage not only to mimic their environment and blend into the background, but also to pretend to be other species. For example, when swimming across a relatively empty sand plain, octopuses have been known to camouflage themselves as flounders, as they're less likely to be preyed on. Further, it's also common for them to mimic being seaweed or floating kelp to hide from predatory eyes.

This unique and interesting trait is achievable due to the cellular makeup of cephalopod skin tissue. There are three main cells that cephalopods rely on to disrupt the outline of their bodies and thus camouflage into their environment are chromatophores, iridophores, and leucophores. Primarily, chromatophores, organs present in the skin that contain pigment sacs, utilize electric activity in the chromatophore nerve to pull the radial muscle fibers outward, expanding the pigment sac. In chromatophores, pigments are usually more reds, brown, or yellow hues. Iridophores help chromatophores through enhancing the color patterns. Iridophores

are stacks of incredibly thin cells that reflect certain shades of light depending on the angle and wavelength they're observed. From above, they tend to be blue, and from an oblique angle they appear more red in color. Additionally, while chromatophores are controlled neurologically, and thus can respond instantaneously, iridophores can take up to several minutes to respond – meaning they're likely controlled by neurohormones. Lastly, leucophores are reflector cells, designed to reflect light in a scattered pattern so that the cell appears white. Unlike iridophores, leucophores don't change appearance based on the angle, but they collaborate with iridophores to help chromatophores by further developing their color.

SLEEP

Octopuses have two phases of sleep: active and quiet. Short periods of quiet sleep are broken up, roughly every hour, by minute-long bursts of activity – signaling a transition into the active stage. In the active stage, the arms and eyes of an octopus twitch, their skin changes colors, and their breathing rate increases. Researchers from the Okinawa Institute of Science and Technology and the University of Washington have found that the neural patterns and skin coloration during the active period of sleep in octopuses closely resemble those observed when they are awake and responding to stimuli. This is analogous to human brain wave activity during Rapid Eye Movement (REM) sleep and wakefulness.The changing of skin color could be due to a variety of reasons: practicing camouflage for when they're awake, simply maintaining the pigmented cells, reliving past experiences, and more. It's also entirely possible that the changes in skin color mean they're doing something very similar to dreaming – the color is a "verbal report" of what they're potentially dreaming (Ellenby). If they are in fact dreaming, however, it's unlikely that their dream structure is similar to the human one – with plots and characters and general storytelling characteristics. Due to the brief period of time in which octopuses are in the active stage, it's more probable that their dreams are small blips, comparable to a gif (Gamillo). The ability for octopuses to transition in between the active, wake-like stage and the quiet stage is incredibly significant, as the only other animals who are commonly known to have two stages of sleep are vertebrates. The fact that octopuses, while so distinct from humans, have developed multiple sleep stages suggests that possessing an active stage in the first place could be a characteristic of complex cognition (Ellenby).

In an experiment to test the qualities of their active sleep, scientists interrupted an octopus during their active phase and prevented them from entering it. In both, the octopus would enter active sleep sooner and more frequently as a result. This compensatory behavior indicates that the active sleep stage is vital for octopuses to function. Scientists also found specific brain waves that closely resemble certain brain waves that can be found in mammals during non-REM sleep. The brain waves they found are called sleep spindles, and although it's not exactly known what they do, it's hypothesized that in humans they help with consolidating memories. In the octopus, sleep spindles were most commonly found in areas of the brain associated with learning and memory, meaning it's likely that they serve a similar function to that in humans (Ellenby).

REPRODUCTION

Reproduction in octopuses is incredibly peculiar. Firstly, it's been hypothesized that males use their coloring to signal their intentions to females, both prompting them to mate and preventing their cannibalistic tendencies. Both the female and male octopuses are "pre-programmed to die" (Klein) after mating – chemicals are released in their optic glands that

prevents them from feeling hunger, and leads to starvation, and ultimately death (Klein). However, the female often lives until the eggs are hatched (whereas the male can die at any point) due to her role as the protector; she blows a constant current of water over the eggs to keep them clean, brush away any bacteria or microscopic predators (Horton), and to keep them oxygenated (Hana). For these reasons, the octopus mating ritual is more so to produce offspring than to create a sense of family (Horton).

