# Octopus Hypnosis: Non-Chemical Sedation in Studying Arm-Sucker Coordination

by

Ekaterina D. Gribkova[1,2]*, Jilai Cui[2], and Rhanor Gillette[2,3]

[1] Coordinated Science Laboratory, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA

[2] Neuroscience Program, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA

[3] Department of Molecular & Integrative Physiology, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA

*Corresponding author

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**ABSTRACT:**

Effective methods of anesthesia for octopuses are important for physiological studies as well as for their welfare in scientific research. Neurophysiological studies of octopus usually use general anesthesia for invasive procedures like electrode implantation. However, commonly used forms of general anesthesia using ethanol, magnesium chloride, and similar agents have certain drawbacks in levels of stress, recovery, and tissue viability in octopuses much as in humans. We explore an old, rarely used method of octopus "hypnosis", in which a still reaction is induced where communication between central and peripheral nervous systems is seemingly decreased. We modify the procedure for better handling, continuous respiration, and isolation of peripheral nervous system of the arm cords from the central nervous system (CNS), providing alternative to general anesthesia. Illustrative small studies of arm-sucker coordination and electrode placements are presented. The modified procedure limits negative side-effects, markedly reduces animals' stress levels, and offers new avenues for octopus neurobehavioral research.

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**INTRODUCTION:**

Effective methods of anesthesia are critical to physiological studies of octopus in scientific research as well as to their welfare. Anesthesia, defined as loss of sensation to the body, is indicated by lack of response to noxious stimuli as well as a state of neural depression [1,2]. Here we describe "octopus hypnosis", a still reaction induced by mild restraint in a mouth-side up position and involving significantly reduced stress and rapid recovery. As an anesthesia-like method, it allows minor invasive manipulations like electrode implants and prolonged measures of peripheral behavior in the arms and suckers.

**General Anesthesia**

Ethanol in sea water at 0.5% - 2% is commonly used general anesthesia for octopuses [3]. However, some potential drawbacks of ethanol anesthesia have been observed. In particular, ethanol anesthesia sometimes causes some stress. Even with slow introduction of the ethanol solution, animals may become noticeably agitated (increased ventilation, jetting water, and escape behavior)[4,5], and as anesthesia takes effect the octopus may ink. We have also noticed a recurring problem with experiments done during ethanol anesthesia: in several instances, an arm implanted with electrodes or isolated seems to show decreased spontaneous behavior and sensitivity after recent recovery from anesthesia. The arms of an octopus implanted with electrodes under ethanol anesthesia appear to show injury responses, including with less fine coordination in the implanted arms and significantly diminished muscular responses to arm stimuli , increased curling at arm tips, and tucking of the implanted arm beneath its web. This apparent increased injury response could be due to activation of sensitized nociceptive afferents in the arm following ethanol washout [3,6,7]. Further, arms amputated under ethanol anesthesia and moved to fresh seawater show severely diminished responses to sensory stimuli and even electrical stimulation, possibly due to summating effects of ethanol toxicity and amputation trauma.

Magnesium chloride solution ($MgCl_2$; 330 mM, closely iso-osmotic to sea water and the animals' blood, pH 8) is also commonly used for octopus general anesthesia and seems to lack some of the negative effects of ethanol anesthesia, such as active behavioral stress responses.

However, the divalent magnesium ion is sticky and typically takes longer to wash out from exposed tissues than ethanol, so recovery from general $MgCl_2$ anesthesia is quite slower. Moreover, recovery from both $MgCl_2$ and ethanol anesthesia can produce behavioral changes in the octopus. We find that typically, even after 15 minutes of post-recovery from ethanol anesthesia back in its home tank, the octopus rarely takes food when offered. For these reasons, both ethanol and $MgCl_2$ general anesthesia pose certain concerns for neurobehavioral studies of the intact or isolated octopus arm.

