Doctoral Thesis

Cephalopod behavioral ecology as a comparative model in understanding visual communication

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ABSTRACT

In the course of evolution, human cultivated the ability to communicate using various methods with respect to the development of sensory organs detecting a certain range of gestural, audio, visual, and tactile information. Over the years, perhaps under cultural conditions, necessitate more specificity and accuracy of information transmission and exchange, these communication methods have further refined into more complex and mediated languages that contain both connotative and denotative information. Furthermore, in the recent years, rapid progress in digital technology has begun to reshape the relationship between physical and mediated reality. The language is now constructed of multi-layered logistical matrix that parallels the complexity of nature that is no longer consciously decipherable other than its facade. This indecipherable complexity of language brought increasing necessity to relay again on the more direct relationship with the physical reality by fully utilizing immediate physiological sensation as cognitive stimuli that governs ones thought and action. In light of this current condition and transition, this study focuses on cephalopod's behavioral ecology as a comparative model to investigate biological empiricism in a visual language shared between cephalopod and human.

Coleoid cephalopod (octopus, squid, and cuttlefish), has developed their unique languages governed by both environmental and biological factors in its' evolution affecting varieties of gene expressions. They have developed an ability to rapidly change their body pattern for both crypsis to avoid predation and for inter- and intraspecific communication. Cephalopod possesses a large brain relative to its body weight, complex nervous systems, and lens eyes. These physiological attributes allow them to control complex layers of neuro-controlled cells (chromatophores and iridophores) in their skin to change their appearances rapidly. This unique ability of cephalopod to process external input into a visually detectable output allows quantitative analysis of not only between the relationship of input and output and more impotently allows detection of their cognition.

This study is divided into four major parts. 1. Current state of cephalopod science and art, 2. Catalog of pharaoh cuttlefish, *Sepia pharaonis* body pattern and quantified analysis, 3. Comparative analysis of oval squid, Sepioteuthis lessoniana species complex's body pattern development. 4. Comparison and application of cuttlefish body pattern in understanding art and design. With these four parts, the study will demonstrate the preliminary analysis of cephalopod body pattern as a comparative model to understand the fundamental principle of visual communication.

CHAPTER1. General Introduction: The origin of visual language and cephalopod

1.1. Introduction

Body patterns play an essential role in predator/prey interactions, such as crypsis (Endler 1978) and disruption (Cott 1940) for many animals. They are also used for inter- and intraspecific communication such as agonistic or mating display. While most animals have unchangeable to slightly changeable body patterns (Cott 1940), coleoid cephalopods such as the octopus, squid, and cuttlefish can rapidly change their body colors and textures, exhibiting unrivaled speed, complexity, and variety of appearances. These appearances, for camouflage and communication, consist of a combination of chromatic, textural, postural and locomotor components (Hanlon and Messenger 1988; 1996; Moynihan 1985; Packard 1972; Packard and Hochberg 1977). Chromatic components are produced by neurally controlled ink filled organs called chromatophore (Messenger 2001), which are connected to a set of radial muscles that expand and contract the pigmented sac, changing its effective surface area (Hanlon 1982). Neurally controlled light reflective cells, iridophores, produce blue, green, and pink colors while leucophores produce white color (Messenger 2001; Wardill et al. 2012). In the case of octopuses and cuttlefishes, chromatic components are also enhanced by altering physical skin texture from smooth to three dimensional by controlling dermal muscles called Papillae (Holmes 1940; Packard and Hochberg 1977). Postural components are defined by positional orientation of flexible muscular arms, tentacles, mantle, head, and fins (Packard and Sanders 1971). Locomotor components are expression and movement of the entire body of the individual (Roper and Hochberg 1988). Each of these components can appear for seconds (acute) or hours (chronic) and can be displayed in wide varieties of combinations to create the total appearance of the animal (Packard and Hochberg 1977; Hanlon and Messenger 1996).

My discovery of the remarkable ability of the cephalopods to change body pattern helped me realize uncanny similarities between the process of layer painting, which fuses multiple independent layers of information into a singular and comprehensive pictorial plane and the structural and cognitive process of cephalopods' camouflage, which is also composed of multiple layers of chromatophores creating a singular whole by altering information provided by its environment. In short, cephalopods' camouflage parallels the process of painting and other image-making practices. Although the objectives for creating images are very different from each other—survival and reproduction for cephalopods and aesthetics and metaphysics for artists—the fundamental triple-step structure (exterior information, individual interpretation, and visual output) remains similar between them.

In the past ten years, I have conducted many types of body pattern experiments with pharaoh cuttlefish (*Sepia pharaonis*) as a study subject at the National Resource Center for Cephalopods in Galveston, Texas, the University of the Ryukyus in Okinawa, and at Okinawa Institute of Science and Technology Graduate University. In these experiments, I started replacing the sediment found in the natural habitat of the pharaoh cuttlefish, such as rocks, sand, and seaweed, with 20th century paintings, photographic documentation of 20th-century events, and short videos, in order to solicit its camouflage behavior. The cuttlefish responded to visual information from each image by interpreting visual attributes of the image into artificially triggered camouflage patterns, which were photographed and video recorded for further analysis. Furthermore, the data gathered from the analysis was used as the fundamental visual structure informing my creative works.

Through this project, I seek to revisit our cultural past through the eyes of a cuttlefish. Our raison d'être and vision of the future rely heavily on the reevaluation of the past, which relies, in turn, on the idea of the linear progress of time. The cultural past of humanity may have followed a much more complex, nonlinear path that intertwines diverse cultural differences with time. The behavioral ecology of cephalopods as an interpretive cultural model not only brings together two different academic fields as a hybrid model but also may present new and exciting insights into our cultural past. In these ways, this project attempts to present an alternative linguistic structure of the visual language that opens up future possibilities in art and humanity.

1.2. Method:

The method of this investigation has taken multiple avenues in the past ten years, which can be divided into two major categories; 1. Creative production comprised of conceiving, producing and exhibiting artworks and or related contents. 2. Scientific research on the behavioral ecology of cephalopod, which took place at both a laboratory and in the field. These two manifestations of investigation methods were usually conducted simultaneously to each other. In this way, both methods informed each other to optimize possible outputs from the knowledge gained. For instance, a photograph and video data gathered from given experiments were used for both scientific analyses and production of art. During the duration of this investigation, creative works were manifested as photographs, drawings, sculptures, and multimedia installations. The scientific work focused on body pattern behavior of the pharaoh cuttlefish, *Sepia pharaonis* and the bigfin reef squid, *Sepioteuthis lessoniana*. In this thesis, I will be arranging these two methods chronologically.

1.3. Structure of this thesis

The present thesis is focusing on various aspects of cephalopod behavior in both creative and scientific investigations. It will attempt to demonstrate the overlapping visual communication principals present in both human and cephalopod communication. This thesis is one of the first attempts for such investigation which required much foundation work including the state of current cephalopod science and art, production of body pattern catalog for future quantifiable analysis, comparative study of the body pattern development of the Oval squid species complex, and finally the attempt to compare the two visual communication systems. These aspects are divided into each respective chapters of the thesis.

Chapter 2 general overview of the current state of the art and the history of how the mechanical reproduction of images starting at the end of the 20th century has affected cultural production following such sample from Pop art and art of appropriation at the end of the 20th century. This chapter will also include a necessary conceptual foundation of this thesis by presenting early influences and thoughts.

Chapter 3 focuses on introducing cephalopod and its general characteristics, current trends in cephalopod science, especially on behavioral ecology and camouflage technology. This chapter will also cover particular representation and interest towards cephalopod in art and popular culture showing how the increasing scientific and popular interest in this heterogeneous class of animals have indeed prompted a high level of integration between scientific, artistic, and sub-popular culture.

Chapter 4 shows the current discourses of cephalopod visual communication. Unlike many other animals, cephalopod has a complex and flexible visual expression that, in most part, difficult to separate and, unlike camouflaging behavior. The chapter breaks communication into three basic behaviors and formulates current knowledge, respectively. Finally, it will also show the connection between the human visual communication system.

Chapter 5 a catalog of the chromatic, postural, and locomotor behaviors was produced for the pharaoh cuttlefish (*Sepia pharaonis*) from coastal waters of Okinawa Island, Japan. In total, 53 chromatic, four supplementary chromatic conditions, three textural, 11 postural, and nine locomotor components were identified and described in detail.

Chapter 6 presents a Comparative study of body pattern development of the oval squid, *Sepioteuthis lessoniana*. There are three different closely related species of oval squid in Okinawa. This chapter focus on the difference in developing their body pattern, indicating pattern synchronicity and diversity.

Chapter 7 focuses on the adaptive coloration of cephalopods' (squid, octopus, and cuttlefish) as comparative models that can code and re-map visual information such as paintings, photographs, and videos. The genetically and evolutionally pure empirical data of the squid and cuttlefish not only uncover certain essential information needed to understand the origin of visual communication.

Chapter 8 represents the overall conclusion of the present thesis.

CHAPTER2. Art

2.1. Creative practice and its conceptual foundation

My creative research focused on issues surrounding contemporary art. Art for me is at once representative models of reality and criticism of those models. I have lived in places all over the world, and have repeatedly faced the relativity of ideologies and ways of life. My experiences in Japan, Switzerland, Lebanon, and the United States have helped shape my need to investigate the multiplicity of truth, rather than to presume its stability. Any artwork necessarily contains a moment of representation, whether of an idea, an initial impulse, or an external object. However, the artwork is never transparent to this “meaning,” whose reconstitution in the art is always distorted. The artist’s function is not to gloss over the ambiguities and complications in this process of translation: instead, it is to intensify them, thereby creating a rich and multivalent object that necessitates the viewer’s active interpretation and engagement. In this way, the painting will possess the unexplainable quality of Nature and be able to exist as an individual, autonomous reality that transcends, although it may include, the painter’s ideology and his socio-political environment.

More specifically, my paintings have investigated in different ways the idea of superimposition, its implications and effects. My paintings have variously tested superimposition through three of its possible manifestations: abstract field over the figurative, tactile field over the figurative, and figurative over the figurative. Although these manifestations are seemingly dissimilar, they nonetheless are based upon the idea of superimposition as such: neutralization, fragmentation, and duration. Through these manifestations, I was not only able to investigate the relationship between my thematic and technical concerns, but also create a sense of multiplicity and complexity for each

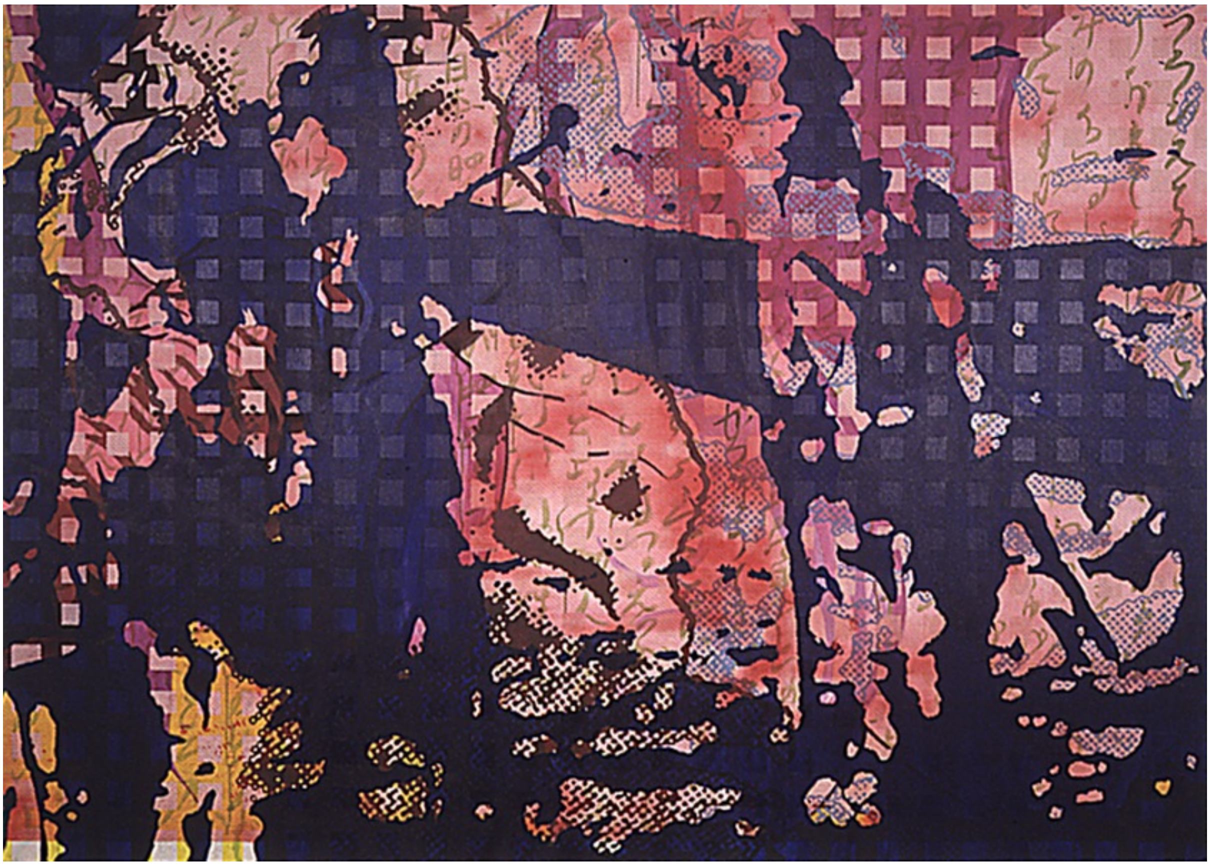


FIGURE 1. *Disappearance of the Flight 206* (1995) was painted as a part of 16 large scale painting set installation, which was first exhibited at the University of California San Diego Graduate Gallery.

individual painting and the painting installation as a whole. My understanding of superimposition gradually shifted away from the simple equation of superimposition to juxtaposition to the creation of heterotopia, a single autonomous space whose proliferation of possible meanings and relationships obscures any unifying ground, thereby dissolving each stable object into an incoherent multiplicity. In this hetorotopia, I seek to visualize a connection between post-structuralist of objectified and non-subjective linguistic model and the Buddhist understanding of the "Self" that pointed towards the existence of decentralized and non-hierarchical experience.

2.2. Contemporary Art and its discontent

In the past two decades, humanity has gone through a massive transformation through rapid development in digital technology. In developing countries, it has become increasingly difficult to conceive of one's life without its dependence on the technology from finances, social relationships, education, consumptions, etc. Art is also not exempt from this transformation. Art as a reflection of a given society in its most naïve sense transposes such change more faithfully than other activities. More specifically, with the advancement in reproduction and distribution of images, exponentially increased the level of exposure to both still and moving images. For instance, at a basic consumer level, there are more than 95 million photographs, and videos are uploaded to Instagram, 5 billion videos watched on YouTube, 300 million images uploaded on Facebook, on any given day of the year. Such level of exposure to the image production machine is exponentially more saturated than something that Walter Benjamin had in mind considering the relationship and function of art under the "age of mechanical reproduction." The aura of an art, which profoundly depends on the unique temporal and spatial experience of being, has dissipated for the public and replaced by a digitally reproducible surface texture and its permutations that carries easily digestible contents embedded with an idea, a fast food for the mind.

Furthermore, these images are recycled, repurposed and regurgitated over and over again without much consideration for their original context and intended meanings grounded in the physical world creating a purgatory of complex connotative alter reality within itself. This complexity only allows subconscious consumption of those images and their permutations of them. Such enormous exposure to mediated information through images profoundly reshaped one's sense of detectable and decipherable reality and formed nth degrees of simulacrum away from one's empirical experience and knowledge. In this way, art has also lost access to the grounded reality and forced to assume the stability of multi-layered Hyperreality, or at its best, criticism of such condition folded on to itself over and over again.

From the late 19th century, artists have been tracking this shift in social and technological paradigm. Georges Seurat's large-scale painting *Bathers at Asnières* show

FIGURE 2. Georges Seurat's large-scale painting *Bathers at Asnières* (1884) is depicting a leisure activities of French life during industrial evolution. Boys in the painting are wearing the same hat, and in the distance, factories can be seen. Collection of the National Gallery, London UK.

two young boys bathing. Both of them are wearing identical red hat. In the distance, a factory is painted. Seurat may have painted these two boys with the same red swimming cap for compositional purpose to create a rhythm with in the painting. At the same time, the relationship between the identical mass-produced objects shared between the boys and the factory across the water show contemporary social phenomenon during the industrial revolution well. Another early example of art and reproducible media can be seen from

Marcel Duchamp's work. Duchamp's readymades are carefully selected out of mass produced ordinary objects (bottle rack, stool and bicycle rack, etc.) of the time. These machine made objects with their sense of detachment from the idea of subjective involvement of a maker was an essential part of Duchamp's criticism against the need of craftsmanship in art. More than his readymade sculptures, his piece *L.H.O.O.Q* is a very early direct use of reproduced image in art. Duchamp just added a moustache and a text on a printed image of Leonardo Da Vinci's Mona Lisa defacing its achievement and making fun of the painting while creating a new context for it. In addition to this whimsical pan, L.H.O.O.Q represents relationship between art, its mass produced copy, and the receptor's mind through Dadaists' cynical and distant vision, which will later become dominant form art making during the 1960's American POP art movement by artists such as Robert Rauschenberg, James Rosenquist, Claes Oldenburg, Andy Warhol and more.

FIGURE 3. Mercel Ducham L.H.O.O.Q (1918) and Robert Rauchenberg's (1965) use appropriated images as ready made and found images. Although, these artists does not belong in the same historical nor social context, they share a conceptual foundation.

Pop art movement and subsequent Industrial realism movement may be the first true wave that fully embraced the development of mass media and mass consumer society. During the early developmental stage, Robert Rauschenberg was using the similar strategy as Duchamp's ready made. Rauschenberg's found images and objects were the product of mass consumer society which has, at this point, completely replaced most of the consumer products from hand crafted to factory made. Rauschenberg's assemblage paintings combined both screen-printing and had painted section implying the level of searching process of the balance between the modernist paradigms of process based physical engagement and reproducible and detached process of screen painting. In contrast to Rauschenberg, Andy Warhol proceeds to fully embrace the idea of mechanical reproduction as a mode of expression and criticism of the socioeconomically and political function of images. Warhol's iconic painting as *Campbell's Soup Cans* has very little traceable difference between the commercial products that one may purchase at a store to his painting that is made at his "factory." Among many other contributions, Pop art and Industrial realism have captured a moment in the history where mediation has overtaken one's empirical experience of the "real" putting the end to the quest of the modernity which seek the universal truth beyond, in western sense, Judeo-Christian mythology and metaphysics. Art at this point has become the "imitation of imitating."

2.3. Art in the age of digital technology

In 1990's, Art faced a new challenge. Rapid progress of computer technology started to transform production, distribution and reception of audiovisual information. Development of digital hardware such as digital camera with a new rewritable recording media and computer software such as Adobe Photoshop and Illustrator (2D image production), Media 100 and Abette (Nonlinear video editing platform), Protool and Qbase (sound editing) not only offered inexpensive production value, but also bridged the gap between a professional expertise and layman. A digital video camera allowed to film thousands of hours of high quality video at very little cost which can be edited and mixed on a desktop computer, and finally distributed and shared through internet at free of charge. This progress was not even imaginable for a film student in 1990 buying a Kodak reversal film for $20 that lasted less than 3 minutes of footage if everything went well during a shoot. Needless to state that this progress of digital technology has exponentially increased number of images including photographs, design, video, and other mediums in circulation, and it continues to increase to this day. A handheld device such as iPhone has a capability of all aspects of a complex video production, postproduction, distribution, and reception. With such device in hand, it inevitable increased over all image production, distribution and reception that profoundly transformed one's understanding of visual experience and knowledge. On the macro scale, urban landscape has become a projection screen that create multilayer experience and at micro scale, a handheld device send constant reminder of the existence of a virtual and distant reality into which one can jump at any point creating another parallel universe away from the physical experience.

Art and artists were not exempt from such drastic technological shift that altered socio-economical and political landscape. Before an artist draw, paint, film, and photograph a subject, he has already experienced thousands of its' mediated variation that it becomes impossible to penetrate to the core of its existence without being influenced by the mediation. In a scene from *Tokyo-ga* (1985) by Wim Wenders, a documentary filmmaker Werner Herzog expresses his concern of not being able to film anything that has not being filmed before. He states "It should all be simple so that there are only pure images. Looking around at all these buildings (referring to Tokyo landscape), it is impossible to see them just as solitary images. We'd have dig like an archeologist, to dig down… before we could find anything pure in this decaying landscape. So often, images are bound to something gigantic and words are never separated…. We need pure and absolute images." This statement ironically represents the condition of art in the digital era. Art is no longer an investigation and criticism of the complexity of the reality through producing a simple yet manageable exaggerated model of it. Instead it has become an assemblage of fragments carefully selected and packaged for another level of mediation that, at any given point, will be consumed under social context of art. In short, artists are no longer a creator but are DJ who samples and rearranges social context of art. In short, artists are no longer a creator but are DJs who sample prefabricated material and combine them to give a temporary meaning to its consumers.

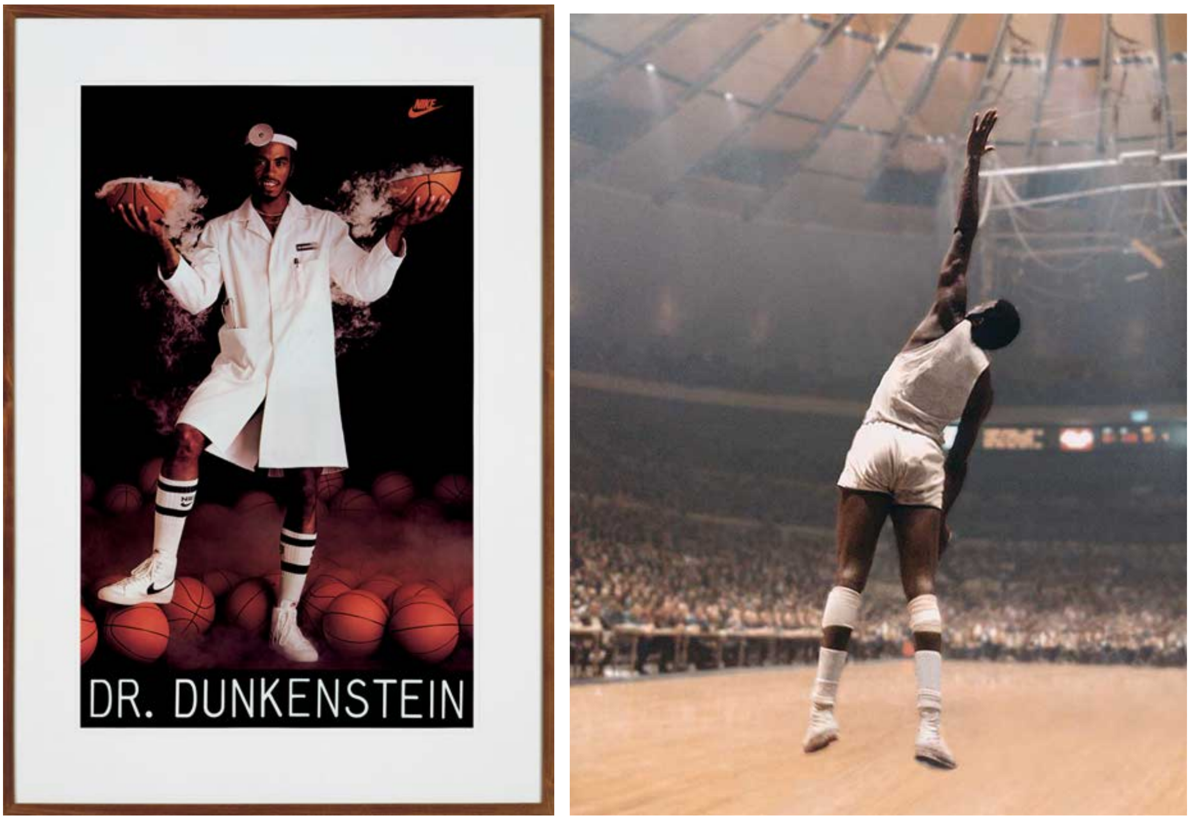


FIGURE. Jeff Koon's *Dr. Dunkenstein* (1985) is a framed Nike poster, and Paul Pfeiffer's *Four Horseman of the Apocalypse (6)*, (2001) is a digitally manipulated NBA poster. Both artists used purchased professional sport merchandize that anyone can purchase as a material for their work.

In light of these changes, it might be safe to say that the quest of modernity may have come to its' final phase in the form of post modernism. Many of the past victorious attempts to define "individualism" and "self" seem to have found the wall of linguistics structure and categorization as governing principals of human consciousness. Postmodernism tends to recycle façade of preexisting methods and theories, thereby creating fragmentation and dislocation. Simultaneously, the presence of computer technology is rapidly reshaping our visual culture by offering the potential for more streamlined production and distribution possibilities. Considering this current environment, it is essential to investigate the effect and implication of the visual culture, by asking such existential questions as Why do we make images, where do they come from and what is their primary function? Through these questions, I aspire to capture the birth of the "pure images" devoid of historical, cultural and personal contexts and meaning.

2.4. Art as a biological activity

Although such technological changes are altering our experience into multi-layered mediation, we remain as a biological machine with physiological characteristics that took millions of years to develop in the course of evolution. The sole purpose of human sensory organs is to navigate the world to avoid danger, to understand three-dimensional space, to find a suitable mate for reproduction, etc. within a specific habitat. Sensory organs are explicitly tuned to gather external information, which is then sent to the processor for expansive inventory matching. The processed information is then sent to the core of the brain for consolidation and simplification of the information. The conscious understanding formulated from this cognitive process finally sends the order to motor output, which connects with the external world. In this way, the perceivable reality is a carefully sampled version of it that suite only to aid human survival and reproduction by creating our self-world.

Production and reception of art depend greatly on this physiological and cognitive process. Art being a model to critically view both the receptive reality and the following cognitive process which translates incomprehensible fragments into an organized whole, is precisely the visualization of the processes that form a concrete and tangible entity giving access to the unknown. Furthermore, during evolution, human as well as many living organisms have accumulated audio, visual, and olfactory cues directly trigger behavioral and emotional responses to minimize any risks. Such cues are epigenetically produced and pass on to future generations regardless of cultural, historical, and personal contexts. Due to the accumulations of genetically driven cues inducing a physiological reaction, they also involuntarily affect one's response to the artwork. In this way, art is deeply governed by the biological principals ingrained in DNA; thus it exists in an extra temporal zone beyond individual experience.

2.5. Aby Warburg's incomplete project

FIGURE 5. Aby Warburg, detail of the *Mnemosyne Atlas*, (1924-29)

In the early 20th century, there was an attempt to map such non-linear cultural memory. Aby Warburg, art historian and founder of Warburg Institute, had a vision. Five years before his death in 1929, he launched a project the *Menemosyne Atlas* that was his attempt to visual map to represent “afterlife of antiquity. In this project consisting of 63 black panels depicting images ranging from ancient astronomy to 20th century, media images were lined up and organized in search for motif archetype that runs through the western history and memory. Warburg, after suffering from depressing and schizophrenia, attempts decode Western visual history by placing reoccurring permutations and variations of images from antiquity fond over a few thousand years. Although the true intention and interpretations of the relationship between individual images and panels of this project will remain uncertain, it suggests that art is the culmination of the universal visual principals that fundamentally governs both production and reception. This further implies that Art is not an act of liner progress nor a product of individual autonomy of thoughts and experience, rather it remains constant as a whole while revealing various permutation and fragments of the universal principals shared beyond cultural, socio-political and individual boundaries. This project influenced other similarly complex projects of artists like Gerhard Richter and Chris Marker. I feel that despite the current social condition of the digital revolution, this universality of visual principals remains valid governing the structure of all artistic and creative activities is allowing contextually independent and expansive empathic connection between individuals.

2.6. Transition

In 2008, when my daughters were watching a PBS documentary film “The King of Camouflage.” The film featured works by such leading experts on cephalopod behavior and cognition including Roger Hanlon, Jean Bowl, Jessie Purdy, and Mark Norman, focusing on cephalopod's ability to rapidly camouflage into its' environment. While watching squid, cuttlefish, and octopus performing wide varieties color, texture, and pattern matching displays, I realize that uncanny similarity with cephalopod's ability to produce a kind of representation of nature and how an artist creates images through various mediums. In both instances, visual information is filtered by a cognitive process and outputted as transformed visual information.

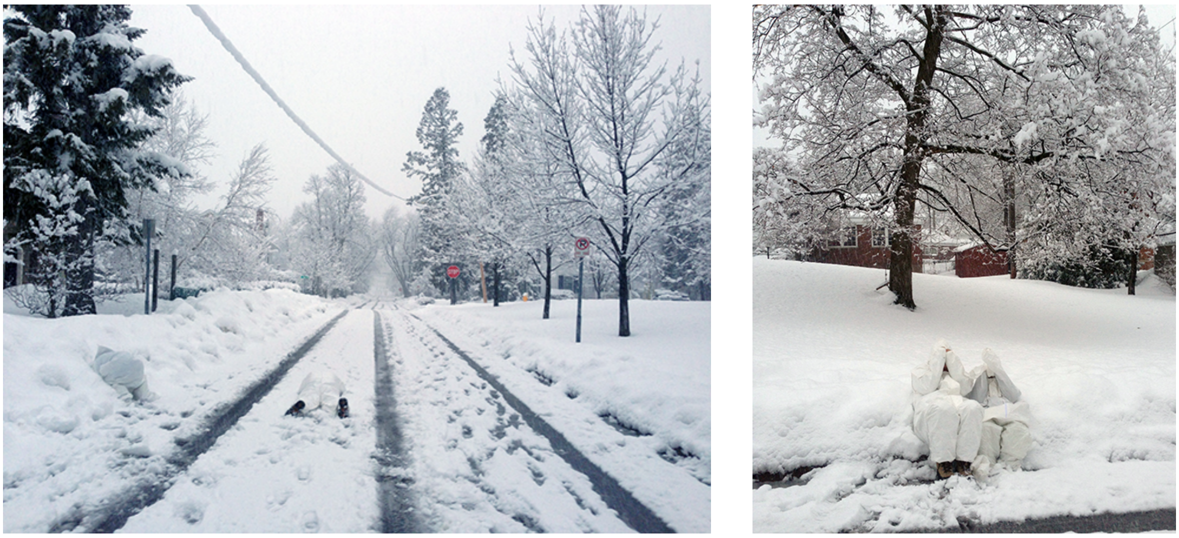


FIGURE 6. My daughter and I are experimenting with camouflage in front of our house in Duluth MN.

In addition to the PBS documentary, I was also influenced by Shinichi Nakazawa's *Philosophy of Squid*. This book introduces a short essay by Ichiro Hatano entitled Philosophy of Squid. Hatano was a Kamikaze pilot who was educated in the Japanese Imperialism during the WWII, communism from a forced labor camp of the Soviet Union, and American pragmatism at Stanford University completing exposure to the three dominant contemporary thoughts. In his short essay, he describes the time he worked at a squid cannery at Monterey Bay. There he comes to fundamental realization paralleling tones of freshly harvested California Market squid and that of millions of people died during the war. When he reached a particular epithetical relationship to the squids and its consciousness and being, he gained an insight into the idea of compassion expressed in Mahayana Buddhism. This non-hierarchical relationship with the all living being informed by squid paralleled with the PBS documentary for me. Hatano has presented a possibility to integrate biological phenomenon to philosophy and religion, and PBS presented an equally interdisciplinary vision of integrating the biological system and creative practices. In both instances, the keyword was “squid.” In some strange way, my previous interest in art, continental philosophy and science, for the first time, started to align together for the common goal in search for alternative visual communication system that is driven by only by biological necessity, thus pure that sat beneath the surface of the ocean. I needed to know more about cephalopod.

CHAPTER3. Cephalopod

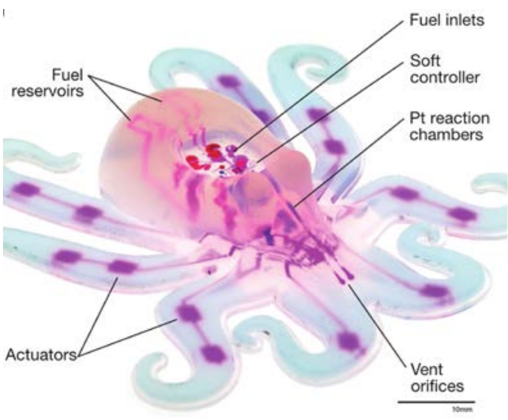
3.1. General Characteristics of cephalopod

Cephalopods are the molluscan class including octopus, squid, cuttlefish, and nautilus. There are over 800 species found in the oceans around the world ranging from shallow tropical water to deep sea at more than 5,000m (Hanlon and Messenger, 2018). Their body size can vary from mere 1 cm to over 18m in its total length and their brain to body mass ratio can be higher than that of some vertebrates (Packard, 1972). They can rapidly change their body pattern and shape to avoid predation and for inter, and intraspecific communication. Many can glow in the dark using bioluminescent ink to create their body double, cross-dress to deceive rivals during the mating season, move through the water column using jet Propulsion, etc. (Nixon and Young, 2003). The list of cephalopods' unique abilities and features continues on and on, not to mention that they also provide the essential protein source for many marine animals and humans alike (section Modern Cephalopod Science). Sperm whales are estimated to consume equal biomass of squid each year as the total annual catch of the world fishing industries (Vidal, 2014). Each one of these diverse abilities and attributes of cephalopods has fascinated people from diverse range of fields and disciplines for centuries.

