Octopus mercatoris Response Behavior to Novel Objects in a Laboratory Setting: Evidence of Play and Tool Use Behavior?

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Abstract Tool use and play behavior are considered expressions of advanced cognitive abilities usually reserved for and extensively studied in vertebrates such as birds and primates. Advanced cognitive abilities are less well studied in invertebrates and are limited to a few model organisms such as the jumping spider, mantis shrimp, and octopus. In this study I investigate play and tool use behavior in *Octopus mercatoris,* a small pygmy species of octopus, that is relatively unknown in the scientific literature. When introduced to a novel stimulus, I hypothesized that *O. mercatoris* would respond to the unfamiliar objects and that these responses could be classified into play or tool use behavior. The two experiments conducted introduced Lego® blocks to the octopuses' environments and found that the octopuses did respond to the foreign objects but not in a manner that was suggestive of play behavior. After a few days of habituating to a novel Lego® block, one octopus showed a clear tendency to use the Lego® as a tool for a short duration. The preliminary findings of my research suggest that, due to their small size, short life expectancy, and propensity towards tool use, *O. mercatoris* has great potential as a model laboratory organism to study the diversity and evolution of advanced cognitive abilities in invertebrates.

Introduction

Animal cognition and animal behavior research have important implications for the evolution and development of behavior and personality in humans (Gosling 2001, Kuba *et al.* 2006). Cognition, as defined by Markl (1985) and used in behavioral research by Mather (1994), is "the ability to relate different unconnected pieces of information in new ways and to apply these results in an adaptive manner" (p. 164). Definitions, however, are widely contested in the fields of psychology and ethology and, it should be noted, different authors will use different cognition definitions in the parameters of their research (Mather 1995, Kuba *et al*. 2006). Studying behavioral responses of animals to novel stimuli and situations is an important step in understanding their cognitive ability (Kuba *et al.* 2006).

When presented with novel stimuli, all animals will respond in some way (Mather and Anderson 1999) and the range of these responses are referred to as neotic behavior (Corey 1978). Neotic behavior includes, but is not limited to, exploration, aggression, and orientation (Corey 1978), and can be further delineated and categorized as neophilic (explorative) or neophobic (cautious) behavior (Sabbatini *et al.* 2007). A neophilic response is one where an individual is quick to explore and extract information from the novel stimulus (Sabbatini *et al.* 2007). Neophobic, on the contrary, is a response that is hesitant and avoidant because the animal cannot determine its safety in relation to the change in environment (Sabbatini *et al.* 2007). Over time, habituation or the diminution of response to an object can occur with the continual or repeated presence of a stimulus (Mather and Anderson 1999). In a laboratory setting, neotic behavior has been well studied in vertebrates with assumed cognitive ability such as primates (Visalberghi *et al.* 2002, Day *et al.* 2003), rats (Mitchell 1976) and birds (Mettke-Hofmann *et al.* 2002) with social learning considered as an influence on an individual's response behavior.

Octopuses, on the contrary, are solitary invertebrates with little documentation of their response behavior but are considered an advanced invertebrates species because of their demonstrated learning abilities (Boal 1996, Hanlon and Messenger 1998, Nixon and Young 2003), complex nervous system including a central brain with areas associated with learning (Young 1971, Mather 1995) and complex personality behaviors (Anderson 2001, Sinn 2001). As advanced invertebrates, octopuses have varied responses to new objects and these responses will depend on the individual personalities (Mather and Anderson 1993, 1999). Personality is a highly debated term in psychological research but is used by Mather (1994, 1995) as the individual differences in behavioral responses, such as an animal's tendency to hide when other individuals of the same species would have a tendency to flee. As solitary individuals and invertebrates, octopuses are a stark contrast to the typical species studied for response behavior.