There is still debate on whether ethanol and $MgCl_2$ provide "true" general anesthesia in octopuses [2,8], particularly with regard to providing a reversible blockade of neural responses to noxious stimuli. Recent introduction of the volatile anesthetic isoflurane for octopuses, combined with pre-treatment with $MgCl_2$, allows rapid recovery from insentience [4,8,9]. Isoflurane is widely used for anesthesia in mammals and fish for the same reasons. With important and appropriate safety measures, isoflurane may prove to be markedly useful for experimental procedures requiring fuller immobilization, presumed block of suffering, relatively rapid recovery, and perhaps less hangover than ethanol. However, chemical sedation of any kind in most animals is generally trailed by anhedonic affect.

Here we introduce a modified procedure of octopus hypnosis that serves well as a potential alternative to general anesthesia for certain experiments not involving surgery on the central nervous system (CNS).

**Octopus Hypnosis**

Octopus "hypnosis" was first described by Vasily Danilewsky in 1890 in a description of handling-induced still responses in various animal species [10], and later reproduced by J. Ten Cate in 1928 [11]. In such responses in our hands, octopuses assume a calm, relatively stationary state, with largely only local responses to sensory stimuli or even local $MgCl_2$ injections. To our knowledge, this method has not been revisited until the present study. In the original studies, hypnosis was induced by holding the octopus out of water for an extended time, mouth-side up and making sure that the arm suckers did not come into contact with anything to receive stimulation [11]. We have modified the hypnosis procedure to minimize stress: instead of holding the octopus out of water, it is nearly fully immersed to maintain its respiration and we use a soft net or mesh-material to gently hold the animal mouth-side up close to the surface of the water.

Octopus hypnosis is not an actual general anesthesia, but in certain instances the procedure is preferable to ethanol and $MgCl_2$ anesthesia. Recovery from hypnosis is quicker and more complete, with the animal often taking food immediately after recovery, in contrast to ethanol anesthesia. Hypnosis also avoids the sluggish and aversive behavior often following ethanol anesthesia and may also prevent potential ethanol-induced, cytotoxic tissue damage. We find that hypnosis combined with local $MgCl_2$ injection is better than ethanol anesthesia for isolating arm nerve cord from the brain and electrode implantation. Ethanol seems to negatively affect the quality of electrophysiological activity as well as arm behavior. Moreover, the hypnosis procedure has so far never suppressed the animals' respiration, as sometimes happens with ethanol.

While octopus hypnosis can take more time and effort to induce than ethanol or $MgCl_2$ anesthesia and appears ineffective for senescent animals, we find that this method is often a

preferable alternative to the most common general anesthesia methods, that it has significant potential for promoting octopus welfare, and that it may facilitate novel neurobehavioral studies.

## METHODS AND RESULTS:

### Animals

Specimens of *Octopus rubescens* trapped in Monterey Bay, CA were obtained from Monterey Abalone Co. (Monterey, CA) and housed separately in artificial seawater (ASW) at 11-12°C. Specimens of *Octopus bimaculoides* were obtained from Chuck Winkler of Aquatic Research Consultants (Long Beach, CA), him, and housed separately in ASW at 18-22°C. 17 female octopus (2 *O. bimaculoides* and 15 *O. rubescens*, ranging from 4 to 200 grams) were used in these experiments. Animals were fed pieces of shrimp or squid flesh every 1-2 days. All experiments were carried out in accordance with protocol #23015 approved by the University of Illinois Urbana-Champaign (UIUC) Institutional Animal Care and Use Committee (IACUC).