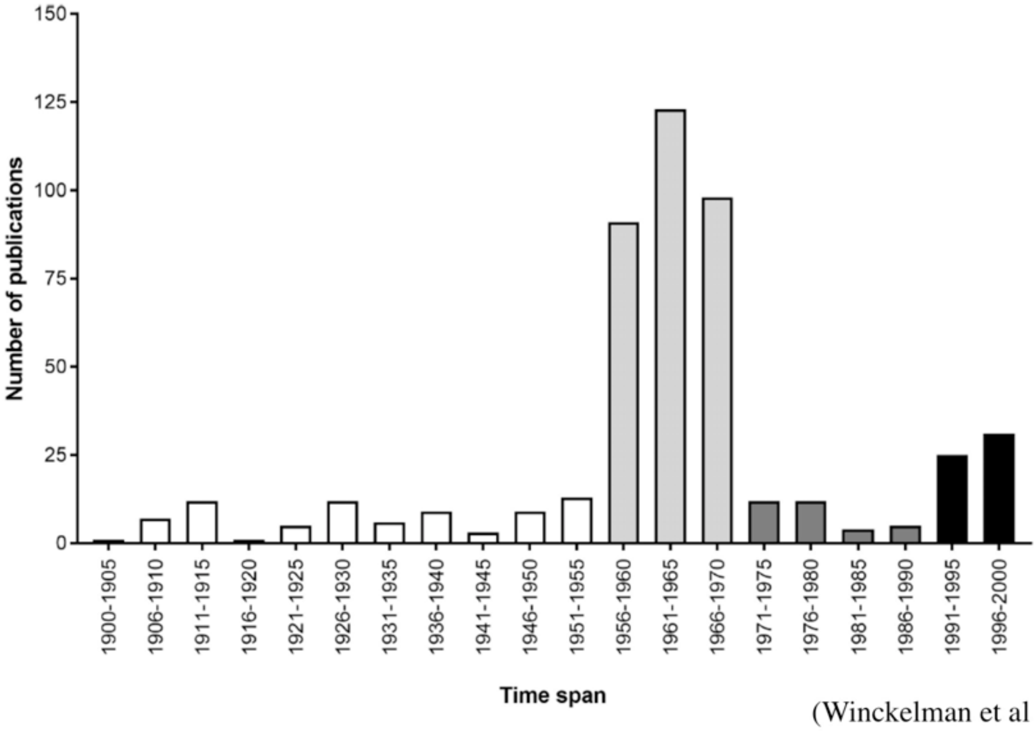
In recent years, with the help of social media and Internet providing access to specialized information and growing interest in interdisciplinary academic collaboration fields, there has been increasing attention to cephalopods not only as model animals but also as a boundary object/subject connecting fields together. Organization of art exhibitions in conjunction with scientific conferences, the establishment of side-by-side collaboration between cephalopod behavioral scientist and art schools and military departments on topics such as camouflage technology, sports fishermen and scuba divers working with scientists in a citizen science project are some good examples of such activities. Although these fields are still in their infancy of interdisciplinary collaboration, the slow but assertive new developments in cephalopod research and culture have certainly began to transform the traditional paradigm of the cephalopod research.

3.2. MODERN CEPHALOPOD SCIENCE

In the 1980's, cephalopod science took a big step. Cephalopods, which have rapid growth rates are abundant in the sea, were considered to be a vital source of protein to feed the including robotics, AI, neuroscience, behavior, and more (Fiorito et al., 2014). This meeting enlightened the multidimensionality of cephalopod research and provided a valuable platform to create a synergy of multiple fields. Among these, the most current and immediate frontier seems to lie in neuroscience, behavioral biology, and conservation. The rich and flexible behavioral repertoire supported by the well-developed brain, muscular structure, and circulatory systems drives and offers multivalent research opportunities to be explored. Since 2006, there are significant increase in cephalopod publications from such fields as behavior, cognition, climate change, welfare (Winckeman et al 2018).

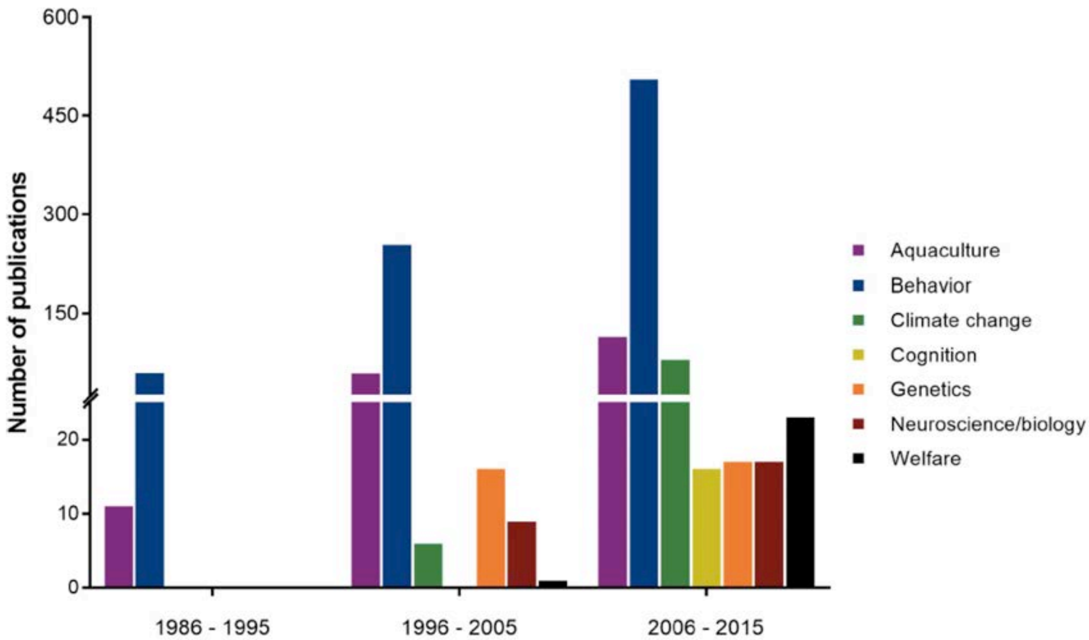


Total number of publications on cephalopods per quinquennium that appeared in a genus-name search of the Zoological Record during the 20th century



(Winckelman et al 2018)

The number of publications per decade between 1986 and 2015 as derived from a search on the Clarivate Web of Knowledge Core Collection (WoS)



(Winckelman et al 2018)

3.3. Behavioral Ecology and Biology

Beyond the traditional knowledge of cephalopod neuroscience and behaviors as summarized in Wells (1978), Mangold (1989), Abbott et al. (1995), Hanlon and Messenger (2018), and Borrelli et al. (2006), recent cephalopod behavioral studies continue to provide many interesting discoveries. Researchers have found new cues for cephalopod novelty or intelligent behaviors, including new body chromatophore coloration, light sensing skin, observational learning, human-like arm use, mimicking, developmental cognition, sociality, and possible tool use and play (Hochner et al., 2006; Zullo and Hochner, 2011; Darmaillacq et al., 2012; Mather and Dickel, 2017 for reviews). These behaviors are supported by a complex and well-developed sensory system that possibly integrates a variety of information coming from different sources such as visual system, motor system, etc. (Budelmann, 1995; Zullo et al., 2009; Hanke and Osorio, 2018).

Moreover, cephalopods are worldwide distributed animals and can occupy almost all kind of marine habitats, an aspect that is reflected in the incredible number and diversification of existent species. Given this ecosystem diversity, any researcher studying cephalopods can face a wide variety of problems connected to the animal collection and lifestyle along with having access to a number of different, and fascinating, scientific questions. As an example, exploring the behavioral ecology of deep sea species has long been challenging, but Kubodera and his team became the first to capture photos of the live giant squid, *Archteuthis dux* and to observe its active pre-capture behaviors (Kubodera and Mori, 2005). The mysterious vampire squid, *Vampyroteuthis infernalis* lives in extreme deep sea conditions and, unlike most cephalopods, it has been shown to have multiple reproductive cycles (Hoving et al., 2015). Furthermore, a deep sea *incirrate octopus sp*. has been shown to breed big eggs almost for 4 years, the longest in any known animal (Barratt et al., 2007; Robison et al., 2014). Another interesting aspect of mesopelagic and deep sea species that live across a broad range of depths 1,200m is their adaptability to aphotic (lightless) depths and a new strategy of visual adaptation has been recently revealed (Chung and Marshall, 2017).

FIGURE 7 | Sepia pharaonis camouflaging against a photograph of pebbles. A consistant mottled pattern across the entire body is matching well to the substrate image.

3.4. Camouflage Technology

Cephalopods have been a source of inspiration in the robotic field also for another important behavioral capability, their amazing capacity of modifying their appearance and their body pattern in response to a variety of different stimuli (Osorio, 2014; How et al., 2017). This aspect has drawn the attention of engineers and material scientists aiming at developing biomimetic artificial skin able not only to match its background but also to fast adapt to a changing environment, all this, without losing flexibility. Few interesting prototypes based on electroluminescent material have been developed taking inspiration from cephalopods skin. For example, researchers from Cornell University have recently produced a synthetic skin able to emit light while undergoing large stretching and surface area modifications. In the latest version, this stretchable surface has been provided with the ability to change “on demand” both color and texture thus transforming from 2D to 3D shape just like it happens in cephalopod skin following environmental stimuli or communication needs (Larson et al., 2016; Pikul et al., 2017).

Although these prototypes are remarkable in their ability to change their appearance they are still far from reaching an active cephalopod-like camouflage system. This should not surprise as camouflage is a feature of immense complexity and, despite many decades of investigation. Comprehension of the biology behind cephalopod visual-spatial perception and accustomization to the surrounding environment is still at its infancy. To make things simpler, recent investigations started disclosing the existence of independent mechanisms of control of the skin pigmentation based on solely “skin perception” of environmental illumination (Kingston et al., 2015; Ramirez and Oakley, 2015). These studies showed that the primary elements of pigmentation in cephalopods, the chromatophore organs, can be light-activated in a manner completely independent of the central nervous system. Interestingly enough this process seems to be based on a common and conserved molecular mechanism of light photo-transduction between the eye and the skin. But, despite the mechanisms underlying the formation of pattern and texture the unique and exquisite endpoint of the chromatophore marvelous machinery is the generation of ordered images and eventually the arousal of “beauty.” We can definitely state that these animals carry a high aesthetic value, and this has been caught early by our ancient predecessors.

3.5. Cephalopods in Contemporary Art

Cephalopods remain popular motifs in contemporary art and continue to draw public attention. Takashi Murakami's solo exhibition entitled The Octopus Eats Its Own Leg at the Museum of Contemporary Art Chicago, which featured over 50 sculptures and large-scale paintings, has broken attendance record in the MCA's 50 year history. More than 193,000 people attending the exhibition came to see Murakami's "Superflat" Japanese pop anime, subculture combined with traditional imageries, including many Octopus-inspired characters. The exhibition at Qatar Museum "What About the Art?" curated by Chinese artist Cai Guo Qiang featured work by Huang Yong Ping's six-ton giant "sea monster" hanging from the museum ceiling wrapping its arms on the large 20-foot Column overpowering the audiences walking underneath. A Japanese painter, Yutaka Mukoyama who paints various marine animals, has been creating incredibly detailed photorealistic oil paintings of squids, which are stunning and mesmerizing. All of these are just fragments of cephalopod inspired art that is produced in the recent years that can be found in the ever expansive artistic realm from artworks in high profile art museums and galleries to the street of San Francisco bringing and nurturing people's curiosity and interests toward cephalopods.

In addition to plastic art such as paintings, drawings sculptures and other traditional mediums, cephalopod motifs have been used in many diverse modes of representation, from an underwater site-specific installation of an 80-foot Kraken sank to the British Virgin Island Seafloor (BVI ART Reef, http://www.divethebviartreef.com) to a rideable large-scale kinetic squid sculpture at Les Machines de l'Île de Nantes (http://www.lesmachines-nantes.fr/en/). While many cephalopods themed artworks have been produced since the time of the ancient Greeks, there are three notable artworks that may represent possible future direction in Cephalopod art as synergy of art and science, Insane in the Chromatophores by Backyard

Brains, Chromatophores simulation system (Figure 6) by Todd Anderson and Octopus Brainstorming: Empathy by Victoria Vesna and Mark Cohen. Insane in the Chromatophores was produced in collaboration with Dr. Roger Hanlon's laboratory at Woods Hole Marine Biological Laboratory. This project connects iPhone music to living tissue of a Longfin Inshore Squid (*Doryteuthis pealeii*) by electrodes. As a result, electric signals of the music contract radial muscle fiber surrounding chromatophores allowing a rhythmical change in the visual appearance of the squid synchronized with the music. In Anderson's Chromatophores simulation system, is an interactive digital simulator of chromatophore movement and change in colors. Anderson's simulator detects the movement of spectators and moves color dots based on an algorithm of cephalopod chromatophores. Finally, Octopus Brainstorming: Empathy is a performance/installation that allows viewers to visually detect performer's thoughts through octopus-like contraptions worn by them. Although these three projects are technically and conceptually different, all of these projects focus on multiple characteristics of cephalopods and represent an innovative fusion of cell biology, neuroscience, computer programing, video, sculpture, performance, and more, thereby expanding the share notion on artistic and creative practice and scientific investigations alike.

The synergy between science and art has been a part of artistic practice, perhaps, since Leonardo Da Vinci's extensive notes on art, biology, and engineering. Other examples may include the use of camera obscura by Johannes Vermeer, hyper-detailed animal illustration paintings of Jakuchu Ito, highly aestheticized biological illustrations of Ernst Haeckel. In 1960's the rise of American Avant-garde movement that explored many avenues of non-traditional art making has drastically opened the door for more conscious and deliberate use of scientific practices in art. Artists such as Harold Cohen (http://www.aaronshome.com/) who pioneered in integrating AI "AARON" system to study the process of painting, Helen Mayer and Newton Harrison (http://theharrisonstudio.net/)

who have combined environmental science, agriculture, activism and art, Nam June Paik (https://americanart.si.edu/artist/nam-junepaik-3670) who explored video texture, have all helped firm down the foundation for the interdisciplinary approaches to art making that evolved into current New Media Arts including Biology Inspired Art practices. These multiplicities not only gather independent fields together but also generate interests and discovery in an unexpected category of audiences and help expand the possibility of each area. As more traditional creative modes such as paintings, sculptures, ceramics, prints, photographs will continue to be active, these contemporary interdisciplinary approach truly removes many boundaries not only between arts and sciences, but also help create deeper mutual understanding between the two areas that provides a tangible platform for intellectual exchange expanding imagination, creativity, and vision.

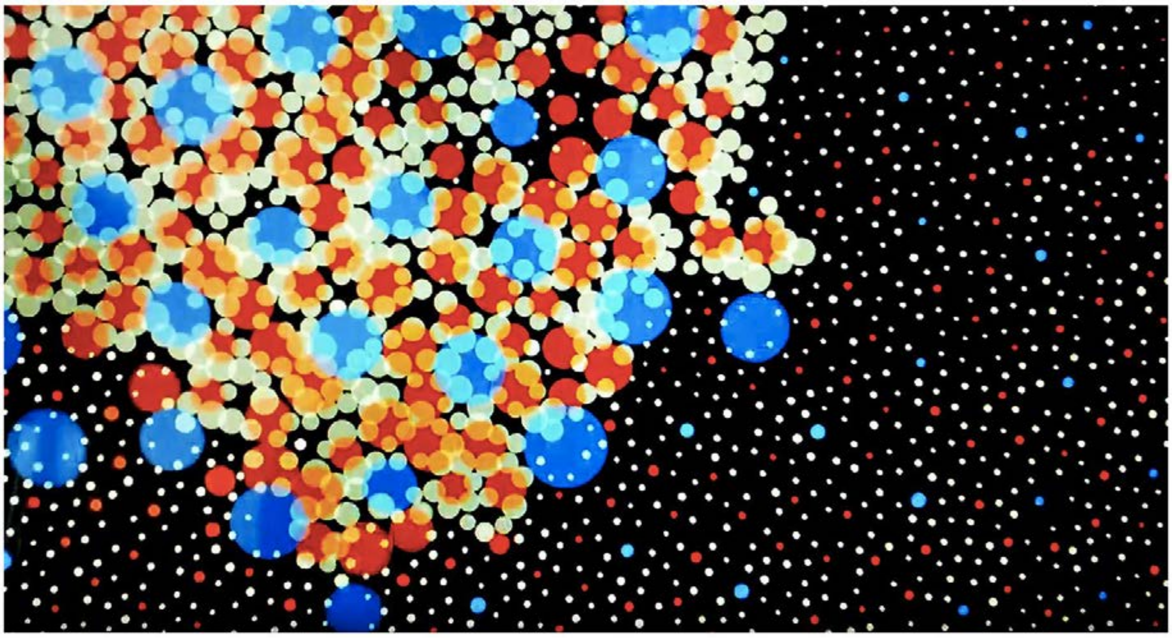


FIGURE 8 | This is a still image of an interactive video installation “Chromatophore simulator” by Todd Anderson. The image is provided at courtesy of the artist.

FIGURE 9 | Image comparison of detail close up of painted frame of Georges Seurat's painting View of Le Crotoy from Upstream (1889), oil on canvas, collection of Detroit Institute of Arts (Top) and octopus skin (Bottom) showing the dense distribution of chromatophores and iridophores. Note: (1) A momentary flash of an anesthetized octopus multi-color skin that was taken with a next-generation KEYENCE digital VHX900F microscope and a 20 Å_ greater depth-of-field VH-Z00R lens under a multi-angle observation. Photographed by S. Shigeno. (2) The detail of Seurat's painting frame was photographed by R. Nakajima at Detroit Institute of Arts in 2017.

3.6. Cephalopods in Popular Culture and Media

High art is not the only place for representations of cephalopods. They can be found in various corners of popular culture including movies, animes, illustrations, toys, video game characters, and more. In 1981, Nintendo released Octopus on a line up of their Game Watch that sold estimate of 250,000 to 1 million copies worldwide. In 2015, Nintendo released Splatoon, which sold 4.87 million copies in just 2 years, and is till now the top-selling video game designed for home console. Cephalopod figures and toys are sold at most aquariums and seaside resort gift shops to be collected (Figure 8). In movies, the five versions of 20,000 Leagues Under the Sea (1907, 1916, 1954, 1985, and 1997), might be one of the most extensive series with a giant cephalopod, which has been adapted from a novel by Jules Verne. More recent films such as Finding Dory (2016), Pirates of the Caribbean, At World's End (2007), SHARKTOPUS (2010), Mega Shark vs. Giant Octopus (2009), and Leviathan (2016) also feature cephalopod as a dominant element in their narrative and many others allude to it.

The original Star Wars (1977) invested 6min sequence where Luke Skywalker, Han Solo, Princess Leia, and Chewbacca are trapped inside a garbage chamber battling with Dianoga, an octopus-like monster. The sequence starts with a statement by Han, "I am beginning to like her (Princess Leia)" to Luke who is his rival over the princess and the sequence ends with the first embrace between Han and Leia. George Lucas cleverly sets up this intergalactic romance by locking up two knights and a prince in a dungeon with a giant octopus. While Luke busies himself with his drone friend C3PO, Han continues to fondle Leia as trash compressor push them closer to each other. This, one of the most memorable and cinematic love scenes of the first Star Wars trilogy, references the legacy of the myth of Kraken as an embodiment of sublime forces of nature but also carefully fuse the story of Saint George and the Dragon with it in the narrative structure.

One other contemporary example of the legacy between myth and public interest can be found in the following happening that in 2010 took the appearance of a modern fairytale. During the FIFA world cup Germany 2010, a common octopus, Octopus vulgaris exhibited at Sea Life Center in Oberhausen, Germany was stealing the show as an animal oracle. During the tournament, Paul the octopus predicted the winning results of 10 out of 12 matches. Scientifically, an octopus selecting or not selecting one over the other is an interesting issue in terms of pattern recognition and color discrimination. However, here the interest is more metaphysical. Despite all religious differences in the world, people were mesmerized by the fact that this little sea creature was exercising its' "supernatural power" that is beyond natural human capability. The Octopus with the name of one of the most important patrons Saint Paul is prophesying the outcome of an important sports event that impacts the social, economic, cultural, and emotional well-being for millions of people. Paul, with much higher success rate than the best bookies in the world, was transformed from an invertebrate to a prophet. This happening together with the international impact and debate arising from it, has been wisely narrated in the much enjoyable documentary "The Life and Times of Paul the Psychic Octopus" (2012) by Philippe (2012).

The concept that the uncertainty of nature can only be accessible and comprehensible by counter parting it with its own natural force is very similar to that of ancient Greek or Chinese oracle and other paganistic and shamanistic practices. The only difference here is that without any shared religious and social foundation, the media frenzy has recontextualized a marine invertebrate into an autonomous being with a superior consciousness that is directly communicating its own thought with its own logic. By stepping on the podium of predictor

FIGURE 10 | A part of cephalopod figure collection of Dr. Yasunori Sakurai at his home office showing incredible variations in cephalopod character designs (photographs by R. Nakajima).

animals, the octopus was the prophet and not an instrument of ritual that required an interpreter and many have accepted it even with slight hesitation. Through news media, music, dance, movies, photographs, illustrations, Internet, articles, and all the other traditional and modern information dissemination methods, the octopus spoke and we listened. This seeming absence of mediator between the octopus and the people made an ordinary hunting behavior into a modern Totemism creating a temporary yet significant universality.

Cephalopod science has been active in the mass media increasing public interest in cephalopods. In 2012, a group of scientists led by NHK (Japan Broadcasting Corporations), and Discovery Channel successfully filmed a giant squid, Architeuthis dux in its natural environment. Combining social network systems and the major mass media sources, the news reached millions of viewers worldwide offering a sense of natural wonder, a joy of discovery and entertainment. The special exhibition “Deep-Sea” organized in conjunction with the release of the footage at The National Museum of Nature and Science Tokyo became the most visited exhibition in Japan in 2013 well exceeding Raphael, El Greco and J.W Turner bringing over 600,000 visitors in 86 days. Not as catchy as the news of giant squid, media coverage of the first complete sequencing of octopus genome published in 2015 was unique. The story was covered in 136 news articles following the initial press release by Okinawa Institute of Science and Technology Graduate University 64 out of 136 articles alluded to the idea of intelligence and/or octopus being an alien promoting the idea of octopus as an intelligent being comparable to human. By bringing Kraken to reality or by promoting the existence of extraterrestrial being and its potential intelligence, cephalopods science, and the media seems to be able to draw and trigger public attention. This unique characteristic of cephalopod helps build a useful information dissemination platform that brings public closer to nature, science, and culture promoting interdisciplinary and multivalent understanding.

CHAPTER4. Cephalopod and visual communication

4.1. Introduction

The catalogue clearly represents the remarkable variety of body pattern expression that *S. pharaonis* can produce. However, isolating body pattern, that used for camouflage can be categorized into three major forms: uniform, mottled and disruptive (Hanlon and Messenger 1988; 1996) with variations within each category (Zylinski et al. 2009), which may not require the entire collection of chromatic components and possible body patterns. The natural progression of question would be to ask What are all these components for and what are the cues that trigger the appearance of them? and ultimately asking such questions as Are they using body pattern for communication and is there an overlap with our communication system? While these questions are certainly important, they are also extremely problematic and abstract.

From impressive repertoires of unique characteristics of cephalopod, their color changing ability is the most intriguing for many artists, designers, and non-specialists alike. While many animals have fixed or slightly changeable appearances, many coleoid cephalopods can rapidly change their appearance using neurally controllable pigment filled cell producing a wide range of total appearance to camouflage into their visual surrounding and for inter and interaspecific communication. In addition to their pattern changing skin, coleoid utilizes their flexible body and skin texture o further enhance both their ability to camouflage and to communicate. The combination of chromatic, textural and postural elements all contribute the overall appearance of the animal transmitting unmatched range of information to their surrounding during predator/prey interaction, secondary defense and courtship. This behavioral trait of cephalopod makes them a truly enigmatic and special group of animal, which has the potential to be using an externally detectable complex form of visual signaling system as human. The current definition of the communication between animals is ‘A process involving signaling between a sender and receiver, resulting in a perceptual response in the receiver having extracted information from the signal, potentially influencing the receiver’s behavior (Bradbury & Vehencmp 2011, and Stevens 2013). This definition is further expanded and explained by defining signal as a ‘strategic aspect’ that points to the specific content or message, and a ‘signal efficacy’ that evolved to affect the behavioral response of receiver

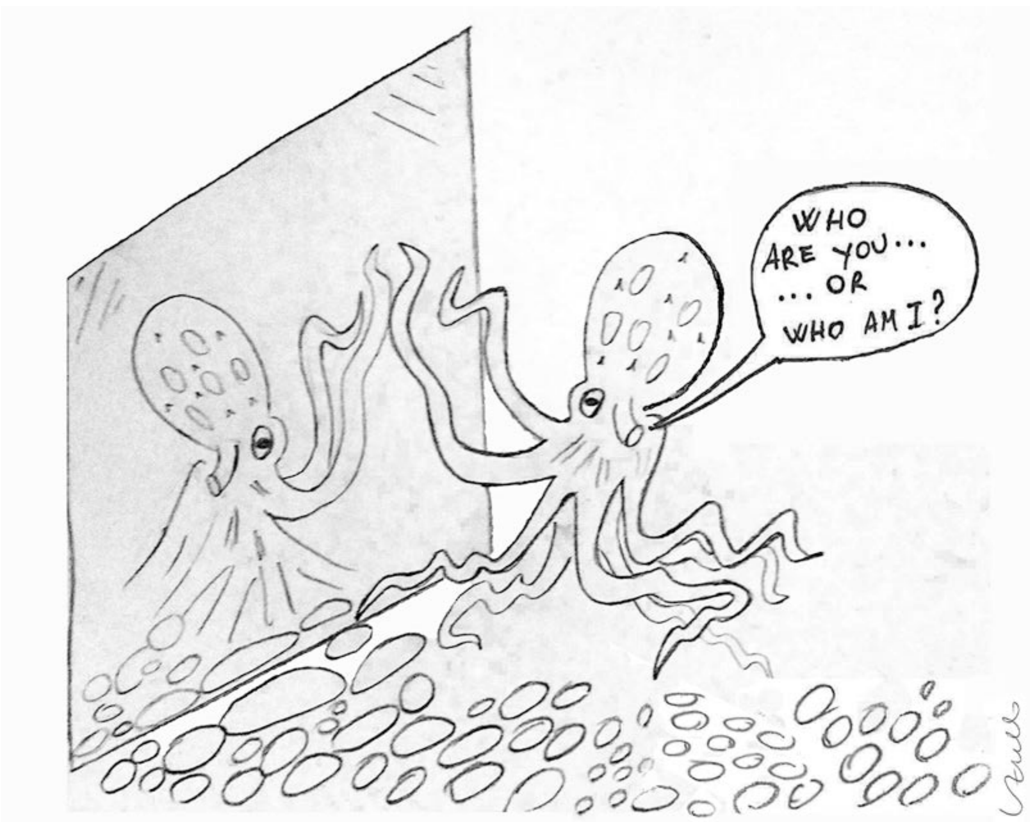


FIGURE 11 | What consciousness in Cephalopods? Sketch representing the Gallup’s mirror test technique applied to an octopus to assess its visual self-recognition abilities (drawing by L. Zullo).

(Guilford and Dawkins 1991, and Endler 1993.) While these definitions described are logical and self-explanatory considering the idea of communication from human perspective, they remain highly sophisticated as a concept. “Strategic aspect” can be understood as a form of representation. A is referring to B while A and B has no logical connection to each other. This notion is identical to the idea of semiological association between a symbol and its signifiers. The mechanism of such association are often, in human cultural sense, depends on the cultural context, i.e. a symbol may not refer to the same “content or message” at different cultural context since it possesses no logical connection between it and what it signify. The second, “signal efficacy’ can be understood as a efficiency of such signals to the receiver. That also depends heavily on the various conditions including receiver’s sensory system, physical visual clarity, and the context, which encompasses both signal giver and receiver. Hence, the definitions are still calling for both scientific and philosophical investigation and clarifications.

While many animals use derivatives of locomotor and postural components and automatic and conflict movement as signals (Hinde 1970, Zahavi 1980, Harper 1991), cephalopods can express complex signals (chromatic, locomotor and postural) by combining individual signals simultaneously or in sequences. These complex combinations of signals are defines as display, which not only has a longer duration than singular expression of a single signal (Hanlon and Messenger 2018). Displays are also been enhanced by such characteristics as redundancy (duration of repetitive signaling), conspicuousness (strength of the signal), stereotypy (classification of signals by receiver), and alerting (anticipation for signaling by receiver) (Wiley 1983). Cephalopod body patterns are further categorized into honest and dishonest signaling (Zahavi 1975 and 1987). Honest signals correspond directly with the motivation of the signaler accurately and proportionally to given condition. Whereas dishonest signals deceive the receiver by sending false information such as luring, mimicking other potentially harmful animals, and scale.

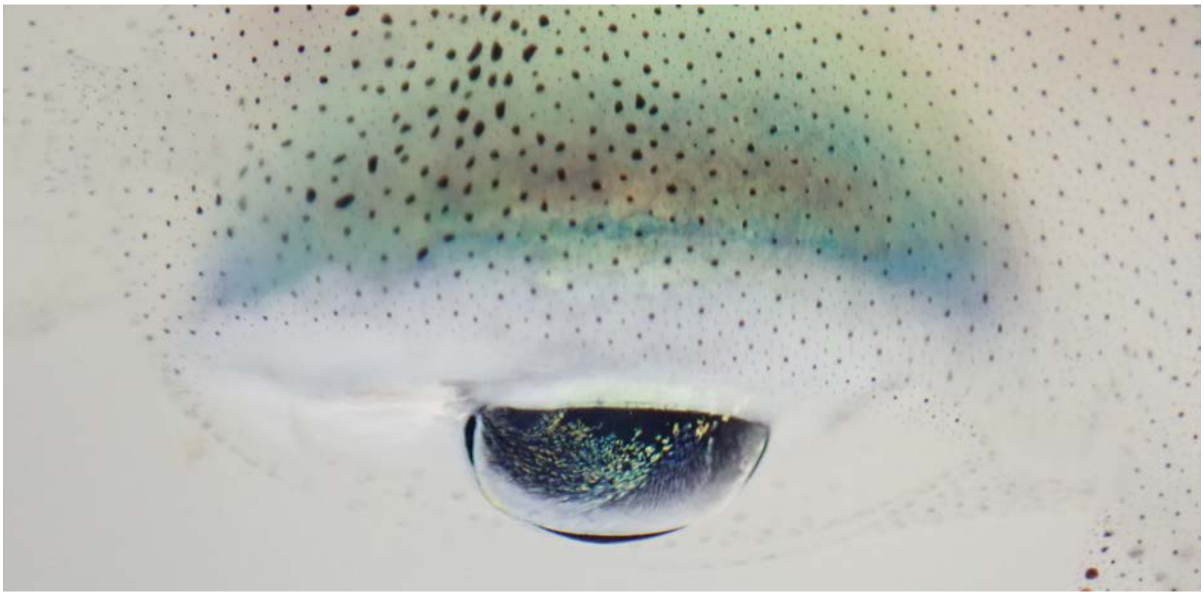


FIGURE 12 | An eye of *Sepioteuthis lessoniana*. Many cephalopod have highly developed set of eyes indicating that they are visual animal that navigate its suroundings by identifying complex visual cues and signals. (Photograph by Ryuta Nakajima)

4.2. Noise or Signal

There has been an ongoing debate regarding crypsis in the context of communication. Moynihan (1975, 1985a) has suggested in his controversial book "communication and non communication of cephalopod," he has categorized crypsis as "non-communication." It is possible to consider crypsis as a purposeful gesture of avoiding signaling. In this case, one may consider camouflage as "anti-displays." On the other hand, Hanlon and Messenger (Hanlon and Messenger 2018) argues that "Display is an attention-getting (Philips & Austad 1992) and most forms of crypsis are the antithesis of this: avoid attention." Although I agree with Hanlon & Messenger that crypsis is not a display, it is important visual information that is expressed within a given environmental condition that interpretation of the body pattern regardless of the implied intention of the animal, effectiveness of the information depends on the receiver of the information. In other words, both crypsis or display are transmitted information and what that information quantify is contextually dependent, i.e. who the deservers are in what visual context. The meaning of any visual information is not an inherent condition of signal. Considering the importance of not acting as one of the most important defensive behavior non-communication is an important communication to minimize information entropy to a receiver. Crypsis fuse with the noise of environment and signals/displays are body pattern minus noise. The former minimize the difference and later maximize the difference to achieve optimal effectiveness regardless of the potential meaning.

4.3. Visual signals of cephalopod (courtship, feeding, deimatic and agonistic)

FIGURE 13 | A school of *Sepioteuthis lessoniana* photographed at Cape Maeda in Okinawa. *S. lessoniana* form a large group in organized fashion indicating their social capability beyond number for protection.

