**The octopus and the unity of consciousness**

**Sidney Carls-Diamante**

sdia185@aucklanduni.ac.nz; sidney.carlsdiamante@gmail.com

**Philosophy, School of Humanities**

**University of Auckland**

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**Abstract** If the octopus were conscious, what would its consciousness be like? This paper investigates the structure octopus consciousness, if existent, is likely to exhibit. Presupposing that the configuration of an organism’s consciousness is correlated with that of its nervous system, it is unlikely that the structure of the sort of conscious experience that would arise from the highly decentralized octopus nervous system would bear much resemblance to those of vertebrates. In particular, octopus consciousness may not exhibit unity, which has long been assumed to be the normal or default structure of consciousness. The octopus nervous system is characterized by the following features: its three anatomically distinct components have extensive functional autonomy and little intercommunication; much of the sensory processing and motor control routines—that in vertebrates are localized in the brain—take place within the peripheral arm nervous system; and proprioception and somatotopic representation (point-for-point mapping of the body) are significantly downplayed. In this paper, I present the octopus as a highly successful biological organism in which it is plausible that the unified model of consciousness does not hold.

**Keywords** Octopus; Octopus consciousness; Unity of Consciousness; Disunified Consciousness

**Introduction: Consciousness, the nervous system, and the octopus**

 This paper presents the octopus as a counterexample to the established notion that where consciousness exists, it is unified. While the octopus is among the non-human animals in which consciousness (in the sense of subjective experience) is believed to be present, it is a highly atypical inclusion due to its being an invertebrate with a functionally decentralized nervous system—the very features that have brought it to the attention of the philosophical community. The most prominent philosophical works on octopuses are those of Peter Godfrey-Smith (2013; 2016), who presents the octopus as a point of reference for tracing the evolutionary history and cladistic distribution of complex cognition. This paper is concerned with a different issue: how the octopus challenges a received view in cognitive science, in particular regarding the structure of phenomenal consciousness.

Where consciousness is defined as the persisting capacity for subjective experience, i.e., as *phenomenal consciousness,* it is almost always taken for granted that it is unified. This long-standing commitment can be expressed via the *unity thesis* (Bayne, 2010)*,* i.e., the claim that it is possible to have only a single set of subjective experiences at any given point in time. While there are numerous construals of consciousness, and consequently various ways in which the unity thesis can be formulated, what has been the most frequent—and vexed—object of investigation is the unity of *phenomenal* consciousness*.* Broadly construed, phenomenal consciousness is a neuropsychological mechanism that affords a creature in which it is instantiated with the persisting sense of “something it is like” to be that creature (Nagel, 1974). Another way of describing phenomenal consciousness is to say that it is what renders a creature an experiencing subject. In the same vein, phenomenal consciousness can be regarded as a property, such that neuropsychological or mental states that are phenomenally conscious are those that are accompanied by a distinct experiential character. Consequently, the issue of the unity of phenomenal consciousness can be parsed as the question of the number of experiencing subjects that can be instantiated within a single organism. At this point, it is important to note that the notion of consciousness that this paper is concerned with is phenomenal consciousness; any and all mention of consciousness refers to the phenomenal sense unless otherwise specified.

Tim Bayne (2010) enumerates various ways in which phenomenally conscious states can be unified: by being experienced synchronically or diachronically by the same subject (*subject unity*), being integrated into a single complex experience (*representational unity*), or by there being something it is like to conjunctively experience distinct mental states (*phenomenal unity*). Bayne also presents a useful distinction between the *field* and *stream* metaphors used in discussions on the unity of consciousness: A *conscious field* is the conjunction of all conscious states experienced at a single time, while a *conscious stream* refers to the series of conscious states experienced over the passage of time (Bayne, 2010).

The time-honored commitment to the unity of consciousness comes as no surprise, in large part due to two factors pervasive in cognitive science. First, a sizeable portion of the corpus of consciousness studies is concerned with creatures with integrated and centralized nervous systems—for the most part humans, and later on, certain cognitively complex vertebrates. Second, there is an abundance of physicalist commitments pertaining to the ontology of consciousness, such that it can usually be—and often is—presupposed that consciousness is neurally grounded (see Bayne, 2010).[[1]](#footnote-1) This assumption that consciousness is neurally grounded—which likewise will be accepted here, and referred to as *neuralization*—is an important one, as it often serves as a starting point that enables ontological and epistemological studies of consciousness to get off the ground. Acceptance of neuralization facilitates acceptance of empirical evidence that the physical features of a creature’s nervous system influence the structure of its phenomenal consciousness. This notion can be referred to as the *isomorphism thesis*.

A commitment to neuralization entails accepting the isomorphism thesis, which holds that the kind of nervous system a creature is equipped with is crucial to determining the kind of consciousness it has, i.e. the types and complexity of conscious experiences it can undergo. However, it is important to note that the nervous system is not alone in shaping consciousness: non-neural factors that have a direct bearing on an organism’s physiological development can also contribute to the structure of its consciousness. As an illustration of the non-neural influences on consciousness, we can consider the cases of congenitally blind individuals, in whom the neural mechanisms for processing visual information remain inchoate (Gallagher, 2005). What can be inferred from these findings is that the conscious experiences of such individuals would be deprived of a visual modality.

Thus, the type of consciousness we humans have arises as a consequence of the properties of our nervous system—especially those pertaining to complexity and organization—taken together with certain non-neural factors that have a substantive impact our neurophysiology. Human neurophysiology is such that it *supports* the robust conscious experiences that arise in us, which in turn are *influenced* by the kind of body or sensory apparatuses that we are equipped with. If neuralization is accepted as true, then it is reasonable to suppose that the more features associated with generating consciousness the nervous system and sensorium of a non-human animal have in common with ours, the stronger the structural resemblance between its consciousness and human consciousness will be. Because human consciousness is typically unified, and has been used as the sole model of subjective experience for a very long time, unity has come to be viewed as a major defining characteristic of consciousness.