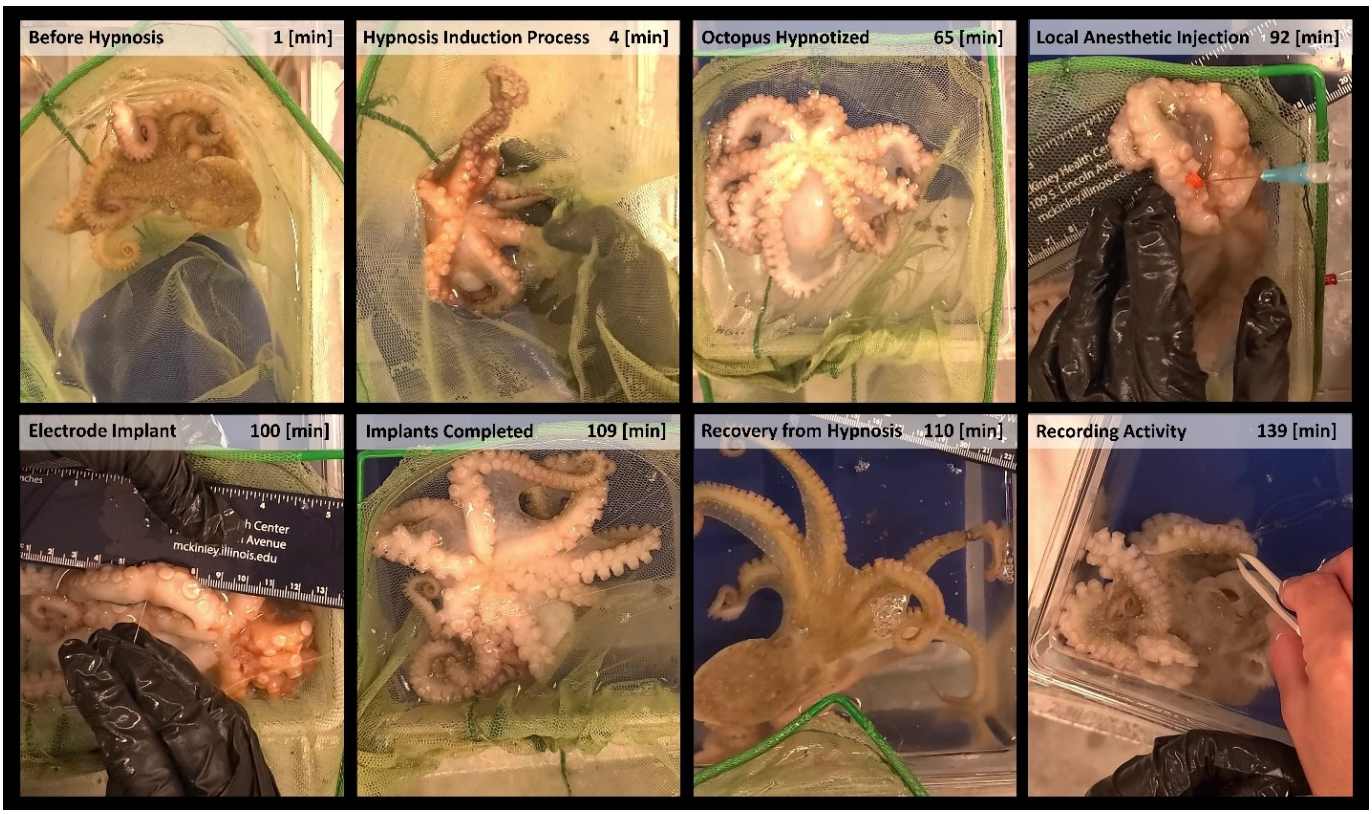


**Figure 1.** Still images from **Supplementary Video S1**, showing the octopus hypnosis procedure and electrode implantation in an *O. rubescens*: induction of hypnosis (t = 1 to 65 min), followed by local anesthesia with $MgCl_2$ injection (t = 92 min), electrode implantation (100-109 min), recovery from hypnosis (t = 109-110 min), and recording of neuromuscular activity from implanted electrodes (t = 110-139 min).

### Octopus Hypnosis Protocol

Our modified protocol for octopus hypnosis is demonstrated in **Supplementary Video S1** and is shown in **Figure 1**. The octopus is first placed in a large hand-net and/or soft mesh material (such as pantyhose) inside a container with aerated ASW maintained at appropriate temperature for the