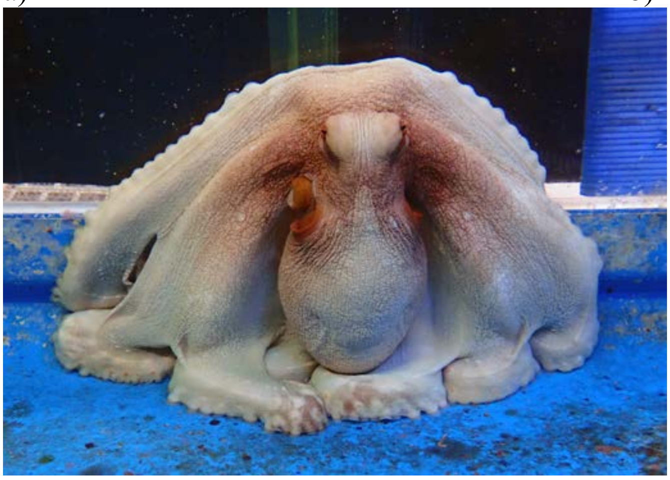
Cephalopod are known to use various different method in communication including tactile, chemical and mechanical water movement (Pitcher 1993, Corner & Moore 1980, DiMarco &

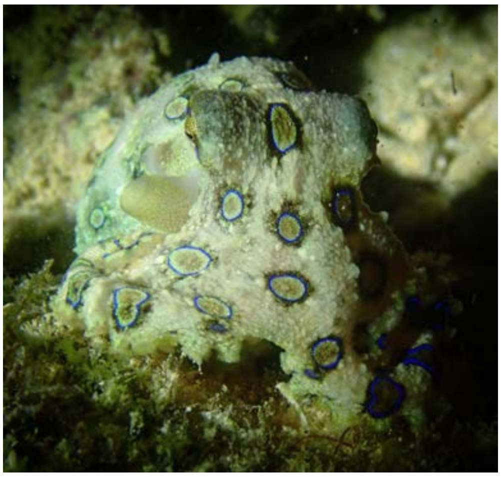
Hanlon 1997, King, Adamo & Hanlon 2003, Lucero, Farington & Gilly 1994, Buch & Robison 2007, Caldwell 2005 and Boal 1997) Although these behaviors have been described and effective in certain instances, visual signaling is the preliminarily form of inter and interspecific communication of cephalopod. There is an advantage in using highly developed eyes and equally well-developed optic lobe of their brain that allows rapid and re-writable reaction to a given situation. Combinations of chromatic, locomotor and postural components that are divided into 4 different behaviors, courtship, deimatic, agonistic, and feeding, express such visual signals.

Current findings related to cephalopod visual communication are scattered across behavioral studies of few species (*Sepoteuthis australius, Sepia officinalis, Sepia apama, Loligo vulgaris, Alloteuthis sublata, Lorigo pealelii, Octopus vulgaris, Hapalochlaens sp., Sepioteuthis sepiodea, Ommastrephes pteropus, Watasenia scintillans, Taningia danae, Chiroteuthis sp., Mastigoteuthis sp. Lorigo plei*) of over 800 know species (Jantzen and Havenhand 2003a, Mather Griebel & Byrne 2010, Hanlon & Messenger 1988, Adamo & Hanlon 1996, Zylinski et al 2011, Packard & Sanders 1971, Stevens et al. 2008, Amther & Hanlon 2006, Boal et al 2004, Mather, Shashar and Hanlon 2009 Mather et al 2012). From these previous studies, visual signals of cephalopods identified are 15 postural signals, 4 locomotor signals, 2 texture signals, 22 chromatic signals, inking and photophores. From these signals, comprehensible messages produced are 1) court me 2) Males keep away; females, stay near 3) I am stronger 4) Don't want to mate 5) stop and watch me 6) See my weapon 7) attack me 8) I am large and fierce (Hanlon & Messenger 2018). Despite the seeming simplicity of cephalopod the messages, it is important to acknowledge that Cephalopods are talking using visual signals produced by chromatophores creating contrast


a)


b)


c)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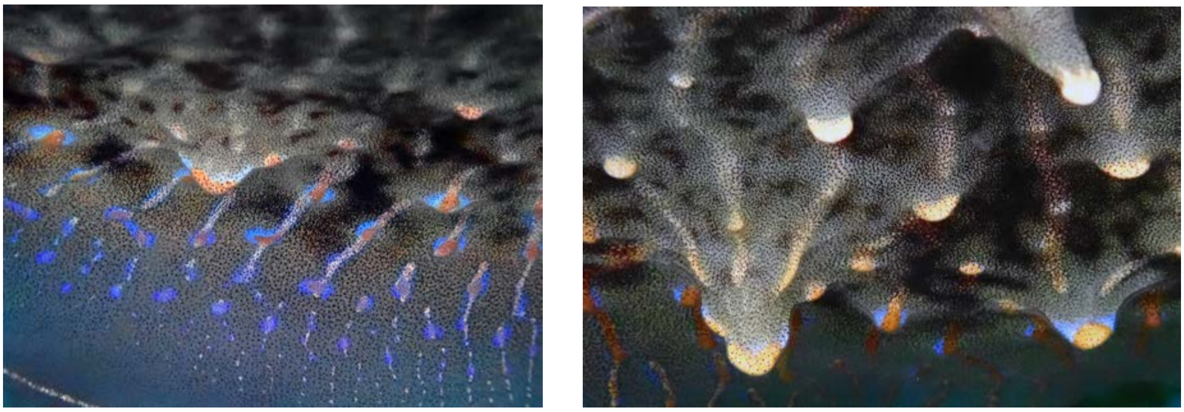
e)


f)



g) h)

FIGURE 14 | a) *Sepioteuthis lessoniana* showing deimatic display with fake eye spots, dark eye rings and spreading fins and arms. b) *Sepia latimanous* lifting first arms and displaying iridophores signals, c) *Octopus cyanea* showing deimatic display with pale skin, smooth texture and dark eye rings. d) *Hapalochlaena sp.* showing distinctive blue rings or iridorphores. e) *S. lessoniana* spreading arms during the night, f) *Sepia pharaonis*'s deimatic display showing dark eye rings, iridophore stripes on arms, blue ring around the mantle, and fake eye spots, g) *S. latimanous* (male) iridophore on the fin edge, h) *S. latimanous*'s papillate changing body texture and accenting iridophores.

changing moving and stationary patterns, iridophores creating secret polarized communication channels and photophores in the deep sea environment. Considering the imbalance between the complexity of the physiological capabilities and flexibility of cephalopod body pattern expression and the extracted messages in the current literature, it is safe to say that there are still much to be discovered of its function and structure.

4.4. Cephalopod as a comparative model in search of beauty

Cephalopod's visual communication capability is still not well understood. However, it's potential is exponentially interesting and high. Cephalopod has the largest brain wait to body weight ration of all invertebrates, which places between reptile and bird in the vertebrate chart. Their highly developed brain and complex sensory and nervous system make them the most intelligent invertebrate with high cognitive and computational capabilities such as good memory, learning ability, and complex social structure, individual recognition. Furthermore, these cognitive function may imply that they have a proactively engaging sense of consciousness and autonomous self that is constantly negotiating its' position against environmental factors. If we consider human at the top of the intelligent chart in vertebrate, cephalopod is at the top of the invertebrate chart. This uncanny parallel between human and cephalopod makes them a great comparative animal.

In addition to physiological and behavioral attribute, cephalopod also have cultural and psychological connection to human that make them an ideal intersection between scientific and cultural investigations Culturally, cephalopod has been represented in many coastal cultures around the world (please see Chapter 3) that show a level of kinship that is unmatched of any marine invertebrates and many other animals alike and unique. In many representation of cephalopod, especially octopuses, suggest that they are organisms of equal counter parts with intelligent consciousness like us. In short, they are only a handful of animals that qualify as “others”. Under casual observations of octopuses depicted in Minoan pottery, one will realize the consistent feature across many different stylistic periods. All octopuses have a pair f large eyes steering directory at the onlooker. Such consistent feature is rare especially with a type of animal that is not domesticated. The gaze from the octopuses indicates a certain psychological equality. Octopuses look at us as we look at them. This phenomenon is common for many octopus keepers working with live octopuses under laboratory and/or aquarium. Octopuses have a strange and explainable ability to make a person think that they are observing thus forming a emotional bond with him. Its' curiosity and playfulness also contribute to even tactile connection of touching. It is not suprising that when an octopus is looking at you in the eyes and shaking your hand, you will most likely be a believer of many myth surrounding the animal. As Jacque Cousteau described , they are the“soft intelligence” of the deep. Hence, octopuses and other cephalopods can bring together phenomenological investigation of science and metaphysical investigation of art on the same platform. Minoan octopus pots are the product of both careful observation of biological attributes of an octopus and its metaphorical application as a symbol of eternal life; it was an inevitable choice.

FIGURE 15 | Octopus motif pots from Minoan culture know as marine style dating back to 1500 B.C. There are some varieties in octopus representation, however, the gaze of octopuses are very consistant through out.

4.5. Visual communication and Cephalopod body pattern

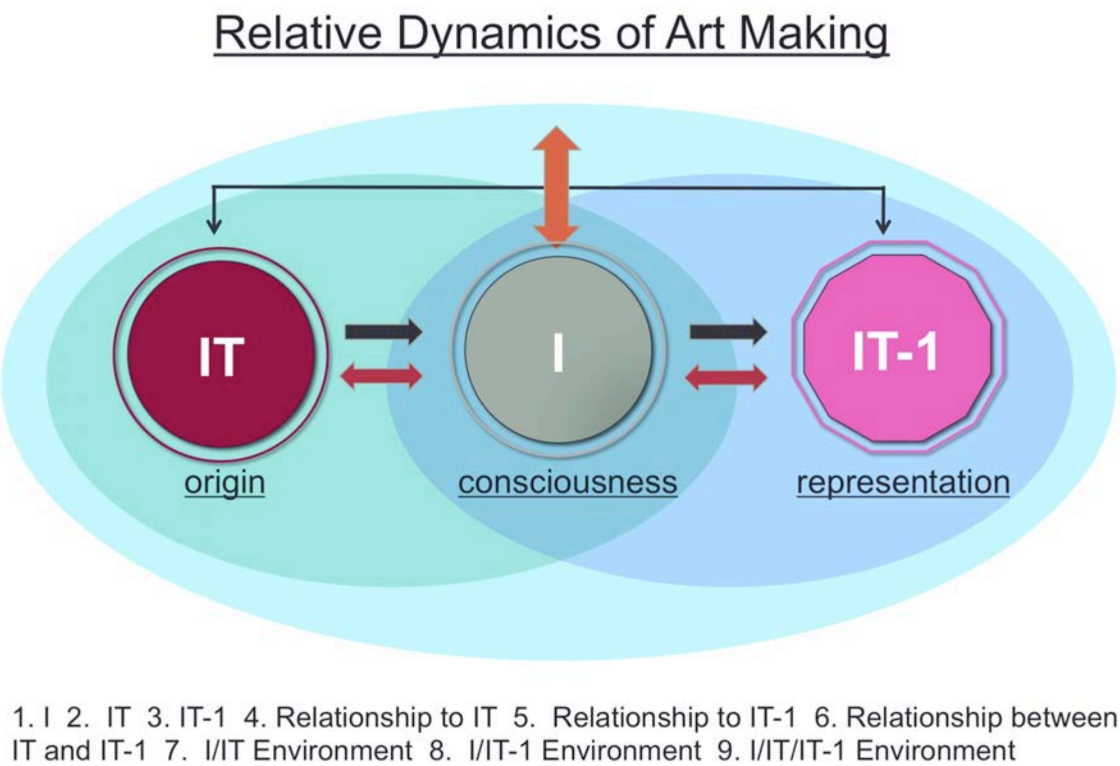


FIGURE 16 | Relative dynamics of Art making showing three levels of investigations

What is a primary function of representation? When the first buffalo painting went up on the wall of Lascaux, it had a pure relationship with a buffalo, the maker and the representation. Upon completing the painting, the simple algorism of investigation was established. The relative dynamics of the relationship between it (origin), maker (consciousness), and it-1 (representation) allows three levels of investigation. At the first level, each one of these three elements can be analyzed independently. The second level looks at the relationship between each element. The third level examines the environment that encompasses the elements. Through these three levels, image-making help understand our surrounding and us.

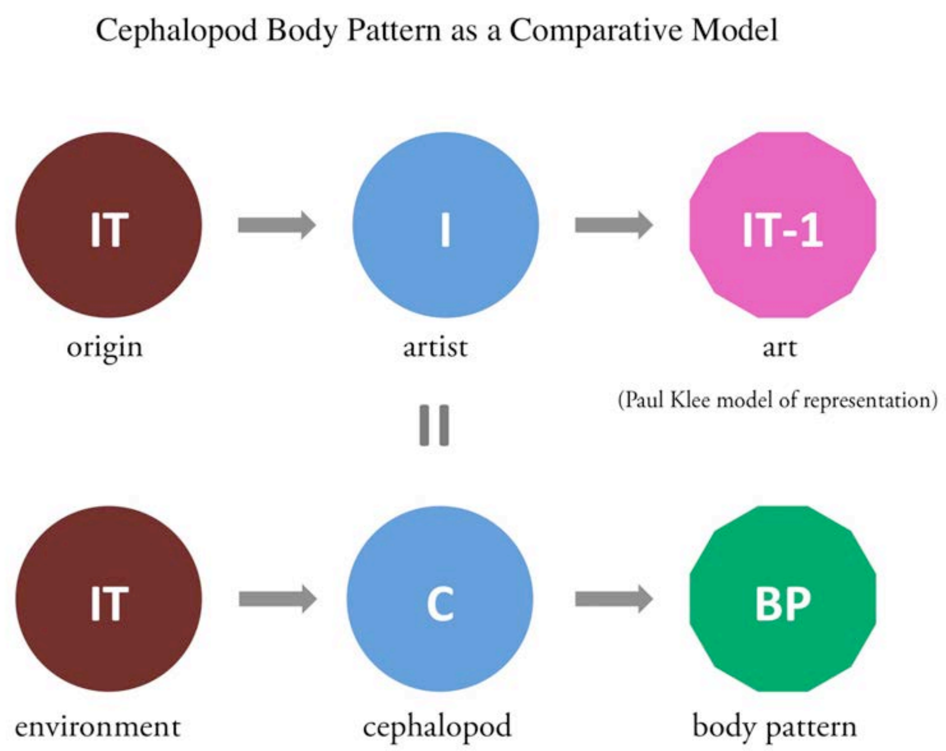


FIGURE 17 | Cephalopod Body Pattern as a comparative model diagram shows that act of creating a representation and cephalopod body pattern follow very similar system.

While act of making image as a means to investigate the presence and function of our consciousness and its' relationship to the external world may not be a shared with cephalopod, the process of translating external information into a type of representation still remains to be similar biological process. Cephalopod is using its own set of sensory organs to intake various aspects of its surrounding information including visual (standard spectrum and polarized light), tactile and chemical stimuli. This information is gathered in the brain to cognitively unify and assess the situation and hierarchically categorize them according to the urgency. Upon unification and assessment, motor output is neurally controlled to produce the final action towards the environment with such motivations as spatial navigation, hunting, escaping, mating and fighting. Despite the differences in both sensory systems and, more importantly, in motivations, cephalopod and human share the basic process of connecting environment, consciousness, and representation. This shared process gives opportunity to draw a comparative study of the tractable differences and similarities between the self world of cephalopod and human.

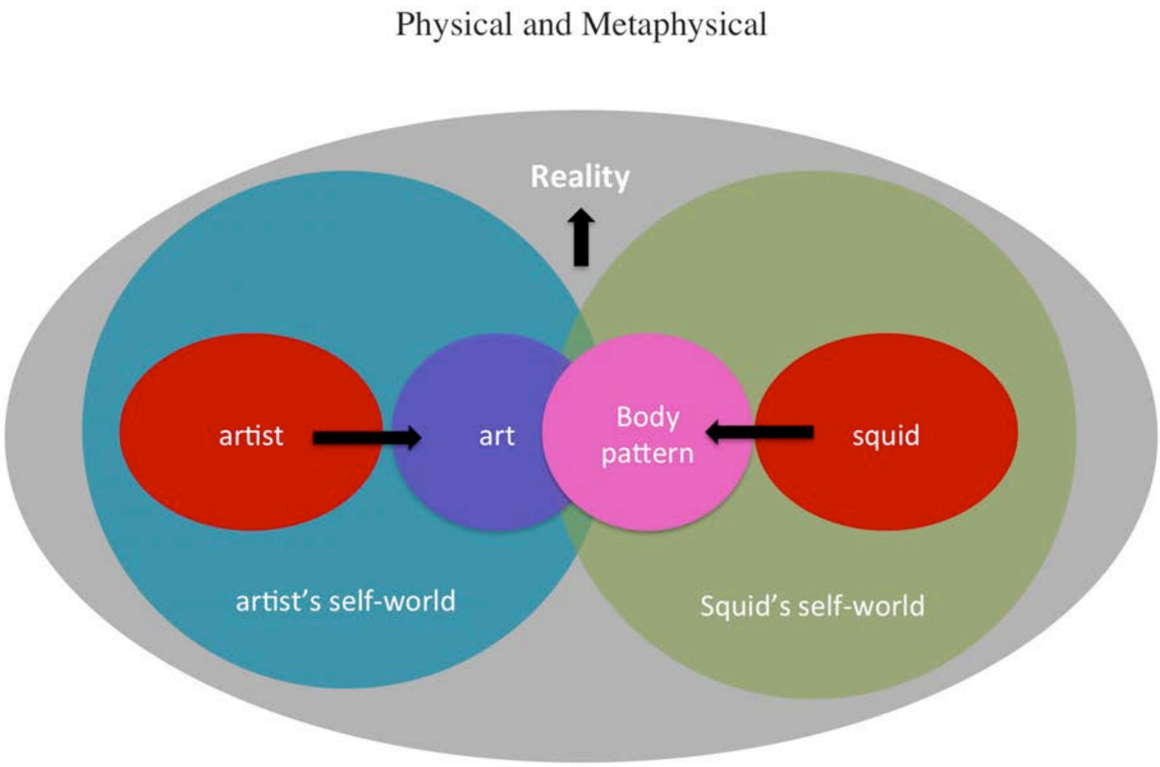


FIGURE 18 | The diagram is showing the relationship between the self-world of artist and squid and how the overlapping area may direct towards the larger reality.

Further expanding the idea of shared process in relationship with the understating the reality, I am hoping that this parallelism will be able to point to the "beauty" that surrounds us. Navajo Indian describe "beauty" in their prayer song for the dead as follows:

Walking in Beauty

> Today I will walk out, today everything unnecessary will leave me, I will be as I was before, I will have a cool breeze over my body. I will have a light body, I will be forever happy, nothing will hinder me.
>
> I walk with Beauty below me. I walk with Beauty above me. I walk with Beauty all around me. My words will be Beautiful. In Beauty, all day long, may I walk. Through the returning seasons, may I walk. On the trail marked with pollen, may I walk. With dew about my feet, may I walk.
>
> With Beauty before me, may I walk. With Beauty behind me, may I walk. With Beauty below me, may I walk. With Beauty above me, may I walk. With Beauty all around me, may I walk.
>
> In old age wandering a trail of Beauty, lively, may I walk. In old age wandering a trail of Beauty, living again, may I walk. It is finished in Beauty. It is finished in Beauty.
> Aho.

It is my understanding that the idea of "beauty" that Navajos are expressing for the dead is the vision of afterlife that collected and consolidated as a mythology from numerous accounts of near death experiences. The near death experiences and the visions during it may be the only indicator of possibilities of the afterlife, and this consolidated vision may also be shared in many other religions across the history and culture described as heaven, nirvana, god, nature, etc. The question is what becomes accessible at the moment of death? The answer lies in the Navajo prayer that tells us that it is all around us at all time. This lead me to think that "beauty" is the incomprehensible reality that surrounds us at any given moment but not entirely accessible due to the limitation of our sensory system and more importantly our brain making simplification and categorization of the incredible and exponential complexity of the reality into codified symbols for faster and simpler navigation and negotiation with the environment. Furthermore, our modern life style allowing almost complete reduction of the real and replace it by easily digestible mediated information that require no translation as it is a translation. This inaccessibility of reality in our daily life makes the experience of the true reality more difficult than ever.

CHAPTER 4 Cephalopod and visual communication

With this project involving cephalopod cognition and behavior, I am hoping to reclaim the possibility to access the true reality beyond already translated world of mediated information. Cephalopod, which has no overlapping generation, has very little sense of transmission of shared culture. Most necessary behaviors are already programed in their DNA, rapid observation learning and empirical knowledge. Since there system and motivations are different from us that if there is an overlap between our visual communication system that derived from our self world and cephalopods body pattern expression equally derived from their self world, it might open up the possibility of seeing the glimpse of the beauty and its fundamental schematics that surrounds us. In this way, the project sees to find both diversion point of reference by investigating cephalopod behavior and cognition through their body pattern and visual communication method, and simultaneously investigate a conversion point between human and cephalopod experience in search for the common and shared ground in represented information that is a simplification and exaggeration of each respective sense of the self world.

CHAPTER5. Creating a Catalog of Body Patterns of the Pharaoh Cuttlefish

5.1. Art work phase 1

The phase 1 of creative production took a form of 22 drawing series. This series was separated into two parts, which both visualized the current fantasy and goals of working with cephalopod. The first set focused on the idea of collaborating with a cuttlefish. It was important that the experimental animals were not exploited or manipulated to behave according to the parameter of the experiment nor the project. In this set, an abstract marking mimicking ink stain overlaid with a photo-based color pencil drawing of octopus, cuttlefish and squid. These drawing was a simple visualization of an artist having a one on one conversation with the animals as inking behavior as cephalopods' version of mark-making process. The second set was another concept drawing of the idea of showing varieties of man made images to a cuttlefish and how their body pattern may change accordingly. In this set, images such as a Kamikaze pilot, 1968 student movement, a Nazi Auschwitz watchtower, etc.… were selected. This 22 drawing sets were exhibited as one complete as an installation rather than as individual drawings. As an artist, accessing a live cephalopod for any experiment is very difficult for both technicality and cost. As a result, creating drawings was a mental exercise of visualizing the future experiments and collaboration with a cuttlefish. These drawings accompanied my initial proposal to the National Recourses Center for Cephalopod where for the first time, I was granted an access to cuttlefish for series of experiments while working and receiving guidance from cephalopod researchers.

FIGURE 19 | Philosophy of Squid 2009 (drawing series) exhibited at Gallery Onion, Tokyo as a complete set. Below two images show two manifestations of the drawing.

5.2. Introduction

More than 100 species of cuttlefishes have been described to date (Jereb and Roper 2005), of which one species——the benthic, shallow-water common cuttlefish (*Sepia officinalis*)——is the most extensively studied for its body pat- tern. These studies have shown that *S. officinalis* can create a wide range of body patterns allowing it to either blend into its visually rich and complex natural habitat or to stand out startlingly, with 87 components (42 chromatic, eight textural, 13 postural, and 24 locomotor) identified and described to date (Holmes 1940; Boycott 1958; Neill 1971; Hanlon and Messenger 1988). Although recent study suggests that cuttlefishes are able to detect colors by chromatic aberration (Stubbs and Stubbs 2016), they possess one visual pigment and are color blind (Marshall and Messenger 1996; Mäthger et al. 2006). Hence, their visual behavior has been directly correlated with multiple visual cues, such as the scale of a light object, the edge detection, the relative tonal differences between the foreground and background, and the two- and three-dimensional visual depths. Visual information is gathered by highly developed eyes, processed by a hierarchically organized set of lobes in their brain, and then converted into an appropriate pattern as a motor output (Muntz and Johnson 1978; Messenger 2001; Zylinski et al. 2009).

In addition to *S. officinalis*, over 20 extensive body pattern catalogs have been produced for other cephalopod species including the flamboyant cuttlefish, *Metasepia pfefferi* (Thomas and MacDonald 2016; Roper and Hochberg 1988); slender inshore squid, *Doryteuthis plei* (Postuma and Gasalla 2015); longfinned inshore squid, *Doryteuthis pealeii* (Hanlon et al. 1999); Large Pacific striped octopus (Caldwell et al. 2015); Humboldt squid, *Dosidicus gigas* (Trueblood et al. 2015); northern shortfin squid, *Illex illecebrosus* (Harrop et al. 2014); deep sea squid, *Octopoteuthis deletron* (Bush et al. 2009); Cape Hope squid, *Loligo reynaudii* (Hanlon et al. 1994); and common octopus, *Octopus vulgaris* (Packard and

Sanders 1971) (reviewed by Borrelli et al. 2006; Hanlon and Messenger 1996). Many of these reports were produced through extensive analysis of photographic and video data recorded from both in situ and in the laboratory. More recently, an automated signal classification system has been used as a less subjective and repeatable cataloging approach (Thomas and MacDonald 2016).

The pharaoh cuttlefish, *Sepia pharaonis* (Ehrenberg 1831), lives in tropical coastal waters in the Indo-Pacific region from 35°N to 30°S and 30°E to 140°E down to 100 m depth (Norman and Reid 2000; Nabhitabhata and Nilaphat 1999). This species is divided into three sub-types depending on the body pattern and geographical distribution: Type I in the Arabian Gulf, western Indian Ocean, and Red Sea; Type II from Japan to the Gulf of Thailand, the Philippines, and northern Australia; and Type III from the Andaman Sea to the Maldives. These three types differ in size, growth rate and in color patterns of mating animals. Type I and Type II males have zebra stripes on their third arms, while Type III males have spots on their third arms (Norman 2000). Previous studies on the body patterns of this species have particularly focused on camouflage and its visual cues. These studies have found that *S. pharaonis*'s disruptive coloration is affected largely by area rather than the shape or aspect ratio of a light colored object on a substrate (Chiao and Hanlon 2001) and that visual orientation of substrate pattern has little effect on its body pattern selection (Shohet et al. 2006). However, aside from 34 chromatic components assumed based on*S. officinalis* (Shohet et al. 2007), there has been no extensive catalog of their body pattern diversity that includes chromatic, textural, postural, and locomotor components. Hence, the aim of this study was to document the range of body pattern components exhibited by *S. pharaonis*. We hope that these findings will provide a useful foundation for the identification of Sepia species and sub-species and for future quantitative behavioral analyses.

5.3. Materials and methods

Egg cases of Type II *S. pharaonis* were collected from the Sunabe beach area (depth ranging from 10 to 12 m, water temperature ranging from 23 °C to 25 °C) in Okinawa Island on April of 2010, 2011, and 2012. Egg cases were immediately transported to the laboratory of the Department of Chemistry, Biology, and Marine Sciences at the University of the Ryukyus, where they were reared and cultured in three 20 L (300 mm diameter x 170 mm depth) cylindrical, acrylic, closed-system tanks (Multi-hydense®, Aqua Co., Ltd Japan). All tanks were filled with artificial seawater (Tetra Marine Salt Pro, Tetra Japan Inc., Japan), and 2 L of seawater was ex- changed in each tank every few days. In addition, fresh water was added to the tanks as required to compensate for evaporation. The water quality (temperature, salinity, pH, and con- centration of ammonia, nitrite, and nitrate) was monitored regularly using an electric pH/temperature meter, a salinity meter, and a commercial-grade water testing kit (Test Lab, Red Sea) to maintain the following levels: temperature = 24.5 − 25.5 °C; pH = 7.8 − 8.2; and salinity =33–35 psu. If the pH dropped below 7.7, a pH/al adjuster (LIVEsea Buffer pH/al, Delphis Japan) was added to the tanks. Lighting was provided by fluorescent light tubes, which were set on a 12 h light/12 h dark cycle.

In total, 75 animals (35 [102–118 days old] in 2010, 22 [81–99 days old] in 2011, eight [105–116 days old] in 2012, and 10 [117–118 days old] in 2014) were used without deter- mining each animal's sex. The animals were separated into three 50 L (400 mm diameter x 360 mm depth) cylindrical acrylic tanks in 2010 and three rectangular polypropylene containers in 2011 and 2012 (540 mm length x 380 mm width x 200 mm height, plastic box 06, Shinwa Japan, in 2011; and 600 mm length x 430 mm width x 380 mm height, plastic box 09, Shinwa, in 2012). The cylindrical acrylic tanks are light gray at the base and polypropylene containers are semi- transparent white at the base. All tanks had black cloth on all four sides to reduce visual stress. The animals were fed frozen Japanese anchovy (*Engraulis japonicus*), Sakura shrimp (*Sergia lucens*), and/or black tiger prawns (*Penaeus monodon*) twice per day. For the observation, each animal was individually taken out of the holding tank, transported to the observation apparatus in a semi-opaque plastic container, and then returned to the holding tank in the same manner after the session. All animals were shared with lab-mates.

During the observation sessions, the animals were placed in ADA Cube Garden frameless glass tanks (450 mm x 270 mm x 300 mm, Aqua Design Amano Co., Niigata, Japan) with and without crushed coral sand substrate. The observations were conducted six times per animal between morning and evening feedings. Animals were allowed 5 min to acclimate to the tank and recorded for 10 min unless the animal showed clear signs of stress (inking, dashing, and smashing into the tank wall). Videos and still images were recorded using a Canon 5D Mark II Digital SLR camera with a Canon EF 50 mm 1:2.5 Compact Macro Lens, a Canon EF 24–105 mm 1:4 L IS USM Zoom Lens, and a Canon EF 50 mm 1:12 L USM Lens (Canon USA Inc., NY, USA).

The camera was mounted on a tripod with a horizontal extension arm and suspended 300–600 mm above the water surface. Still images were approximately 5616 x 3744 pixels, while videos were recorded in full high-definition (HD) (1080p) at 30 frames/s (1920 x 1080 pixels). EOS Utility (version 2.13.0) was used to remotely capture both videos and photographs to reduce disturbance to the animals. The ambient light was provided by a fluorescent tube suspended 2.5 m above the tank, and the animals were sheltered from any direct light. Still frame photographs and videos of the under- side of each animal were obtained by placing a mirror beneath the tank at a 45° angle and then placing a camera in front of the mirror.

In total, 325 HD videos (duration ranging from 42 s to 15 min) and 9799 still images of the animals were obtained. These were then filtered to select only acute (lasting more than a few seconds to several minutes; sensu Hanlon and Messenger 1996: Box 3.1) total body pattern expressions and to remove any repetitive images without noticeable changes, which resulted in 784 still images being extracted from the set for detailed analysis. *Sepia officinalis* chromatic components have been organized into light and dark components, reflecting the expansion and contraction of the chromatophores (Hanlon and Messenger 1988). In this study, we employed a graphic image construction method that is used by the graphic design industry. Both Adobe Illustrator (v. CS6; Adobe, San Jose, CA, USA) and Adobe Photoshop (v. CS6; Adobe, San Jose, CA, USA) were used manually to break down digital photography into separate visual layers. Illustrator is vector-based graphics software that allows graphic elements to be organized as layers rather than pixel based organization. All of the components can be stored as individual layers that can be easily combined (Fig. 1) like puzzle pieces to create an overall body pattern appearance of any given image. Furthermore, the catalog can be edited and updated by others using the same software. This method provides flexibility as a visual catalog of components that track body patterns and behavior with better accuracy and may contribute to the greater database of cephalopod body pattern and behavior when combined with database of other species.

5.4. Results

The body pattern components observed and documented comprised 53 chromatic components, 11 postural components, nine locomotor components, three textural, and four supplementary chromatic conditions (Table 1). Detail descriptions of the components are as follows.

5.4.1. Chromatic components

Uniform (1–4, Fig. 2a) – Four uniform colors were identified:

1. Pale (observed number (n) = 471)

2. Yellow (n = 230)

3. Dark brown (n = 70)

4. Dark red (n = 13) Colors ranging from pale (1) to yellow (2) were often observed often (701/784 cases, or 90% of the total images analyzed). By contrast, dark brown (3) was only recorded in only 70 cases (8%) and mainly in smaller animals with a mantle length <5 cm. Base colors form the chromatic foundation, to which other components are added to produce the complete body pattern. White (#1) was the most basic color and is very similar to the pale mantle category of Boal et al. (2004). It has been shown that animals appear to be white as a result of chromatophore contraction making the leucophore layer visible (Messenger 2001). By contrast, animals appear dark brown when there is maximum expansion of the chromatophores and yellow coloration falls between these two extremes. We also observed S. pharaonis turning reddish purple (4) in 13 cases, usually following heavy inking and jetting behavior. Head and arm (5–21, Fig. 2a) – A total of 17 head and arm chromatic components were identified:

5. Anterior head bar (n = 69) (Packard and Sanders 1971; Hanlon and Messenger 1988). A dark or light line that crosses the anterior part of the head and the base of the arms. It also lies at the boundary of the dark arm.

6. Arm bar (n = 22). A dark line at the anterior of the head bar that is visible half way between the anterior head bar (6) and the tips of the arms.

7. Posterior head bar with stripe (n = 69) (Hanlon and Messenger 1988). A dark brown band that is located along the edge of the posterior region of the head. The band

extends the pattern into the center axes of the head with finer horizontal lines branching out to the posterior head margin.

8. Red posterior head bar with stripe (n = 107) (Hanlon and Messenger 1988). A reddish band that is located along the edge of the posterior region of the head that is similar to Posterior head bar stripe.

9. White landmark head spots (n = 80). A total of 4–6 prominent white spots between the anterior and posterior head bars.

10. White head bar (n = 173) (Holmes 1940; Hanlon and Messenger 1988). An almost transparent white band that connects the dorsal-most part of each eye. This was most commonly observed when the animals were using very few chromatic components. However, when it appeared in combination with a darker anterior mantle bar (12), dark arms (13), and a posterior mantle bar (14), it created a striking tonal contrast.

11. Dark arms (n = 73) (Hanlon and Messenger 1988). Expressed as darkening arms (I, II, and III), which create a triangular form, the boundary of which starts at the anterior head bar (6).

12. Dark eye patches (n = 122). Dark brown to black patches on the dorsal side of the eyes. These patches can be connected by eye-lines (Neill 1971) to create dark, circular shapes surrounding the eyes. They can also appear independently from the dark patches on the ventral side.

13. Eye rings (n = 32) (Packard and Sanders 1971; Hanlon and Messenger 1988). Dark semicircular bands that follow the lower perimeters of the eyes and often appear with dilated pupils, creating complete circles and giving the impression of larger eyes.

