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Awareness in the Brain: A Mechanistic and Descriptive Account

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Abstract

An exploration of the different aspects of consciousness and their biological underpinnings, followed by a review of existing theories of awareness in the brain and a critique of the existing research. This paper conducts a review and critique of the contemporary research and finds that no existing theory currently offers an account of awareness in the brain that is both mechanistic and descriptive in nature. Thus, this paper proposes a new theory of the process of awareness in the brain, wherein Attention Schema Theory is considered as the mechanism of awareness and Global Neuronal Workspace Theory as its nature.

Introduction

For millennia, philosophers and scientists alike have been attempting to decipher the mystery of human consciousness. Even with massive technological leaps appearing to occur on a daily basis, today's scientists are still looking for the definitive answer to a seemingly simple question: How does the brain produce awareness? We have many theories, but we still do not know what exactly it is that enables our brains to become aware. In this paper, I will attempt to answer both the above question, and its parts. The question can be broken down into a few sub parts. What are the aspects or parts of awareness? What are their biological underpinnings? What's our present understanding of the process wherein awareness arises, in terms of how it actually happens, and what are we missing? Awareness, in this paper, is defined as the knowing of the knowing. It is the step beyond basic sensory information, where the brain says, "I know this information." It is not just a water bottle in your frame of vision – it is seeing a water bottle, focusing on the water bottle, knowing that what you are seeing *is* a water bottle, and being able to take that information and say, "I am seeing a water bottle." The process through which awareness occurs is not known at present, and that is what I am seeking to uncover. In the first part of this paper, I will cover the aspects of consciousness and their biological underpinnings, then in the second, I will dive into the current theories of awareness and what they are missing. I will utilize scholarly articles and studies as well as online books from university libraries for the first part of this paper, and then scholarly articles on theories of awareness for the second. I will then provide a critique of the current research, and offer my own proposal.

The Aspects of Consciousness and Their Biological Underpinnings

Attention – Focused Attention

Attention is generally defined as "the important ability to flexibly control limited computational resources" (Lindsay, 2020). Selective attention will be defined here as the ability to selectively funnel the brain's sensory input to focus on the relevant information. However, researchers today struggle with a single definition of what exactly attention is. Some argue that no one actually knows what attention is (Hommel, Chapman, Cisek, Neyedli, Song, & Welsh, 2019). The full course of the argument is that attention "is used to refer to both the explanandum (the set of phenomena in need of explanation) and the explanans (the set of processes doing the explaining)" (Hommel et al.). In other words, when we talk about attention, we discuss both its aspects and their bases as part of the same construct. While this may be the case, it is inarguably true that attention's general description is the ability to select aspects of our present experience and block out the others. Furthermore, although it does not alone substantiate it, attention is "absolutely necessary" for consciousness (Pereira, 2011). It's often equated with consciousness, but for the time being, we can only look upon attention as an aspect (Pereira). Dr. Pereira gives an example to emphasize this. If someone has never seen a refrigerator before, they might believe that the refrigerator light is always on, because it's on whenever they see the refrigerator's interior with the door open. Similarly, it's difficult to clearly denote where "unattended entities" fall in the consciousness question, because, as Dr. Pereira puts it, "very act of verification calls for the focusing of attention on those entities unattended to earlier" (Pereira). Thus, as of now, we will work with attention as an aspect of consciousness.

Focused or concentrated attention is absolutely crucial to our conscious ability, leading some researchers to postulate that it is top-down attention control itself which lends us conscious thought (Graziano & Webb, 2015). If the brain were incapable of attention control – in other words, if the brain had no ability to capably select the most important sensory information for prime processing – the experience would be similar to that of a young Clark Kent in the 2013 film *Man of Steel*, when the future Superman's enhanced senses first kick into gear in a classroom setting and he is overwhelmed by the surge of sensory information into his brain (Warner Bros., 2013). Attention control is what enables the brain to avoid this outcome and focus on the most important sensory inputs for decision making. This selective attention gives us the capability to focus our neural resources on processing one sensory input at a time, a process which helps increase the precision of our analysis, although this does limit the width of our overall perception (Farrell, 2016).