species (11-13°C for *O. rubescens* and 16-22°C for *O. bimaculoides*). The octopus is gently turned mouth-side up and kept close to the surface of the water by adjusting the net mesh, ensuring that the head and mantle are always submerged and that the octopus breathes. Maintaining an optimal water level is critical, such that the submersion is sufficient for breathing but not enough to fully cover their arms or mouth. If, during hypnosis induction, the octopus attempts to right itself and move to the edge of the net, we gently move it back to the center of the net to maintain its mouth-side-up position by adjusting the net. This is repeated as needed. Typically, as the hypnosis induction process continues, the octopus stays still for longer times and attempts to right are less frequent. Positioning the octopus in a cradle-like manner, keeping the arms and suckers at or above the surface of the water and unattached to surfaces, covering their eyes, and generally limiting exposure to visual stimuli appears to help the hypnosis induction process. The hypnosis induction process is continued until the octopus remains mouth-side up with its arms and body still except for breathing for at least 5 minutes. Typically, for *O. rubescens*, this state is also accompanied by a marked reduction in pigmentation of the suckers and oral side of the arms. At this stage we define the hypnosis as successful if we can lightly touch and squeeze one of the octopus' arms and only observe local responses, such that only the stimulated arm moves without recruiting activity in the other arms and the animal shows no other changes in its behavior. Notably, the responses of a hypnotized octopus are markedly similar to those of a sleeping octopus.

**Local Anesthesia**

Hypnosis facilitates administration of local anesthetics, such as $MgCl_2$ injection in an arm. Local arm anesthetization was done by injecting the base of an octopus arm by the margin of the web with iso-osmotic 330 mM $MgCl_2$ solution with 10 mM HEPES buffer, pH = 7.6 [3]. This appears to temporarily disrupt communication between the octopus's arm peripheral nervous system (PNS) and its CNS. This has been tested in both hypnotized and awake animals by strong tactile stimulation of the injected arm without other recruited responses in other arms or the body. Successful anesthesia also commonly results in a blanching of the octopus arm distal to the injection site. Typically, $MgCl_2$ injection using thinner needles (30 ga), more precise depth control (aided with rubber stopper on needle) to target the arm central nerve cord, and relatively small volumes (0.1 ml for the arm sizes of the small animals we worked with here) yielded better arm anesthetization.

**Use of Octopus Hypnosis in Broader Experiments**

***Sucker Stimulation in Hypnotized Octopus***

A marked advantage of octopus hypnosis in behavioral studies is that local responses of the arms are preserved, unlike for general anesthesia. In a successful hypnosis the octopus is quite still in its mouth-side-up position with suckers easily accessible and where moderate tactile stimulation produces only local arm responses that have little or no effect on all other arms or the octopus' body. Thus, octopus hypnosis is particularly suitable for characterizing local responses in the arm, as seen in our experiments with sucker orienting responses.

Following hypnosis induction, sensory stimulation of suckers was done in locally anesthetized and non-anesthetized arms. A blunt-end syringe was used to precisely deliver chemotactile stimuli to octopus suckers, such as either an ASW jet or squid extract mixed with red food dye for tracking of chemical plumes. Plumes of squid extract seen to contact the arm and suckers at specific points elicited approach or avoidance responses in which the suckers extended towards or retracted away from the plume, recruited neighboring suckers, and even produced arm

retraction or reaching behaviors (**Fig. 2A, left**). While a similar range of behaviors was observed in both anesthetized and non-anesthetized arms, it remains to be explored whether there are differences in approach/avoidance behaviors dependent on CNS-PNS communication, internal appetitive state of the octopus in terms of hunger and stress, as well as in distal/proximal sucker stimulation. We expect the hypnosis procedure to facilitate further relevant experiments.