14. Anterior eye spots (n = 23). A pair of dark spots located between the anterior perimeter of the eyes and the anterior head bar (#6), creating an impression of frontally elongated pupils.

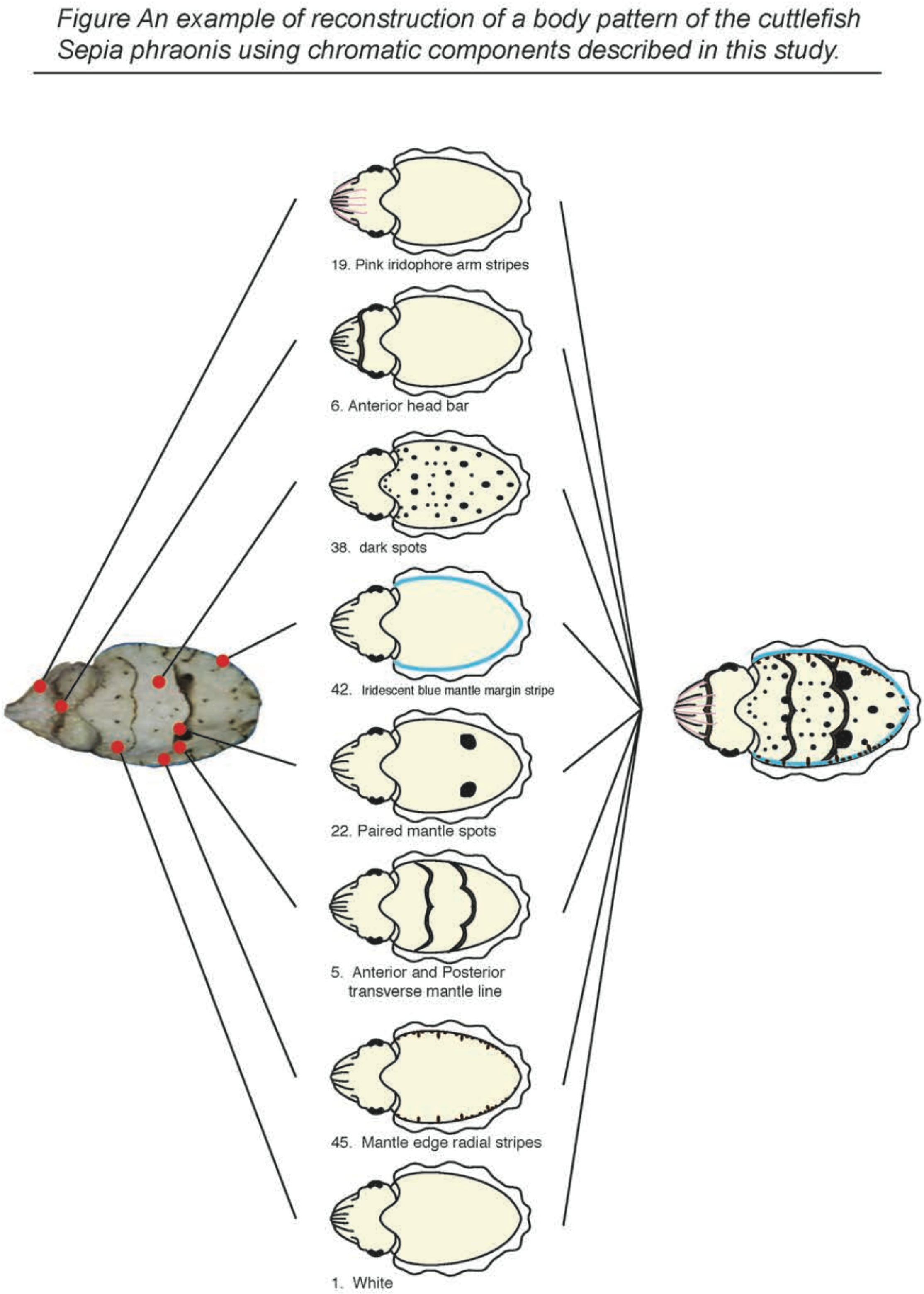


FIGURE 20 | An example of reconstruction of a body pattern using chromatic components in this study

15. Dark arm stripes (n = 13) (Hanlon and Messenger 1988). Darker longitudinal lines that appear on all arms, which, in combination with the lighter lines of the iridophores on the outer edges of the arms, create high-contrast stripes.

16. Pink iridophore arm stripes (n = 73) (Hanlon and Messenger 1988). Thin, pink iridophore lines that begin at the anterior of the head and extend to the tip of each arm. These lines run along the center of arms I and II, and along the outer edge of arms III and IV. Although the lines most often appear as an iridescent pink color, they can also have iridescent green and light blue hues at times. The line on arm IV most often appears white.

17. Red arms I (n = 10). Expressed through the color of arm I changing to red. This component was observed during two behavioral circumstances a) during a confrontation with an- other member of the same species, where arm I was extended straight toward the opponent with the bright red color concentrated at the tip of the arm and b) while the individual was completely submerged under the sand, with only arm I extending through the surface. 18. Brown arms I (n = 12). A thin, triangular-shaped area that is created by the darkening of arm I from its posterior base to the tip. This component symmetrically divides the arm in two.

19. Extended head crown (n = 51). A crown-shaped area that is created by three jagged and scalloped stripes extending out from the posterior head bar (7) towards the arms.

20. Head crown (n = 19) (Thomas and MacDonald 2016). A crown-shaped area that is created by three jagged stripes extending out from the posterior head bar (7) towards the arms. It is a compact version of the extended head crown (19) described above with smaller area coverage.

21. Head spot (n = 13). A dark circular spot located at the central axis of the head between the posterior head bar and the arms (7). Dorsal mantle (22–47, Fig. 2b and c)– A total of 28 dorsal mantle chromatic components were identified:

22. Anterior and posterior transverse mantle lines (n = 404) (Hanlon and Messenger 1988). Thin and dark scalloped lines that cross the entire mantle width at 1:1:1.5 division ratios between the anterior and posterior mantle margins. These lines are perhaps the most important chromatic components for S. pharaonis, defining the visual boundaries for many other components. In some instances, these lines appeared to be thicker than usual.

23. Anterior mantle bar (n = 78) (Hanlon and Messenger 1988). A dark banded area that is situated in the anterior quarter of the mantle between the mantle margin and the anterior transverse mantle line (22).

24. Fragmented anterior mantle bar (n = 127). This component has the same attributes as anterior mantle bar (23) component described above, while not fully completing the component. It has a more jagged and flame-like design that emphasizes Anterior transverse mantle lines (22), as well as the anterior mantle margins. In many occasions, it appeared together with the fragmented posterior mantle bar (27) creating disruptive body pattern.

25. Anterior mantle crown (n = 19) A crown shaped area situated along the central axis of the mantle, bordering the anterior transverse mantle lines (22). It often appears together with the fragmented paired mantle spots (32) and the head crown (20).

26. Posterior mantle bar (n = 43) (Hanlon and Messenger 1988). A dark banded area that is situated in the posterior third of the mantle between the posterior mantle edge and the posterior transverse mantle line (5). There are many variants that give the impression of this component, such as a thickened posterior transverse mantle line (22), paired mantle spots (33), and triangular wedges (41). This area can also be broken up into a combination of a fragmented posterior mantle bar (27) and joined paired mantle spots (31).

27. Fragmented posterior mantle bar (n = 127). This com- ponent has the same attributes as posterior mantle bar (26) component described above, while not fully

completing the component. It has a more jagged and flame-like design that emphasizes posterior transverse mantle lines (22), as well as the posterior mantle margins.

28. Posterior mantle crown (n = 46) (Forsythe and Hanlon 1988) . A dark, trapezoid-shaped area at the central posterior margin of the mantle. The top of the shape reaches the halfway point between the posterior transverse mantle lines (22) and the posterior mantle edge.

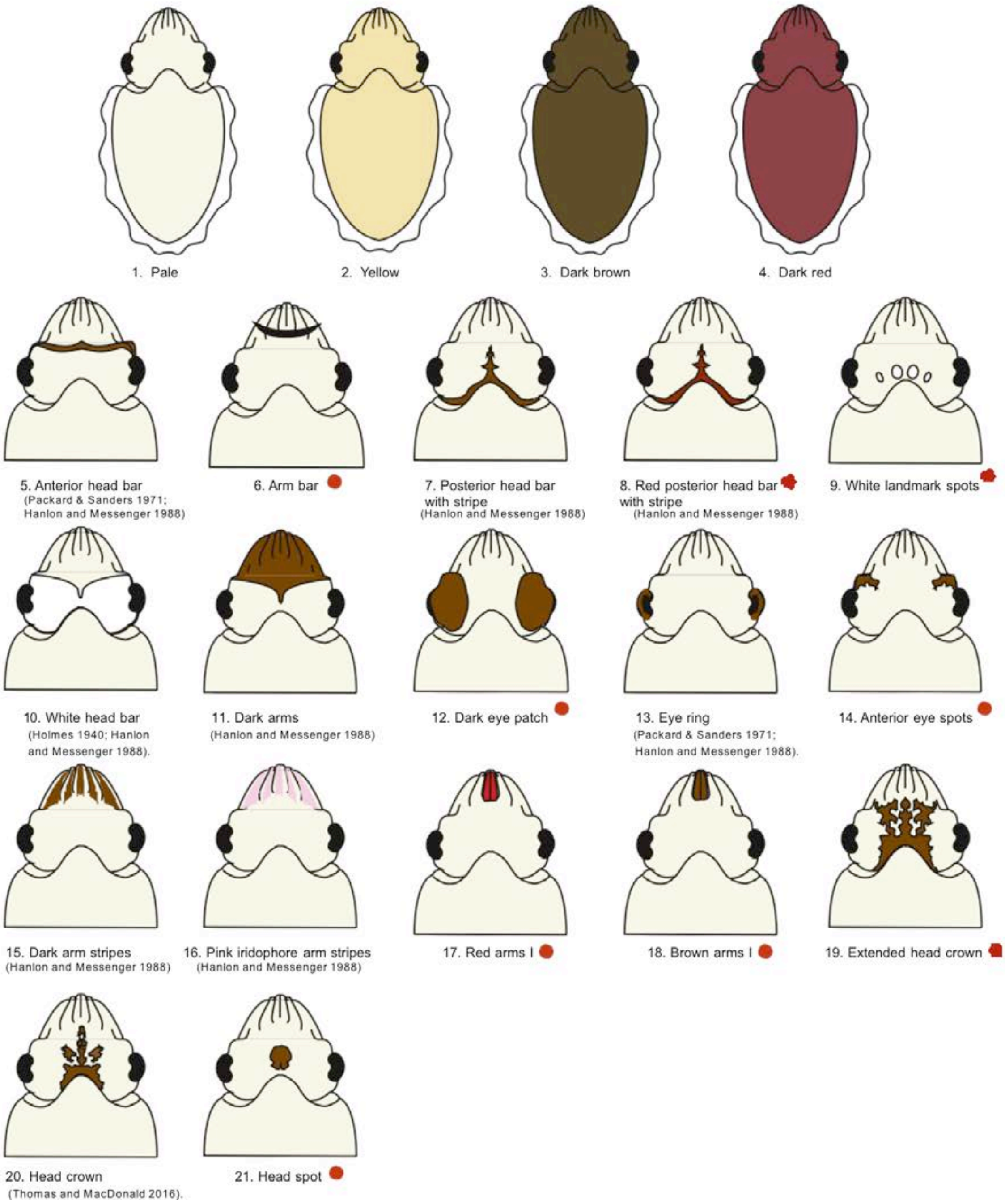
29. Central dark mantle shield (n = 13). On the mantle, a negative shield-like shape is created by connecting paired central mantle spots (40), paired mantle spots (33), and the upper central region of the posterior mantle bar (26).

30. Posterior mantle spot (n = 13). A single small circular shape located near the center of the posterior mantle bar (26.)

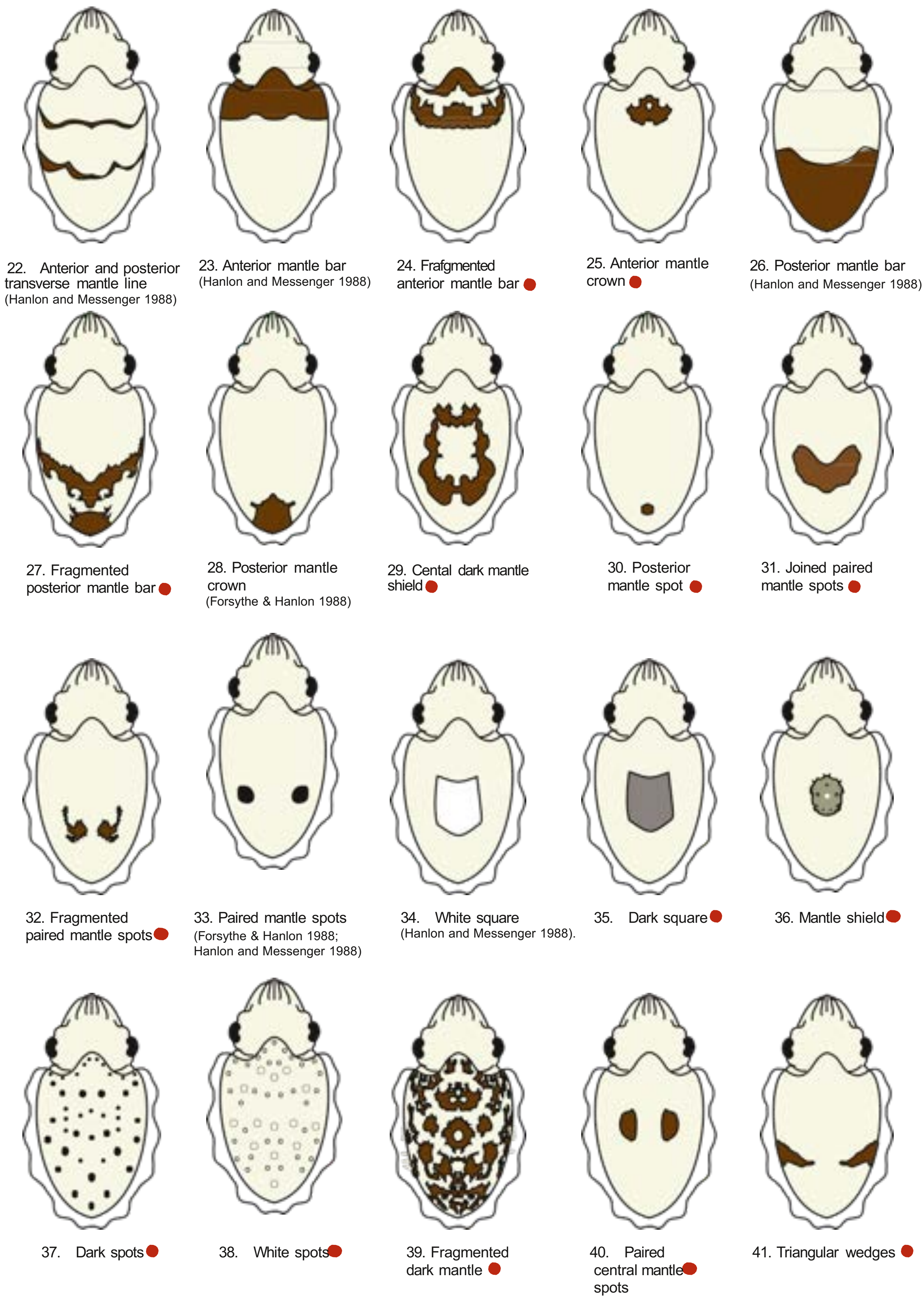
31. Joined paired mantle spots (n = 94). A butterfly-shaped dark area that is created by connecting paired mantle spots toward the center of the mantle.

32. Fragmented paired mantle spots (n = 19). A pair of spots located at the joined paired mantle spots (31) with two larger spots at the posterior of the mantle with thinner stripes extending towards the center of mantle.

33. Paired mantle spots (n = 209) (Forsythe and Hanlon 1988; Hanlon and Messenger 1988). A pair of very dark spots that appear posterior to the posterior transverse mantle line (22). These spots are also known as eye spots and are associated with a deimatic pattern (Hanlon and Messenger 1988), which is an interspecific signal that is induced by and directed toward a potential predator (Moynihan 1975). In S. pharaonis, we detected only one pair of spots, which were either round or rectangular in shape. The spots can appear as pair or as single spot on either right or left side of the mantle.


1. Pale
2. Yellow
3. Dark brown
4. Dark red
5. Anterior head bar
(Packard & Sanders 1971; Hanlon and Messenger 1988)
6. Arm bar
7. Posterior head bar with stripe
(Hanlon and Messenger 1988)
8. Red posterior head bar with stripe
(Hanlon and Messenger 1988)
9. White landmark spots
10. White head bar
(Holmes 1940; Hanlon and Messenger 1988).
11. Dark arms
(Hanlon and Messenger 1988)
12. Dark eye patch
13. Eye ring
(Packard & Sanders 1971; Hanlon and Messenger 1988).
14. Anterior eye spots
15. Dark arm stripes
(Hanlon and Messenger 1988)
16. Pink iridophore arm stripes
(Hanlon and Messenger 1988)
17. Red arms I
18. Brown arms I
19. Extended head crown
20. Head crown
(Thomas and MacDonald 2016).
21. Head spot

a)


22. Anterior and posterior transverse mantle line (Hanlon and Messenger 1988)
23. Anterior mantle bar (Hanlon and Messenger 1988)
24. Frafgmented anterior mantle bar
25. Anterior mantle crown
26. Posterior mantle bar (Hanlon and Messenger 1988)
27. Fragmented posterior mantle bar
28. Posterior mantle crown (Forsythe & Hanlon 1988)
29. Cental dark mantle shield
30. Posterior mantle spot
31. Joined paired mantle spots
32. Fragmented paired mantle spots
33. Paired mantle spots (Forsythe & Hanlon 1988; Hanlon and Messenger 1988)
34. White square (Hanlon and Messenger 1988).
35. Dark square
36. Mantle shield
37. Dark spots
38. White spots
39. Fragmented dark mantle
40. Paired central mantle spots
41. Triangular wedges

b)

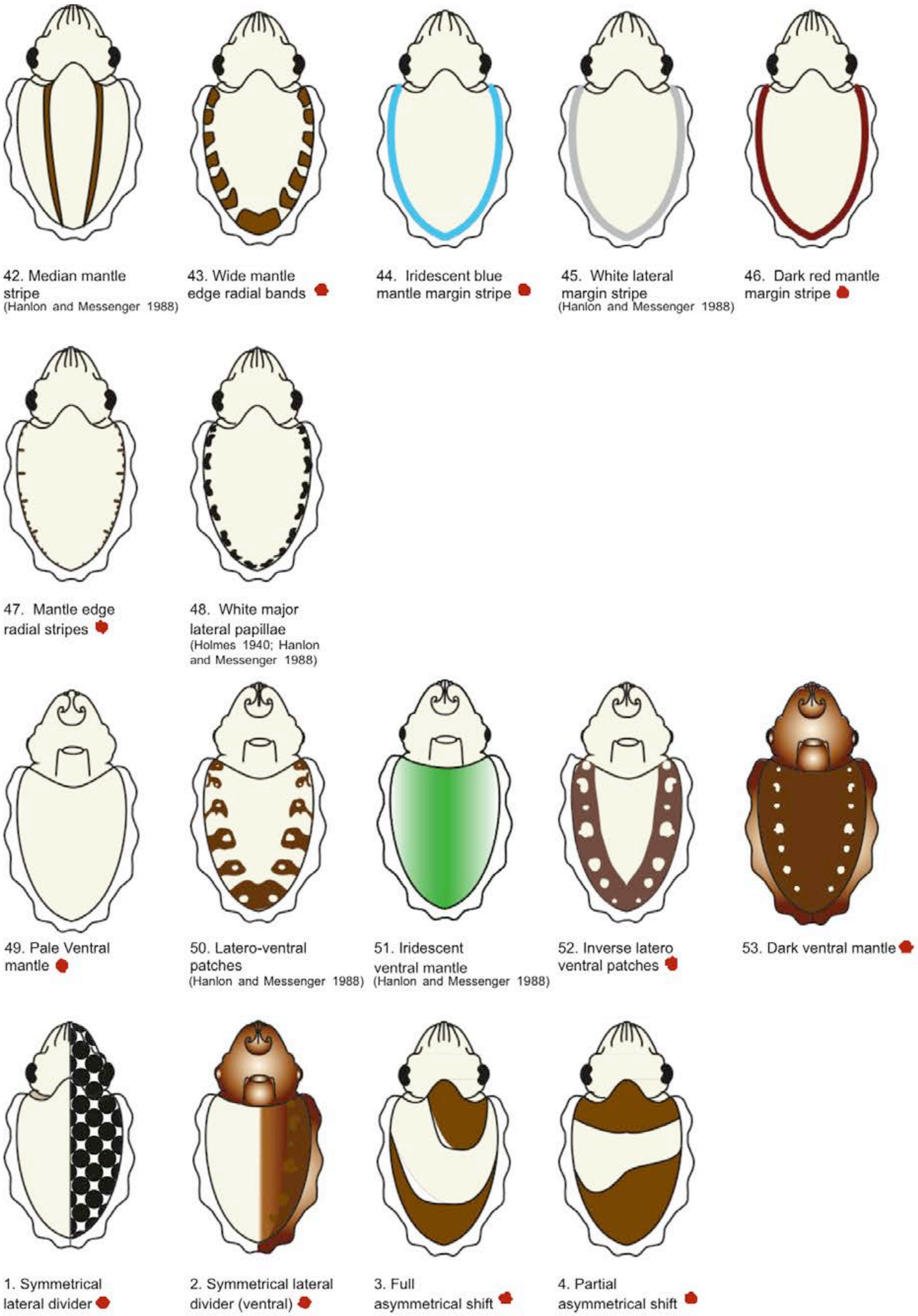


FIGURE 21 (a, b, and c)| Diagrammatic representations of chromatic components of body patterning in the cuttlefish Sepia pharaonis. Red dots in the figure indicate that component is newly described.

34. White square (n = 23) (Hanlon and Messenger 1988). A white, square-shaped area at the center of the mantle between the anterior and posterior transverse mantle lines (22). This component can also appear asymmetrical at times when the posterior edge of the white square is unevenly stretched down. This does not seem to be created by chromatophore arrangement, but rather to be brought about by stretching the skin downward towards the posterior mantle margin.

35. Dark square (n = 35). A brownish, dark, square-shaped area at the center of the mantle between the anterior and posterior transverse mantle lines (22). Unlike the white square (34), this square has edges undefined by contrast color.

36.Mantle shield (n = 101). Dark and light dots that appear in the same area as the white square at the center of the mantle between the anterior and posterior transverse mantle lines (22). This complex arrangement of both light and dark chromatic components creates a radial and symmetrical design. In some instances, a central white dot is a very large and dominant compositional element of this component.

37. Black dots (n = 620) & 38. White dots (n = 568). Small dark brown to black or white dots, respectively, that are homogeneously distributed across the entire dorsal mantle, head, and arm area. The combination of black and white dots produces a visual transition from a uniform body pattern to one that is stippled or mottled by regulating the overall tonal and two-dimensional textural expression of the animal. Subtle differences in color and the contraction/expansion of the chromatophores create a diverse range of tones within the mottled body pattern from light mottle to dark mottle (Holmes 1940; Hanlon and Messenger 1988).

39.Fragmented dark mantle (n = 51). Larger, high-contrast patches that are evenly and symmetrically distributed on the mantle, giving an overall appearance that is similar to damask ornamental design (Ward 1817). Each patch appears between the anterior and

Table 01

The ethogram of body pattern components for juvenile Sepia pharaonis. *(n) is the number of times each component was observed on video. Compare Figure 2*

Chromatic components:	n=
White	(471)
Yellow	(230)
Dark brown	(70)
Dark red	(13)
Anterior and Posterior transverse mantle line	(404)
Anterior head bar	(69)
Arm Bar	(22)
Posterior head bar	(69)
Red posterior head bar	(107)
White landmark head spots	(80)
White head bar	(173)
Anterior mantle bar	(78)
Dark arms	(73)
Posterior mantle bar	(43)
Dark eye patch	(122)
Eye ring	(32)
Anterior eyespots	(23)
Dark arm stripes	(13)
Pink iridophore arm stripes	(73)
Red arms	(10)
Dark arm triangle	(12)
Paired mantle spots	(161)
Unilateral mantle spots	(48)
White square	(20)
Dark Square	(35)
Asymmetrical white square	(3)
Emblem	(101)
Full Hellenistic mottled combination	(51)
Fragmented Anterior and Posterior mantle bar combination	(127)
Light Hellenistic combination	(19)
Trophy	(13)
Fragmented posterior mantle bar	(46)
Joined paired mantle spots	(97)
Split circle	(22)
Triangular Wedges	(60)
Unilateral Triangular Wedges	(6)
Dark spots	(620)
White spots	(568)
Median Mantle Stripe	(18)
Wide mantle edge radial bands	(30)
Iridescent blue lateral stripe	(62)
White mantle margin stripe	(43)
Dark red mantle margin stripe	(48)
Mantle edge radial stripes	(479)
White major lateral papillae	(316)
Symmetrical lateral divider	(46)
Full asymmetrical shift	(6)
Partial asymmetrical shift	(17)
(Fluorescent)	
Fluorescent reflective area	(10)
Pale Ventral mantle	(26)
Latero-ventral patches	(26)
Unilateral latero-ventral patch	(37)
Symmetrical lateral divider (ventral)	(15)
Iridescent ventral mantle	(25)
Inverse latero-ventral patches	(6)
Dark ventral mantle	(2)
(Frontal expression)	
Pale head and arm	(178)
Weak Deimatic combination	(16)
Light mottled combination	(297)
Dark mottled combination	(190)
High contrast frontal striping	(4)
Light disruptive combination	(38)
Dark disruptive combination	(11)
Red arm triangle combination	(8)
Dark head and arms	(36)

	n=
Textural components:	
Smooth skin	(234)
Coarse skin	(338)
Papillate skin	(77)
Postural components:	
Bipod	(5)
Extended first arms	(16)
Flattened body	(96)
Extended and curled fourth arms	(40)
Fully extended arms	(27)
Streamlined extension	(23)
Diamatic flare	(62)
Deimatic vertical lift and roll	(7)
Deimatic frontal flare	(3)
Bipod headstand	(2)
Crustaceans like aggressive mimicry	(12)
Berried	(57)
Sitting	(548)
Locomotor components:	
Frontal lift	(38)
Sideway roll	(34)
Escape (jetting)	(8)
Bottom suction	(24)
Hovering	(465)
Inking	(15)
Sand digging	(173)
Swimming	(553)

posterior transverse mantle lines (22). The patches along the mantle margin are created by the aggregation of dark chromatophores into long scalloped patterns. This is the most visually complex combination of chromatic features.

40.Paired central mantle spots (n = 22). Two half-dome- shaped components that appear between the anterior and posterior transverse mantle lines (22). The domes touch the lateral margins of the white square.

41.Triangular wedges (n = 66). Two V-shaped patterns located on the posterior transverse line (22) toward the posterior mantle edge. Laterally, these border the mantle boundary at the base of the fins. The posterior side of the shape tends to fade toward the posterior mantle margin. This component can appears on either the right- or left-hand side of the posterior transverse line toward the posterior mantle edge.

42.Median mantle stripe (n = 18) (Hanlon and Messenger 1988). A pair of distinctive dark lines that run along the full length of the mantle from the posterior end to the anterior margin.

43. Wide mantle edge radial bands (n = 30). Fourteen dark and robust rectangular blocks (seven each on the right and left sides), which form a wide radial band around the mantle edge. At the posterior mantle edge, the last two dark patches merge to form a larger block. This component is very similar to its ventral counterpart latero-ventral patches (51) (Hanlon and Messenger 1988).

44. Iridescent blue lateral stripe (n = 62). A bright blue iridescent stripe that runs longitudinally along the entire mantle margin at the base of the fins that outline the mantle. This stripe is often visible with other components, contributing to the deimatic pattern.

45. White lateral margin stripe (n = 43) (Hanlon and Messenger 1988). A white stripe that runs longitudinally along the entire mantle margin at the base of the fins that

outline the mantle. It appears at the same place as the iridescent blue lateral stripe described above and the dark red lateral stripe described below.

46. Dark red lateral margin stripe (n = 48). A dark red stripe that runs longitudinally along the entire mantle margin at the base of the fins that outline the mantle. It appears at the same place as the iridescent blue and white lateral margin stripes described above.

47. Mantle edge radial stripes (n = 479). Short to long dark lines that extend from the lateral margin toward the center of the mantle, running longitudinally along the en- tire mantle perimeter. The position of these radial lines seems to correspond with the mantle margin scalloping the major lateral papillae and the lateroventral patches (51) (Hanlon and Messenger 1988).

48. White major lateral papillae line (n = 316) (Holmes 1940; Hanlon and Messenger 1988). Six to eight white lines created as a result of papillae contraction located along the mantle margin by the base of the fins. When papillae contracted, they have a white line-like appearance as a result of the iridophores (Hanlon and Messenger 1988). Ventral mantle (49–53, Fig. 2c) – 5 ventral mantle chromatic components were identified:

49. Pale ventral mantle (n = 26). Similar to the Pale mantle of Boal et al. (2004), which has been described as a base color component that is produced by contracting the chromatophores to create a pale, white appearance.

50. Lateroventral patches (n = 63) (Hanlon and Messenger 1988). Six patches that are located on each side of the ventral mantle directly below the base of the fins along the lateral mantle margin. Each patch has a small circular opening that contracts and expands according to the darker portion of the patch. Lateroventral patches can only appear on either side of the ventral mantle.

51. Iridescent ventral mantle (n = 25) (Hanlon and Messenger 1988). A green, smooth, iridescent area distributed equally on the ventral surface of the mantle and on the edge of arm IV, and can be seen from the side or underneath.

52. Inverse lateroventral patches (n = 6). The light and dark areas of the lateroventral patches are inverted, creating a much larger dark area. The tonal contrast is reduced by increasing the surface area of the darker lateral band around the ventral mantle margin while leaving six to seven smaller white circles on both sides.

53. Dark ventral mantle (n = 2). This component is produced by homogeneously expanding the darker chromatophores on the ventral mantle, creating a solid and continuously dark appearance. Some of the small white circles along the edge of the ventral mantle are the only areas that remain slightly lighter in tone.

Supplementary chromatic condition (1–4, Fig. 2c)–The following four chromatic conditions were identified. These are not independent components; however, they supplement other chromatic components in describing the total body pattern expression of the animal.

1. Symmetrical lateral divider (n = 46). A chromatic condition where two complete body patterns coexist on two sides of the animal, divided by the central axis. This condition seems to be more apparent when fewer chromatic components are present, i.e., paired mantle spots, triangular wedges, pale mantle, anterior and posterior transverse mantle lines, and black and white dots.

2. Symmetrical lateral divider (ventral) (n = 15). A chromatic condition where half of the ventral mantle becomes darker with the expansion of the chromatophores. Although it is not a conventional understanding of countershading where the ventral surface is lighter than the dorsal of an animal, this chromatic condition has been previously described as an example of the counter- shading reflex of cuttlefish (Ferguson et al. 1994). The dark and

light sides are divided along the central axis of the ventral mantle. In some instances, the latero-ventral patches are slightly visible.

3. Full asymmetrical shift (n = 6). A condition where the anterior and posterior transverse mantle lines (22) are warped asymmetrically toward the anterior mantle edge. This condition does not appear to be created by the arrangement of the chromatophores but rather is brought about by uneven contracting of the skin which distorts body pattern.

4.Partial asymmetrical shift (n = 17). This mechanism appears to be similar to the Full asymmetrical shift (3) except that only the posterior transverse mantle line is shifted by unevenly stretching the skin toward the posterior mantle edge, without affecting the anterior side.

5.4.2. Textural components

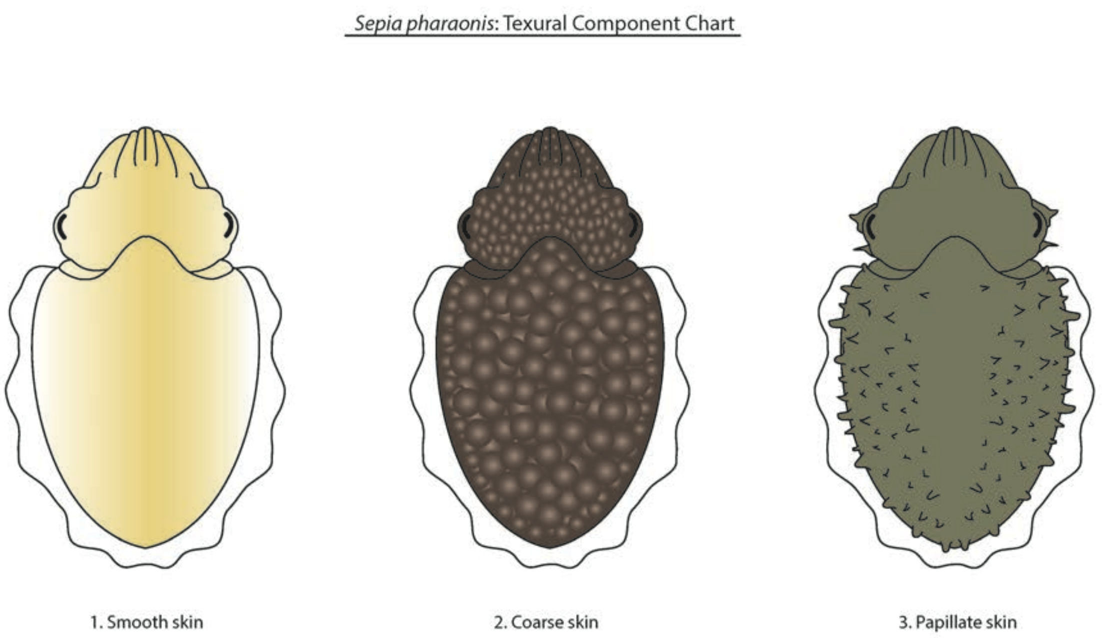


FIGURE 22 | Diagrammatic representations of texural components of body patterning in the cuttlefish *Sepia pharaonis*.