These lines of argument are reflected in Bayne’s endorsement of the position that *human* consciousness is necessarily unified. However, he firmly states that unity should not and cannot be expected to hold for *all* forms of consciousness, i.e., phenomenal consciousness as it may be instantiated in different organisms. While unity may be the default structure of human consciousness, he points out that there are no binding theoretical or empirical reasons to presume that forms of phenomenal consciousness idiosyncratic to other animal species should be the same. His commitment to neuralization allows him to argue that non-human consciousness does not have to be unified by way of the fact that “some creatures simply won’t have the cognitive machinery required to integrate the contents of the mental states in the appropriate manner” (Bayne, 2010: 106).

One of the most compelling pieces of evidence for neuralization is the *split-brain syndrome*. First brought to philosophical attention by Thomas Nagel (1971), the split-brain syndrome is often observed in individuals who have undergone brain bisection, a surgical procedure used to prevent the inter-hemispheric spread of epilepsy. While there are variants to the procedure, the basic principle is that fibers in the corpus callosum, which connects both hemispheres of the brain, are severed. In humans, many cognitive domains are localized to a single hemisphere, resulting in an asymmetric distribution of neural processing. Severing inter-hemispheric connections, in whole or in part, deprives the brain of conduits through which information is transferred. Interestingly, brain bisection patients often do not exhibit impairment in their everyday behavioral and cognitive tasks, yet under experimental conditions the discrepancy between information transfer and first-person reports of conscious experiences is revealed.

The pathology of consciousness characteristic of the split-brain syndrome is demonstrated by the well-known “key-ring” test. Here, a compound word such as “key-ring” is presented to the patient so that the visual field of each eye sees only half of the word, i.e. the left eye can only see “key” and the right eye only sees “ring”. Due to the contralateral nature of visual processing, input to the left visual field, i.e. “key”, is processed in the right hemisphere, while input to the right visual field, i.e. “ring”, is processed in the left hemisphere. Because the domain responsible for speech is located in the left hemisphere, the patient verbally reports that all she sees is the word “ring”. However, when instructed to reach for a key with her left hand, she is able to do so, although she is unable to issue verbal reports about the object. Although minor variations have been made to the experiment’s setup, the basic findings are that “information presented in the [right visual field] will be unavailable for left-handed grasping behavior while information presented in the [left visual field] will be unavailable for verbal report” (Bayne, 2010: 192). It thus appears that patients may be able to have two distinct yet simultaneous conscious experiences, one for each side of the body, and in such a way that each side does not appear to be “aware” of the experiences of the other.

In an earlier work on the same subject, Bayne explicitly states that “it is possible that the unity of consciousness might fail in nonhuman animals” (Bayne, 2008: 300). Presupposing the isomorphism thesis, or the claim that there is correspondence between the structure of an organism’s phenomenal consciousness and that of its neural architecture, an animal in which a disunified consciousness is most likely to appear would be one with a decentralized nervous system, which precludes complete integration of mental or neural states. An animal that fits this bill perfectly is the octopus. The Cambridge Declaration on Consciousness of 2012 includes octopuses in its list of non-human animals in which subjective experience is likely to be found, on the basis of possessing neural substrates associated with consciousness as well as its repertoire of sophisticated and intelligent behavior (Mather, 2008; Vitti, 2013)*.* Notably, unlike the other species to which phenomenal consciousness has been attributed, the octopus is an invertebrate with a nervous system that is functionally decentralized, a neural organization that entails a distributed cognitive architecture.

The octopus nervous system is divided into three specialized and functionally independent anatomical components with little intercommunication between them. The most interesting of these components is the peripheral nervous system of the arms: It processes sensorimotor information, generates motor commands, contains the spatiotemporal details of stereotypic motor programs (Sumbre et al. 2001), and allows an amputated arm to respond to stimulation the way an intact one would (Rowell, 1963)—all of this independent of the brain (Graziadei 1971; Sumbre et al. 2001; Sumbre et al. 2005; Rowell 1963). Even more interesting is that due to the octopus’s neuroanatomy, its brain does not receive proprioceptive information about the arms (Graziadei, 1971), and does not support *somatotopy* or point-for-point mapping of the body (Zullo et al. 2009), findings that have been confirmed by stimulation experiments. Proprioception and somatotopy are closely related: proprioception provides a sense of movement and position, which is relativized to the rest of the body through the somatotopic map. These features—especially proprioception—are considered vital to structuring consciousness, especially with regards to the motor control function attributed to it. The absence of proprioception and somatotopy in the octopus brain indicates that spatial information about its body is not integrated within a single neuroanatomical structure, but is distributed throughout the nervous system. This in turn raises questions about whether phenomenal consciousness in the octopus has a proprioceptive component.

Furthermore, the extent to which the sensorimotor system of the arms is self-contained, as well as their capacity to retain responsiveness to stimuli even after being amputated suggests that octopus arms may be capable of experiencing local phenomenally conscious states. Now, if the brain and the arms can generate local conscious fields, the issue arises as to whether subjective experience in an octopus would be integrated or unified, given the sparseness of interactions between the components of its nervous system. Indeed, the very organization of the octopus nervous system itself calls into question whether it can support a unified consciousness at all (Godfrey-Smith, 2013). Thus, the objective of this paper is to present the octopus as a highly sophisticated organism in which a unified model of consciousness is not likely to hold. The approach taken here is a conditional one: *If* the octopus were indeed phenomenally conscious, then what would the structure of its consciousness be like? For the purposes of this paper, it will be assumed that the octopus has conscious experience, leaving our hands free to dig into its nature.