Reactions to various stimuli have been studied in many species of octopus such as *O. dofleini* (Mather and Anderson 1999), *O. bimaculoides* (Sinn *et al.* 2001), *O. rubescens* (Mather and Anderson 1993), and *O. vulgaris* (Kuba *et al.* 2006). Early research in octopus behavior characterized responses as an approach and avoidance dichotomy (Maldonado 1963, Mather 1995), whereas current studies suggest that responses can be characterized in three dimensions - activity, reactivity and avoidance - dependent on personality (Mather and Anderson 1993). Activity is any response eliciting interaction between the animal and the stimulus such as investigative exploration of a toy. Reactivity is any defensive reaction as a result of the new stimulus such as the arm going between the eyes and over the head of the octopus. Avoidance is any response where the octopus would retreat and hide from the stimulus. Analyses of these responses have resulted in conclusions about octopus in terms of personality traits (Mather and Anderson 1993), early temperamental traits (Sinn 2001), tool use (Mather 1994), and ability to play (Mather and Anderson 1999; Kuba *et al.* 2006). Personality traits can refer to the behavioral variation among individuals within species such as an individual's tendency to attack whereas other individuals may hide more frequently in response to a stimulus. Tool use behavior is displayed when an animal manipulates an object to help achieve a goal – for example primates using a stick to harvest termites from termite dens. Play behavior and exploratory play (Mather and Anderson 1999) is displayed when an octopus, for example, repeatedly shoots an object with a jet of water for no clear reason (Mather and Anderson 1999). Here play is defined as "activity having no immediate benefits and structurally including repetitive or exaggerated actions that may be out of sequence or disordered" (Burghardt 1998, Mather and Anderson 1999).

Understanding the existence of play behavior is important in understanding its evolutionary history (Kuba *et al.* 2006). Past studies by Mather (1999, 1998) and Kuba *et al.* (2006) have shown octopuses to have the cognitive and manipulative ability to display play behavior. Mather's (1999) study allowed *O. dofleini* to respond to floating empty pill bottles in eight individuals and Kuba *et al.'s* (2006) study analyzed the responses on fourteen *O. vulgaris* to two Lego® objects and two food items. Both studies found individuals displaying play behavior and highlight the two different evolutionary origins of play behavior - in vertebrates and mollusks (cephalopods) (Mather and Anderson 1999; Kuba *et al.* 2006). If this behavior can be determined in octopuses then it suggests the convergent evolution of the behavior in two different taxonomic lineages, mollusks and vertebrates, which are believed to have split 1.2 billion years ago (Wray *et al.* 1996, Kuba *et al.* 2006). The classic example of convergent evolution between these two taxonomic groups is the octopus (cephalopods) and vertebrate eye (Mather 1995). Although there are different functional uses, the structure of the cephalopod eye is very similar to the vertebrate eye with only one main difference; the cephalopod retina contains no rods or cones (Hanlon and Messenger 1998). Similarly, demonstrating the play behavior in octopuses provides another example of convergent evolution between vertebrates and mollusks, giving insight into evolutionary processes, and provides researchers with more clues to the phylogenetic origins of these behaviors (Kuba *et al.* 2006, Mather and Anderson 1993).

In addition to play behavior, studies by Mather (1994) have described octopus responses to objects and the use of objects as tools to manipulate habitat. Using Beck's (1980) definition of tool use,

> A manipulation of an object free of any fixed connection, outside the user's body and held or carried prior to manipulation; the user must establish proper orientation between it and the incentive, thus altering the form, position or condition of user, object or organism. (p. 3)

Mather (1994) found that octopuses choose shelters that may not be suitable, but modify these microhabitats to make the shelters more suitable as possible evidence for tool use behavior.