Consider a computer with a limited hard drive. The hard drive can only handle so much information. When that limit is surpassed, it has detrimental impacts to the entire computer.

Processing slows, and eventually the computer crashes. The system simply cannot function due to the information overwhelming its limits.

The conscious brain, in this metaphor, is the computer (and, for all intents and purpose, the brain is very much like a computer). To avoid overloading the brain's hard drive with sensory information and causing a system crash, our selective attention enables us to load the important things onto our hard drives and leaves the rest on our brain's equivalent of a zillion-gigabyte thumb drive.

Most research shows that the ability for selective attention arises in certain areas in the parietal and frontal lobes of the brain. Newer studies have also demonstrated that the temporal lobe plays a role in this critical task, helping us focus our attention on the most relevant inputs (Freiwald, 2019). The network that orients us centers on the ability to prioritize these inputs by selecting a location. Imaging shows that both frontal and posterior areas are involved in this process. Both target detection and awareness of said target are associated with the anterior cingulate cortex and the midline cortex. These processes are critical to focal attention, which as mentioned is vital to the ability of the mind to be in a conscious state, although the specific mechanisms for the emergence of this consciousness are unknown.

Sensory selection resides in the cortex. The prefrontal cortex is able to regulate the sensory thalamus' activity through a basal ganglia pathway (Nakajima et al., 2019). When this PFC-BG-thalamus pathway is engaged, it performs the role of enabling selection between visual and auditory sources by suppressing the source that is distracting attention. This same pathway simultaneously enhances sensory discrimination (the ability to perceive and attribute the qualities of stimuli) and is used to suppress "background noise" or unimportant input, in pursuit of an objective. Studies show that this pathway is important for selective attention and demonstrates several roles in the overall process of defining sensory input.

Michael Graziano, a Princeton University Professor of Psychology and Neuroscience, posits that the process of top-down attention control through our brain's internal modeling is what gives rise to consciousness. Graziano's theory draws from our evolutionary background to pinpoint the processes of selective attention. Between 600-700 million years ago, selective signal enhancement evolved from the basic nerve nets demonstrated by creatures such as the hydra, a relative of the jellyfish (Graziano, M. S., & Webb, T. W., 2017, p547). Basic nerve nets react to every touch the same no matter where it is – the entire net reacts. Selective signal enhancement, on the other hand, was a way of dealing with only the most important touches. Then, during the Cambrian explosion, about 500-550 million years ago, the tectum, or central control system, evolved (Graziano, M. S., & Webb, T. W., 2017, p548). The tectum is shared by all vertebrates, but not all invertebrates. The essential function of the tectum is to coordinate attention among all senses – so not only does the tectum deal with the most important touches, but it sees, smells, and hears them coming (Graziano, M. S., & Webb, T. W., 2017, p548). Because this is a lot of information, and the tectum must process it efficiently, the tectum creates an internal model, a simulation of what is currently occurring in the body. The tectum then compares the simulation to the actual sensual input to help with movement control (Graziano, M. S., & Webb, T. W., 2017, p548). When a human shifts their eyes, the world shifts in the other direction – an example of the tectum at work. After the tectum, 350 million years ago, reptiles evolved, along with a brain structure called the wulst, which is similar to a shrunken version of what came next on the evolutionary pathway – the mammalian version that humans have today, called the cerebral cortex (Graziano, M. S., & Webb, T. W., 2017, p548). Humans still have the tectum, underneath the cortex, and it still performs its same functions – but it has a key difference with the cortex. The tectum focuses attention in a way known as overt attention – like a spotlight, brightly focused on one thing (Graziano, M. S., & Webb, T. W., 2017, p548). The cortex handles what is known as covert attention – which is the shift of the brain's processing.

Memory

Memory is split into two types: implicit and explicit. Explicit memory is "knowledge or experiences that can be consciously remembered" (Stangor & Melinga, 2014). This itself is split into episodic (our firsthand experiences) and semantic memory (worldly facts and concepts). Explicit memory can be consciously accessed by an individual making an attempt to access the memory. Implicit memory, on the other hand, is "the influence of experience on behavior, even if the individual is not aware of those influences" (Stangor et al.). There's three kinds of implicit memory: procedural (our memory of how to do things), classical conditioning (learning to associate one stimuli with another), priming (behavioral changes due to frequent or recent events). Implicit memory is knowledge that cannot be consciously accessed in the same fashion as explicit memory.