Three textural components (54–56) were identified:

54. Smooth skin (n = 234) (Packard and Hochberg 1977; Hanlon and Messenger 1988). A smooth texture with a total absence of any textural projections.

55. Coarse skin (n = 338) (Hanlon and Messenger 1988). A homogenous distribution of small projections on the surface of the skin, creating a more matte overall impression.

56. Papillate skin (n = 77) (Packard and Sanders 1971; Hanlon and Messenger 1988). A highly textured skin created by papillae (Holmes 1940) that protrude three-dimensionally away from the mantle surface. The papillae are most obviously observed along the mantle margin at the base of the fins. The papillae found on the mantle margin are flattened (Hanlon and Hixon 1980) and triangular shaped when viewed from above and the dorsal mantle papillae (Hanlon and Hixon 1980) are often cone shaped.

5.4.3. Postural components

Sixteen postural components (57–67 Fig. 4): were identified:

57. Bipod (n = 5) (Roper and Hochberg 1988). Arms IV are lowered to touch the substrate while the mantle is hovering parallel to the substrate. Arms I, II, and III can be either spread or together.

58. Extended first arms (n = 16). Arms I are extended out very much like the raised arms component only opening up into a V-shape. All of the other arms are tucked closer to the head, making Arms I an isolated forward protrusion.

59. Flattened body (n = 96) (Hanlon and Messenger 1988). The entire body is widened to reduce its thickness of the animal. This change in the entire shape of the animal forces the eyes to move from a lateral and frontal position to a more upward position.

60. Extended and curled fourth arms (n = 40) (Hanlon and Messenger 1988). One Arm IV is extended outward to the side of the head, often curled up at the tip. This interactions that are described by Hanlon and Messenger (1988).

61.Fully extended arms (n = 27). All arms are fully extended forward into an elongate triangular shape. In some in- stances, the arms appeared to be stretched forward as water extruded from the funnel, making a wave-like movement.

62.Streamlined extension (n = 23). While swimming, the animal's body transforms into a hydrodynamic shape. All of the arms are extended forward and together, and the mantle is slightly flattened and elongated.

63.Deimatic flare (n = 62). A flattening of the body combined with various other chromatic components such as eye spots, an iridescent mantle stripe, an eye patch, and a yellowish skin tone in response to a potential threat. The animal's head and arm regions are also flattened and widened with exaggerated Arms IV. The pink iridophore stripes are also very prominent.

64.Deimatic frontal flare (n = 3). While the animal hovers, Arms IV flare outward to make the animal look bigger. Simultaneously, chromatic components such as dilated pupils with dark eye rings and pink iridophore lines are expressed. In some instances, the animal also quickly reverses the chromatic expression from a Weak deimatic combination (56) to High- contrast frontal striping (59). This component was most often expressed during intraspecific interactions.

65.Bipod headstand (n = 2). A variation of Bipod (68), Arms IV are extended and touch the substrate. Using the con- tact points between the tips of the arms and the substrate as pivot points, the entire body is suspended in the water column at a sharp angle. This component was observed only twice in very small animals that exhibited a very dark chromatic component combination. Thus, it may be a type of masquerade, although this requires further investigation in the future.

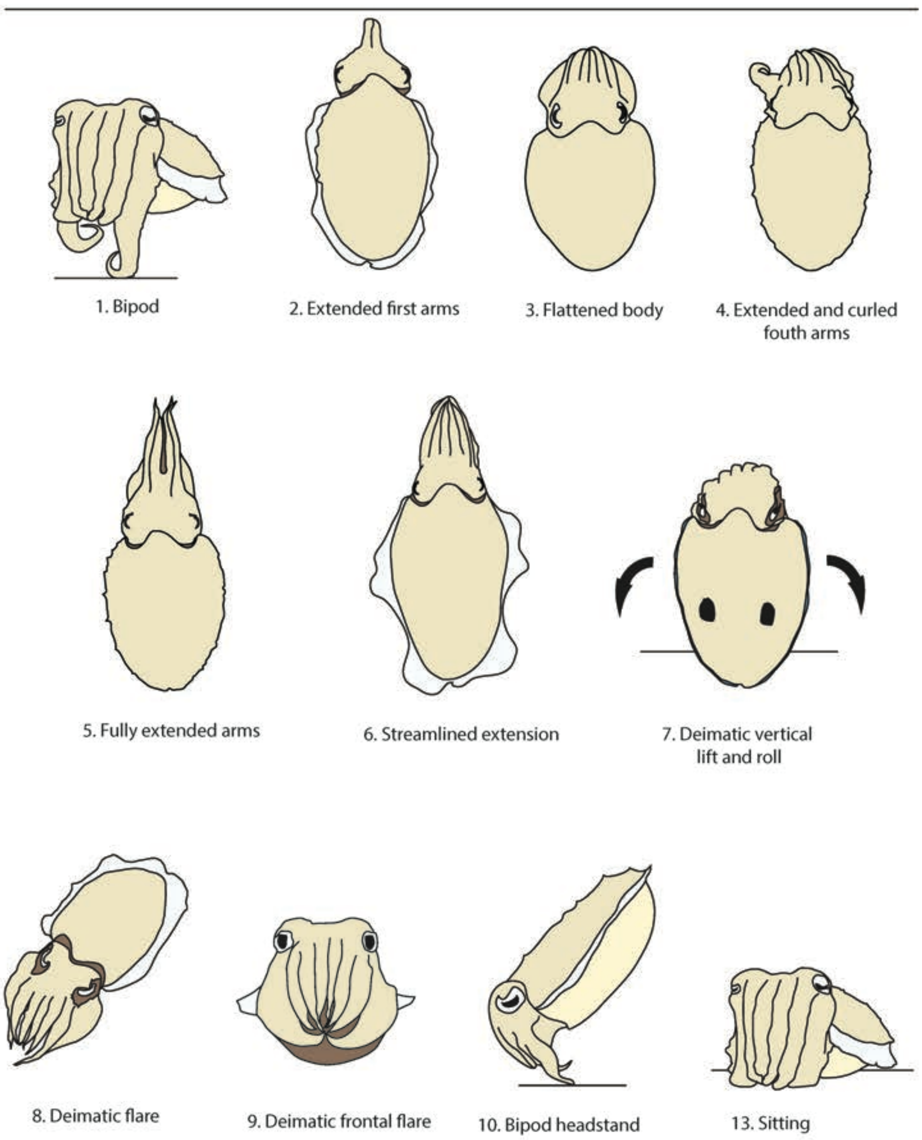


FIGURE 23 | Diagrammatic representation of postural components of body patterning in the cuttlefish Sepia pharaonis in crustacean like aggressive mimicry. a) frontal view b) ¾ view, c) side view with thicker mantle profile, d) mantle flatting during forward movement, e) fully flattened streamlined profile is expressed after fully engaged in hunting.

66. Sitting (n = 548) (Forsythe and Hanlon 1988; Hanlon and Messenger 1988). The animal rests on the substrate with- out burying itself. In many occasions, anterior mantle of the animal is held up so that the funnel is out of the sediment.

67. Crustacean-like aggressive mimicry (n = 12). (Fig. 5) The physical configuration of the arms is very similar to the Flamboyant (Hanlon and Messenger 1988; Okamoto et al.

submitted) and bipod (57) displays described previously. However, the posture described here is more similar to actively moving crustaceans rather than passively floating pieces of algae. Arms I are raised vertically with high-contrast stripes that range in color from red to dark brown. Arms II and III are extended forward with a similar dark stripe pattern. These arms are all bent in a way that resembles crustacean leg joints. Arms IV are spread out and positioned on the sides of the head, much like the pincers of a crab and/or lobster. The mantle is flattened down and almost invisible from the direct frontal view. The bases of Arms IV at the edge of the anterior head bar have distinctive and pulsating dark patches on both sides, similar to a passing cloud. This component was observed specifically during predation, with active side and frontal movement.

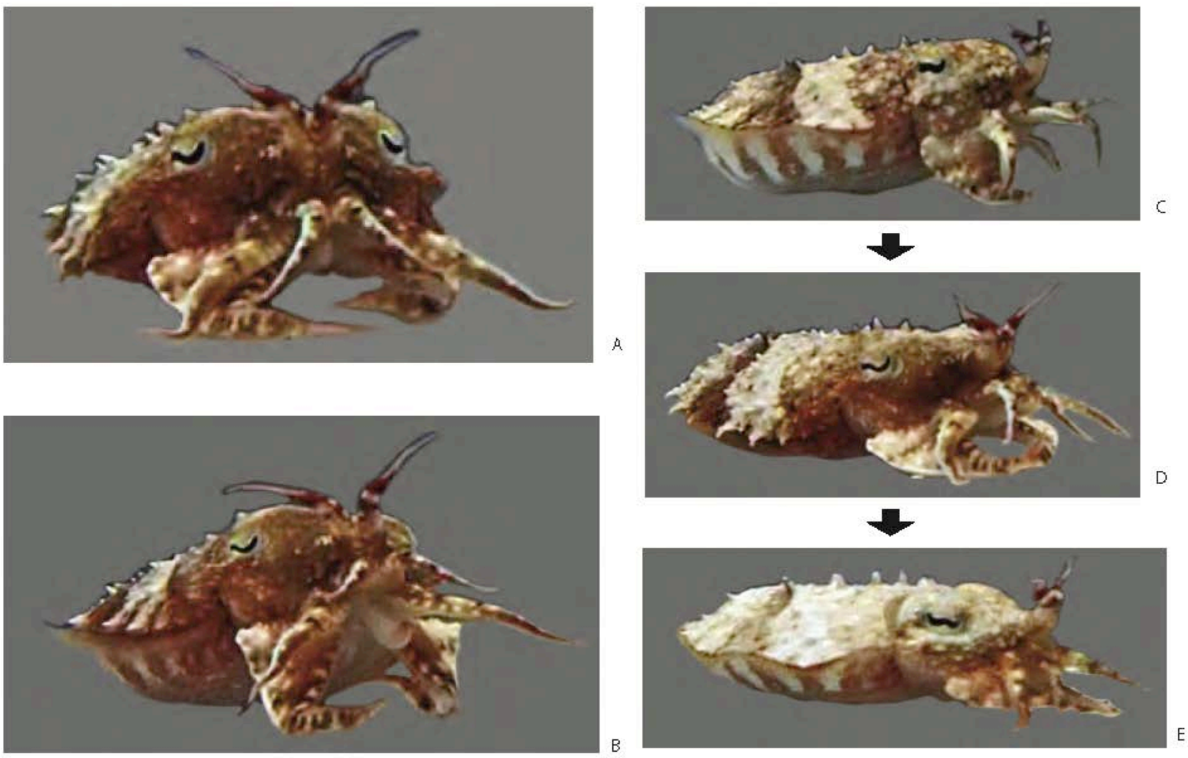


FIGURE 24 | Diagrammatic representation of postural components of body patterning in the cuttlefish Sepia pharaonis in crustacean like aggressive mimicry. a) frontal view b) ¾ view, c) side view with thicker mantle profile, d) mantle flatting during forward movement, e) fully flattened streamlined profile is expressed after fully engaged in hunting.

5.4.4. Locomotor components

Nine locomotor components (68–76 Fig. 4) were identified:

68. Frontal lift (n = 38). The animal raises its head as it moves backward, showing its iridescent ventral mantle.

69. Sideways roll (n = 34). The animal hovers sideways as it rotates on its central axis to expose its ventral mantle, particularly the latero ventral patches. This movement was frequently observed when multiple animals were in close proximity to each other.

70. Bottom suction (n = 24) (Hanlon and Messenger 1988). Juvenile animals sit on a smooth surface by creating a pocket of space between the external perimeter of their arms and the ventral mantle, which produces a suction cup, allowing them to adhere to the substrate.

71. Deimatic vertical lift and roll (n = 7) The animal lifts its head up, body almost perpendicular to the substrate while displaying distinctive deimatic chromatic components in both the mantle and head/arm regions in response to an alarming stimulus from above. Upon lifting its body, the animal swims sideways in a circular motion while maintaining its distance from the potential threat. This component combined with the chromatic expression makes the animal resemble a much larger fish-like animal when seen from the front.

72. Hovering (n = 465) (Hanlon and Messenger 1988). The animal maintains a steady position in the water column by using a combination of fin movements, water jetting from the funnel, and the buoyancy of the cuttlebone. It can also rotate its orientation without changing its location.

73. Escape/jetting (n = 8) (Hanlon and Messenger 1988). The animal jets water from its funnel to rapidly move back- ward to avoid predation. The body posture is streamlined, with the arms kept together in a central symmetrical line to create the maximum

hydrodynamic position. This component may also occur in combination with various types of inking and a change in color to dark red.

74. Inking (n = 15) (Hanlon and Messenger 1988). This is expressed in two forms: pseudomorph where dense ink with a higher mucus content that holds the shape of the ink together in salt water and a less dense puff of ink.

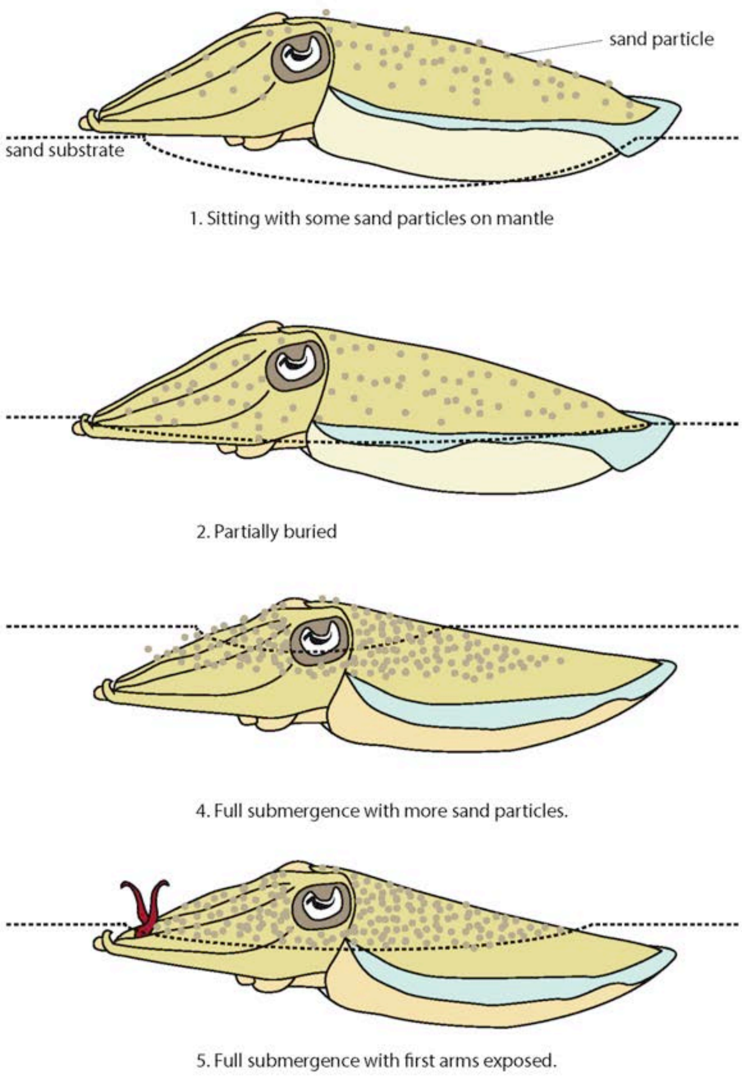


FIGURE 23 | Diagrammatic representation of postural components of body patterning in the cuttlefish *Sepia pharaonis* during sand-digging behavior

75. Sand digging (n = 173). (Fig. 6) (Mather 1986; Poirier et al. 2004; Packard and Sanders 1971; Hanlon and Messenger 1988). The animal digs into the sand to bury itself

under the substrate. Mather (1986) described this process as three different motor patterns. Sand digging can result in a sitting, partially buried, or fully buried animal. We have observed four different manifestations of this behavior: a) sitting with some sand on its mantle - most of its body is visible from above with some sand particles on its mantle; b) partially buried – much of the mantle is lower than the average substrate height with flattened body (3); c) full submergence with more sand – most of the animal is burial under the substrate and much of its mantle is covered with sand particles; d) full submergence with first arm exposed – posture is the same as c) with its first arm protruding out of the sand. In many cases, the arm pair is red (Figs. 7, 8 and 9).

76. Swimming (n = 553) (Boycott 1958; Wells 1958). The animal swims around in the water column and is able to move forward, backward, or to either side without any rapid jetting movement.

5.5. Discussion

Sepia pharaonis expressed a remarkable diversity of body patterns, which included 53 chromatic components, 11 postural components, and nine locomotor components and three textural components, which together provide this species with a wide range of behavioral expressions. This diversity is made possible by this species' well-developed central nervous sys- tem (Boycott 1961), neurally controlled chromatophore and iridophore organs, and flexible, soft-tissue arm design that lacks a skeletal structure. The number of body-pattern components that was observed in *S. pharaonis* (76) is comparable to the number that has been observed in other shallow water to coastal species: 87 in *Sepia officinalis* (Hanlon and Messenger 1988), 42 in *Sepia papuensis* (Hanlon and Messenger 1996), 39 in *Idiospius pigmaeus* (Moynihan 1985; Hanlon and Messenger 1996), 48 in *Loligo reynaudii* (Hanlon et al.1994, 2002), and 58 in *Sepioteuthis sepiodea* (Moynihan and Rodaniche 1982) (Table

2). Upon comparison among the species, it appears that benthic Sepia species show larger body pattern repertoires than more pelagic species. This may be due to more complex visual environments caused by wide varieties of substrates with which Sepia needs to blend. Since comparative data have been collected in situ and may be limited to specific behavioral conditions such as mating behavior, this remains speculative. The function and effect of each individual and/or collective body pattern expression remain undetermined. However, they may function in interspecific inter- actions, such as hunting prey and avoiding predator detection, and intraspecific interactions, such as mating, agonistic behavior, and species identification. These attributes help increase fitness of the species.

Prior to the present study, the most extensive cephalopod ethogram had been developed for *S. officinalis* (Hanlon and Messenger 1988), which has been the basis of our understanding of the behavioral ecology of the genus Sepia, particularly in terms of the chromatic components. Some of the components described in the present study have been

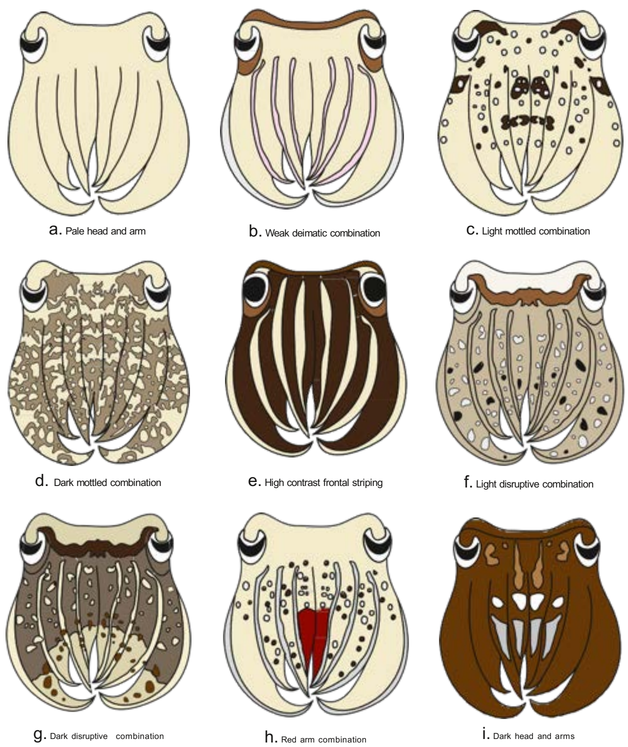


FIGURE 24 | Head and arms chromatic combinations- The head and arm chromatic components are slightly more difficult to observe due to variation in the postural components. However, if the animal stretches itself horizontally, parallel to the substrate surface, its thickness is reduced, and the e nti re body, head, and arms c an be vis ibl e simultaneously, allowing easier component detection. a) Pale head and arm - The entire head and arm region remains homogeneously pale due to the contraction of the chromatophores. b) Weak deimatic combination - Combines the dark posterior head bar (7) and lower eye ring (13) (Hanlon and Messenger 1988) components and also includes white stripes that accent the outer edge of each arm. These three visual elements give a slightly deimatic appearance. c) Light mottled combination & d) Dark mottled combination. Small dark brown/black (37) and white dots (38) homogeneously and symmetrically distributed across the entire head and arm regions, creating a diverse tonal difference between dark and light mottled appearances. e) High-contrast frontal striping A combination of the posterior head bar (7), lower eye ring (13), and dark arms (15) (Hanlon and Messenger 1988), giving a reddish brown to dark brown impression. This is also characterized by a set of large, dilated pupils, and distinctive stripes (16) (the polarization region described by Hanlon and Messenger 1988) in the middle of each arm, creating extremely high- contrast stripes that are laterally distributed evenly across the entire frontal area. f) Light disruptive combination & g) Dark disruptive combination - Consists of a white head bar (10), anterior head bar (5), and dark arms (15) and may also include dark dots (37) and white dots (38). The distinctively contrasting tones divide the head into two regions, giving it a disruptive (Hanlon and Messenger 1988, 1996) quality. The dark disruptive combination has the same components as the light disruptive combination only with more highly contrasting tones. The anterior regions of Arms I, II, and III beyond the arm bar may also have a lighter tone, which divides the head and arm regions into three distinctive areas. h) Red arm combination - A component that includes red Arm I (17) expression. In some instances, the animal is fully submerged in sand, making it impossible to determine the exact combination of chromatic components for any body part except Arm I. i) Dark head and arms - A uniformly dark coloration across the entire head and arms area, with four sets of smaller light patches on Arms I and II, and three sets of lighter brown patches between the anterior (5) and posterior head bar (7). This component appeared with other equally dark components, creating a very dark, rock-like expression. This component was observed in smaller juveniles

previously described in *S. officinalis*, while others are unique to S. pharaonis. In total, 53% of the dorsal mantle chromatic components, 14% of the ventral mantle chromatic components, 56% of the postural components, 100% of the textural components, and 66% of the locomotor components have been observed in both species. By contrast, the following components were observed by Hanlon and Messenger (1988) in *S. officinalis*, but not in the present study: white posterior triangle, white landmark spots, white neck spots, white fin spots, white fin line, paired mantle spots, dark fin line, tri-radial marking, white square papillae, wrinkled first arms, flanged fin, and raised head. Although these two species are not morphologically similar and do not share the same habitat. *S. officinalis* of the 107 described Sepia species, has the most extensive ethogram. Thus, comparison between these two species provides us with unique visual cues for species identification and may also provide us with a better understanding of the differences and similarities in the behavioral strategies of Sepia spp.

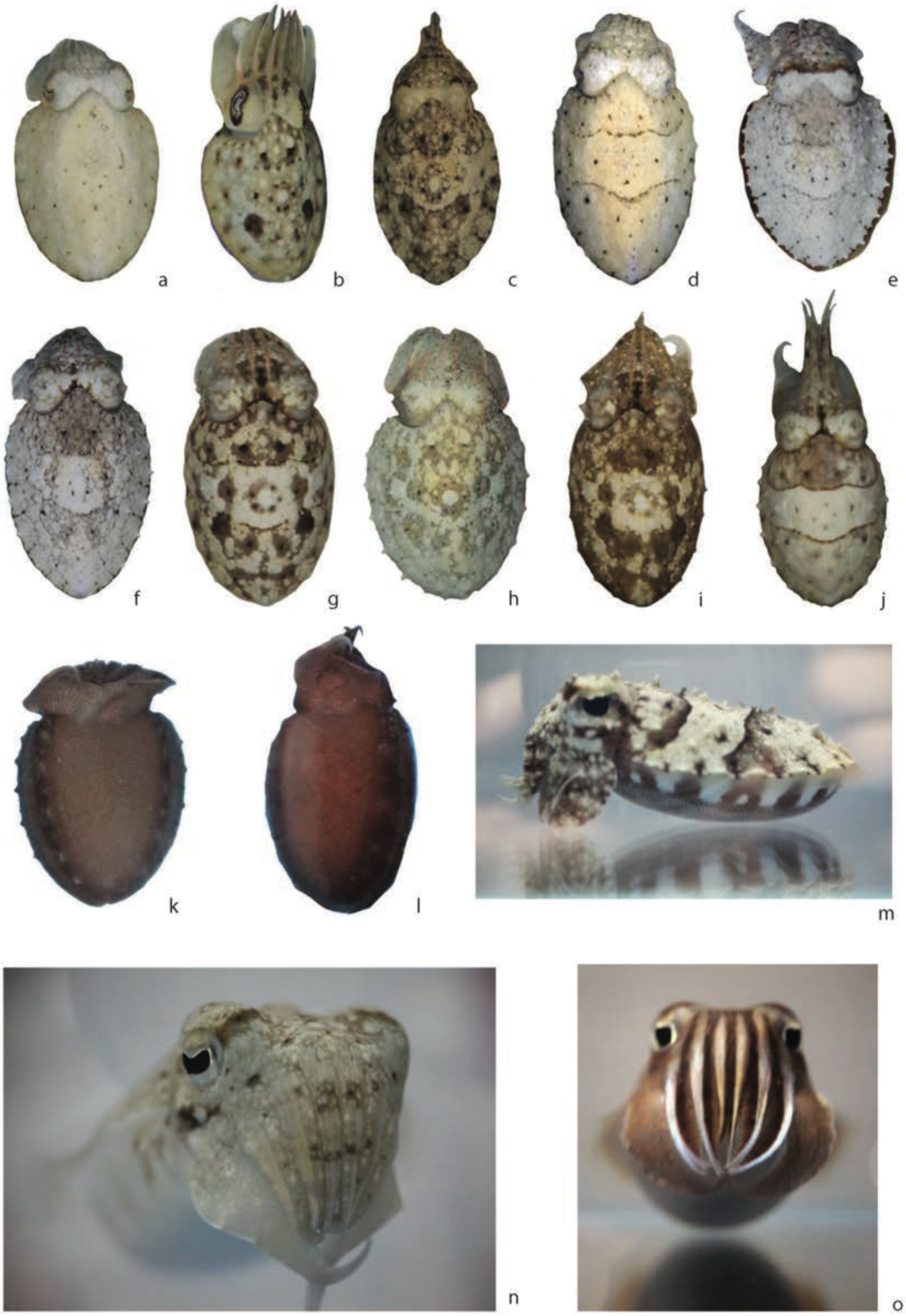


FIGURE 24 | Sample photographs of body patterning in the cuttlefish Sepia pharaonis. Each photographs listed contains specified components in numbers corresponding to the other charts. a) 1, 9, 10, 37, and 47 and 41; b) 1, 13, 16, 20, 33, 37, 38, and 47; c) 2, 6, 11, 14, 24, 27, 33, 36, 37, 38, and 47; d) 1, 10, 22, and 47; e) 1, 7, 11, 16, 37, and 47; f) 2, 16, 19, 28, 29, and 36; g) 1, 10, 13, 16, 36, 37, 38, and 39; h) 3, 16, 19, 24, 27, 29, and 36; i) 1, 7, 10, 16, 22, 23, and 37; j) 1, 19, 8, 5, 37, 13, and 12; k) 52; l) 2; m) 1, 11, 13, 24, 27, 37, 47, and 53; n) 3, 15, and 16

In this study, we included chromatic components produced by the iridophores that are green, pink, and blue. In *Sepia officinalis*, visual polarization sensitivity appears to play a 1998, 2002), improving their ability to detect prey items in the water column against the lighter water surface. In addition, there is evidence that some cephalopods also use the polarized reflective components produced by the iridophores for intraspecific communication (Shashar et al. 1996; Land and Nilsson 2012; Boal et al. 2004; Mäthger et al. 2006). The polarized light that is produced by cephalopods is not detectable by role in hunting behavior. Cuttlefish use their polarization sensitive vision to cut through the silvery reflection that helps many finfish species evade their predators polarization sensitive vision. Therefore, cephalopods are able to have a discreet communication channel using visual signaling. More recent studies have demonstrated that such reflective organs are also neurally controlled, indicating that they play an active role in cephalopod body patterns (Wardill et al. 2012) during intra- and interspecific interactions. The components produced by iridophores in *S. pharaonis* may also be important for such interaction.

Three forms of *S. pharaonis* have been recognized: *S. pharaonis* I in the Western Indian Ocean (Red Sea and Arabian Gulf); *S. pharaonis* II from Japan to the Gulf of Thailand and northern Australia; and *S. pharaonis* III in the Indian Ocean to Andaman Sea (Norman 2000). However, morphological and genetic studies suggest that it is a species complex (Reid et al. 2005), and a more recent phylogenetic study (Anderson et al. 2010) has divided this complex into five clades: western Indian Ocean, northeastern Australia, Persian Gulf/Arabian Sea, western Pacific, and central Indian Ocean clade. That study also suggested that *Sepia ramani* Neethiselvan 2001 is part of this complex (Anderson et al. 2010). These studies clearly indicate the complexity and diversity of this species and demonstrate that more extensive morphological and phylogenetic studies are still required, as well as more comprehensive study of body patterning. However, we hope that this catalog of type II *S. pharaonis* will complement such studies and help with species identification once extensive ethograms have been produced for the other 5–6 morphological/taxonomic groups. Such data are required to further understand the species' distribution and population size, as well as its life cycle and reproductive rate. Sepia pharaonis makes up a large percentage of the cuttlefishes that are harvested in the Indian Ocean and south- east Asia region, and so improved species identification will also play an important role in future stock assessments and protection from overfishing.

We believe that this catalog of the chromatic, postural, and locomotor behaviors provides a comprehensive list of the body patterns produced by type II *S. pharaonis*, at least in captivity, which will not only help with species identification, but can also be used as a tool for analytical and quantifiable behavioral studies. Most existing ethograms of cephalopods have been produced from direct observations in their natural habitats. Such

Table 2 Comparison of body pattern component among coleoid cephalopods

	Body pattern component					Distribution
	Chromatic	Textual	Postural	Locomotor	Habitat	
Sepia pharaonis	63	3	13	8	Benthic	Indo Pacific
Sepia officinalis	42	8	13	24	Benthic	Mediterranean
Sepia papuensis	14	12	9	7	Benthic	Indo Pacific
Idiospius pignaeus	17	14	4	4	Benthic	Indo Pacific
Sepioteuthis sepioidea	33	0	13	12	Pelagic	Caribbean
Euprymna scolopes	14	0	7	8	Benthic	Hawai'i
Loligo reynaudii	35	0	4	9	Pelagic	South Africa
Doryteuthis pealeii	32	0	9	12	Pelagic	N. America to S. America
Doryteuthis plei	22	0	13	11	Pelagic	Caribbean to S. America
Lolliguncula brevis	12	0	1	3	Pelagic	N. America to S. America

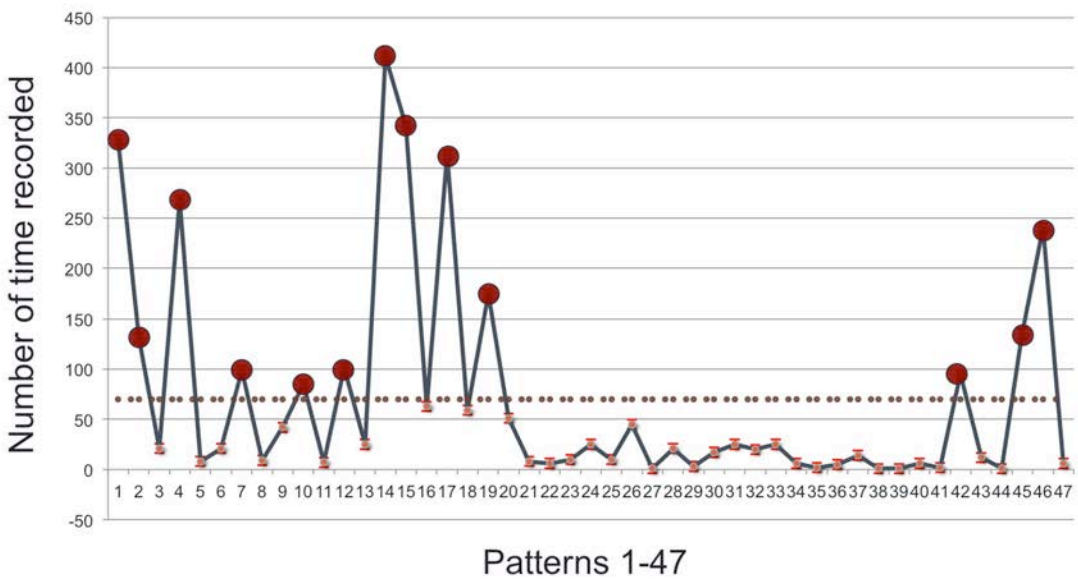
1) Holmes 1940, 2) Boycott 1958, 3) Hanlon and Messenger 1988, 4) Boal et al. 2004, 5) Adamo and Hanlon 1996, 6) Neill 1971, 7) Mather 1986(b), 8) Roper and Hochberg 1988, 9) Moynihan 1983b, 10) Moynihan and Rodaniche 1982, 11) Boycott 1965, 12) Byrne et al. 2003, 13) Moynihan 1983a, 14) Anderson and Mather 1996, 15) Hanlon et al. 1994, 16) 15) Hanlon et al. 2002, 16) Hanlon et al. 1999, 17) Hanlon et al. 1983, 18) Hanlon 1978, 19) Hanlon 1982, 20) DiMarco and Hanlon 1997, 21) Dubas et al. 1986

natural habitat observations are an effective method for producing ethograms, as there are significant and abundant external stimuli to trigger behavioral responses in the animals. In addition, *S. pharaonis* reared in an enriched environment exhibited significantly better growth rates and memorization abilities (Dickel et al. 2000; Yasumuro and Ikeda 2016), indicating that the environment in which this species lives alters its physiological condition and behavior. Therefore, animals that are in their natural habitat should be equipped with more complete behavioral repertoires. However, the natural habitat observation method also brings challenges due to the difficulties in making underwater observations, which results in limited access to the animal's behavior, e.g., during the mating season. Sepia pharaonis has been reported to live at a depth of 100 m, which requires a remotely operated underwater vehicle (ROV) and other similar devices to observe it in its natural habitat. Therefore, during this study, we observed the body pattern components of *S. pharaonis* in an artificial environment, which resulted in a comparable number of components being recorded as for other shallow coastal species. There are three possible explanations for this similarity: 1. Animals are also able to produce a rich variety of behavioral patterns in an artificial environment; 2. In situ observations that are made under selective conditions, such as during mating, can produce a much larger number of behavioral patterns than other conditions combined; and 3. There is a large overlap in the behavioral patterns recorded in situ and under laboratory conditions. Regardless of which of these is the case, our ethogram should provide a solid foundation and catalog of *S. pharaonis* body patterns that can be built on in the future.