Although research is accumulating on particular species of octopus, studying the behaviors of non-model species will help in understanding how universal these behaviors are to the genus *Octopus*. All previous studies on octopus response to stimuli have focused on medium to large species (greater than 5 inches in length) and have ignored the smaller pygmy species of octopus such as the *Octopus mercatoris*. *O. mercatoris*, first described by Adam (1937) and later redefined by Forsythe (1991), is a relatively unknown organism as it has had a confused past with *O. jubilini* (Forsythe and Toll 1991). From my initial data, *O. mercatoris* can be raised from infancy to adulthood in a laboratory setting but suffers from high rates of infant and juvenile mortality. The care of the species, however, is not demanding and only requires a small space, daily change of water, and feeding. Its ability to be raised through its entire life cycle (approximately 1 year) with minimal care lends the possibility of *O. mercatoris* being a good study species as its entire life cycle and many generations can be studied in a relatively short time. In addition, as an octopus species, *O. mercatoris* could have increased value to researchers as an invertebrate species of higher intelligence compared to other invertebrate species, although quantitative studies of intelligence on this species of octopus are undocumented.

In order to better understand and expand the general and behavioral knowledge of *Octopus mercatoris*, this study documents the responses of *O. mercatoris* to novel stimuli in a laboratory setting to determine (1) if the octopus respond to novel stimuli and (2) if these responses can be categorized into behaviors of "play" or "tool" use. Based on the findings of studies by Mather and Anderson (1999) and Kuba *et al.* (2006), looking at *O. doleini* and *O. vulgaris* respectively, which found significant responses of the octopus to novel objects, I hypothesize that the *O.mercatoris* will demonstrate a detectable response to the novel stimuli. Play behavior studied by Mather and Anderson (1994) and Kuba *et al.* (2006) and tool use behavior studied by Mather (1994) all found results favoring the further study of these behaviors. Therefore, I further hypothesize that the *O. mercatoris* will manipulate the object (e.g. moving, squirting it with water, using it to block the entrance of its shell den) thereby providing evidence of play and tool use behavior.

Methods

To test how octopuses respond to novel objects in their environment, the responses of *Octopus mercatoris* were studied in two experiments in a controlled laboratory setting.

Subjects Subjects were five wild-caught adult male *Octopus mercatoris* from the Gulf of Mexico ranging in size from 50-100 grams and one laboratory raised adult male *O. mercatoris,* hatched from wild-caught *O. mercatoris* parents, with an approximate size of 2 grams. After arriving at the Caldwell Lab at UC Berkeley, the five wild-caught octopuses were acclimated to their new environment for a period of one week before the commencement of observations.

Environmental Conditions Each individual was housed separately in transparent containers of varying sizes each with a capacity of at least 250 mL with a lid that was always on except during water changing and feeding. These smaller containers were all housed in larger salt water tanks with filtration systems. Additionally, each small container had holes or slats so that water could flow freely into and out of the small tank. Feeding occurred at various times daily and the five wild-caught were octopuses fed grass shrimp (*Palaemonetes pugio*). The one laboratory raised octopus was fed brine shrimp (*Artemia spp.*), amphipods, and occasionally small pieces of grass shrimp due to its small size. During this study, individuals were fed 30 minutes after each day's study as food may be a source of motivation for object play (Hall 1998, Mather and Anderson 1999, and Kuba *et al.* 2006). Each individual used a snail shell, hollow rock or piece of PVC pipe as a den.

Materials Test objects were distinctly different from any objects previously encountered by octopuses to avoid habituation. To this extent, the object was chosen based on its shape, color, and utility – the possibility for it to be used as a barrier to the shell entrance. The first objects of choice were 1x1 Lego® blocks (approximate length 8.0mm, width 8.0mm, and height 9.6mm) either black or white because octopuses are colorblind but have shown the ability to discern light and dark objects (Messenger *et al.* 1973, Mather and Anderson 1999, Kuba *et al.* 2006) and these experimental conditions have previously been used to test for play behavior in the congener *O. vulgaris* (Kuba *et al*. 2006). For Experiment 2, 2x2 Lego® block plates (approximately length 16.0mm, width 16.0mm, and height 3.2mm), again either black or white, were used to test for tool use as it would be an appropriate size to block the entrance of a shell, rock, or PVC pipe.