**Consciousness attribution**

Why attribute phenomenal consciousness to a creature, sophisticated behavioral repertoire or no, in the first place? How does consciousness in this sense contribute to an organism’s biological or adaptive success? It has been argued that phenomenal consciousness is a mechanism that integrates information from various neural subsystems that do not have direct access to each other, thereby facilitating communication and coordination (Baars, 1983; 2002; 2005). The structural idiosyncrasies of these contributing systems have causal influence on the format of their respective outputs, preventing them from having direct access to each other’s information. This multiplicity of formats can lead to conflicting or inconsistent information, which when directly transmitted to the motor effectors can wreak havoc on behavior production.

The integrative nature of phenomenal consciousness entails that one of the functions of its underlying mechanisms is synthesizing information from various sources before making it available to the motor system, thereby ensuring that the organism’s movements are coherent. Furthermore, by integrating the input of diverse subsystems, neural resources that would otherwise have been used to process their individual contributions can be reserved for decision-making operations that pertain to organism-level behavior control (Merker, 2005). The integrative function of consciousness also sets the stage for complex cognitive capacities, such as self-monitoring, control and adjustment of behavior, decision-making, and adapting to novel or unpredictable situations, as it enables information exchange between a wide range of cognitive domains (Baars, 1997). In its highly sophisticated forms, consciousness has also been linked to planning and mental time travel, as it allows the subject to construct mental models of actions and their possible consequences (Mandler, 2003).

It has been proposed that the evolutionary emergence of consciousness was influenced by the need of sensate organisms capable of self-generated motion to delineate between their bodies and the external world (Merker, 2005). In these motile organisms, sensory states can be triggered not only by external stimuli, but also by internally generated causes. Thus, in order to determine whether a behavioral response to such states is warranted, the organism must be capable of distinguishing whether they are internally or externally induced. Because interoceptive information is an important component of consciousness, the organism is thus provided with a means of monitoring its overall physical state. The importance of this monitoring function is highlighted when it comes to motor control, in which the organism requires an effective mechanism for keeping track of the trajectories, appropriateness, and effectiveness of its actions.

It has been argued that in order for consciousness to perform its integrative and monitoring functions, it must be unified (Baars, 1983). Because the neural mechanisms responsible for generating conscious experience work towards coherence, they will inevitably try to smooth out any discrepancies or conflicting input, such as that which can arise from simultaneously experiencing multiple conscious fields. Furthermore, due to the spatio-temporal constraints of human and vertebrate anatomy—which models of consciousness have long been based on—maintaining a single, unified conscious field allows the effectors to be used in a coordinated manner to produce coherent and organized behavior.

It thus appears that the notion that phenomenal consciousness must be unified is heavily influenced by the neuroanatomical features of vertebrates. However, the octopus, with its decentralized cognitive system and arms that are all capable of the same motor repertoire, does not face the same physical constraints as vertebrates. Consequently, the question arises as to whether attributing phenomenal consciousness to the octopus also entails committing to the unity thesis.[[2]](#footnote-2) That is to say, if it is accepted that the nervous system of the octopus does indeed generate a persisting field of consciousness in the sense of subjective experience, does it follow that *only one* such field can arise within the animal? How many fields of phenomenal consciousness can be instantiated within any given octopus?

**The octopus: Evolutionary history and nervous system**

At this point, it is time to say more about the octopus in light of its evolutionary history, so as to better understand why its nervous system and cognitive architecture are philosophically interesting.

Modern cephalopod mollusks are divided into two subclasses: the anachronistic external-shelled *nautiloids (Nautilus)*, of which there are only two surviving genera, and the soft-bodied *coleoids,* a species-rich group consisting of cuttlefishes, squids, and octopuses. Living cephalopods are for the most part coleoids. While all coleoids are descended from a common ancestor and share an evolutionary history, octopuses are distinct from their relatives in terms of body plan, anatomy, behavioral repertoire, and intelligence. Descended from neurally and behaviorally simple mollusks, octopuses evolved to have both the largest and most complex nervous systems and most sophisticated behavioral repertoire among invertebrates. With 500 million neurons, the octopus nervous system is well within the vertebrate size range (Hochner 2004). Furthermore, the sophistication of its behavior and cognitive capacities is of a degree associated with vertebrates rather than invertebrates (Vitti, 2013).

A well-accepted theory about coleoid evolution was formulated by Andrew Packard(1972). Known in the literature as the *Packard scenario,* it holds that ancestral, external-shelled cephalopods that inhabited shallow waters were forced farther out into open waters by predation and competition by *teleost* (bony) fishes. The water pressure of the deep sea led to the loss of the external shell, significantly increasing their mobility and consequently allowing them to return to coastal waters where they were now able to successfully compete with teleosts, an ecological relationship that holds true to this day. Sharing an ecological niche with vertebrate competitors led to the development of perceptual and motor systems that could afford them the same competence as their competitors. Specifically, these were the evolution of a visual system with the same capacities as those of vertebrates, and the highly autonomous peripheral arm nervous system, which has extensive sensory processing and motor control responsibilities. The increased complexity of the perceptual and motor systems necessitated a parallel increase in the complexity of the nervous system, in order to accommodate the robustness of the information being inputted via the former (Vitti, 2013).