5.5.1. Frequency and relative frequency analysis of chromatic components

Preliminary dataset for appearance frequency of chromatic components tested total 502 images extracted from total video footages. These images were analysed individually for 47 chromatic components described above by observed (1) / not observed score (0). Result shows that the frequency of these components displayed a huge difference among all components, maximum appearance was recorded at 411/502 (#14) and minimum at 1/502 (#27, #38, #39 and #44). 13 components, #1 (n = 328, 65%), #2 (n = 131, 26%), #4 ((n = 268, 53%), #7 (n = 99, 20%), #10 (n = 85, 16%), #12 (n = 100, 20%), #14 (n = 411, 82%), #15 (n = 131, 26%), #17 (n = 342, 68%), #19 (n = 310, 62%), #42 (n = 95, 19%), #45 (n = 135, 27%) and #46 (n = 239, 48%), scored higher than the average frequency per component at 70.2 times (n = 502, 14%, SD±20.9%, SE 3%).   This indicates that 13 components (27.7%) of total 47 chromatic components produced 82.5% (2723/3301 observed) of all components recorded. These results were comparatively analysed to second dataset calculating number of components used per one complete body pattern expression. This shows that *S. pharaonis* is using one to twelve components to produce an over all visual composite expression (n = 502, average frequency 41.75 times, SD 40.79 times, SE 1.82). The results also show that *S. pharaonis* is most likely to be using eight chromatic components (23.3%±8%) at average number of components at 6.58 components.

Pattern Frequency Table



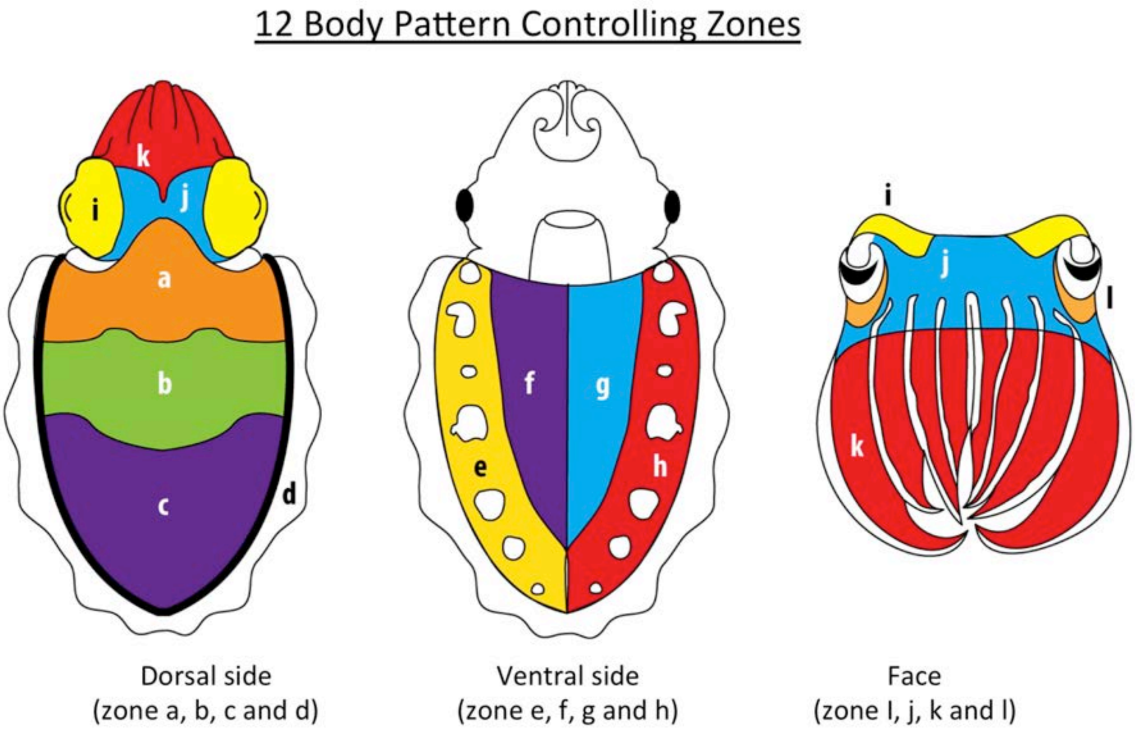
Sample number: 501, average: 70.23, SD: 105.35, SE: 4.707

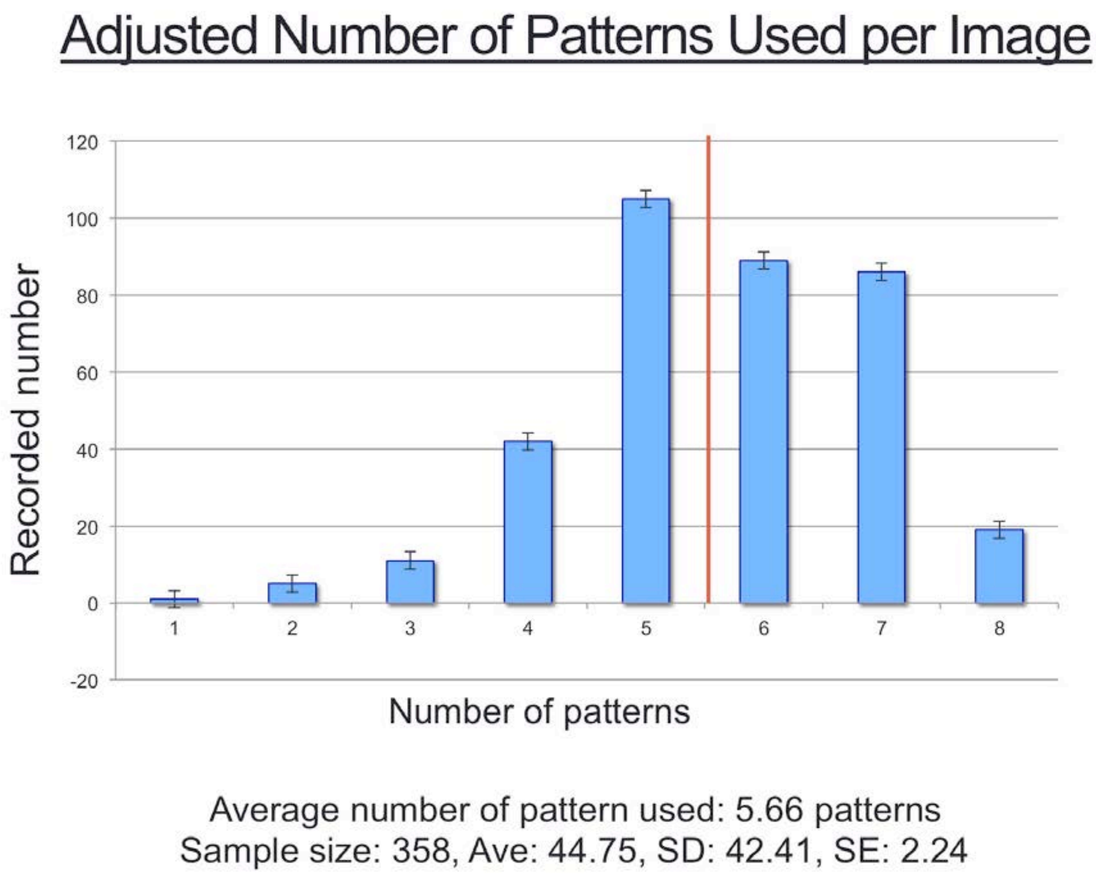
Combining these two datasets, we have resampled the original 502 images to 358 images (71%) by isolating 13 major components (82.5%), which scored higher than average and images using 1-8 (85.4%) components per image (roughly the same percentage as the first dataset). The resampled images (n = 358, Average frequency 44.75 times, SD 42.41, SE 2.24) shows that five components combination has the highest frequency (29.9%±11.84%) at average value of 5.65 components per image.

This combined statistical data comparatively suggests the following 1) *S. pharaonis*, under complex and diverse visual stimuli, expressed wide range of body patterns, which may includes such behavioral categories as cryptic, disruptive agonistic and deimatic display previously identified. 2) The body patterns were constructed of 47 different chromatic components found on dorsal mantle, ventral mantle and head/arms regions that are divided into 12 Chromatic Components Controlling Zones. 3) There are 13 major chromatic components, which are more frequently used to compose an overall body pattern than other 34 components. This suggests that chromatic components of *S. pharaonis* are hierarchically organized into two or more layers according to situational necessities. 4) Of 13 major chromatic components, average of 5.65 components appeared simultaneously composing a body pattern at a given condition.

5.5.2. Single and double conditional relative component frequency

Upon identifying the 13 major components, we investigated the relative relationship between the components by calculating Single and Double Conditional Component Frequency. The calculating method is simple; figures are determined by, if A is present what is the chance of B, C, D, etc. to appear (single condition) and if A and B are present, what is the chance of C,


12 Body Pattern Controlling Zones
k
i
j
a
b
c
d
f
g
e
h
i
j
l
k
Dorsal side
(zone a, b, c and d)
Ventral side
(zone e, f, g and h)
Face
(zone I, j, k and l)

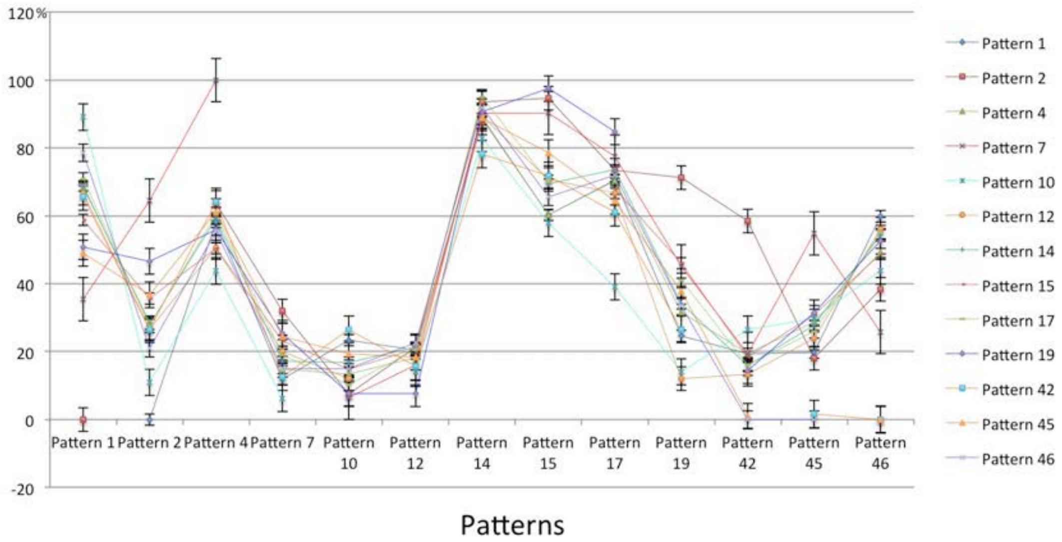

Adjusted Number of Patterns Used per Image
120
100
80
60
40
20
0
-20
Recorded number
1
2
3
4
5
6
7
8
Number of patterns
Average number of pattern used: 5.66 patterns
Sample size: 358, Ave: 44.75, SD: 42.41, SE: 2.24

D, E, etc. to appear (double condition). For example, if component #1 is present what is chance of component #2 to appear? Considering the previous data, this calculation method should be able to identify the six components that most likely to appear together.

The results from The Single Conditional Relative Component Frequency calculation (SCRCF) (table 1) from 358 images show that component #1 (61.7%±25%), #4(63.3%±17.3%), #14(89.6%±5.4%), #15(75.9%±14.9%), #17(70.8%±13.8%), and #46(44.9%±26%), have the highest average frequency rate among the 13 components, which consistently placed within top five highest frequencies (62% -100% rate to be selected) in SCRCF. Other seven components scored between 24 – 34% to be included with in the top five, which are significantly lower than the other more dominant components. SCRCF score also indicated that component appearance frequencies were more or less independent from each condition and the statistic did not fluctuate at this level.

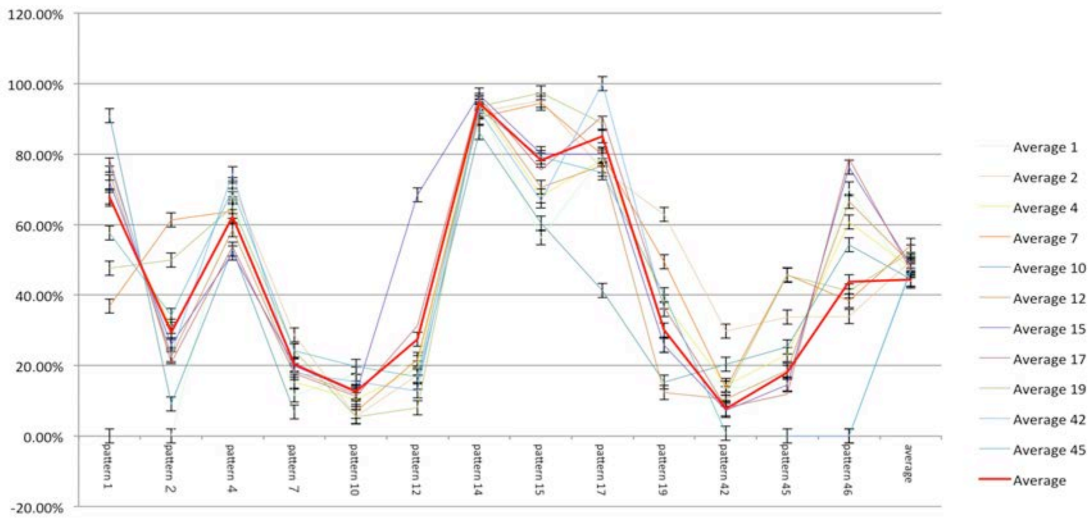
The same method was used to calculate Double Conditional Relative Component Frequency calculation (DCRCF). Since this method requires that two components are present simultaneously to be a condition, any duplications are omitted from the statistic, i.e. component #1 and #4 as a condition is the same condition as #4 and #1 and so on.
The each datasets were averaged out and compared (Figure 10). Although each double-conditions result showed diverse differences within each individual set and between each datasets, the overall average of DCRCF expressed a very similar trend as SCRCF. Component #1 group (67.8%±26%), #4 group (62.2%±8%), #14 group (94.4%±3%), #15 group (78.2%±14.1%), #17 group (85.1%±14.5%), and #46 group (43.8%±27.8%) had the highest average frequency rate among the 12 component groups. The average SCRCF and DCRCF scores are almost identical to each other. These results seem to represent that *S. pharaonis* uses components #1, #4, #14, #15, #17, and #46 as the most dominant chromatic group that often appear in unison. In contrast, components #2, #7, #12, #19, #42 and #45 are

Single Condition Relative Pattern Frequency Table

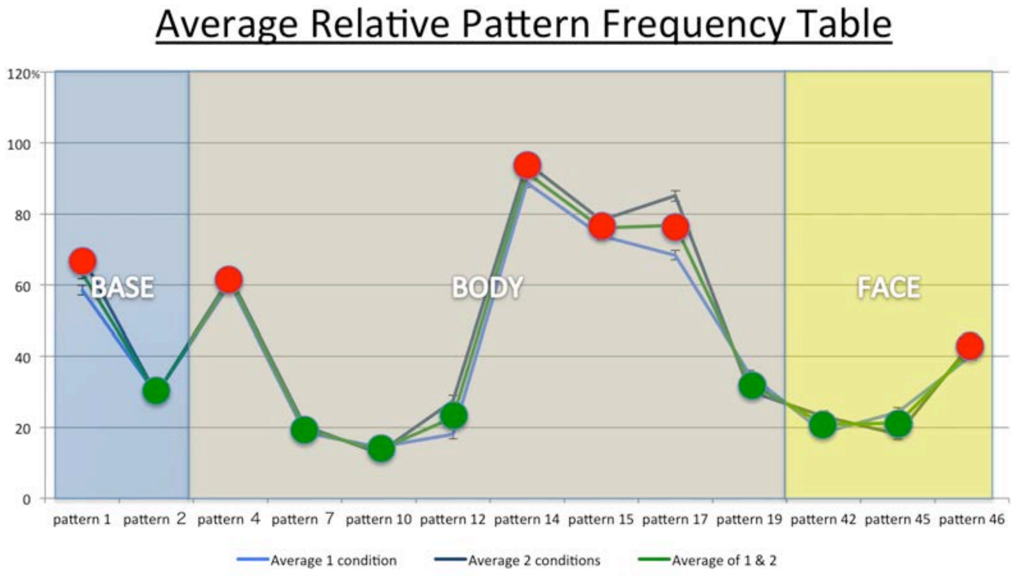


Sample number: 359, average: 44.75, SD: 42.41, SE:2.24
Average number of patterns used per image:5.66 patterns

Two Conditions Relative Pattern Frequency Table



Sample number: 359, average: 42.17, SD: 24.94, SE:1.316
Average number of patterns used per image:5.66 patterns



Sample number: 359, average: 42.17, SD: 24.94, SE:1.316
Average number of patterns used per image:5.66 patterns

subdominant components that appear less frequently and independent from other components additive behavioral signifier to the dominant chromatic group changing the visual impression of a complete body pattern appearance.

These results can be divided using chromatic component categories, base color, dorsal mantle and head/arms. Component #1 and #2 belong to the base color category. Components #4, #7, #14, #15, #17 and #19 belong in dorsal mantle category. Finally, component #42, #45 and # 46 belong in head/arms category. Considering these categories, each of these 13 components can be further categorized within these three categories. In base color category, component #1 is dominant and #2 is subdominant. In dorsal mantle category, component #4, #14, #15 and #17 are dominant and #7, #9, #12 and #19 are subdominant. In head and arms, #46 is dominant and #42 and #45 are subdominant element. For Base color and Head and arms categories, components are mutually exclusive to each other, i.e. cuttlefish can have pale white and yellow appearance at the same time. Similarly, it cannot have light and dark mottled appearance at the same time. In dorsal mantle category, all eight components can appear simultaneously, thus they are independent and autonomous within the category. With a simple probability calculation, this 2-8-3 combination, *S. pharaonis* is capable of producing 420 different body patterns which produce multivalent rage of appearances and component combination #1, #4, #14, #15, #17 and #46 is the most dominant and frequent combination (Figure 11 & 12) that is functioning as a base foundation of all the other permutations. These 420 possible combinations occupy a fraction of total body pattern that *S. pharaonis* can produce using all 47 chromatic components postural, textual, and locomotor components.

Through this investigating the body patter behavior of *S. pharaonis*, we have discovered that, in many instances, its wide repertoires of chromatic components were capable of matching to numbers of highly complex artificial images, such as painting, photographs and movies. Considering the fact (it is probably safe to assume) that animals that participated in our

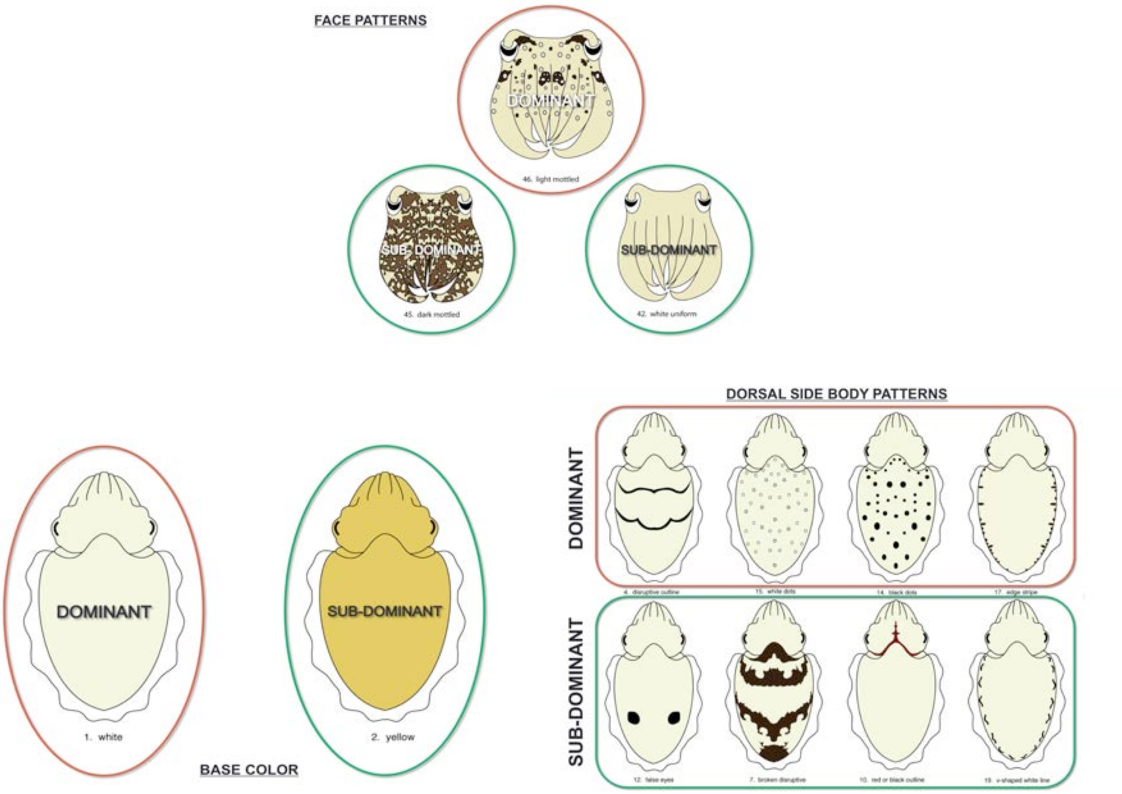


FIGURE 25 | Diagram describing both dominant and subdominant chromatic components for head, base color and dorsal mantle patterns according to number of appearance.

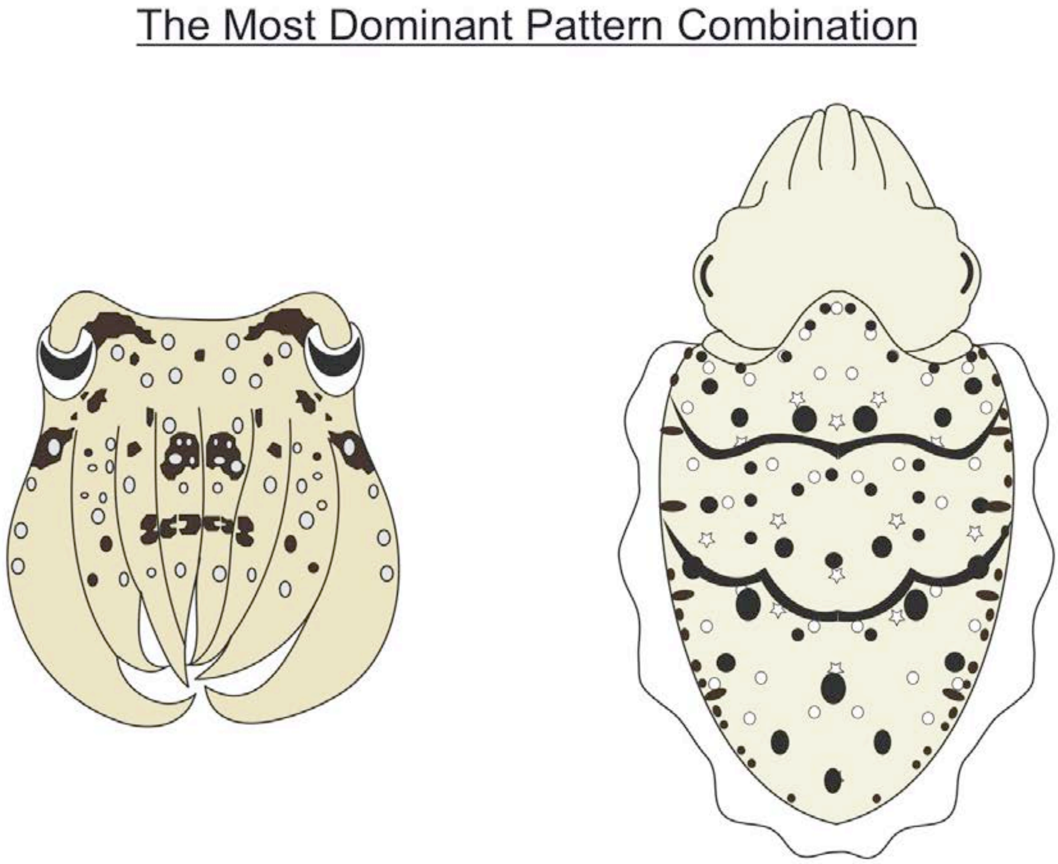


FIGURE 26 | The most dominant chromatic components combination created by combining all dominant components together. From the simple statistical analysis, it seems that *S. pharaonis* expressed this particular combination more often than others. This also coincides with the empirical knowledge of observation.

experiment have no prior knowledge of each images contextual background (historical, cultural or conceptual), they reacted to each images as simple visual inputs. Hence, the visual stimuli were processed and outputted as body pattern expression without cultural discrimination. Here, it is important to also note that, in many cases, cuttlefish could not visually match the images and we are not claiming that their body patterns can match any complex images with consistency.

S. phraonis's body pattern matching highly culturally driven images has a potential to cultivate a new discourse in visual production. The phenomenon that we have observed

FIGURE 27 | The most dominate chromatic combination may look similar to the photographic image shown above.

during our experiment suggests that a set of body patterns developed in the course evolution is paralleling our own visual language. The history of human image production found in fine art, architecture, entertainment, fashion and design has been, among many other criterions, a quest for and expression of individuality at highest philosophical and visual order. Certainly, Claude Monet's impressionist painting and Jackson Pollock's abstract expressionist painting appear differently to many of us and this visual difference directly correlates with maker's conceptual, personal, contextual differences that most often consolidated in to the idea of genius.   However, when an invertebrate animal, such as cuttlefish is so perfectly mimicking a genius, then the genius suddenly lose his/her novelty and credibility of their uniqueness and sucked into a much larger realm of codified visual language governed by biological system necessary for an organism to relate to its immediate surrounding, a squid's realm. In other words, this phenomenon not only speaks about cuttlefish's incredible visual adaptation, but also represents an interspecies visual design strategy cultivated in evolution. Hence, the results of this study may function as a catalyst in re-establishing our understanding of visual expression as a whole at least in metaphorical way but hopefully through both scientific and artistic realms.

This study detected and described 47 chromatic components of *S. pharaonis* by maximizing the stimuli, deconstructing each body patterns into autonomous visual fragments and reconstructing the fragments into a whole. Although, we feel that we have detected successful numbers of components through this two-step method, the list of far from completion. We have observed number of chromatic components during our daily interaction with the animals that have been omitted due to lack of sufficient documentation. We feel that it is necessary to continue building the list of components including textual, postural and locomotor components for further investigation of cuttlefish adaptive coloration. Thus far, we understand that *S. pharaonis* is using average of 6 chromatic components as a base foundation which other components can be added or subtracted depending on its surrounding changing its over all appearance with least amount of effort, hence allowing it to adapt to wide range of substrate changes and other external conditions very quickly. In short, it controlling very significant but fewer visual element to maximize the effect of its body pattern while conserving its energy. Continues investigation of its body pattern behavior is necessary in understanding its mechanism as well as relationship with our own visual culture.

5.6. Art work phase 2: Camouflage to pixel

Creative work phase 2 consists of two different works that relate to the experiments conducted at NRCC. 1) Mixed media installation with resin coated photo-panels and video, and 2) Mixed media installation with live cuttlefish and streaming video display. After 2nd visit to NRCC where many photographs and videos were recorded while major 20th century art works were shown to S. pharaonis via computer-regulated substrate-monitor.

1) 61 CUTTLE was made from photographic data collected. Photographs were pasted on each individual circular wooden panel and coated with polymer resin. There are 61 different images describing cuttlefish body pattern displayed according to the images bellow. The selected art works range from Pablo Picasso, Henri Matisse, Hugo Balla, Jackson Pollock, Mark Rothko, Takashi Murakami, Gerhard Richter Sigmar Polke, etc.… covering most of the major 20th century art movement and their key artists. The concept of this piece was to create pixels made of each data, which also refer to each chromatophore on the cuttlefish skin. 61 panels can be arranged in any way to create flexible total impression while maintaining the individual autonomy of the image. The work was first exhibited in Paris during an international art fair in 2010, which was further refined and exhibited in Okinawa at Okinawa Jikan Museum and Okinawa prefectural Art Museum (currently called Okimu.) A video work titled Selfworld (2010) was also produced during this time. In this video, one may be able to track the body pattern change based on the images shown to the cuttlefish. During the exhibitions, both photo-panels and videos were exhibited together to create a sense of cohesive installation.

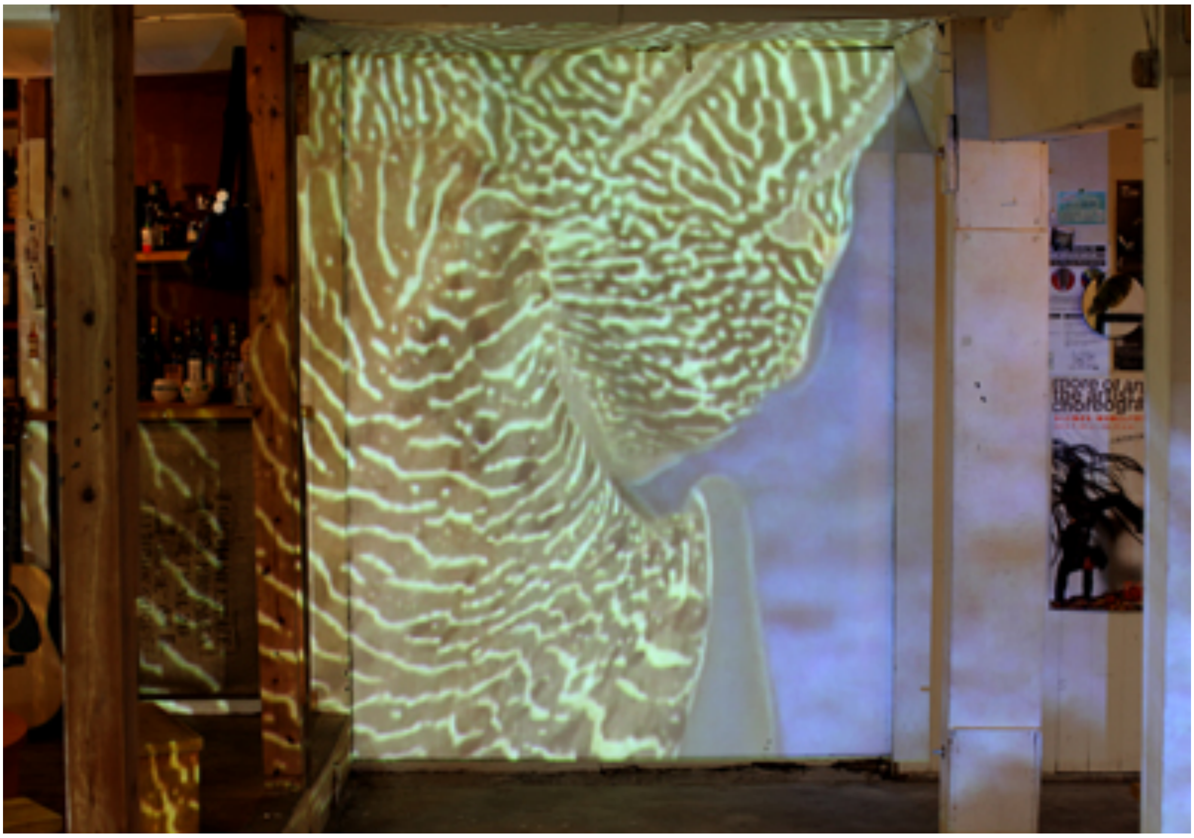
2) CEPH LAB was produced based on the actual experiment conducted at NRCC. The experimental system that I have design was never in use at the time by any ceph researcher. During this exhibition at Okinawa Kodomonokuni Wonder Museum, a new and compact experimental apparatus was designed to house two juvenile cuttlefish in a

tank. Here, it is important to note that keeping live cephalopod in a small tank still remains to be challenging and difficult. An outside video camera is streaming a video to a monitor placed under the tank. Two cuttlefish body patter changed according to the real time change of the environment, which then was filmed using second camera and projected to a large sphere suspended from the ceiling. The spectators were able to experience cuttlefish body pattern shift in real time as an animal and in the large-scale projection.