ARMS

Octopus arms are very peculiar, and the term is often used interchangeably with octopus tentacles, despite the two not being the same. Octopus arms are limbs covered with suction cups from the beginning to the end, while the tentacle only has suction on the end, and is usually wider as well. More importantly, octopus arms all have their own brain, meaning they can be operated locally or with the central brain (Benningfield).

Each sucker on an octopus arm can have as many as 10,000 neurons, all of which help with not only touch but taste as well. In terms of taste, octopus suckers have specialized cells that allow them to detect chemicals produced by certain aquatic creatures (Lambert). Not only can octopus arms help them understand more about their environment, but they're also extremely pliable. There are four main ways to categorize movements: bending, torsion, elongation, or shortening. Bending is the most common in octopuses, and the animals have a "theoretically unlimited range of movement along the entire length" of their arm due to the wide variety of movements they can make (Kennedy). However, despite the continuous changing of their shape, octopus arms still have a constant volume due to "densely arranged incompressible muscle tissues" that help them maintain it (Kennedy). Further, even after being surgically removed, octopus arms can still perform basic functions like grasping and reaching (Birch).

DISCUSSION & CONCLUSION

CONNECTION TO CONSCIOUSNESS

INTELLIGENCE

The mirror self-recognition (MSR) test is a widely-accepted potential indicator of consciousness. The test consists of placing a mark on an animal, putting them in front of a mirror, and then watching to see how they react to the mark – do they recognize themselves enough to notice that the mark is not a part of their physical appearance? In multiple studies led by Piero Amodio, octopuses tended to explore the mark with their arms. Additionally, seven out of eight octopuses actually attempted to remove the mark (Amodio and Fiorito). Further, octopuses also display consciousness through their ability to utilize both visual and tactile information to perceive objects and their surroundings (Kawashima). These demonstrations of octopus behaviors ultimately point towards high levels of intelligence, and thus a sense of consciousness.

CAMOUFLAGE

The ability of octopuses to intentionally or unintentionally control the color of their cells to blend into their surroundings suggests attributes of a conscious being. Even more so, using basic chemoreception requires an octopus to have an understanding of their environment –

meaning they're able to perceive and understand their surroundings to some extent. More complex forms of crypsis, or disguise, signal an even higher understanding of not only one's environment, but also self-awareness. Although scientists don't fully understand how the brain is able to send signals dictating when and where to change the colors of certain cells, the ability to do it all indicates some higher form of consciousness (Carls-Diamante).

SLEEP

Being able to sleep in it of itself is an indicator of higher consciousness – falling asleep is the process of changing from high to lower levels of consciousness, a sign that an organism can maintain higher levels of consciousness (Carls-Diamante). Further, the ability to dream in octopuses displays an even higher level of consciousness, even if they are just short gif-like moments, it's possible they're remembering past memories, consolidating information, imaging future scenarios, or even potentially lucid dreaming. The functional aspects of dreams in regard to one's survival skills are numerous, so even if octopuses aren't conscious of the fact that they're dreaming, it still points towards a higher level of consciousness.

REPRODUCTION

The reproductive behaviors of octopuses are a key distinction from humans, highlighting their fundamental nature as animals.Their animal instinct prompts them to ensure the continuity of their lineage, thus reproducing early on in comparison to the rest of their lifespans. This trait doesn't necessarily point to consciousness, but it also doesn't concretely point away from consciousness. Ultimately, there needs to be more studies around reproductive behaviors in octopuses to be able to fully determine if it's a conscious decision to reproduce early, and whether or not that characteristic connects to a higher level of consciousness.

ARMS

Octopus arms are incredibly unique – unlike any body part on any other organism. There's a large gap of knowledge in terms of the full extent of their use; scientists know that they're used to help with tasting and touching, but, as neurologist and specialist in octopuses Tamar Gutnick said, "knowing it and understanding how it's actually working is a very different thing," (Lambert). Additionally, similar to how it's "like" something to be another animal – monkey, butterfly, even octopus – there also exists the potential for it to be "like" something to be an octopus arm, seeing as they each have a sort of individual brain and autonomy (Carls-Diamante).

Even more so, octopuses have displayed the ability to regenerate parts of their nervous system that connect their arms to the centralized brain. In an experiment in Italy, scientists found that if a pallial nerve (connects the centralized brain to the ganglia) was cut, it repaired itself within five months. The pallial nerves are a cornerstone of an octopus' lifestyle – they allow for communication, aid in camouflage, and control their respiratory muscles in the mantle, or a sac-like muscle behind the eyes that contains the internal organs (Yandulskaya).