Memory, like many of the other aspects of consciousness explored here, finds its storage in various areas of the brain. Explicit memories, focusing on your experiences along with general knowledge and information, rely on the hippocampus, the neocortex, and the amygdala (Queensland Brain Institute, 2019). Implicit memories, also known as unconscious or automatic memories (information we don't store on purpose, such as motor memories), rely on the cerebellum and basal ganglia (QBI). Short-term working memory is mainly reliant on the prefrontal cortex.

Experiments have demonstrated that memories in the brain are stored in two ways – a whole memory, or a comprehensive experience, and individual details of that memory. The comprehensive experience or overall memory finds storage in the hippocampus, which has generally been considered the home of memory, but the details of the memories are stored and processed in the prefrontal cortex (Yadav, Noble, & Niemeyer et al. 2022). The purpose of this structure is so that individual stimuli in the future activates the prefrontal cortex to accurately parse the details, and then reach into the hippocampus to recall the full memory. This enables the brain to recall memories relevant to ongoing experience, a crucial step for processing. The entorhinal-hippocampal pathway is critical for forming the brain's conception of and storing these experiences, but the sensory aspects of the memory are sent to prefrontal neurons. When these sensory features are then encountered, the neurons then communicate with the hippocampus to access the relevant memory for these features. This experiment was backed by further research suggesting that the creation of memory is mainly carried out by the hippocampus, but that other structures in the temporal lobe play a significant role in the function of memory in the brain (Ackerman, 1992).

Cognition/Motor

Cognition describes our brains' various mental processes, which includes attention, thinking, learning, language, and perception (Cherry, 2023). These mental processes are not all separate abilities. Instead, they are a set of skills which interact to produce our brain's cognitive functioning. The concept of cognition therefore includes all processes, conscious and unconscious, that are involved in perception, reason, and thought. Cognition examples include directing attention towards an environmental stimulus, sensing and perceiving that environmental stimulus, decision making, problem solving, language processing, learning, and accessing memory for present use (Cherry, 2023).

Our motor is the system responsible for our body’s movement. The system controls walking, breathing, eating, facial expressions, and pretty much everything else we do (Berni, 2023). The motor systems are what enable us to move through the world, affect it, and communicate, both in a verbal and non-verbal manner. These systems also give us the ability to maintain our posture and our balance, along with guiding the contractions of muscles involved in more unconscious functions like our breathing and movements of the gut (Berni, 2023). Lastly, they’re also important in our ability to sense – for example, controlling the movement of our eyes as we track stimuli. Even though we execute an incredibly diverse array of movements, motor control is generally seen as a simple undertaking (Berni, 2023). This is likely because much of our movement is unconscious and does not require significant concentration. Despite this, though, even the most simple and basic body movements actually require a fair amount of work on the part of our motor systems, as they necessitate coordination of all muscles involved in the movement, which in turn requires complex computation by the motor systems.

Motor and cognition are functionally related and likely share evolutionary history (Leisman et al., 2019). Some regions in the brain are shown to have both cognitive and motor functions. Data demonstrates that motor and cognition each influence the other in a complex relationship. The motor cortex is made of three separate areas of the frontal lobe, right in front of the central sulcus (the boundary between the frontal and parietal lobes) (Knierim, 2020). The areas are the primary motor cortex, the premotor cortex, and what’s known as the supplementary motor area. The primary cortex is “located on the precentral gyrus and on the anterior paracentral lobule on the medial surface of the brain. Of the three motor cortex areas, stimulation of the primary motor cortex requires the least amount of electrical current to elicit a movement" (Knierim, 2020).