Procedure Experiment 1 tests the responsiveness of the octopuses to the 1x1 black and 1x1 white Lego® blocks in two separate trials. In Trial 1, each octopus was observed with one of the Lego® blocks and the color of the Lego® was randomly assigned to ensure that confounding factors associated with the color of the objects eliciting a specific response from the octopus were eliminated. Each object was inserted into the octopus's individual tank with minimal disturbance and so that the octopus could see that object. Observations were then recorded for 30 minutes. Trial 2 observed the octopus's reactions to a Lego® of the opposite color in Trial 1 (example if Trial 1 used a black Lego®, Trial 2 would use a white Lego®). Responses were analyzed using one-sided t-test to determine if *O. mercatoris* respond to novel objects. Using the criteria set forth by Kuba *et al.* (2006) for levels of play behavior, the responses of *O. mercatoris* were then categorized to determine if these responses were examples of play behavior (Figure 1). Based on the criteria, responses indicative of play behavior in octopus are numerous passing of the object between arms, and towing the object for longer than 30 seconds, and pushing or pulling the object multiple times (Figure 1).

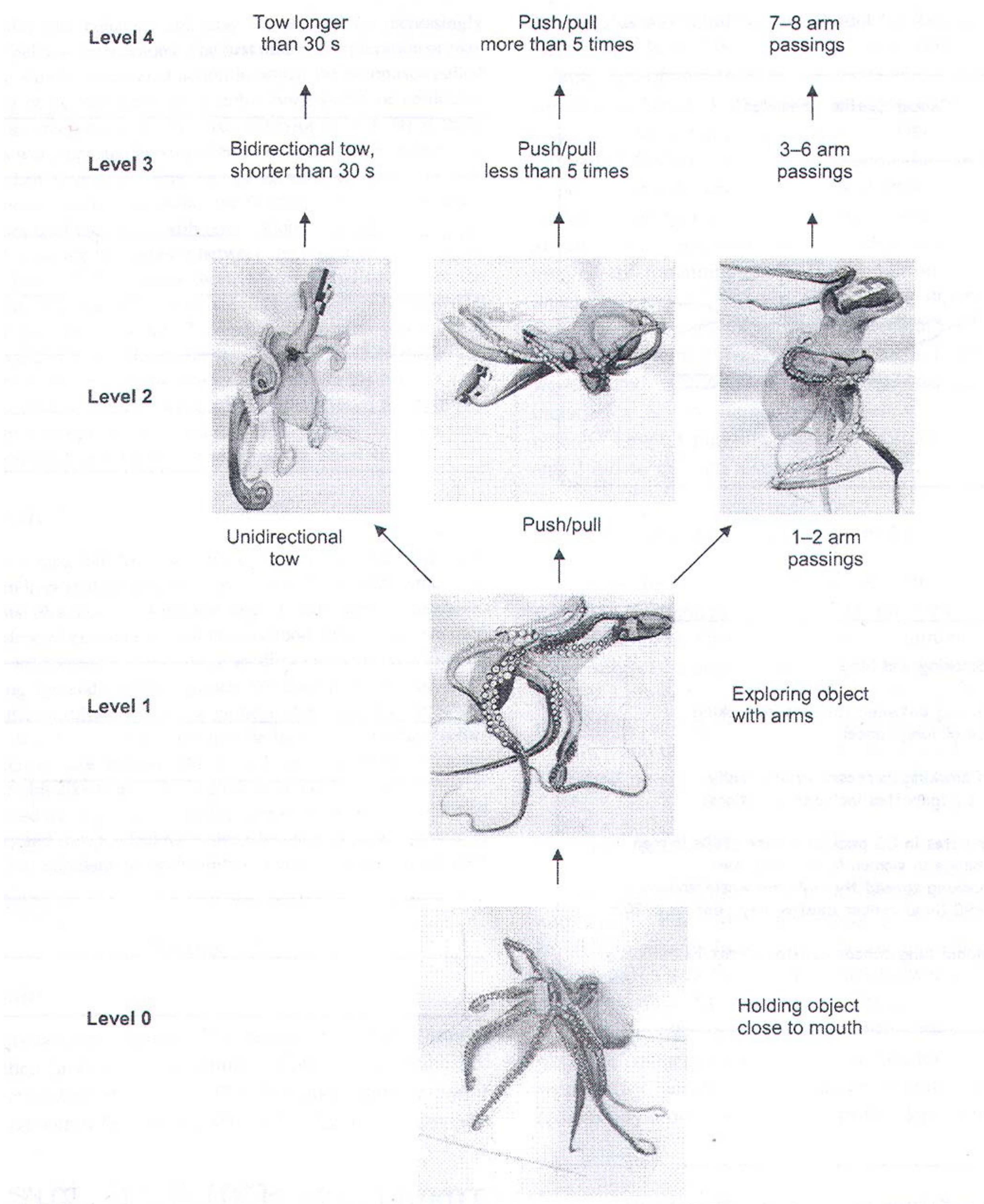

Figure 1. Kuba *et al.* (2006) Chart for 5 different levels of play behavior and exploration for *O. vulgaris*

In Experiment 2, I randomly assigned and placed a 2x2 black or white Lego® block in the octopus tank in a manner similar to Experiment 1. Observations of the octopus use of the Lego® started three days after the Lego® was first introduced and ended 4 weeks after the first observation was made. Observations were made four times a day in the morning (7 a.m. - 11 a.m.), midday (11 a.m. – 3 p.m.), early evening (3 p.m. – 7 p.m.) and night (7 p.m. – 11 p.m.) at arbitrary times during those intervals to prevent confounding factors such as peak activity times in observational sampling. If the octopus was covering any part of the den entrance with the object, it was documented as tool use behavior. Chi-squared analysis tested the use of the Lego® as tools where the expected values are the absence of tool use by the octopus. The new objects require the octopus to comprehend the block's utility and alter the orientation and location of the block to then use as a barrier to its den thereby clearly demonstrating tool use.