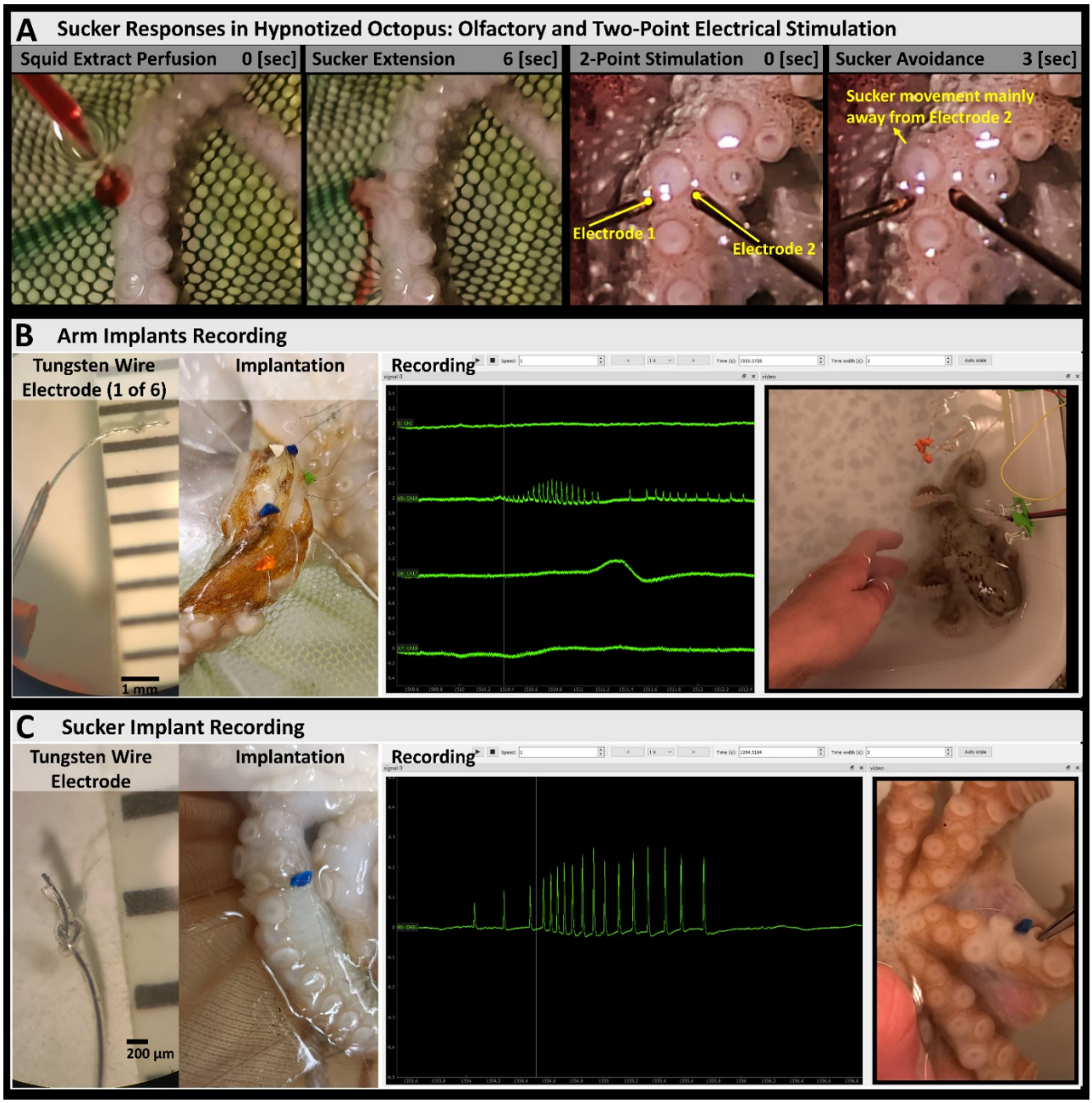


**Figure 2**. Application of octopus hypnosis in broader experiments. **A)** Hypnosis facilitated the testing of sucker responses to different stimuli. The left panels show a chemical stimulus (squid homogenate, with red food dye) being perfused primarily onto one sucker at t = 0 sec, followed by a precise (appetitive) extension of the sucker towards the chemical stimulus (t = 6 sec), with a few slight movements in neighboring suckers, and no noticeable responses in other arms. The right panels show two bipolar concentric electrodes positioned on the outer rim of a sucker (labels in yellow). A train of electrical pulses (at 10 Hz, each pulse 4 V and 1.5 ms duration) was delivered through both electrodes simultaneously starting at t = 0 sec and lasting for about 1.5 sec. This caused aversive movement of the sucker (t = 3 sec), primarily away from the rightmost electrode. **B)**

Octopus hypnosis was combined with local anesthesia ($MgCl_2$ injection) to implant tungsten wire electrodes in the octopus arm (insertion points labeled with colored rubber markers) and obtain electrophysiological recordings in a freely-moving octopus. **C)** Octopus hypnosis facilitated implantation of a tungsten wire electrode in an octopus sucker (insertion point labeled with a blue rubber markers), as well as for testing sucker electrophysiological responses with tactile stimulation.