 It is in octopuses that the ancestral external shell has almost completely disappeared, a significant contributor to their being the most complex of cephalopods (Grasso & Basil, 2009). The almost total loss of the shell eliminated all possibilities of neutral buoyancy, forcing the octopus to adopt a benthic, or sea floor, habitat. The benthic ecology of octopuses led to their developing a more diverse diet than squid and cuttlefish, thus requiring a larger variety of hunting strategies (Godfrey-Smith, 2013). These hunting strategies are cognitively demanding, and can be realized only if the underlying neural structures are sophisticated enough to support them. To cope with this new lifestyle and ecology, the octopus nervous system underwent radical modification. The brain, while retaining its molluscan trademark of being arranged around the esophagus, underwent shortening of the fibers connecting its constituent ganglia, resulting in their becoming fused and concentrated into lobes (Borrelli & Fiorito, 2008). This new compact arrangement made it possible for the octopus to develop cognitive capacities that recruit multiple brain areas, thereby increasing their complexity (Vitti, 2013). In addition to the fusion of ancestral ganglia, new neural structures were developed, to form the brachial ganglia that control the arms and the suckers (Borrelli & Fiorito, 2008).

However, the concentration of the molluscan ganglia into a brain is not the most interesting feature of the octopus nervous system. Instead, what is significant and fascinating is the extensive functional autonomy of the three components of its nervous system: the central brain, the optic lobes, and the peripheral arm nervous system. Even more surprising is how the neurons are distributed among these parts: the central brain contains roughly 45 million, the paired optic lobes have 120 million between them, and the arm nervous system has 350 million—two thirds of the octopus’s total neurons. The high concentration of neurons in the octopuses’ arms is consistent with the extent of information processing that takes place in the arm nervous system. Each arm receives massive amounts of sensorimotor information from millions of receptors in the suckers, skin and muscles. The nervous centers of each arm are responsible not only for processing sensory information, but also for controlling reflexes and issuing motor commands to their respective appendages. This information is processed locally by nervous centers within each arm, and consolidated in the *interbrachial commissure*, a ring of fibers that interconnects the arms. Interestingly, the arm nervous system is connected to the brain by a relatively small number of fibers, indicating that what it transmits to the brain is information that has already been extensively processed (Hochner, 2004).

What role, then, does the brain play in the octopus’s cognitive system? Neuroanatomical evidence suggests that the octopus brain is incapable of somatotopic representation, so that what are represented in the brain are motor programs and not body parts (Hochner, 2012; Zullo et al., 2009). The brain functions as a decision-making center that integrates information from the different components of the nervous system and distributes it as higher-order global commands (Hochner, 2013). These commands pertain to the selection of motor patterns, the speed at which the movement is to take place, and orienting the arm so that it extends towards the direction of a stimulus. It was discovered early on, based on neuroanatomical evidence, that information about the stretch of the arm muscles, i.e. proprioceptive information, does not reach the brain (Graziadei, 1971). In more recent studies, stimulation throughout the higher motor centers of the brain resulted in the extension of multiple adjacent arms rather than a single one, implying that central motor commands are transmitted to several arms at a time (Zullo et al., 2009). When a single arm is used to perform a task, selection of which one to activate is done at the level of peripheral motor centers, with local sensorimotor feedback refining the global motor command (Zullo et al., 2009). Due to the distribution of labor between the brain and the arm nervous system—with the former being responsible for global motor control, and the latter supplying the spatial parameters of the movement—the need for somatotopic representation of the arms is eliminated (Hochner, 2012).

**The octopus arm**

 The octopus’s lack of a rigid skeleton entails that it does not have proprioceptive landmarks by which motor control can be guided and simplified. This extreme flexibility, combined with the massive deluge of sensory information received from hundreds of millions of receptors, poses an overwhelming challenge to any neural control system (Sumbre et al., 2005). To avoid overloading the brain, the octopus’s unique evolutionary solution to this problem was to offload the bulk of motor control responsibility to the arms (Hochner, 2013). To simplify motor control, the octopus makes use of stereotypic motor patterns that are incorporated into its various behaviors (Sumbre et al., 2001).

One such motor pattern is the *propagated bend* used to extend an arm. Here, a bend is formed and pushed down the arm all the way to its tip by a wave of muscle stiffening. The motor programs of stereotypic movements are contained within the neuromuscular system of the arms (Sumbre et al., 2001), as evidenced by the fact that octopus arms that have been amputated or neurally disconnected from the brain are able to produce sensorimotor responses to stimulation that are identical to those of intact arms. For instance, when the arm is pricked with a pin, the skin surrounding the area of contact flinches, and the arm moves away from the direction of the stimulus (Rowell, 1963). More recently, it was discovered that applying electrical stimulation to neural centers of the arm that normally receive commands from the brain elicits movements that resemble those used in natural behavior (Sumbre et al., 2001).

Another significant feature of the octopus arm is its use of dynamical muscle activity to determine the spatial parameters of movements, something that is best demonstrated in fetching movements. Fetching movements in the octopus involve what has been termed *pseudo-articulating* an arm in a way that is functionally analogous to the human arm (Richter et al., 2015; Sumbre et al., 2006). Here, the octopus forms a bend in the arm, which it uses as a pivot point around which the distal segment is rotated to bring an object to the mouth. The location of the bend is crucial to the accuracy of the fetching movement: If it is too high the arm will overshoot, whereas if it is too low then the arm comes short of the mouth. Significantly, determining the location of the bend takes place exclusively through activation of the muscles of the concerned arm, without the involvement of the brain. When the distal segment of the arm grasps an object, it triggers muscle activation waves that run in both directions between the base of the arm and its tip. The collision point of these waves is where the bend is formed (Sumbre et al., 2005). Thus, fetching is an excellent example of a goal-directed movement that demands utmost precision, yet whose kinematic control takes place entirely in the periphery.