FIGURE 28 | SW series (2011) *Sepiotheuthis lessoniana* is watching Death Star exploding on a monitor.

FIGURE 29 | 61 Cuttle (2011) Each panel have a Sepia pharaonis reacting to various 20th century art works. The panels can be rearranged freely to produce another impression of an image.

a)



b)

FIGURE 30 | Ceph Lab (2011) Bothe images are from the installation installed at a) Okinawa Prefectual Art Museum and b) Okinawa Jikan Museum (Maejima Art Center)

FIGURE 31 | An example of 61 Cuttle exhibited at Okinawa Prefectural Art Museum. For this exhibition, photo panels were arranged into a triangle configuration.

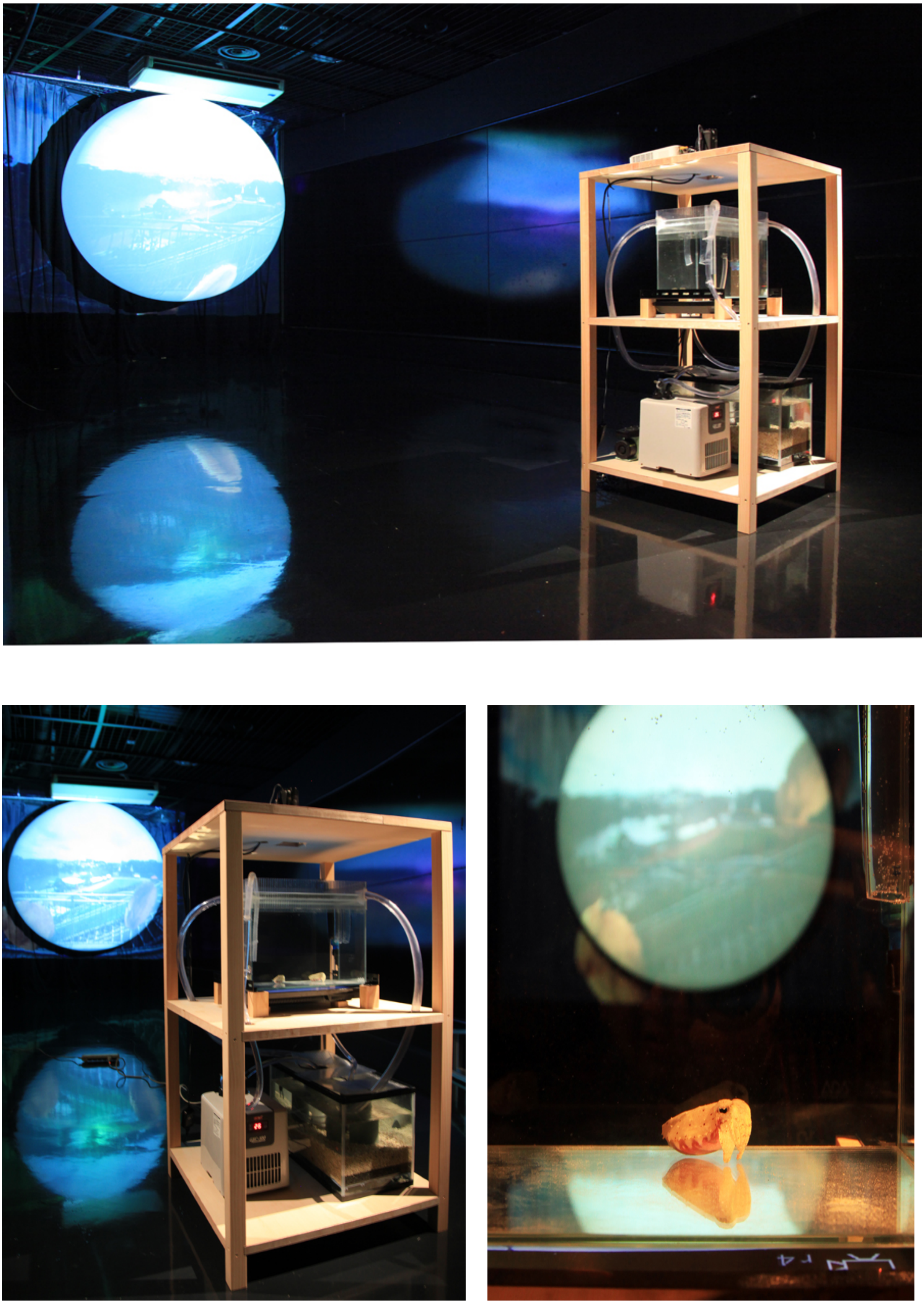


FIGURE 32 | CEPH LAB/イカラボ exhibited at Wonder Museum in Okinawa. A compact cuttlefish husbandry system was installed with streaming video unit and projection.

5.7. Art work phase 3: camouflage to communication

Completing new sets of art based on cuttlefish camouflage, my focus moved away from the idea of visual representation that camouflage has presented. Thus far, it was clear that cuttlefish camouflage could adapt well to certain types of paintings. This finding has shown that there is an overlap between total expression of cuttlefish chromatic components combination and techniques and modes used in paintings. Cuttlefish body patterns matched more accurately to landscape and abstraction better than figurative work. This was a natural and expected outcome considering that subject depicted are similar in their origin, nature. A painting is a culmination of strategies t capturing a certain essence of a landscape by simplifications and/or exaggerations detectable elopements of the nature. A cuttlefish camouflage is also a mimesis of nature combined visual parts that are simplified and exaggerated. In this way, it is evident that in translation process, human and cephalopod share a type of visual conversion of natural information despite the physiological difference in each respective sensory system.

Unlike in ethological understanding which discriminates crypsis from communication, the non-communication established by camouflage that deny receiver's response by reducing all potential signals to the surrounding noise is an important indication of special recognition which, philosophically speaking, transmits, massive amounts of information that clearly exceeds individual signals expressed by a animal. Hence, the important difference is that signals are a type of information that does not naturally occur as a passive voice in nature. In other word, communication requires different manifestation of visual information as non-communicative patterns, and both of them co-exist simultaneously in the total body pattern system of cephalopod and most likely in art. Hence, it has become more important for me to investigate this dualism and relationship through both Art and Science.

1) Cuttlefish Body pattern Communication Module (CBCM) consists of 10 painted resin casted sculpture of a cuttlefish. Each on is painted with distinctive cuttlefish body patterns gathered from photograph and video. Each one of these cuttlefish can and have been exhibited as a simple sculpture. However, the main porpose of these sculptures are meant to be viewed by a live cuttlefish rather than human. As we feel kinship with a 3D model of human figure, cuttlefish may also react to these figures as a type of curiosity. Furthermore, each body pattern painted may express different signals that alters behavior of the animals. These sets of sculptures are my first attempt to verify cuttlefish signals and non-communication. Upon placing each figiures to cuttlefish, the behavior was video recorded for movement tracking and body pattern response.

FIGURE 33 | Some examples of Cuttlefish Body pattern Communication Module (CBCM)

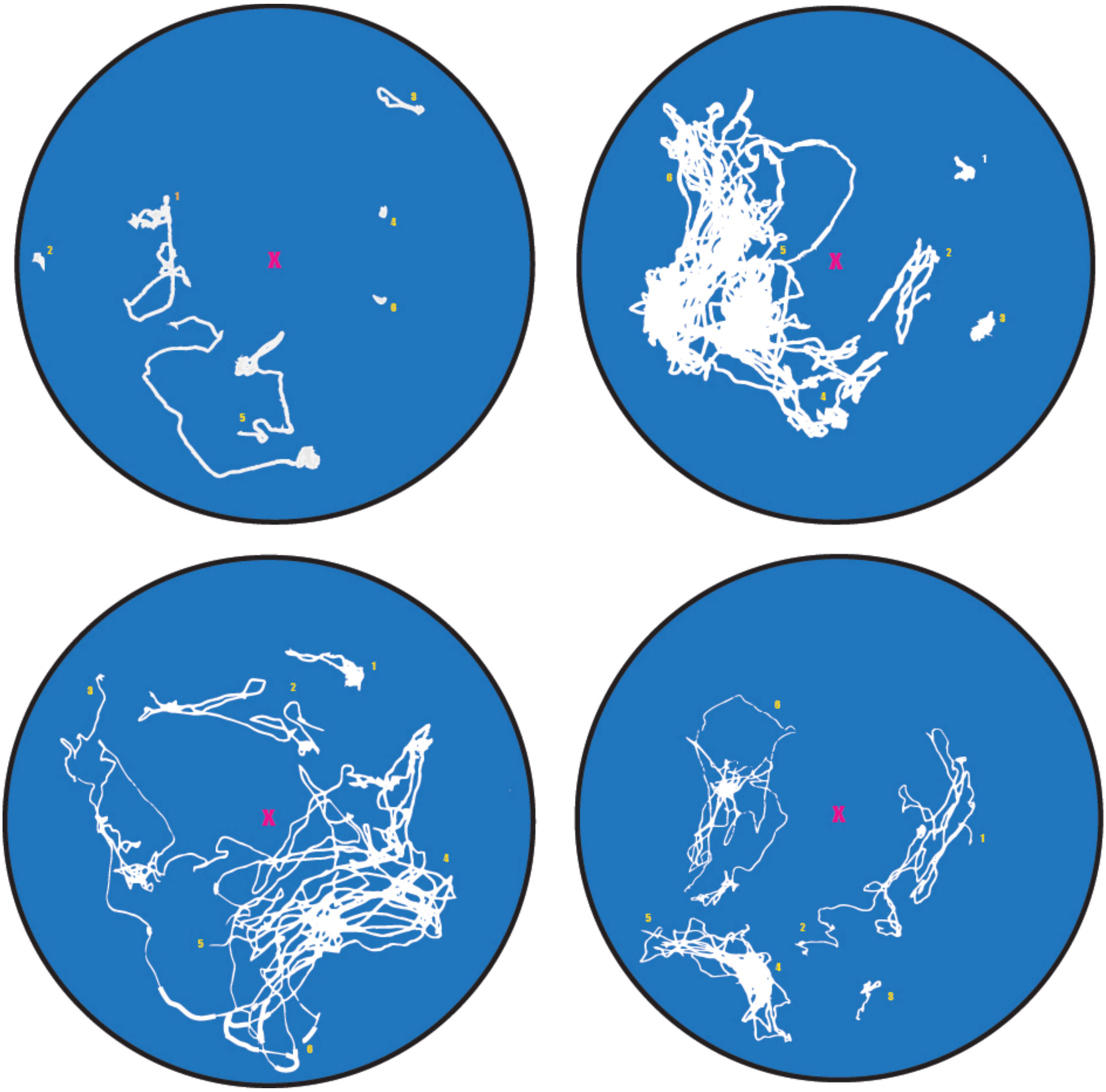


FIGURE 34 | Movement tracking date of 6 animals after presenting the Cuttlefish Body pattern Communication Module (CBCM) in a tank. Each model is showing different response from the animals.

2) 2000 Miles / Pablo (Firefly squid Bioluminescent communication Module) are two separate works focusing on the bioluminescent communication of cephalopod. Bioluminescence is the most widely use form of communication on the plant, which occurs in deep sea environment by many invertebrates and vertebrates. These projects attempt to par

take in this communication via cephalopod engaging in the firefly squid, *Watasenia scintillans* of Toyama Bay Japan. Firefly squid appear annually at Toyama bay Japan which otherwise live in deep sea. It has a set of large photophores on their third arms as well as many smaller blue and green photophores on their mantle and head. It is generally believed that smaller photophores are used as a countershading to conceal their silhouette against water surface light seen from the ventral side of the animal, and large photophores are used to startle its predators and for communication purpose with other members of the species in the dark. Firefly squid also possesses three pigments in its' eyes and physiologically possible to have a color vision or something similar to it. Currently, there is no evidence of their color vision behavior, however, considering its large eyes, firefly squid in highly visual animal.

FIGURE 35 | The commercial fishing vessel of Shinminato Fishery Association. I spent 10 days on a vessel in search of Firefly squid, *Watasenia scintillans.*

<u>CHAPTER 6 A Comparative study of body pattern development of the oval squid, Sepioteuthis lessoniana</u>

This first project *20,000 Leagues Under the Sea* is a collection of photographs taken of various deep sea cephalopod species collected at Smithsonian Museum of Natural History. The museum has collection of cephalopod samples from 19th century on wards and is extensive Under the supervision of Michael Veccione, I was able to record both fixed samples from Atlantic coast expeditions and many video sample from the past expeditions, both of which are not easily assessable without participating in the expeditions. The project was making resin coated photographs as a preliminarily research for the project. Pablo (Firefly squid Bioluminescent communication Module) was then produced to participate in Firefly squid conversation. Pablo was a painted transparent resin model equipped with a blue LED light with different frequency of flickering. With a generous support from Shinminato Fishery organization, I spent 10 day on a fixed net fishing vessel attempting to communicate with a school of Firefly squid which has gathering in the net. The process of recorded with various underwater cameras for later analysis.

a) *Heteroteuthis (Stephanoteuuthis) atlantis Voss*

b) *Octopoteuthis deletron*

c) *Chiroteuthis picteti*

d) *Watasenia scintillans*

e)Pablo

f) Pablo

g) detail

FIGURE 36 | *20,000 Leagues Under the Sea* (a, b and c) and Pablo (e,f, and g), and *Watasenia scintillans* which was used for behavioral experiments including video response experiment.

3) AORI ROV is a squid shaped Remote operative underwater vehicle. The idea was to create a ROV to record squid behavior in its natural environment without disturbing it. There has been a series of such attempt by BCC in the recent years and shown some success. AORI ROV was equipped with two GoPro cameras for recording and three motors for mobility. Unfortunately, it was two big to use it as strong current in the ocean pushed the ROV despite of its full power thrust. Simultaneously, I learned that such device is possible to make with a bit more effort in engineering knowhow that I did not have. This project is calling for a perfect opportunity to collaborate with other more knowledgeable expert.

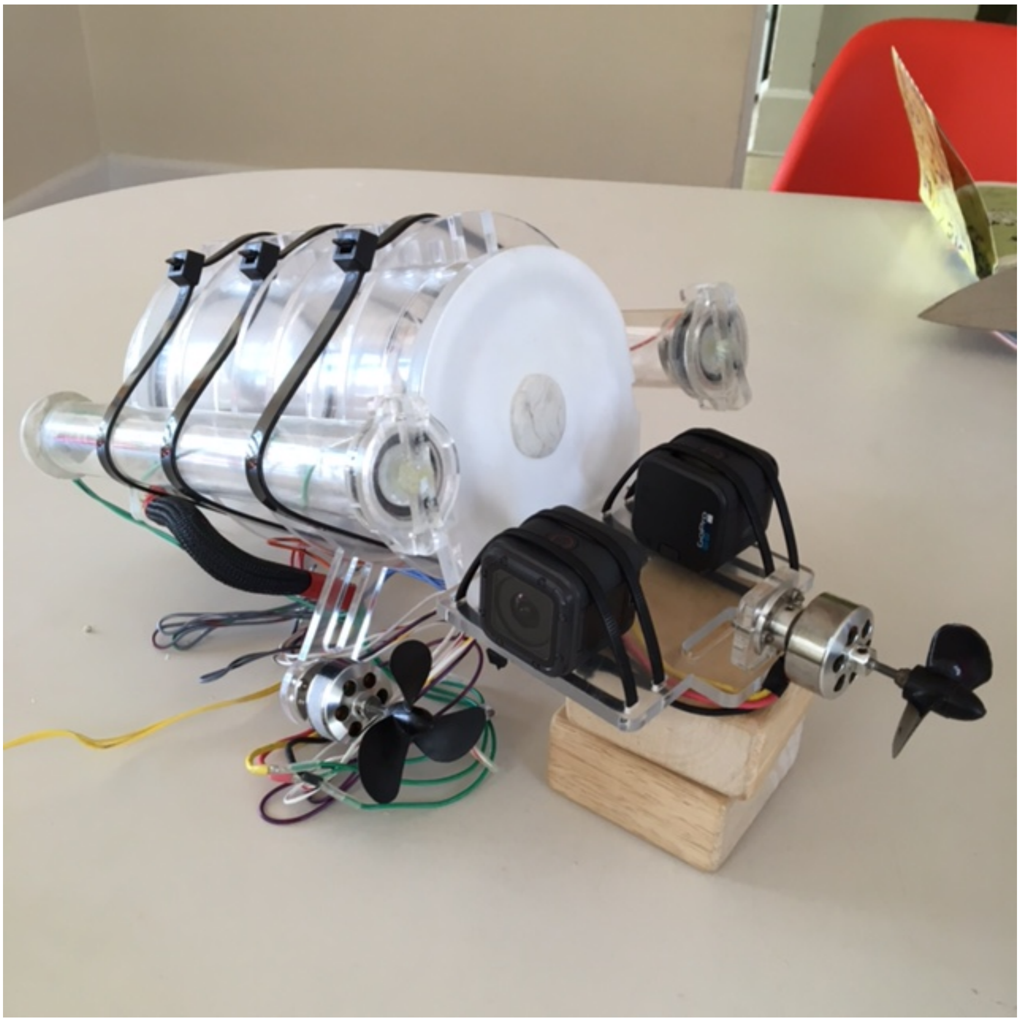
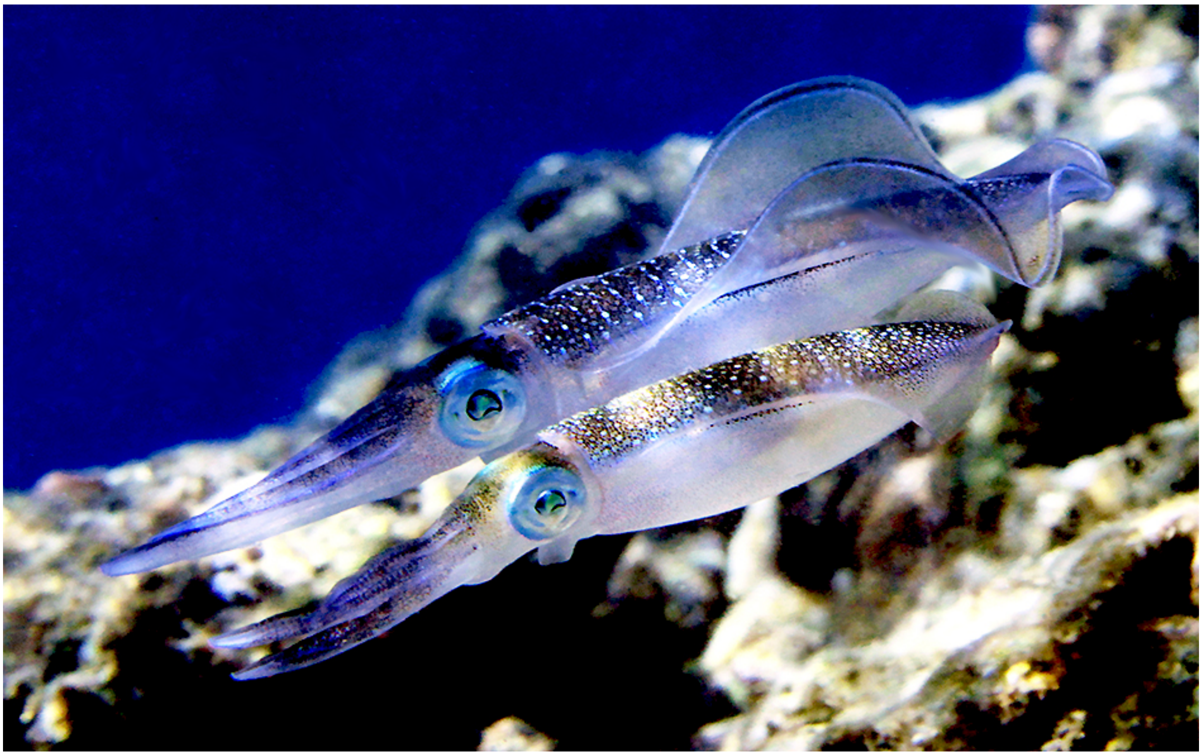


FIGURE 37 | The interior mechanism of AORI ROV. The center is the main CPU chamber connected to a plate holding two Gopro cameras.

FIGURE 38 | Testing AORI ROV at University of the Ryukyus Cephalopod Laboratory. A live *S. lessoniana* was also placed in the tank to see the reaction of the animal.

FIGURE 39 | An underwater view of the AORI ROV.

CHAPTER6. A Comparative study of body pattern development of the oval squid, *Sepioteuthis lessoniana*

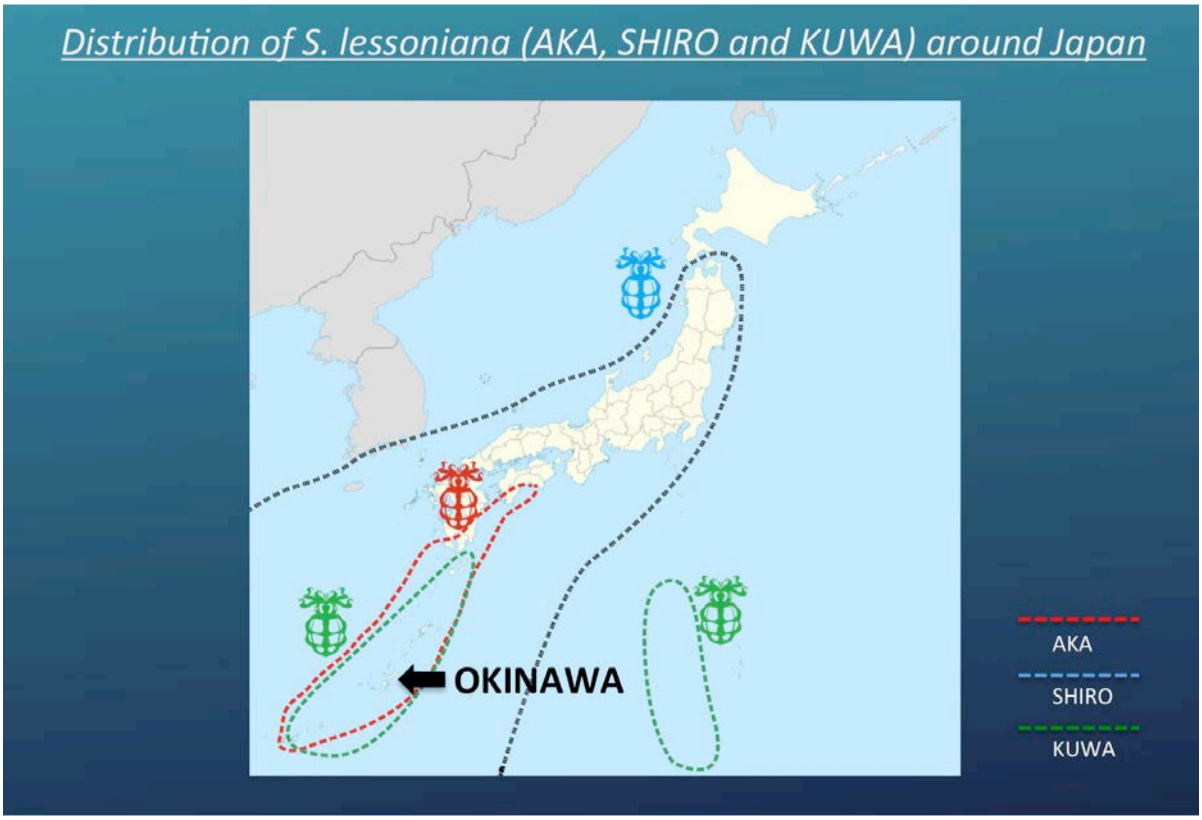


6.1. Introduction

Oval squid, Sepioteuthis lessoniana is widely distributed in temprate to tropical water ranging from northern Japan to Australia, Hawaii to Medetranian, and is know to form cryptic species complex. Grouping behavior is observed in both aquatic and terrestrial animals. In marine environments, many fishes show conspicuous grouping behaviors, namely shoaling or schooling, for defense and/or offense purposes. Pitcher defined a shoal and a school as cohesive aggregations for foraging, spawning, and predator evasion for a social group of fish; schooling behavior can be exhibited by fish in a shoal and appears as synchronized swimming behavior characterized by polarization. Accordingly, the structure of a school depends on the polarity and synchrony among the fish. On the basis of this theory, many researchers have studied the schooling behavior of fish. In addition, abundant information on the formation and function of schooling behavior in fish is available. With regard to ontogeny, many pelagic fish gradually develop schooling behavior following hatching, and it is related to metamorphosis or development of the central nervous system. The onset of a fish school can be discerned based on the decreases in the distance and angle between individuals within a population.

Squid is a major competitive counterpart of fish in the marine environment, and they are often presented as an example of convergent evolution in terms of mode of life, morphology, and behavior. Similar to fish, some squids demonstrate schooling behavior, and several studies have evaluated shoaling or schooling behavior of loliginid and ommastrephid squids, both in captivity and in nature (California market squid *Loligo opalescens*, Caribbean reef squid *Sepioteuthis sepioidea*, short-finned squid *Illex illecebrosus*, and oval squid *Sepioteuthis lessoniana*. The main sensory modality regulating the schooling behavior of squid is vision, in contrast to fish that use both the lateral line and the eyes. In *L. opalescens*, a school is composed of uniformly sized individuals, as seen in fish, and becomes more compact and more parallel with increasing squid size. In *I. illecebrosus*, the inter-individual distance between schoolmates decreases with increasing school size (i.e., the number of schoolmates). In *S. sepioidea*, the belt-shaped arrangement and parallel orientation of schoolmates and the specific roles of some individuals as scouts or sentinels have been documented in natural populations. In *S. lessoniana*, a phylogenetically close species of *S. sepioidea,* the same school formation has been preliminarily reported in nature, in addition to the size-based arrangement of individuals in a school.

Similar to fish, the onset of schooling behavior in juvenile squid has been partially reported for some species; however, these studies did not refer to the ontogenetic pro- cess of schooling behavior in detail. In the case of S. lessoniana, Lee et al. recorded that schooling behavior was observed within two weeks of hatching. However, their definition of a school is unclear, and the ontogenetic changes of schooling behavior, particularly in terms of the spatial arrangement of schoolmates, were not described. Thus, it was not possible to precisely compare the schooling behavior of fish and squid. Such a comparison may provide basic information on the population dynamics of these two major fisheries resources, and moreover, this information may add useful insight to the control of squid behavior in aquaculture. In the current study, in order to elucidate the details of the ontogenetic process and morphological features of schooling behavior in squid, we observed hatchlings and juveniles of S. lessoniana in captivity.



UMINCHU (Okinawan fishermen)

Okinawan fishermen (Uminchu) have been dividing *S. lessoniana* into three different types, AKAIKA, SHIROIKA, and KUWAIKA based on size, coloration, and habitat because of the differences in taste and market value. Recently, recreational fishers have adopted this type descriptions.

	AKA	SHIRO	KUWA
Color	reddish	whitish	darker
Body type	Narrow and long mantle	thick and wide mantle	small
weight	over 5kg	M: 3kg F: 1.5kg	100-200g
habitat	outer reef at 60-100m depth.	widely distributed in both inner and outer reef	shallow inner reef

Currently descried differences between species

	AKA	SHIRO	KUWA
Coloration	1. Reddish in color 2. Red and brown chromatophores are fund in the ventral side of the funnel.	Brown chromatophores are fund in the ventral side of the funnel.	Dark appearance. Red and brown chromatophores are fund in the ventral side of the funnel, and no chromatophores or scattered red chromatophores are present on the dorsal side of the funnel.
Number of eggs in an egg capsule	9	5	2
Spawning bed	deeper location than SHIRO (20m or more?) staghorn coral	seaweed and sunken twigs	inside a dead table coral found in shallow water
ML	35cm	35cm	12cm

Okutani (2005)

6.2. Materials and Methods

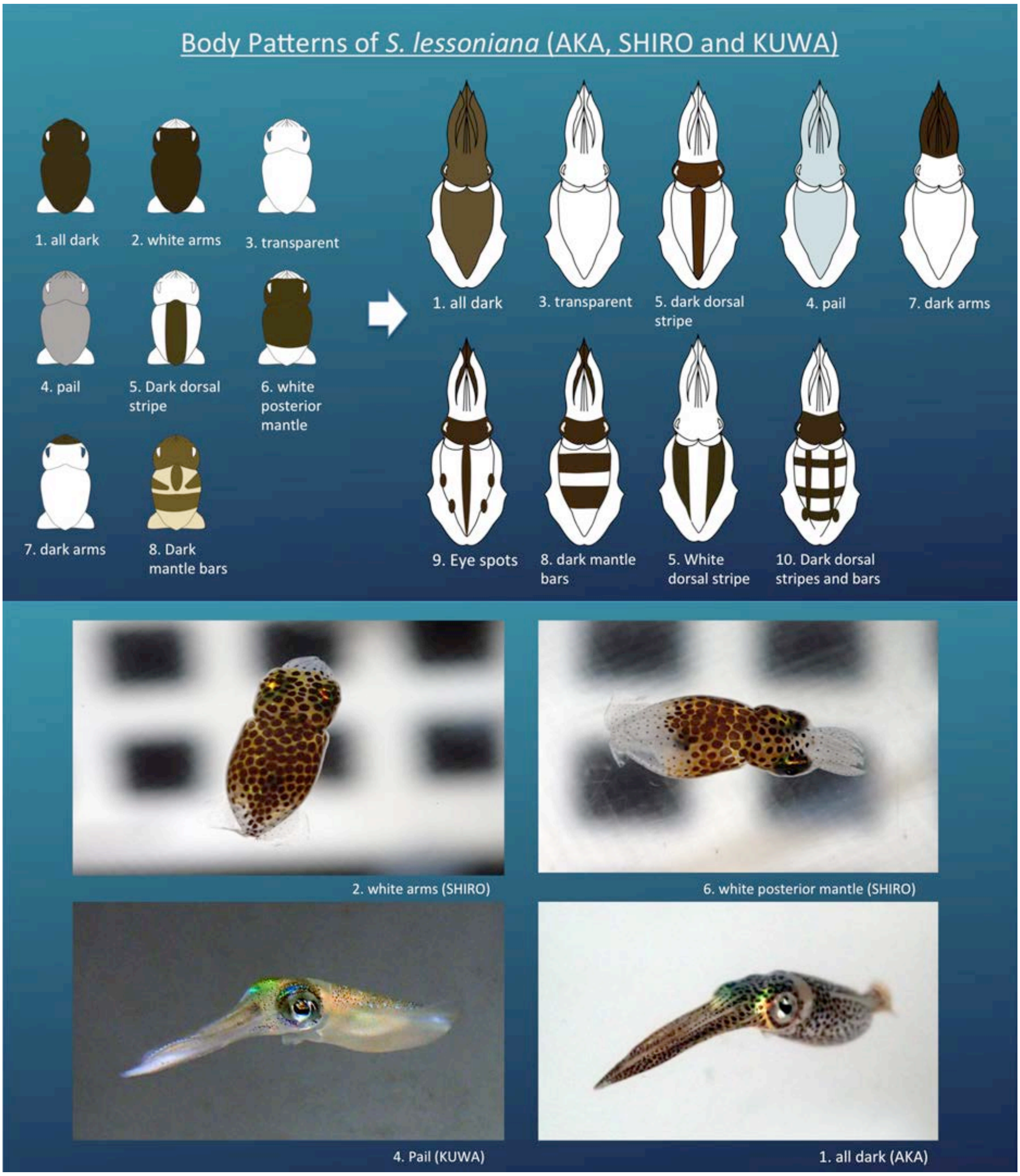
Egg cases of S. lessoniana were collected from inshore waters near Cape Zanpa, Okinawa Island, the Ryukyu Archipelago, Japan. The egg cases were transported to the Department of Chemistry, Biology and Marine Sciences at the University of the Ryukyus, where they were reared in the tanks of a closed system (volume of rearing tank, 50 l). We defined the day when most hatching occurred as day 0. Hatchlings were transferred to a circular enclosure made using a 3 mm black mesh (300 mm height, 400 mm diameter) immersed in a circular tank of a closed system (rearing unit, 120 l volume, 340 mm height, 700 mm diameter; Open-Field tank, Aqua Inc.). *S. lessoniana* individuals were maintained in the rearing unit up to 61 days of age. We calculated the daily survival rate as the percentage of live squid that were left in the rearing unit compared with the number alive on day 0.

Throughout the experiment, natural light was provided through the windows and light was also provided by fluorescent lamps above the tanks, with the light intensity at the tank surface ranging from 200 to 300 lux. Artificial seawater (LIVESea® Salt, Delphis) was predominantly used, along with the supplementary use of natural seawater. Temperature, pH, salinity, ammonia, nitrite, and nitrate were regularly measured using an electric pH/temperature meter, salinity meter, and commercially available water- testing kit (Test Lab®, Red Sea), respectively. Tempera- ture, pH, and salinity were maintained at 24.5–25.5°C, 7.8–8.2, and 33–35 psu, respectively, during the experi- ment. Once a day, 3–6 l of seawater were changed in each tank, and a pH/al adjuster (LIVESea® Buffer pH/al, Del- phis) was added to the tank when the pH of the rearing water dropped to less than 7.7. Freshwater was added to the tank when the salinity rose above 35 psu.