The studies on cognition as an aspect of consciousness have found that cognition resides in specific areas of the prefrontal cortex, and when activated, this leads to the conscious experience of thinking (Snow, 2016). Two hypotheses explain how the PFC can sequentially elaborate four qualitatively different cognitive operations to serve the psychosocial, material, temporal and hypothetical domains of human thought. The first, that all four are located in a single area of cortex, would require this area to sequentially enable the development of each of the four, vastly different, operational systems (neural networks) required for emotional, temporal, practical and abstract intelligence; and maintain the independence of these four domains of cognition, throughout adult life (Snow, 2016). If this area of the cerebral cortex did exist, it would more or less make up the human mind.

The second hypothesis, and the preferred hypothesis of the author of the study, is that 4 areas of the PFC mature over time, and this enables these cognitive domains (Snow). These domains are named in the study. Firstly, Brodmann Area (BA) 9 "enables our emotional intelligence, engaging the psychosocial domain." The next region, BA47, "enables our practical intelligence, engaging the material domain." BA46 (or BA46-9/46), "enables our abstract intelligence, engaging the hypothetical domain." Finally, BA10 "enables our temporal intelligence, engaging in planning within any of the other three domains." The author proposes that these areas be known as the social (BA9), material (BA47), abstract (BA46-9/46) and temporal (BA10) mind (Snow).

Reasoning

Reasoning is the ability to take conclusions from all information that can be accessed, or the ability to draw conclusions from all accessible information. Reasoning as a process is the ability to take the information that is presently available and analyze it with intent (Shuren & Grafman, 2002). Reasoning can be divided into 2 categories, deduction or deductive reasoning and induction or inductive reasoning, based on the type of relationship between the premise and the conclusion (Shuren et al.). Deductive reasoning is reasoning which is able to reach conclusions that are entirely limited to the accessible information found within the original set of premises that kicked off the chain of reasoning. These premises or arguments lead to one conclusion. By contrast, inductive or probabilistic reasoning has the ability to draw conclusions that extend beyond that original set of premises that encompasses the conclusions drawn through deductive reasoning.

Reasoning, along with several other executive functions, is considered to occur in the frontal lobe (QBI). In examples of patients with injuries to this region of the brain, reasoning skills are often declined. Furthermore, in frontotemporal dementia, a common early indicator of the disease is behavioral changes. This is due to the localization of higher order executive function to the frontal lobe.

Planning

Planning is the process of choosing an action or a set of actions based on their possible outcomes (Mattar & Lengyel, 2022). This process includes two separate things. Firstly, estimating the outcomes of one’s actions, and then assessing the relative utility of such outcomes. Planning is differentiated from reflex in that planning allows premeditated reactions to unfolding events, whereas reflex is instinctual reactions. Planning as an aspect of consciousness "encompasses the neurological processes involved in the formulation, evaluation and selection of a sequence of thoughts and actions to achieve a desired goal" (Mattar et al.).

In terms of brain regions most closely associated with this process, much of the attention is focused on the prefrontal cortex. When lacking a fully functioning prefrontal cortex, human behavior is reflexive. Multiple studies have demonstrated the activation of the PFC when participants are asked to complete tasks requiring sequential decisions, and patients with frontal lesions struggle comparatively (Mattar et al.). Beyond the PFC, the striatum, a subcortical structure in the basal ganglia, is similarly very involved in the process of planning. Related studies have established the structure's importance in planning and decision making (Mattar et al.).

Emotion

According to the American Psychological Association (APA), emotion is defined as "a complex reaction pattern, involving experiential, behavioral and physiological elements" (University of West Alabama, 2019). In a physical sense, it could be described as a conscious and subjective mental reaction to an experience, generally towards an object, person, or relationship (UWA). Emotional states can significantly impact the brain's attention, memory, perception, and problem solving (Tyng, Amin, Saad, & Malik, 2017). Emotion is also a part of the process of encoding memories in the brain (as explored in the memory section, the experience is stored in the hippocampus and the prefrontal cortex stores sensory aspects of the memory). Although we know where emotion occurs in the brain, it is more difficult to understand exactly how it effects the other cognitive processes of our brain. Interestingly, Tyng et al. noted that top down attention control plays a role in the emotional encoding of memories.