A final example of the extent to which motor control is offloaded to the periphery is the use of *pushing by elongation—*another stereotypic motor pattern—in crawling or walking (Levy et al., 2015). Due to its use of more than one arm, crawling calls for coordinated motor control. In vertebrates and arthropods, coordinated motor control is made possible through the use of a *central pattern generator,* which specifies a rhythmic pattern for the concerned effectors to follow. In contrast, it was discovered that the coordination of the pair of arms used by the octopus for crawling was non-rhythmic, indicating that the behavior was not controlled by a central pattern generator. Instead, crawling is enabled by pushing by elongation, in which the proximal section of each arm shortens, allowing the suckers in that area to come into contact with the surface being crawled across, thereby serving as a leverage point. These same sections are then lengthened, generating a combined thrust that propels the animal forward. As such, the direction of the crawl is determined by which arms are used (usually those at the back, but other combinations are commonly used as well). Just like the process of bend formation, pushing by elongation is not generated by fine-grained central motor commands, but by the intrinsic mechanical properties of the arm muscles. As such, the motor centers of the brain do not have to specify the detailed spatial coordinates for the arms to occupy in order to carry out the movement. Instead, central control over crawling only involves activation of the peripheral motor program for pushing by elongation, and selection of the arms to be used.

The great degree of functional self-sufficiency of the octopus arm, and the sparse connections between the central and peripheral components of the nervous system indicate that sensorimotor information from the arms undergoes extensive local processing before being sent to the brain (Hochner, 2004). Presupposing neuralization, this motivates the notion that octopus arms may support local phenomenally conscious fields that are independent of the main field whose substrates are found in the brain. That is to say, there is reason to believe that the octopus arm contains neural mechanisms that are necessary—and perhaps sufficient—for generating and supporting a *persisting capacity* for subjective experience. If so, then the sensorimotor responses of an amputated octopus arm to stimulation would be accompanied by corresponding subjective experience, so that there would be something it is like to be an octopus arm.

What these empirical findings suggest is that an isolated octopus arm supports a field of *primary consciousness,* a single-level form of phenomenal consciousness in which the capacity for subjective experience is unpacked in terms of sensory awareness. For primary consciousness to be attributed to an organism or a system, all that is called for is that it be capable of “direct awareness of the world without further reflection upon that awareness” (Barron & Klein, 2016: 4901). The substrates of primary consciousness must thus be able to register sensorimotor information in such a way that they give rise to “an integrated simulation of the animal’s own mobile body within the environment” (Barron and Klein 2016: 4901). That the octopus arm contains and can activate the motor patterns of stereotypic movements, and retains its capacity to respond to stimulation suggest that such an internal model may be present in it.

Due to fact that the arm nervous system is relatively simple (in comparison to the brain), in that the modalities of information that it traffics in are limited, it should not be expected to give rise to anything more complex than primary consciousness. That is to say, it is well within reason to suppose that arm-based conscious fields provide the arm with sensory information that serves as a model of the external world and that can be used as the point of reference for formulating appropriate motor responses to environmental conditions. However, trying to attribute a more complex form of consciousness—such as *higher-order consciousness,* which involves reflection, broadly construed, on the contents of primary consciousness—would be unnecessarily and unrealistically demanding. Thus, it suffices to describe arm-based consciousness as being a persisting field of subjective experience whose contents can be identified as first-level sensorimotor information.

In vertebrates, attributing distinct conscious fields to components of the nervous system that have sensorimotor processing and control functions is an ill-advised move. While such neural structures can carry out their operations with a certain degree of autonomy, they do not have the same extent of influence over behavior production as the octopus arm does. The centralization of vertebrate nervous systems entails that while some sensorimotor operations are distributed to peripheral components, the bulk remains concentrated within the brain. As the result of a unique evolutionary development, the reverse is true of the octopus: The arm nervous system has the main responsibilities when it comes to fine-grained motor control and processing sensory—tactile, mechanical, and chemical—information. Consequently, the organization of the octopus nervous system is such that its central and peripheral components are functionally specialized, with the brain and the *axial nerve cords*—neuronal tracts found within each arm that connect it to the brain, and integrate local sensorimotor information—alike being high-level processing and control centers (Richter et al., 2015). Thus, it is the extent of functional self-sufficiency of the octopus arm that renders attributing consciousness to a peripheral neuroanatomical structure a plausible move, where it is not in vertebrates.

 Interestingly, despite the fact that the arms are not somatotopically represented in the motor centers of the brain, the octopus appears able to alternate between central and peripheral motor control. Peter Godfrey-Smith writes that while octopus arms are “curiously divorced” (quoting Hanlon and Messenger, 1996) from the brain, “octopuses can exert a significant degree of central control over their arms when they need to” (Godfrey-Smith, 2013: 8). In a study demonstrating that octopuses are “capable of guiding a single arm in a complex movement to a location”, which entails integrating “peripheral arm location information with visual input to control goal-directed complex movements” (Gutnick, Byrne, Hochner, & Kuba, 2011: 460), subjects were tasked with retrieving food from a maze. The test conditions were such that they unequivocally demonstrated that the octopuses could only use visual input, and not chemical or tactile information, to successfully complete the task—which they did. The maze was designed to ensure that while the octopuses could use stereotypic movements such as extension and probing, reaching the reward required their arms to enter into positions not typically used under natural conditions. The task itself thus demanded a degree of precision that could be brought about only through visual guidance, which indicates central motor control: feed-forward control, or the use of preplanned motor commands, was ruled out as unlikely, due to the “’crawling and probing’ nature of the search movements” (Gutnick et al., 2011: 462).