Results

Octopus mercatoris responses to novel stimuli were quantified by first observing the physical reactions of the octopuses to new objects introduced into their environment. The overall trend throughout the both trials showed that the *O. mercatoris* will respond to novel stimuli in some way (8.5 $\pm$ 2.3 responses, n=11) (t=3.8, df=10, p<0.01) [note: one octopus died between Trial 1 and Trial 2 resulting in n=11]. Generally, responses were observed within the first six minutes of the object's introduction (325.4 $\pm$ 162.4 seconds, n=9) and there was not a significant increase in the mean time of the second trial as compared to the first trial (t=-0.058, df=5.4, p=0.48) Response times and types of object interactions of the *O. mercatoris* to novel stimuli were observed (Table 1), but none of the responses were found in all or nearly all the octopus, rather each type of response was generally found in only a few individuals. Furthermore, the mean number of movements toward or away from the Lego® was recorded in this way since the observers could not distinguish the direction of the octopus movement.

Table 1. Observations in 6 individuals in 2 different trials.

	Trial 1	Trial 2	Totals for both Trials
Mean number of responses	8.3 $\pm$ 3.8 responses, n=6	8.4 $\pm$ 2.5 responses, n=5	8.5 $\pm$ 2.3 responses, n=11
Mean time until first response/contact (s)	313.8 $\pm$ 302.1s, n=4	334.8 $\pm$ 200.4s, n=5	325.4 $\pm$ 162.4 seconds, n=9 [note: three trials were omitted due to insufficient

			data]
Mean number of movements (toward or away from Lego®)	6.3 + 3.1 movements, n=6	7.2 + 2.4 movements, n=5	6.7 + 1.9 movements, n=11 [note: three octopus were observed to have no movement]
Number of tactile contacts (octopus touched the Lego®)	0	5	5
Occurrences of flashing colors	9	3	12
Occurrences of jetting water	3	3	6

Using Kuba *et al.* (2006) criteria for five levels and three modes of exploration and play (Figure 1), the observed octopus responses to the new stimuli were categorized to determine if any of the *O. mercatoris* could be displays of play behavior. Only one individual expressed Level 3 play-like behaviors and none of the octopus expressed Level 4 play behavior. In fact, only three octopuses ever touched a Lego® and on two of the occasions it was due to the Lego® block falling on top of the octopus.