Emotions are understood to occur when specific subsets of specialized neurons in the cerebral cortex are activated. Parts of the cerebral cortex known to participate in this include "anterior cingulate, insula, ventromedial prefrontal, and subcortical structures, such as the amygdala, ventral striatum, putamen, caudate nucleus, and ventral tegmental area" (Simic et al., 2021). Modern theories and research on emotion focus on the importance of the amygdala, seen as the central subcortical emotional structure in the brain, which "constantly evaluates and integrates a variety of sensory information from the surroundings and assigns them appropriate values of emotional dimensions, such as valence, intensity, and approachability" (Simic et al.). Similar to top-down attention control, this vital process enables the brain to accurately perceive its surroundings without sensory overload. From an evolutionary perspective, these emotions played an important role. Whereas reflexes are defined as "automatic and uncontrollable narrowly-tuned responses to specific stimuli," emotions helped humans adapt better to an environment constantly undergoing change (Simic et al.). Feelings are thus defined as the emotional and conscious experience of the activations of the neuron networks, which help moderate language, behavior, and thoughts, and improve the brain's capabilities for learning, prediction, and accessing memories to help better assess the surrounding environment and its stimuli.

Part 2: Existing Theories of Awareness

This brings us to the second part of this paper. We will cover the main existing theories of awareness, and how it arises in the brain. There are several prominent theories of awareness, both in what it is and how it comes to be. Both will be covered in this section. I will offer a critique of the current research, and offer my own proposal.

Attention Schema Theory

Attention Schema Theory (AST), proposed by Michael S. Graziano, posits that the human concept of our own awareness occurs due to the brain's internal modeling of the aforementioned shifts in deep processing. When the cortex handles a shift in deep processing, it does the same thing as the tectum – it constructs a model, or a simulation of the brain's workings, called attention schema to help with top-down attention control (Graziano, M. S., & Webb, T. W., 2015). What humans think of as awareness is actually this model of attention at work – so the theory holds. Essentially, the human brain is an information-processing machine – comparable to the overall content of the entire human internet – and this model of top-down attention control, to help with that processing, causes humans to attribute "awareness" as we know it (Graziano, M. S., & Webb, T. W., 2015). The model is constructed because humans lack a complete innate comprehension of the remarkably complex processes within the cortex, and so thus it must be simulated (Graziano, M. S., & Webb, T. W., 2015). As Graziano put it in his 2015 study on the topic, if one were to pay attention to item x, the attention schema then models that state. However, the brain doesn't understand the specific interactions taking place in the neurons, so the model constructed doesn't include them (Graziano, M. S., & Webb, T. W., 2015). Instead, the model causes one to attribute awareness to oneself: "I have a subjective awareness of item x." The mind creates subjectivity because, in Graziano's words, it is a good enough "cartoon sketch" of attention. To summarize, due to limited understanding of its own mechanical processes, the brain makes an attempt at modeling attention, and the model gives the brain the experience of subjectivity in order to focus that attention. This links back to the evolution of selective attention outlined in the attention section, because it is the specific model of top-down attention control performed by the cortex that, under AST provides the attribution of awareness. But a theory without evidence is just that – a theory.

The initial evidence gathered from scientific studies is very promising for AST. According to Western University (Canada) philosophy professor David Bourget in a 2017 study, AST holds up on a theoretical scientific basis. Bourget writes that phenomenal theory (which is theory on self-aware consciousness, according to a 2000 paper on concepts of consciousness by Michael Antony) fits into the idea that the human mind's information processing is a largely unconscious system – or, in other words, parts of that unconscious information processing system are what lead to the discovery of the consciousness of information, as AST says. Furthermore, a 2015 study conducted by Zhicheng Lin and Scott O. Murray at the University of Washington found intriguing evidence that supports AST. The study found a link between shifts in focus of the human top-down attention control system and subject awareness of subliminal stimuli – meaning that as attention processing shifts, so too does awareness (Lin, Z., & Murray, S. O., 2015). This does not prove AST, because the mechanisms at play are not fully comprehensible yet due to the lack of necessary technology, but it is exactly what would be expected if AST were true – because it is the model of those shifts in processing that cause humans to attribute awareness. Similarly, a 2020 study at Princeton University found evidence that awareness helps regulate attention control, which is again exactly what would be expected were AST to be true (Wilterson, Kemper, Kim, Webb, Reblando, & Graziano, 2020). The previous paragraphs established AST as the system that causes humans to attribute awareness, and given the evolution that led to this awareness, it would thus be reasonable for awareness to have an important purpose in attention regulation, as established by the study's findings. Thus, although AST hasn't been proven yet, there is initial evidence that AST is the correct explanation for the human awareness.