The integration of visual information with motor commands was interpreted as indicative of central control over the arm as it executed the retrieval task. These findings suggest that the brain and the arm nervous system are capable of an online exchange of information about the position and location of the arm, which is significant given “the lack of somatotopic representation of the body in the higher motor centers as well as the inability to elicit single-arm responses in stimulation experiments” (Gutnick et al., 2011: 462). Such precision in motor control is not unheard of in the octopus: much of its behavioral repertoire is comprised of actions that demand fine movements, such as stacking and carrying around halved coconut shells to use as portable shelters, and using their arm tips to cleanly pick the flesh of crabs apart from their shells. These factors make the octopus a puzzling, almost counter-intuitive, case in motor control: It is able to execute complex movements that call for precise and detailed control, without the benefit of proprioceptive information and somatotopic representation in the motor centers of the brain.

Gutnick et al.’s findings are surprising, given the way in which the octopus nervous system is functionally organized: How does integration of visual and proprioceptive information come about, if neuroanatomical evidence indicates that the latter does not reach the brain? Or perhaps they are not integrated at all: If the brain and the axial nerve cords are high-level control centers, then they separately process central and peripheral input, respectively. What may be the case is that the motor control scheme underlying the retrieval task—and other movements that require deviation from familiar motor patterns—is the outcome of the *coordinated* operations of brain-based and arm-based control centers, rather than centrally generated motor commands that subsume peripherally sourced information.

Presupposing the neuralization and isomorphism theses, such a motor control scheme gives credence to the possibility of distinct and separate brain-based and arm-based conscious fields in the octopus. If the structure of consciousness divides along the same lines as the functional organization of the nervous system, it is likely that octopus consciousness is constituted by local fields that are experienced simultaneously, but are not integrated. Such non-integration would be due to the structural and functional dissimilarities between the brain and the arm nervous system, which entails the strict localization of neural routines.

Consequently, the contents of the distinct conscious fields would vary according to the sensory modalities their substrates support and traffic in. Brain-based consciousness would subsume visual experiences and presumably global sensations of position and motion, while chemotactile and proprioceptive information about the state of the arms would be encompassed within the arm-based field (or fields). There may be some overlap of contents between central and peripheral consciousnesses, but only to the extent that they can be supported by the respective substrates of either field.

**The octopus and the unity thesis**

So far, I have argued that octopus consciousness, granted that it indeed exists, would be disunified; as such, the octopus stands as a biological counterexample to the unity thesis, which holds that wherever consciousness is instantiated, it is unified. Presupposing neuralization, the integrated structure of the brain makes it the most plausible location for the substrates of consciousness. Thus, it is likely that the qualitative experiences accompanying neural processes excluded from the brain do not enter into the brain-based conscious field. However, this does not entail that such neural operations are entirely non-conscious: They may still be consciously experienced, albeit not as part of the main conscious field, which is localized in the brain. Bayne (2010) argues that this is not possible in humans, due to the neurophysiological and anatomical limitations of our nervous system. However, he does not extend this claim to other creatures; indeed, both the nervous system and body plan of the octopus are such that they can plausibly support multiple, non-unified conscious fields. To provide a broader context within which to nest the issue at hand, I will present a number of alternatives or opponents to the unity thesis and discuss how they contribute to the investigation.

*Nagel: Uncountable minds*

In his discussion of the split-brain syndrome, Thomas Nagel (1971) argues that such patients do not have a countable number of minds. He points out that their capacity to experience more than a single phenomenal field at a time suggests that they do not have just one mind, yet the normalcy of their everyday behavior precludes a clean and unequivocal division into two streams of consciousness. Furthermore, the usual epistemic ports of call are not of much help here: neither behavior nor neuroanatomy can decisively settle the question of how many minds split-brain patients have. The apparently incomplete integration of conscious experiences taken together with sufficiently unimpaired behavior they exhibit thus undermines the claim that conscious states have to be unified in order to produce coherent behavior. In subjects with intact brains, conscious experience may be completely integrated, but it follows from Nagel’s account that consciousness does not have to be unified in order for it to be a functional control system. Thus, Nagel’s view entails that unity is not a necessary condition for consciousness to play its functional role. Nagel even goes as far as suggesting that our concept of unity may run counter to the way the physiological operations responsible for controlling our behavior actually work. He writes that in maintaining that normal consciousness is unified, we may be “subtly ignoring the possibility that our own unity may be nothing absolute, but merely another case of integration, more or less effective, in the control system of a complex organism” (Nagel, 1971: 410).

*O’Brien and Opie: Multi-track polyphony*

An outright denial that consciousness is unified comes from Gerard O’Brien and Jon Opie (1998). They introduce a *multi-track polyphonic* *model* that construes the field of phenomenal experience as an amalgam of distinct cross-modal contents experienced simultaneously. Based on an analogy to music, the polyphonic model holds that multiple conscious contents are experienced simultaneously, i.e. as part of a single experience. They caution that this view is easily misread as meaning that input from different modalities must be transmitted to mechanisms that will bind them into a single experience, which is then broadcast to cognitive systems. They clarify that polyphony is correctly understood as the mingling of voices to produce a single sound wave, in which case a single experience arises from the contribution of distinct components. While the end result is a coherent and connected product, the components do not lose their independent qualitative properties, so it is still possible to identify and distinguish between the parts. In endorsing multi-track polyphony, O’Brien and Opie retain the basic principle behind polyphony, i.e. simultaneous cross-modal experiences, but do not accept that they are unified. That is, they do not endorse the notion that cross-modal experiences have to undergo *binding*; they are experienced simultaneously, which is why they feel like they are a single experience. Thus, consciousness is not unified, but *manifold* because it is a composite of numerous distinct and discrete experiences, and *distributed* because the mechanisms that generate these experiences are spread throughout the brain (O'Brien & Opie, 1998: 393).