Previously we and others have observed that responses in arms isolated by amputation rapidly decline, impeding tests of sucker responses to chemotactile stimulation. Therefore, we tested arms under hypnosis. $MgCl_2$ was injected under hypnosis in a proximal arm site to isolate it from the CNS. Keeping the octopus in a convenient position for extended time periods, we conducted experiments with one- and two-point stimulation with bipolar concentric electrodes and a Grass S-5 stimulator to deliver shocks (bipolar pulses of 1.5 ms duration, ranging 1-6 V in amplitude, in single-pulse regime or 10 Hz train of pulses ranging in duration from 0.5-3 sec) at one or two different sites on a single sucker's outer rim (**Fig. 2A, right**). A sucker responds to a single point stimulus (tactile, chemical, or electrical) on its outer rim with a very precise movement directly towards or away from the stimulus. It appeared to us that the sucker could estimate the bearing to a single point stimulus and use it to generate very accurate motor output for approach/avoidance. We tested arms in intact animals for two-point stimulation to see whether suckers might average the stimuli loci in their directional responses. While data are still being gathered, early results suggest suckers produce a winner-take-all response [12,13] to only one of the two loci stimulated simultaneously, rather than averaging the two response sites to move at an angle between them as has been observed in turn responses of the sea slug *Pleurobranchaea californica* [14,15]). These results are consistent with neuronal circuit architectures in the sucker like lateral inhibition [16,17] and are useful in modeling work. In future, we hope to elucidate the mechanisms behind sensory processing in the local circuitry of the sucker, as well as recruitment of neighboring suckers.

**Electrophysiology in Freely-Moving Octopuses.**

Tungsten wire electrodes were implanted into octopus arms to record electrical activity. Electrodes were PFA-coated tungsten wire (0.1 mm diameter, A-M Systems) with a terminal half-hitch knot to anchor in the tissue (**Fig. 2B-C**). For implantation (**Supplementary Video S1**, **Fig. 1**), after hypnosis chilled 330 mM $MgCl_2$ solution was injected at the base of the arm to disrupt arm-brain communication. The wire electrodes were carefully inserted into the tissue coaxially within a 30 ga needle (with an optional rubber stopper on the needle for additional control over implantation depth) [18-20]. Data were recorded with a headstage (Intan RHD 32-channel) and an acquisition board (Open Ephys) with a sampling rate of 20 kS/s and amplifier hardware bandwidth from 0.1 to 7600 Hz. Videos were recorded with a phone camera at 30 fps, and synchronized with electrophysiological recordings using a simultaneous visual and electrical signal: the flashing of a light-emitting diode (LED) coupled with a 5 V stimulator. Synchronized recordings were visualized and reviewed using the Python library ephyviewer [21,22] (ver. 1.5.1, Python ver. 3.9.7) , with the stand-alone viewer slightly modified to display both electrophysiological recordings and video. Modified code for viewing synchronized recordings and video is available at https://github.com/KatyaGribkova/ephyviewer.

The arm implant recordings showed spiking activity during arm movements in a freely moving octopus, while the implant by the sucker base (expected near the sucker ganglion) recorded the

most activity with inner-central tactile stimulation of the sucker (**Fig. 2B-C**). To our knowledge, this may be a first successful sucker electrode implantation and recording.

### Variability in Octopus Hypnosis Onset and Duration

There was appreciable variability in latency to hypnosis onset as well as hypnosis duration across the animals we worked with. We define “latency to hypnosis onset” as the time taken for the octopus to achieve an uninterrupted still state of at least 5 minutes, and with only local responses to stimuli as described earlier in the Octopus Hypnosis Protocol. "Hypnosis duration” is the length of time that the hypnosis was maintained in any particular experiment, whether spontaneously recovered or interrupted by the experimenter to test procedures (electrode implantation, sucker stimulation, etc.).