Integrated Information Theory

The communication and integration of information between brain regions is at the heart of many theories of consciousness. One of these theories, IIT, uses a mathematical equation to calculate a being's level of consciousness, based on its ability to integrate information (Kingsman, 2023). Based on this equation, inanimate objects (teapots and rocks are given as examples, but it extends to anything) have at least some flicker of consciousness (Kingsman).

In 2008, Balduzzi and Tononi introduced and described a time- and state-dependent measure of integrated information, given as φ, which is intended to capture the whole system's entire inventory of causal states (states of a process which always lead to the same kind of behaviors). The φ works by quantifying the information generated when a system enters into a specific state through its elements interacting, separate from the independent generation of information by the parts of that system (Balduzzi & Tononi, 2008). The reason for the mathematical representation of this is given as the fact that integrated information is key in describing two properties of conscious experience: " (i) there is a large repertoire of conscious experiences so that, when one particular experience occurs, it generates a large amount of information by ruling out all the others; and (ii) this information is integrated, in that each experience appears as a whole that cannot be decomposed into independent parts" (Balduzzi et al.).

The theory thus argues that consciousness *is* integrated information, or the integration of information, beginning from what is termed a phenomenological analysis. The theory defines integrated information and suggests how integrated information could be measured. It then demonstrates how this theory gives an explanation for things we already know about the brain's relationship with consciousness.

To explain the theory, Balduzzi and Tonini use the example of a megapixel digital camera, with a sensor chip that is for all intents and purposes a collection of a million photodiodes. Even if each individual photodiode in that sensor chip were binary, the camera would have the ability to distinguish 21,000,000 separate states, which corresponds to 1,000,000 individual bits of information (Balduzzi et al., 2008). For each individual frame of every movie ever made, the camera would be in a different state – but no one would say the camera is conscious.

According to the theory, the difference between you and this camera has to do with integrated information. The camera could be seen as one singular system with 21,000,000 possible states. However, the chip is not integrated: each photodiode cannot interact, meaning the state of each is independent from the others. It's just 1,000,000 different photodiodes, and each has 2 possible states. If you were to slice the chip into individual photodiodes, the camera wouldn't skip a beat. However, your possible conscious states can't be divided like this, because they're not available to individual components of the system – proof that they are integrated (Balduzzi et al., 2008). By contrast, your vast repertoire of conscious states truly belongs to an integrated system, since it cannot be subdivided into repertoires of states available to independent components (Balduzzi et al.). Therefore, conscious experience is always as an integrated whole. This means that the state of each element of experience within your brain as a whole is dependent on the others, which is untrue of the camera. Thus, the theory claims, consciousness is the integrated information of the entire system, as it would not exist without it (by taking parts away, you remove our ability to be aware).

Global Neuronal Workspace Theory

The global neuronal workspace theory (GNWT)'s basic thesis is that there is a "global workspace" in the brain, an interconnected network of long-range connections across the brain (Mashour, Roelfsema, Changeux, & Dehaene, 2020). When neural information enters this workspace, it becomes conscious. Consciousness is useful in this regard because it lends the ability to broadcast, in a sense, this information throughout the brain, which includes the biological underpinnings for memory, selective attention, motor, and more.

The GNWT theory says that, while conscious, a network's activation allows for global awareness, enabling local processing (Mashour et al., 2020). It's a psychological construct which argues that "perceptual contents," which local processors act upon, become conscious when they are globally broadcasted, to processors across the entire brain, allowing us to be aware of the contents. This information being globally accessible is thus believed to be our conscious experience, as the global accessibility constitutes our awareness. Many tasks in the brain require interaction between different cortical processors with distinct functions (Mashour et al.). The GNW is the web that connects these processors and allows them to exchange information about stimulus that is the present focus of attention.