*Two-streams and partial unity*

Although he argues that the unity of consciousness holds even in split-brain patients, Tim Bayne notes that there are two models of consciousness commonly used to account for the purported disunity experienced by split-brain patients (Bayne, 2008; Bayne, 2010). First is the *two-streams model*, on which the subject’s phenomenal states can be divided into two sets, where the states within one set are all phenomenally unified with each other, but there is no unity of states across sets. The other is the *partial unity model,* which holds that some experiences are unified with each other but not with others, so that an experience *e3* would be unified with *e1* and *e2,* but *e1* and *e2* would not be unified with each other.

Both models call the unity thesis into question in related but slightly different ways. The two-streams model is an upfront denial of the main claim of the unity thesis, that humans can only have one stream of consciousness at any given instance. With regards to the functional role of consciousness, the two-streams model demonstrates that it is possible to generate coherent behavior even though the subject has multiple fields of consciousness. That is to say, it runs contrary to empirical claims that the mechanisms of conscious experience have to remediate conflicting, inconsistent, or simply non-complementary information in order for it to be useable in behavior production (e.g. Baars, 1983).

The partial unity model can be read as a more nuanced view of the two-streams model; it does not connote two self-sufficient conscious streams, but suggests that there is a principal conscious stream and straggler conscious states. While the principal stream would be responsible for the bulk of behavior production, the “loose” states are not epiphenomenal. They would be involved in certain sub-tasks of behavior, but would not be experienced as part of the principal stream. A messier interpretation is also possible, such that instead of a principal conscious stream and individual unified ones, some loose conscious states would be unified with some others, producing sub-unified states that could even overlap with each other. Much like Nagel’s view, this would be highly problematic when it comes to determining how many conscious streams are present. Thus, the partial unity model differs from the two-streams model in its disagreement with the unity thesis is that it does not allow consciousness to be divided along clean lines.

*Assessing the views*

Rather than an outright debunking of the unity thesis, I treat Nagel’s view as taking it on on modal grounds. Nagel accepts the correlation between the neural and mental structure, yet points out that the resulting dissimilar consciousnesses still produce coherent behavior, thereby blocking the way of any functional claims to necessity the unity thesis may make. Thus, the conclusions arising from Nagel’s view establish a firm foundation for arguments that the behavior of creatures with neural architectures that make the endowment with a unified consciousness unlikely or uncertain should not be dismissed as non-cognitive.

O’Brien and Opie cite temporal simultaneity as being responsible for why we feel that conscious states occurring at the same time are a single, unified state. Due to their dismissal of binding, their account sets a theoretical stage for the possibility that the substrates of consciousness can be found in various parts of the body. While all they claim is that the mechanisms of consciousness are distributed throughout the brain, the same principle is applicable to a creature such as the octopus whose nervous system is distributed throughout its body in such a way that its peripheral components are complex enough for it to be reasonable to suppose they can support primary conscious experience. The notion of binding implies that conscious experiences must be transmitted to a mechanism or mechanisms that integrate them with each other. Such mechanisms must thus have access to information provided by the distinct substrates of individual conscious states, which undoubtedly include proprioception.

On the contrary, the multi-track polyphonic model makes it possible (at least theoretically) that conscious states can be experienced as such wherever they are physically localized. Now, there is reason to think that an octopus arm on its own is capable of at least primary consciousness, due to its ability to respond to stimulation and exhibit pain behavior even when isolated from the brain. However, the octopus’s neuroanatomy suggests that detailed interoceptive information about the arms does not reach the brain. If conscious states can be experienced locally and without the involvement of a binding or integrative mechanism, then it is possible to arrive at a positive answer to the question of whether an octopus can feel its arms even without central somatotopy and proprioception, as well as a plausible explanation of how this takes place.

The two-streams and partial unity models come into close proximity of what an octopus’s consciousness might be like given the organization of its nervous system. The interbrachial commissure is a neural structure that interconnects the octopus’s eight arms, and allows them to communicate with each other at the peripheral level. If so, it may be the case that the interbrachial commissure functions as an integration mechanism that permits the arm nervous system as a whole to give rise to a consciousness of its own. This *peripheral consciousness*would not be as complex as the one whose substrates are in the brain, which can be termed the *central consciousness*, being limited to sensorimotor experiences from the individual arms. Nevertheless, it would be distinct from the central consciousness, thus endowing the octopus with two conscious fields.

The partial unity model, on the other hand, can be applied if we were to do away with the proffered integrative role of the interbrachial commissure. Instead, the unified peripheral consciousness will be replaced with individual conscious streams for each arm, i.e. *arm consciousness***.** Like peripheral consciousness, consciousness in an arm would consist of local sensorimotor experiences, but would not be unified with the streams of other arms. There are empirical bases to support arm consciousness, the most notable of which is the capacity of amputated arms to behave “normally” when stimulated. While they differ slightly from each other, the two-streams and partial unity models both offer theoretical precedents that are helpful to understanding what octopus consciousness may be like.

**Octopus consciousness: Unified or disunified?**

The morphological arrangement and the extent of functional autonomy of the components of the octopus nervous system gives reason to question whether it can support unified conscious experience (Godfrey-Smith, 2013). Furthermore, the position that favors disunity is motivated by its lack of central somatotopic representation, proprioception, and the extent to which sensorimotor processing and control responsibilities are offloaded to the periphery. Indeed, the octopus is an exemplar of an animal in which “the unity of consciousness might fail” (Bayne, 2008: 300), thereby demonstrating that consciousness is not necessarily unified.