Multiple factors may affect latency of hypnosis onset, including octopus species, age, size, circadian rhythm, senescence, hunger, and other characteristics and dynamic internal states of the octopus. Notably, we approximated the masses of the octopuses used in hypnosis experiments, based on previous mass measurements and still images of the hypnosis procedures, and compared them against the latencies (**Fig. 3A**). There is a significant positive correlation between octopus mass and latency of hypnosis onset (Spearman’s rank correlation: $r_S = 0.600$, $p < 0.002$). This is explainable in a number of ways, including difficulty in handling larger octopuses as well as secondary factors that also correlate with size, like age and senescence.

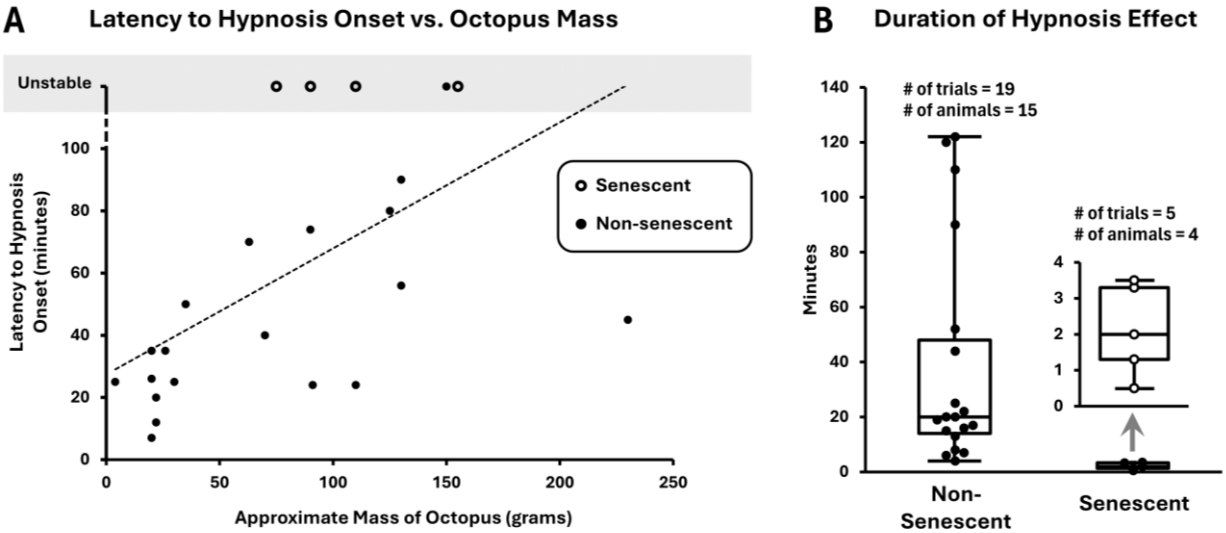


**Figure 3**. Exploring the variability of octopus hypnosis onset and duration. **A)** Latency to hypnosis onset has a strong positive correlation with approximate octopus mass (Spearman’s rank correlation: $r_S = 0.600$, $p = 0.00194$). **B)** While the number of observations for clearly senescent octopuses is presently small, hypnosis for these animals was quite unstable: still states were typically maintained for less than 5 minutes (mean 2.12 min, std. dev. 1.15) whereas in almost all non-senescent animals still states were maintained for at least 5 minutes (mean 38.4 min, std. dev. 39.4), and up to 2 hrs, with a significant difference (2-tailed Mann-Whitney U test: U = 1, z-score = 3.34, p = 0.00084). The inset shows a closer look at the box-and-whisker plot of hypnosis effect duration for senescent octopuses.

In particular, while our number of observations for clearly senescent octopuses [23-27] (1 *O. bimaculoides*, and 4 *O. rubescens*, all of which had stopped taking food after having laid eggs) was