As it is termed within the article, "local, specialized cortical processors are linked, at a central level, by a core set of highly interconnected areas (A) containing a high density of large pyramidal neurons with long-distance axons (B). At any given moment, this architecture can select a piece of information within one or several processors, amplify it, and broadcast it to all other processors, thus rendering it consciously accessible and available for verbal report" (Mashour et al.). Local processing within the brain is woven together by the neuronal network, and this framework has the capability to select information from local processing and transmit it globally, making the brain aware of the information. This is the GNW.

Organization of Energy Processing Theory

This theory hinges on a basic premise: Energetic activity is necessary for all processes within the body and is the primary driver for biological behavior. Although the brain is only about 2% of the mass of the human body, it takes some 20% of the body's total energy (Pepperell, 2018). Recent research from the field of neuroscience provides evidence that consciousness could exist as a product of the way the brain's energetic activity is organized. Several biological features of the human brain, which include the lengths of neural connections, blood vessels per unit of space, the width of axons, and the ratio of brain size to stomach size are believed to be determined by the high levels of energy necessary for complex cognitive processes (Pepperell).

In 2009, Robert Shulman studied the progressive loss of behavioral response to an external stimulus while going from a state of wakefulness to deep anesthesia, and found a reduction and localization of cerebral metabolism (which is used as a marker for energy being consumed). Stemming from this, Shulman argued that high global metabolism is fundamental for consciousness. The current methods for imaging the human brain cannot detect the active processing of information, but they can detect changes that are associated with an increase in consumption of energy (fMRI and PET) or fluctuations of electrical potential energy (EEG), and these have been shown to have correlation with shifts in brain function and overall behavior

(Shulman, 2009). Based on these observations, it can be said that the brain functions based on the principle of the processing of energy (Pepperell). This evidence suggests a determination of awareness stems from the overall organization of energy processing, and more wakeful states of awareness have an association with increased complexity of organization. Thus, the theory is that a specific kind of dynamic organization of electrical activity in the brain is the cause of our conscious experience.

Critique of Current Research – Part 3

This brings us to a crucial part of this paper – the critique of the current research and what it is missing. Much of the existing research covered here is critically important to our understanding of awareness and what it is, but it falls far short of giving a definitive reason for the brain's ability to become aware. GNWT offers a reasonable perspective on the nature of consciousness that squares with experimental evidence, but it does not itself give a mechanism – it is much closer in substance to Newton's law of gravitation than it is to Einstein's law of general relativity. IIT and the theory on the organization of energy processing have the same issue, in that they are descriptive and not mechanistic accounts of awareness. They tell us about what awareness may be, and how it may work, but it doesn't answer the question posed at the beginning of this paper: how does the brain create awareness? IIT tells us that by taking away parts of the integrated information of the system, you remove our ability to be aware – but this doesn't tell us how that awareness comes about. Attention Schema Theory (AST) is the clearest singular explanation for how we become aware, but it does not describe the mechanism through which the shift of attention gets translated into global awareness, only that it happens as part of the process.

The existing research fails to manage both sides of the awareness coin. AST gives a mechanism, but no real description of what awareness is, while the GNWT and IIT explain what awareness is but not how it works. Pepperell attempts to give both, but the theory instead really does neither. The argument that the specific organization of energy processing just gives rise to consciousness still doesn't explain how that structure then produces it. It is just arguing that it must be some process in that dynamic structure that makes us aware, without any description. There is nothing explaining how the structure gets from energy to awareness. Furthermore, another issue with the organization of energy theory as a mechanistic account is that it fails to explain the why of that mechanism in the first place. What would cause energy to be organized in such a way that generates awareness as a byproduct? What is the evolutionary advantage of using so much energy in this way? Consider again that the brain uses 20% of the body's energy. For Pepperell's theory to be the case, awareness must first be absolutely essential to *Homo sapien* survival (which could be easily argued). From an evolutionary perspective, in this view, both options were tried. Either the brain used less energy and could not produce awareness, and these hominids thus lacked something essential to survive, or it used more and the body could not function, so the hominids again could not survive. Of course, this isn't what happened – we have an evolutionary record explaining the origins of biological underpinnings of aspects of awareness and why they exist. We know that they have some role in our complete awareness. However, it would also be illogical to believe that such a vast amount of energy plays no role in consciousness, which was the basis of Pepperell's theory in the first place. It's also worth considering that evolution as a process does not necessarily give rise to the most efficient structure, just a sufficient one. It goes just far enough to solve the problems that it is given. If it were a process of energy organization that produces awareness, evolution would not land so precisely – it would get just far enough to reach awareness, and call it a day. But this itself assumes that awareness was a necessity of evolution and not a product of the evolution of awareness' aspects. We have enough evidence of the interconnection between these aspects that we know awareness is the product of the entire brain working together. We know it somehow arises from all this. We simply do not know what that mechanism is.