WHAT DOES THIS MEAN FOR OUR FUTURE

OCTOPUS FARMING

Octopuses have the ability to feel pain through their somatosensory system, which receives sensory input and stimulus from the surface of the body. Somatosensory processing occurs due to the presence of receptors for temperature, pressure, touch, chemicals, poison, and more. Although pain is multidimensional, and scientists have no current way of measuring the scale of which any animal experiences it, it's still important to avoid triggering it – and to treat it whenever possible. Although different pains have been known to activate different areas of the nervous system, all pain interrupts other stimuli, and the higher the intensity, the more difficult it is to ignore (Le Neindre et al).

The fact that octopuses feel pain complicates modern industries. Octopus farming, the process of breeding octopuses to harvest them, is currently expanding and becoming more popular. The Canary Islands is home to the world's first octopus farm – with the plan of raising roughly 1 million octopuses annually. Not only will this be a challenging task due to the fact that larvae only eat live food, but octopus farming is a newer industry, and scientists predict it will be cruel for their lifestyle. Studies have shown that the "ice slurry" method of slow death used in aquatic animal farming can be incredibly stressful and therefore result in poor animal welfare (Marshall), making the entire process unethical – especially when coupled with the knowledge that octopuses can, in fact, feel pain. Many feel that "it would be an environmental disaster to farm octopuses," (Longnecker) as the waste created as a result of octopus farming can then pollute nearby ecosystems and underwater communities (Longnecker). Specifically, the nitrogen and phosphorus waste creates algae blooms, which then create dead areas with low oxygen levels, and ultimately disrupt local ecosystems (Food Empowerment Project). In fact, lawmakers in Washington, US, have already begun discussions for banning octopus farming (Marshall).

POSSIBLE INSIGHTS INTO HUMAN BIOLOGY

Octopus anatomy has the potential to be incredibly insightful into the anatomy biology of other organisms. The notion of a center brain, as well as the brain network split between the arms can give scientists an understanding of an alternate form of intelligence and problem-solving. It wouldn't be easy to implement octopus problem-solving strategies into human lifestyles, seeing as humans have only two arms, but it's still an opportunity to learn more. Furthermore, the behavioral adaptations (camouflage) that octopuses have mastered have the potential to further explain the evolution of intelligence, especially in complex environments). Even an octopus' ability to regenerate limbs can be insightful – creating potential for human healing processes and generally a better grasp for regenerative medicine. This is speculative and not directly applicable to humans, but understanding the molecular pathways octopuses use to regenerate could help scientists better understand a possible translation into human anatomy.

Bibliography

Ahvenharju, Sanna, et al. “The Five Dimensions of Futurs Consciousness.” *ScienceDirect*, Dec. 2018, www.sciencedirect.com/science/article/abs/pii/S0016328717301611#:~:text=The%20analysis%20is%20grounded%20in,systems%20perception%2C%20and%20ethical%20perspective.

Amodio, Piero, et al. “Grow Smart and Die Young: Why Did Cephalopods Evolve Intelligence?” *Trends in Ecology & Evolution*, vol. 34, no. 1, Jan. 2019, pp. 45–56, https://doi.org/10.1016/j.tree.2018.10.010.

Amodio, Piero, and Graziano Fiorito. “A Preliminary Attempt to Investigate Mirror Self-Recognition in Octopus Vulgaris.” *Frontiers in Psychology*, 29 Aug. 2022, www.frontiersin.org/journals/physiology/articles/10.3389/fphys.2022.951808/full#h4.

Benningfield, Damond. “Arms vs. Tentacles | Science and the Sea.” *Www.scienceandthesea.org*, 13 Aug. 2023, www.scienceandthesea.org/program/arms-vs-tentacles.

Birch, Jonathan, et al. “Dimensions of Animal Consciousness.” *Trends in Cognitive Sciences*, vol. 24, no. 10, Oct. 2020, pp. 789–801, https://doi.org/10.1016/j.tics.2020.07.007.

Carls-Diamante, Sidney. “Where Is It Like to Be an Octopus?” *Frontiers in Systems Neuroscience*, vol. 16, Mar. 2022, https://doi.org/10.3389/fnsys.2022.840022.

Cecconi, Benedetta, et al. “Can Human Neurological Tests of Consciousness Be Applied to Octopus?” *Animal Sentience*, vol. 4, no. 26, Jan. 2020, https://doi.org/10.51291/2377-7478.1667.