small, we observed striking differences when attempting to induce hypnosis with these animals as compared to non-senescent animals (Mann-Whitney U test for duration of hypnosis effect: $U = 0$, $p < 0.001$). In 5 trials with these senescent octopuses, we were unable to maintain a still state for more than 5 minutes (**Fig. 3B**), even though most of our attempts lasted more than 2 hrs (**Fig. 3A, unstable**). Notably, in one of these animals, a large *O. rubescens*, when the octopus was not yet senescent, a still state was successfully maintained for at least 40 minutes in 3 different trials. But once this animal had laid eggs, turned senescent, and was no longer taking food, we were unable to maintain a still state for more than 4 minutes. In another curious case, we observed a female *O. rubescens* that had laid sterile eggs, but was not paying particular attention to them and was still taking food. At this stage, we were able to induce a stable still state with her after about 24 minutes, that lasted for at least 22 minutes. However, after about 17 days later, this octopus had stopped taking food, and we were then unable to induce hypnosis with her for more than 4 minutes, even though the attempt lasted for more than 2 hrs.

While senescent animals could be sufficiently calmed to conduct certain experiments, such as testing of sucker orienting responses, they seemed much more likely than non-senescent animals to respond to light arm touches or squeezes with more general responses involving recruitment of other arms. This may have been due to sensorimotor and neurobehavioral changes that occurred with onset of senescence in octopuses, particularly those associated with the care and guarding of octopus eggs [23,24,28]. The octopus optic gland plays an important role in regulating these reproductive behaviors, with removal of optic glands in senescent octopus often resulting in the animal taking food again and delaying senescence-related starvation [23,26,28]. In particular, we note the case of successful hypnosis with the *O. rubescens* that still took food after laying eggs, which was then followed by unsuccessful hypnosis attempts when this octopus had stopped taking food. This case raises some interesting questions about how optic gland signaling might affect octopus sensorimotor processing and behaviors during hypnosis induction, in addition to feeding behaviors, and how it affects the efficacy of the hypnosis procedure. Further, octopuses in decline also seem to lose their vestibulo-ocular reflex [28] that would normally orient their pupils horizontally with respect to gravity, which may also have an effect on hypnosis induction.

## CONCLUSIONS:

In summary, the still reaction induced by the hypnosis procedure as we describe it has distinct advantages over general anesthesia where strongly invasive surgical procedures are not necessary.

While general anesthesia with ethanol and $MgCl_2$ is often essential in octopus research, there are certain negative effects of these commonly used methods that can be avoided with octopus hypnosis. Notably, general anesthesia affects both CNS and PNS function and impedes testing of local sensorimotor responses. To our knowledge, our modification of octopus hypnosis (**Fig. 1**) may be the only reported method to sufficiently calm non-senescent octopus to test local sensorimotor responses. This induced still state appears similar to the tonic immobility seen in various other species [29], including sharks [30], though unlike some of these cases, octopus hypnosis does not seem to significantly suppress some of the local peripheral responses. With hypnosis, even without local anesthesia, there seems to be decreased communication between octopus CNS and PNS, such that lightly squeezing the arm of a sufficiently hypnotized octopus generally produces only local

responses, without responses in other arms or body. This effect facilitates administration of local anesthetic like injection of $MgCl_2$ solution, and since the octopus lays still in its mouth-side-up position, it offers a markedly convenient opportunity for testing local arm and sucker responses (**Fig. 2A**). Thus, isolation of the arm from the brain and the rest of the peripheral nervous system to test autonomous behavior may be easily gotten without amputation in hypnotized animals by local $MgCl_2$ injection. Further, the combination of local anesthesia and octopus hypnosis greatly facilitates implantation of electrodes for recording neuromuscular activity (**Fig. 1**, **Fig. 2B-C**). In our various experiments, we noted interesting variability in octopus hypnosis onset and duration, closely correlated with both octopus size and senescence (**Fig. 3**). Hypnosis may basically be ineffective for senescent animals; however, further testing is needed to explore this difference.

The modified octopus hypnosis procedure can therefore provide new opportunities to advance both octopus laboratory welfare and neurobehavioral studies. There yet remains much to be learned about the mechanisms that give rise to the still reaction, whether it might serve similar potential functions as the tonic immobility states observed in other species, and what particular neurophysiological effects it may induce in CNS-PNS communication. As the procedure involves holding the animals mouth-side up, the vestibular system might be involved. Whatever the mechanisms, if ways could be found to manipulate them directly it might further facilitate experiments to further unravel details of the complex brains and behaviors of these intriguing creatures.

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