Qualitative results Experiment 1 produced many interesting results that could not be described quantitatively. The most interesting results came when the Lego® brick dropped directly on top of an octopus. Initially, the octopus would try to move the Lego® brick away using its arms but after a few minutes it stopped its attempts and instead used the block as an additional barrier. Furthermore, in every situation where the brick fell onto the octopus, the octopus would not relinquish the block and the observers were forced to let the octopus keep the Lego®.

Additionally, during Experiment 1 the octopuses had a tendency to try and hide from the Lego® by moving further into its den or moving itself away from the Lego®. On one occasion, an octopus that was outside of its den used its tentacles to move a rock larger than itself across the tank. The rock had a large hole in its center which served as the octopus den and after moving the rock, the octopus then proceeded to retreat into the rock.

Experiment 2, conducted after Experiment 1, began with only three octopuses. Two were given a white Lego® brick and one was given a black Lego® brick. Within a week of introducing the white Lego® bricks to the tanks, the two octopuses died having never used the white brick to block the entrance of their den or manipulated the object in any other way. The one remaining octopus, however, did use the black Lego® brick to block the entrance of the den on all observed occasions except late at night. The octopus used the black Lego® brick consistently for 14 days and then spontaneously stopped using the Lego® and was never again observed using the Lego®. As there were only three individuals, two of which died during the experiment, no comprehensive statistical analysis were conducted.

Discussion

The results of this study suggest that the *Octopus mercatoris* do respond to novel stimuli introduced into their environment. However, these reactions and interactions cannot be classified in to play behavior. Responses observed were movements toward or away from the object, tactile contact with the object, skin color flashing, or water jetting. Responses were generally observed within six minutes of the object being placed in the octopus tank. Additionally, after a three day habituation period one octopus was observed exhibiting tool use behavior consistently over the course of two weeks suggesting that although a small species, *Octopus mercatoris* has a high cognitive capacity comparable to intelligent vertebrates. The habituation period proved appropriate since, as indicated in the first part of the experiment initial contact with the object was made within the first six minutes of the novel object's introduction.

Response to Novel Stimuli The octopuses demonstrated that movement toward or away from a newly introduced object is the likely response of this species upholding the hypothesis that a novel stimuli would elicit a physical response from the octopus. The results are in line with other studies that have categorized the responses of various octopus species including *O. rubescens* (Mather and Anderson 1993), *O. dofleini* (Mather and Anderson 1999), and *O. vulgaris* (Kuba *et al.* 2006). It is important to note, however, that these studies assumed that the octopuses would respond to the presented stimuli and so their experiments did not test if the octopus would respond, but rather how the octopus would respond.

The response data does not show a significant change between the responses recorded in Trial 1 and Trial 2. This is important to note because habituation, which has been found in other studies of other species of octopus such as the results of Mather and Anderson (1999) findings of habituation in *O. dofleini* to a novel object, is not clearly displayed here in *O. mercatoris*. This could have major implications in future studies and choosing this species of octopus over others as it will provide for better experimental design and results without having to constantly being introduced to new stimuli.