Furthermore, the octopus directly challenges the functional claim made by the unity thesis, i.e. that the only structure of consciousness that can generate coherent behavior is a unified one. Indeed, the evolutionary success of the octopus bears itself out as evidence that an organism whose consciousness is disunified consciousness can nevertheless have psychological and behavioral capacities on a par with those associated with organisms with a unified consciousness. This in turn casts long shadows on discussions on the role of consciousness with regards to intelligence and behavior: Rejecting the notion that intelligent behavior presupposes a unified consciousness revokes the privileged status of models of cognition that put a premium of centralized nervous systems, which dominate cognitive science and which the unity thesis has implicit commitments to.

 The structure of consciousness of human patients with proprioceptive deafferentation, or the pathological deprivation of sensation, bears resemblance to what octopus consciousness can be expected to be like. Empirical data shows that somatosensory information, especially proprioception, is crucial to internal awareness of one’s own body, which in turn enables fine-grained control of behavior; in other words, the interoceptive information that enters into the field of consciousness is what makes it possible for consciousness to carry out its functional roles, especially those that pertain to self-monitoring and behavior control. However, there exist cases wherein precise behavior can be produced without the subject’s awareness of what is going on. A well-known clinical example is that of Ian Waterman, who lost all proprioceptive sensation from the neck down (Gallagher, 2005). Although deprived of internal awareness of his body, Ian is able to get on with his day-to-day activities by visually guiding his movements. Interestingly, although for the most part he has to use visual monitoring to perform bodily actions, he has retained his ability to gesture naturally. A similar case is autobiographically reported by István Aranyosi (2013), who sustained temporary damage to his peripheral nervous system as a result of chemotherapy. Consequently, his proprioception and motor control were compromised. He describes a number of compensatory measures he took to guide his movements, such as using vision and coarse-grained proprioception from proximal body parts, as well as mechanical constraints imposed by the external environment and the structure of his own body.

Cases such as these suggest that the motor centers of the brain receive proprioceptive information from the relevant body parts, but this proprioceptive information fails to enter into the subject’s conscious experience. In such cases of proprioceptive deafferentation, it may be that the unity of the patient’s consciousness is not fractured into multiple streams or fields. Instead, it appears that such consciousness is not *comprehensive,* or inclusive of all the states associated with conscious interoceptive monitoring and motor control. That is, the brain receives, processes, and utilizes information from deafferented bodily sources, but this information does not enter into conscious experience. (It must be noted that *comprehensive unity* differs from partial unity in that it does not claim that the states that do not enter into the main phenomenal field are nevertheless conscious.) Likewise, the octopus brain would receive and use information from its arms, but it is doubtful that such information is of the conscious sort. Assuming that the mechanisms responsible for generating consciousness are only found in the brain, brain-centered octopus consciousness can be expected to exclude interoceptive experience of the arms. Thus, if consciousness were only generated by brain-based mechanisms, an octopus would have a single conscious field, but it would not be a comprehensive one.

 However, there is a crucial difference between the octopus and deafferented humans. Due to the structure and organization of the human nervous system, it would make little sense to ask whether there is something it is like to be the foot of a deafferented human. The neural equipment of the foot is insufficient to support, much less generate, conscious states when taken in isolation from the brain. On the contrary, an octopus’s arm is self-sufficient in terms of its sensorimotor functions. As discussed earlier, such a neural organization leads to principled reasons to believe that an octopus arm may be able to support conscious experience. Yet, this remains an open question, as it may well be the case that the responses to stimulation exhibited by isolated or amputated octopus arms are unaccompanied by phenomenal character. What, then, are the consequences the presence or absence of arm consciousness have for what it is like to be an octopus? Each option will now be examined in its turn.

If the brain and the arm network give rise to distinct streams of consciousness that are independent of each other, the lack of proprioceptive information transfer implies that the octopus would simultaneously experience multiple, disunified conscious fields. At any given point in time, the octopus would experience any conscious central and peripheral states occurring then, but they would not be bound into a single multi-modal experience. Instead, these states would be experienced at the same time, giving them the feel of being part a single conscious field, but they are not integrated with each other. This runs along the lines of what O’Brien and Opie (1998) propose. In this case, conscious unity fails altogether, thereby rendering the octopus as a counter-example to the claim that consciousness has to be unified to produce coherent, intelligent behavior.

But what would the outcome be if the arms, on their own, do not generate consciousness at all? Any phenomenal experiences the octopus would have of its arms would have to be centrally generated—but without somatotopic representation and proprioception, it is difficult to see how this is even possible. Thus, while the octopus would have a single, central conscious stream, it would not subsume experiences of the motor states of its arms, and hence would not be comprehensive. In this case, motor control over the arms would take place through the use of non-conscious local and dynamical mechanisms, thus demonstrating that behavior control can take place even though the relevant effectors do not enter into conscious experience.

In summary, the nervous system of the octopus is such that it may neither generate nor support a unified consciousness. Furthermore, the neurophysiology of the octopus is an actual organic instantiation of a system that does not require full, comprehensive conscious access to internal control mechanisms to produce behavior. The following lessons can thus be learned from the octopus: first, that it is an actual evolved example of an animal in which the unified model of consciousness is not likely to hold; and second, that it is a counterexample to the claim that a unified consciousness is prerequisite to intelligent behavior.

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1. However, there remains an explanatory gap between consciousness and its neural substrates; it is yet unknown exactly how the nervous system gives rise to conscious experience. This is a vexed issue that lies outside the objectives of this paper. [↑](#footnote-ref-1)
2. For clarity, it must be emphasized that the sense of consciousness to which I am referring is the phenomenal one, i.e., the persisting capacity for subjective experience. Other variants of consciousness, e.g., *access consciousness* or *higher-order consciousness,* may yield conclusions different from the ones in this paper when applied to the unity thesis. However, space constraints prevent me from exploring these possibilities, which I am grateful to an anonymous reviewer for pointing out. [↑](#footnote-ref-2)