Dennett, Daniel. “Review of Other Minds: The Octopus, the Sea and the Deep Origins of Consciousness.” *Biology & Philosophy*, vol. 34, no. 1, Dec. 2018, https://doi.org/10.1007/s10539-018-9650-2.

Ellenby, Dani. “Octopus Sleep Is Surprisingly Similar to Humans and Contains a Wake-like Stage.” *Okinawa Institute of Science and Technology OIST*, 28 June 2023, www.oist.jp/news-center/news/2023/6/29/octopus-sleep-surprisingly-similar-humans-and-contains-wake-stage#:~:text=Like%20humans%2C%20octopuses%20transition%20between.

Food Empowerment Project. “The Ethical and Environmental Impacts of Octopus Farming - Food Empowerment Project.” *Food Empowerment Project*, 2021, foodispower.org/animals-of-the-sea/the-ethical-and-environmental-impacts-of-octopus-farming/.

Gamillo, Elizabeth. “Like Humans and Mammals, Octopuses May Have Two Stages of Sleep.” *Smithsonian Magazine*, Smithsonian Magazine, 26 Mar. 2021, www.smithsonianmag.com/smart-news/octopuses-have-two-stages-sleep-similar-mammals-180977353/.

Gilmore, Ryan. “Cephalopod Camouflage: Cells and Organs of the Skin | Learn Science at Scitable.” *Nature.com*, 2016, www.nature.com/scitable/topicpage/cephalopod-camouflage-cells-and-organs-of-the-144048968/.

Godfrey-Smith, Peter. “The Mind of an Octopus.” *Scientific American Mind*, vol. 28, no. 1, Dec. 2016, pp. 62–69,.

Hana. “How Does an Octopus Reproduce?” *Wild Wet Coast*, 10 Mar. 2012, wildwetcoast.wordpress.com/2012/03/10/how-does-an-octopus-reproduce/.

Horton, Jennifer. “How Octopuses Work.” *HowStuffWorks*, 13 Mar. 2008, animals.howstuffworks.com/marine-life/octopus5.htm.

Kawashima, Sumire, and Yuzuru Ikeda. “Evaluation of Visual and Tactile Perception by Plain-Body Octopus (Callistoctopus Aspilosomatis) of Prey-like Objects.” *BioOne Digital Library*, 17 Nov. 2021, doi.org/10.2108/zs210037.

Kennedy, E. B. Lane, et al. “Octopus Arms Exhibit Exceptional Flexibility.” *Scientific Reports*, vol. 10, no. 1, Nov. 2020, https://doi.org/10.1038/s41598-020-77873-7.

Klein, Corinne. “How Do Octopus Mate?” *OctoNation - the Largest Octopus Fan Club!*, 29 June 2022, octonation.com/how-do-octopus-mate/.

Lambert, Jonathan. “How Octopuses ‘Taste’ Things by Touching.” *Science News*, 29 Oct. 2020, www.sciencenews.org/article/octopus-taste-touch-arm-suckers.

Le Neindre, Pierre, et al. “Animal Consciousness.” *EFSA Supporting Publications*, vol. 14, no. 4, Apr. 2017, https://doi.org/10.2903/sp.efsa.2017.en-1196.

Longenecker, Madison. “The Incredible Intelligence of Octopuses.” *Ciwf.com*, Compassion USA, 23 Aug. 2024, www.ciwf.com/media-and-news/blog/2024/08/the-incredible-intelligence-of-octopuses.

Marshall, Claire. “World’s First Octopus Farm Proposals Alarm Scientists.” *BBC News*, 15 Mar. 2023, www.bbc.com/news/science-environment-64814781.

Mason, Adrienne, et al. *YouTube*, Hakai Magazine, 2 Feb. 2022, www.youtube.com/watch?v=mU64zgVrtNU.

Schnell, Alexandra K., et al. “How Intelligent Is a Cephalopod? Lessons from Comparative Cognition.” *Biological Reviews*, vol. 96, no. 1, Sept. 2020, https://doi.org/10.1111/brv.12651.

Yandulskaya, Anastasia. “No Nerves Lost: Octopuses Can Regenerate Their Nervous System.” *Oceanbites*, 19 Nov. 2019, oceanbites.org/no-nerves-lost-octopuses-can-regenerate-their-nervous-system/.