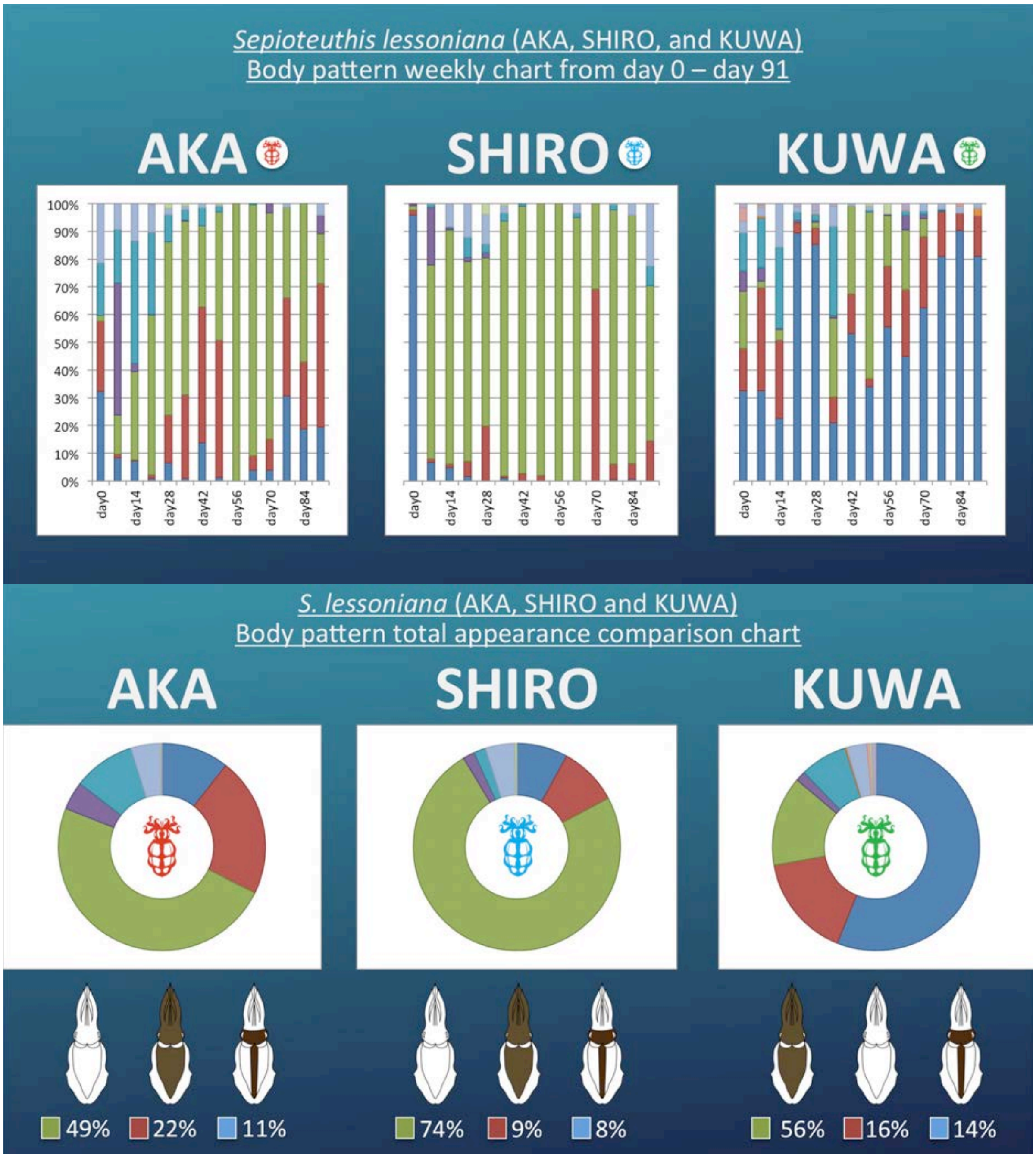
S. lessoniana were fed three times a day with the following: for hatchlings, live and frozen larval brine shrimp *Artemia franciscana*, live adult brackish mysid *Neomysis japonica*, and live fry and adult guppy *Poecilia reticulate*; for [11-day-old squid, frozen larval Japanese anchovy *Engraulis japonicus*; and for [30-day-old squid, frozen adult pelagic shrimp *Sergia lucens*. Dead *S. lessoniana*, excrement, and any remaining dietary organisms were removed from the tank at every feeding session.

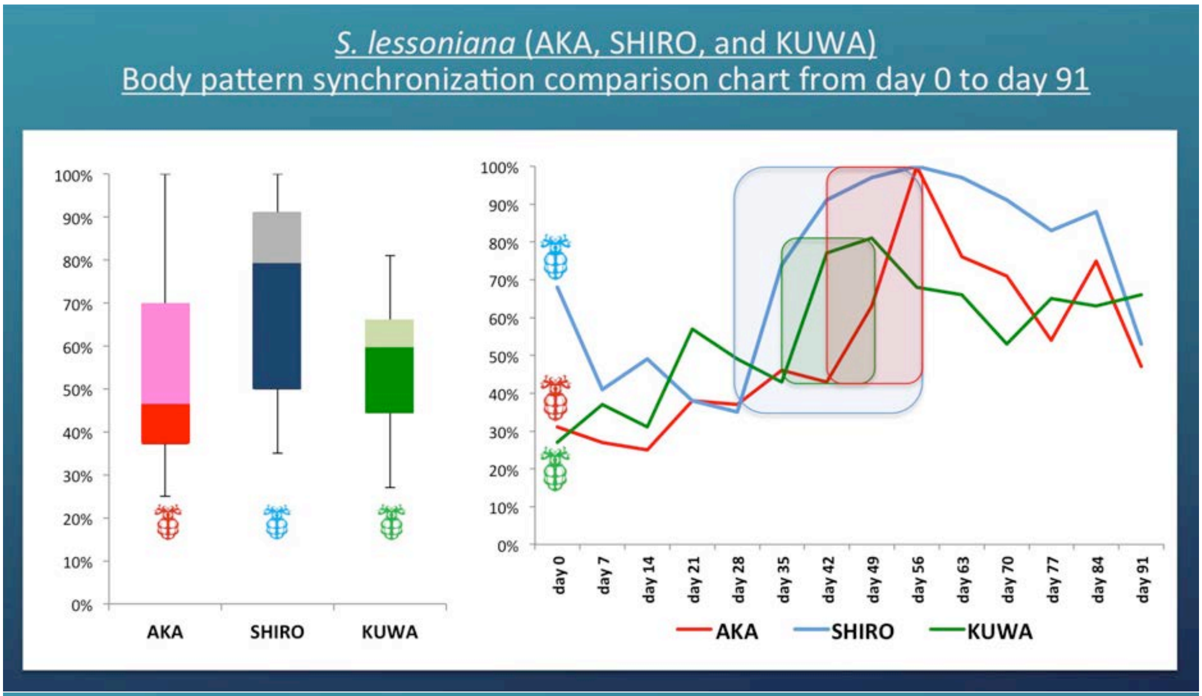
Recording behavior

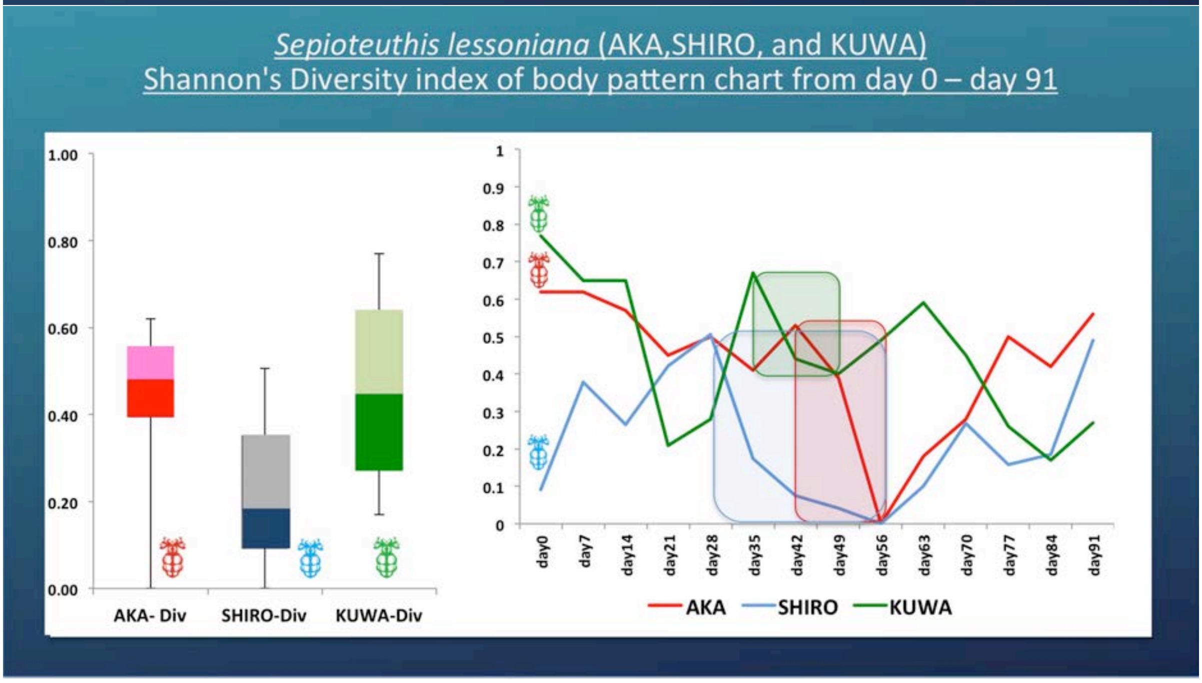
The behavior of the *S. lessoniana* populations was recorded using a digital video camera (Panasonic NV-GS250) mounted above the tank. The squid population was recorded for 20 min every sixth day, 2 h after the feeding time


Body Patterns of S. lessoniana (AKA, SHIRO and KUWA)
1. all dark
2. white arms
3. transparent
4. pail
5. Dark dorsal stripe
6. white posterior mantle
7. dark arms
8. Dark mantle bars
1. all dark
3. transparent
5. dark dorsal stripe
4. pail
7. dark arms
9. Eye spots
8. dark mantle bars
5. White dorsal stripe
10. Dark dorsal stripes and bars
2. white arms (SHIRO)
6. white posterior mantle (SHIRO)
4. Pail (KUWA)
1. all dark (AKA)

6.3. Results


Sepioteuthis lessoniana (AKA, SHIRO, and KUWA)
Body pattern weekly chart from day 0 – day 91
AKA
SHIRO
KUWA
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
day0
day14
day28
day42
day56
day70
day84
S. lessoniana (AKA, SHIRO and KUWA)
Body pattern total appearance comparison chart
AKA
SHIRO
KUWA
49%
22%
11%
74%
9%
8%
56%
16%
14%





6.4. Discussion

CHAPTER7. Intersection of Visual Communication

Upon conducting the experiment of replacing a cuttlefish's natural substrate (sand, rocks, corals, etc.) with varieties of 20th century paintings from the geometric abstraction of Piet Mondrian to the Japanese anime-influenced "super flat" paintings of Takashi Murakami, it is clear that the cuttlefish is able to match its' body appearance to the given images. This experiment, which was conducted from 2009 through 2011, tested over 100 individual animals with 80 stylistically unique paintings and yielded hours of video data. A careful review of still images taken from the videos showed certain specific trends. Due to their physiological limitation of chromatophores and iridophores, the cuttlefish could not produce a highly saturated color combination.

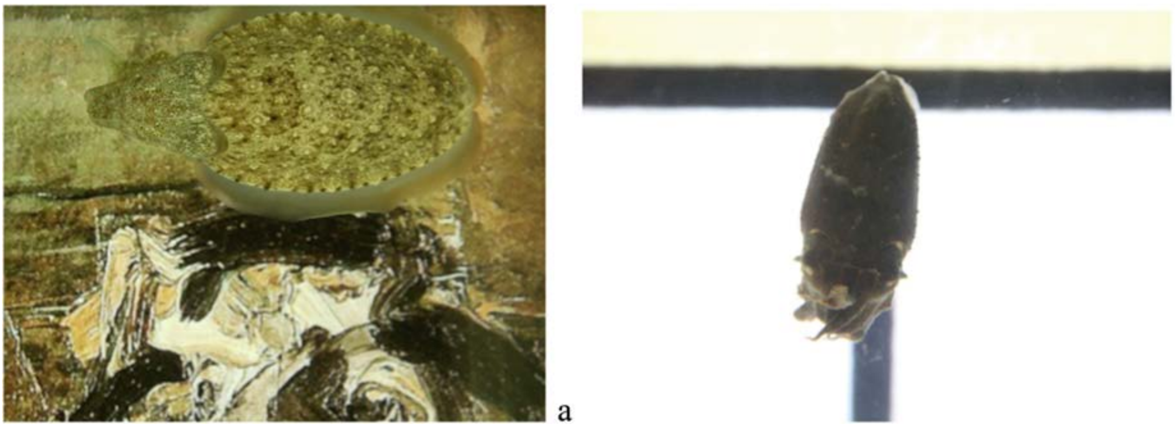

a b

FIGURE 40 | These images show *Sepia pharaonis* matching its body pattern to Frank Auerbach (a) and Piet Mondrian (b)'s painting. (Photographed by Ryuta Nakajima.)

In addition, their responses to dangerous predators depicted in some of the paintings did not include defensive postures that the cuttlefish would exhibit in nature. On the other hand, cuttlefish performed very well to both gestural and geometric abstraction in paintings, matching their patterns more accurately to the paintings. Such paintings are constructed mainly with formal measures, qualities and weights, such as line, tone, colors, shapes, hues, and salutations, without, in most cases, any figure or object representation (Klee 1924). Ironically, this lack of specific objects and figures produces images that resemble natural landscapes or cityscapes and contain organic elements. It is precisely within these natural elements, organized according to a certain aesthetic and geometric principle, that the cuttlefish exhibited at ease in matching its body patterns, which are a simplified and geometrically organized representation of Nature. It is also important to note that there seems to be a certain visual threshold where the cuttlefish differentiates between animate and inanimate. For instance, the painting of Frank Auerbach is a gestural, figurative abstraction in which most viewers see a figure; the reaction of a group of cuttlefish indicated more of a landscape with no sense of a figure.

7.1. Cephalopod Art Phase 3: Ceph to Art/ Art to Ceph

The data collected are used to produce various types of artwork for exhibition. In the early stage, paintings and drawings were used to track the body pattern change of the cuttlefish in relationship with the substrate images. After gaining access to laboratory animals, the visualization methods changed to predominantly photograph, video and sculpture installation. One of the most comprehensive solo exhibitions was produced in collaboration with the Minneapolis Institute of Art [MIA] and the University of the Ryukyu Cephalopod Research Laboratory. In this exhibition, there were six large-scale photographs (*Amburghese di cuore No. 1 -6*) of the cuttlefish disguises formed in response to selected art works from the MIA collection, 51 cuttlefish sculptures (*Akoroshi - 48 aspects of cuttlefish body pattern No. 1 – 51)* with images taken from the videos painted on them as their body patterns. This exhibition created a sense of synergy between art and science, nature and culture, animate and inanimate. In this way, it displayed the interconnection between nature and culture by using a cephalopod as a metaphorical vehicle inviting curiosity and discovery.

a)

b)

c)

d)

e)

f)

FIGURE 41 | Some examples of *Amburghese di cuore* (a, b, and c), (2013) and *Akoroshi - 48 aspects of cuttlefish body pattern* (d, e, and f), (2013)

7.2.1. Agonistic body pattern

Agonistic behavior is a display of aggression which includes threats, retreats, placation and conciliation (Scoot and Fredericson 1951). Of the 9,799 images which were used to create the catalog, one image was particularly unique. In this image (Fig. 5.) the chromatic components of the cuttlefish and the visual components of the Ngady mask showed incredible similarity. Both contain the dark eye ring, blue mantle-like pink lines on each arm and a mottled pattern on the mantle. This similarity between the cuttlefish and the mask is clearly not manifested from the necessity to camouflage; rather both are functioning as an embodiment of aggression. The chromatic components and the overall body pattern expression are intended to induce certain fear and a startling reaction to the object upon which the pattern is projected. In short, the pattern functions as a trans-species communication symbol that is genetically programed and can be read without depending on rhetorical knowledge of visual language. Hence, this particular agonistic display may possibly possess the clue to understanding the shared visual schematics.

7.2.3. Zombies' Chromatic Components Analysis

In order to further understand the relationship between agonistic display found in both cuttlefish body pattern and Ngady mask, zombies were used as a comparative model. Zombies are an imaginary construct that is designed to induce an interspecific emotional response of fear. Zombie folklore originated in Haiti in the 17th century when African slaves were brought to Haiti to work on the sugar cane plantations. Although there are many versions of cultural fascination with reanimated human corpses, for this study, 100 zombie samples are taken from the Post George Romero's film Night of the Living Dead, which later became an American pop culture icon. The sampled Zombies are from commercial films, Halloween costumes, makeup tutorials, etc., from an Internet image search. Every image was deconstructed and analyzed for chromatic components.

FIGURE 42 | *S. pharaonis* is displaying fully articulated agonistic body pattern with dark eye ring, blue mantle-like, pink lines on each arm, flat and expanded body shape etc., reacting to Ngady mask show below. There is an uncanny similarity between the chromatic components of the cuttlefish and the mask. (Color figure online)

34 chromatic components (Fig. 7.) were detected which were divided into 7 facial zones, where each component is mutually exclusive within the zone. The average number of occurrences is 15.9 times with an average number of chromatic components per image of 6 components. The component with the highest number of occurrences was #18, dark eye patches, at 87 times. 12 components (1, 2, 6, 8, 13, 18, 21, 23, 24,27, 29 and 31) were above the mean of which 6 components had significantly higher occurrences within the zone. Based on this simple observation and analysis, it appears that there are four dominant components (pale complexion, dark eyes, white pupils and bloody mouth) that are absolutely necessary to create a zombie and four more components (missing lips, dark lips, cuts, and decomposition) that are subdominant and enhance overall appearances. The four dominant components can be combined together to create a total appearance that might be considered the archetype of zombie, which is the visualization of human interspecific fear. Combining the archetype zombie with

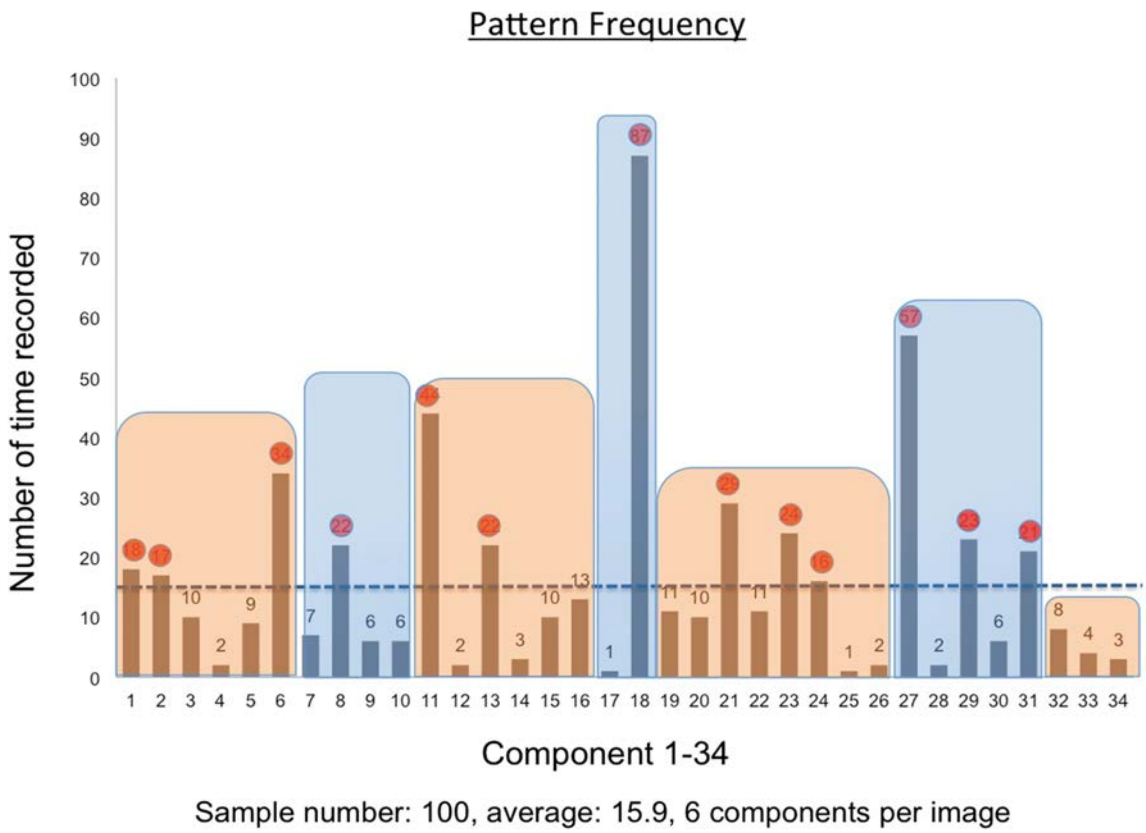


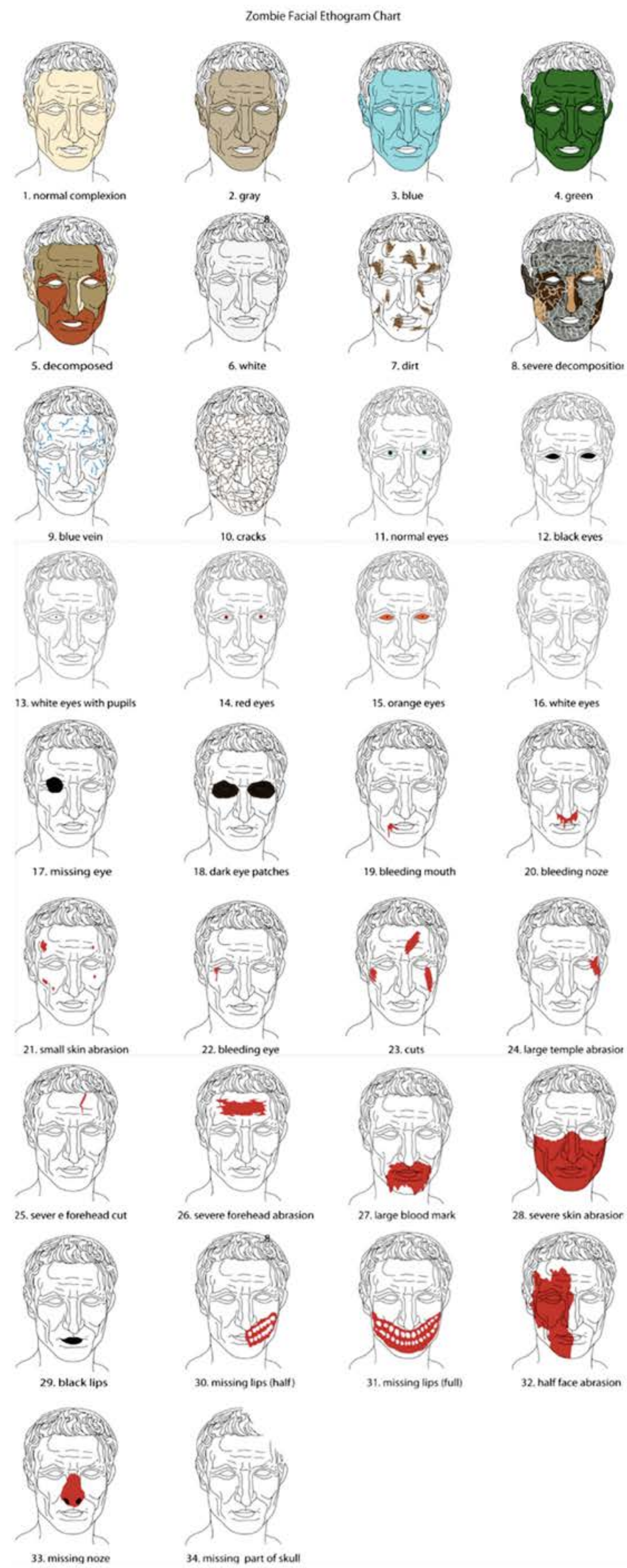
FIGURE 43 | Zombie chromatic components frequency chart

four subdominant components produces 12 different overall appearances that cover most of the visualization of zombies produced by the media industries (Fig. 8).

Comparing the chromatic components of cuttlefish, mask and zombie archetype, there is a considerable similarity between them. Although this is a pseudo-scientific experiment and comparison between these three seemingly dissimilar visual elements, it seems to me that there is a definite collation between chromatic components that induce fear responses across species. These components function as signs or visual cues that communicate potential danger in engaging with the displayer. In this way, it reduces the chance of predation and physical engagement with the receiver of the information. Hence, the body pattern has to be trans-specifically effective as a basic level of inter- and intraspecific communication.

FIGURE 44 | Zombies sampled from the internet. Some of them are home made as Halloween makeup and others are special make up for a movie.

Comparing the chromatic components of cuttlefish, mask and zombie archetype, there is a considerable similarity between them. Although this is a pseudo-scientific experiment and comparison between these three seemingly dissimilar visual elements, it seems to me that there is a definite collation between chromatic components that induce fear responses across species. These components function as signs or visual cues that communicate potential danger in engaging with the displayer. In this way, it reduces the chance of predation and physical engagement with the receiver of the information. Hence, the body pattern has to be trans-specifically effective as a basic level of inter- and intraspecific communication.


Zombie Facial Ethogram Chart
1. normal complexion
2. gray
3. blue
4. green
5. decomposed
6. white
7. dirt
8. severe decompositio
9. blue vein
10. cracks
11. normal eyes
12. black eyes
13. white eyes with pupils
14. red eyes
15. orange eyes
16. white eyes
17. missing eye
18. dark eye patches
19. bleeding mouth
20. bleeding noze
21. small skin abrasion
22. bleeding eye
23. cuts
24. large temple abrasio
25. sever e forehead cut
26. severe forehead abrasion
27. large blood mark
28. severe skin abrasior
29. black lips
30. missing lips (half)
31. missing lips (full)
32. half face abrasion
33. missing noze
34. missing part of skull

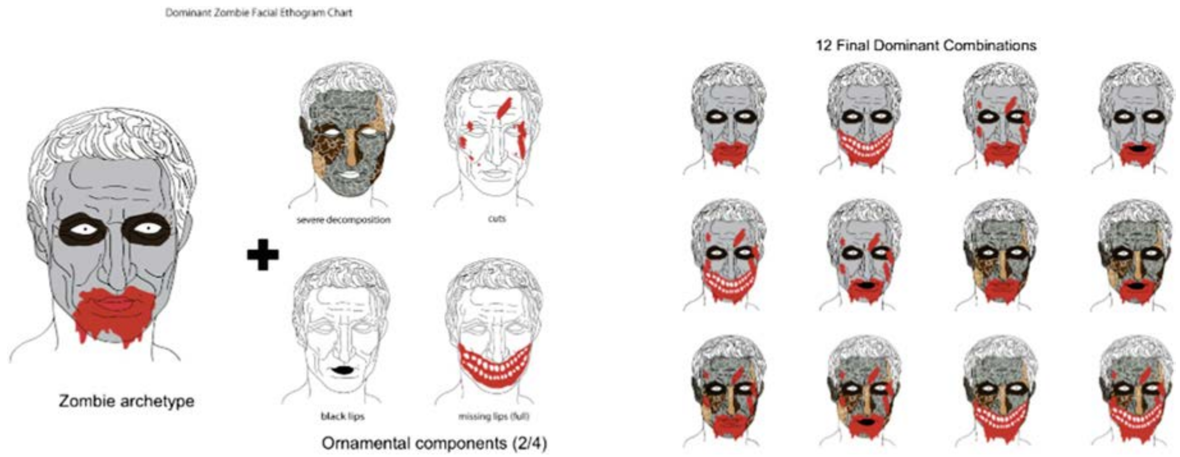


FIGURE 45 | 4 dominant Zombie chromatic components are combined to produce the zombie visual archetype. Four ornamental components are added to produce 12 possible total appearances.

FIGURE 46 | Chromatic components are very similar between cuttlefish, zombie and Ngady mask

7.2.4. Cuttlefish Cosplay

I further investigated the notion shared visual components to induce a sense of fear, I asked Myu Amatsuka, a professional Japanese cosplayer, to recreate 3 selected body patterns of cuttlefish. The objective of this experiment was not communicated to her during this experiment. 3 body patterns were produced and photographed. The result (Fig. 10.) also shows considerable similarity with zombie make-ups. Although, there are evidences of Amatsuka's interpretation has been influenced by Ika musume (squid girl), a famous Japanese anime character, three manifestations expressed the gradual transformation of Amatsuka into something resembling zombie like character rather than a cuttlefish. Furthermore, it is important to note that the Amatsuka's postural presentation has also changed as the make up changed expressing a potential shift in her psychological state. Here, the chromatic components have effected not only the viewers reception of them, but also effected the psychology of the subject applying the makeup. It is also interesting that the final outcome (image on the right) is very similar to the Ngady mask as well. From these comparative studies, the trans-specifically effectiveness of body pattern is reconfirmed.

FIGURE 47 | Cosplayer's interpretation of three distinctive body patterns of cuttlefish.

From art to science, my work tries to find a new and more direct communication method. I believe that artwork is not a product of self expression, rather it is a product of biological necessity that helps us connect with our environment. The human sensory system has been fine-tuned in the course of evolution to detect and isolate specific information which is important for spatial navigation, predator prey interaction, selecting mating partner and so on. In order to reduce the margin of error, the system is designed to omit and simplify millions of variables and details that constantly surround us. Similarly, cephalopods, in their self-world, are doing the same. By comparing the human and the cephalopod visual communication systems, I hope to isolate important visual cues that induce certain emotional reactions without depending on linguistic categorization or logical understanding. Further more, if one is able to create a visual communication model that is based on this minimal yet effective visual communication system, that increases the level of empathy and understanding with others that helps to cultivate a new consciousness.

CHAPTER8. Overall conclusions

Looking back at my life, I faced many challenges derived from differences. There were differences in race, culture, religion and language. These differences may be important markers of cultural diversity and history of a given group, it certainly created difficulty to communicate with group other than one's own. Something simple as a color can have many names and multiple of meanings that are specific to the context and cannot be easily understood and shared with other groups. During my initial investigation of art, I focused on this relativity of language and multiplicities for interpretation, which questioned the existence of universality, and implied the impossibility in accessing the metaphysical hierarchy of consciousness beyond language and its linguistic structure. In short, nothing has inerrant meaning until a name and context are given to it. Furthermore, the complexity of such context that included both connotations and denotations has exponentially multiply to create an inaccessibility of meaning with or without its original self. What did Van Gogh meant by his Sunflower? The answer is who cares! We would never know. Despite the fact that some interpretations are more valid than the others, all still remain to be interpretation.

During my early investigation of painting, I was confortable with the idea that contextual dependability of a language and the complexity caused by the fragmentations and folds. The idea naturally matched my personal experience of miscommunication and its difficulties. However, as time passed, I started to think that this idea is only a problem within a certain logic of language and culture, but human experience is not a product of language rather it is fundamentally more emotional and physiological. We may never know what Van Gogh meant by his sunflower painting but we can certainly feel certain warmth of that specific yellow that triggers our physiological reaction to that motif and the color. In this way, we can hold empathically connection with Van Gogh himself as well many millions that felt the physiological reaction that genetically ingrained in all of us and beyond. This realization necessitated my investigation of such raw emotional reaction triggered by an external condition, object, sound, etc.… Here I found a hope for universality that moves and governs us beyond differences in language, culture, time, and many other contextual differences. Hence, it was the unification or identification of similarities that became more important for me rather than stating obvious differences.

The essence of visual communication is to create a signal that triggers rapid reaction (including non reaction.) During an ordinary situation, our visual world is remaining as a noise that allows overall scanning of one's peripheral world. When there is a transformation of information caused by a movement, color change, shape change, etc., the field will be divided into much focused fragments. These focused fragments are the signals that immediately demand one's neurological and physical responses, which are necessary for spatial navigation, predator and pray interaction, cripsis and reproduction. In this way, these signals are not learned from the experience but are genetically controlled and driven. If this is a case, one's respond to an art as a culmination of visual signals does not corresponds to his empirical knowledge, rather it is also driven by his DNA. Visual communication is a technique of controlling attention and desire of receptor by transforming an overall noise to signals that require reaction. Stronger the signal is, lower the possibility of interpretation in reception.

Cephalopod is also a master of visual communication. When they are doing nothing (this is also an essential behavioral pattern) they become the noise. The principal of camouflage is not to visually match to its surrounding environment. Instead, it is to integrate into the average of visual noise of the environment. When this is achieved. It will not be detectable as prey, a predator, a mate, and a competitor. It just becomes an inanimate object like rocks, sand, dead weeds, etc. As long as a squid does not send a detectable and readable signal to the environment, the visual equilibrium of the environment is also be maintained as status quo. On the other hand, if the squid is forced to react to a situation, its body pattern will change according to the situation. This will create an unbalanced dynamics, which require action and reaction. In short, the appearance of a signal necessitates a new equilibrium in the environment. For example, a grouper confronts a squid. The squid's first defense is hidden from the predator. If the first defense does not work, it will be forced to appear and react to the predator by choosing various behavioral repertoire such as displaying agonistic body pattern, swimming away, inking, and so on. The new equilibrium will be established when the grouper swims away.

It has been almost 10 years since I have started to study cephalopod body pattern as a comparative model. Thus far, I was able to closely examine five species, Sepia pharaonis, Sepia latimanus, Sepioteuthis lessoniana, idiosepius sp., and Octopus cyanea. From this experience, there are certain understanding of cephalopod behavior and body pattern. However, considering the number of species and its diverse distributions and habitat, my work has just started. Deep down I feel that there is a true sense of connection between other species, a sense of universality and oneness. If there is such universality, I think that it may be a new foundation in human consciousness.

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