Play Behavior Although the octopuses did respond to the novel stimuli and occasionally touched the object, these responses cannot be considered evidence for play behavior using the criteria set forth by Kuba *et al.* (2006). Thus, my hypothesis that the responses to novel stimuli could be categorized as play behavior is not supported. The exhibited responses and behavior of *O. mercatoris* could not be classified into any of the categories of play behavior. There was only one instance where the octopus's interactions would fall into Level 3 play-like behavior when the octopus grabbed the Lego® block and towed it for approximately three seconds. This result is not consistent with the findings of Kuba *et al.* (2006) where nine out of fourteen *O. vulgaris* showed Level 3 and/or Level 4 play-like behavior. The lack of observed play behavior in this study could be a result of multiple factors such as observing the octopus and introducing the object at the wrong time of day when the octopus is least active or relatively inactive. Other possibilities include that the size, shape, and texture of the object did not engage the interest the octopus, the octopus felt confined or not comfortable enough to play, or that the octopus was aware of the observer and was threatened by their presence. An alternative explanation is that the *O. mercatoris* do not have high cognitive capacity because of their small size to exhibit such behaviors as play behavior.

Tool use Behavior Tool use behavior was exhibited by one of three *O. mercatoris* individuals when a Lego® block was introduced and left in the tank. The two other individuals did not use the white Lego® blocks placed in their tanks and soon died from unknown causes after the introduction of Lego®. Additionally, the octopus that did exhibit tool use behavior was the only octopus with a black Lego® block. As each of the octopuses had a white PVC pipe to serve as a den, perhaps the white Lego® was not used to block the entrance because it was merely an extension of the current den or perhaps the octopus could not make the distinction between the white Lego® and the white PVC pipe as separate entities. The octopus that used the black Lego® brick as entrance blocker used the Lego® consistently in this manner over the course of 14 days except when it was outside of its den. This agrees with the previous findings of Mather (1993) where *O. vulgaris* were shown to choose suitable dens and modify unsuitable ones by manipulating the objects around the dens. The *O. mercatoris* use of Lego® blocks to block the entrance to the dens also meets the criteria of "true" tool use in the literature that specifies the object must be detached from the substrate and directly held by the animal in the hand or mouth (Beck 1980, van Lawick Goodall 1970).

Tool-use behavior is important because it shows the cognitive ability of this species and has important implications to the evolutionary origins of intelligence (Mather 1993). Furthermore, octopuses have complex nervous systems different than other invertebrates which also provoke the question as to how such a nervous system evolved independently from vertebrates (Budelmann *et al.* 1997). If play behavior were present in this species, it too would have evolutionary significance as to how this behavior evolved independently in two taxonomic lineages that split over 1.2 million years ago (Wray *et al.* 1996, Kuba *et al.* 2006).

This study of *O. mercatoris* is not comprehensive as very few individuals were studied, but it does provide insight to the behavior of this rarely studied species. A larger sample of individuals would have provided a better representation of the behavior of this species and a more thorough study could have been conducted. Furthermore, in the responses of the *O. mercatoris*, there was no indication of play behavior among all the individuals which may be a product of the individual personalities of each octopus as suggested by Mather (1995). This may be a point of interest for future research or perhaps should be factored into future studies of octopus play behavior.

The expression of play behavior in this study may have been significantly influenced by the presence of the observer in plain sight of the octopus. The octopus may have felt threatened by the presence of the observer therefore less likely to engage in play behavior with the object. Future studies may explore the effects of an observer on the expressed behaviors of the octopus and possibly eliminate the effects of an observer by documenting the octopus behavior through video recording to ensure nonbiased results.

In summary, this study showed that *O. mercatoris* do react to novel stimuli and exhibit tool use behavior with the modification of their environments, whereas the data on the octopuses exhibition of play behavior was inconclusive. *O. mercatoris* are small and relatively unstudied but they have great potential as a laboratory study species and have proven that their behaviors are worth examining closely. With such uncertainty as to the true evolutionary origins of intelligence and various behaviors, scientists should conduct thorough examinations of a vast array of species, not just species that are common or have been studied previously. The scope of this project was limited but like the *O. mercatoris,* it showed that small things can prove to be interesting.

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