My Proposal – Part 4

Take Graziano's work on the evolutionary background of attention control and bring it into the picture. This is a legitimate mechanism that could realistically have led to awareness, and explains how awareness could have evolved.

What if Pepperell's theory, like GNWT and IIT, is considered as a descriptive one? In other words, what if energy organization is removed as the mechanism for awareness and considered as a functional necessity for awareness? This would still follow the basic assertion made by Pepperell – that the brain functions on the principle of energy processing – but instead, the actual mechanism creating or causing awareness is not included in that view. The brain's function remains structural.

To sufficiently operate upon new information, the brain processes it in the neuronal workspace, a workspace itself constructed by the attention schema, to make us aware of the information and enable us to decisively act upon it. The attention schema models our selective attention, and this model is the main function of the global neuronal workspace. The massive energy usage of the brain and its organization goes into constructing and maintaining this workspace – which is why energy usage by the brain stopped where it did. Evolution just used enough to fully model top-down attention control and maintain the GNW, giving the brain awareness. Once that was achieved, there was no point using more.

The workspace is the most energy-efficient method of utilizing the brain's numerous neuronal connections to correctly judge an attended stimulus. The EM field of the brain is enormous, but if the brain used any more of the body's energy beyond the 20% it already does, it would not be possible for our body to function. It is the old basic question of how hominids get smarter. Evolution tried increasing head size to allow increasing brain size, but human birth canals literally could not get any wider - females could not walk. Thus, *Homo sapiens* come out half-baked and grow into it. This is why our infants are so comparatively weak when looking at other species. Evolution needed another answer for us to get smarter and survive - and this is how we became aware. In order to enhance our information processing and decision making under our energy constraints, the brain is consciously aware of that processing and is able to sift through the information the brain does provide - through the GNW ignited by the attention schema. Once that was achieved and we had enough energy usage in the brain to maintain it, we had awareness.

Think of the attention schema as the key that opens the door, then the GNW as the light switch. The attention schema necessitate the model, and the GNW is the model at work. Attention schema gets you into the room, but there's nothing visible in the room until the GNW turns on the lights. And the brain's EM field sustains the connections that make up the GNW.

This theory is backed by studies that have already been conducted. Existing evidence suggests that selective attention is the filter that controls the information that enters the GNW (Mashour et al.). The workspace is a global broadcast of the stimuli selected by the attention schema as the most important, which allows the brain to consciously act upon it. In the attentional process, attended items are given a signal boost in the brain, thus leading to deeper processing and more influence on output. GNWT, meanwhile, says that local processors select information to be broadcast to all parts of the brain, making the brain aware, allowing greater control over the output based on the attended stimuli. These are describing the same thing. GNWT, then, should be considered as a law of awareness, not a theory of awareness. In the GNW framework of awareness, awareness is the entrance of information into the neuronal workspace, information that is selected by our attention systems. The modeling of this process occurs in the neuronal workspace, which allows us to be "aware" of the process and thus direct our attention to items which necessitate it.

Furthermore, this theory explains at least in part the mystery of the human subconscious. Under this framework, subconscious processing becomes conscious when an attended stimulus causes localized (subconscious) processing and information to be projected into the neuronal workspace, thus allowing the brain to become aware of it.

Perhaps without realizing it, the study of awareness has circled the importance of selective attention to the concept without emphasizing the role of selective attention in creating awareness itself. Research indicates the crucial role that the prefrontal cortex plays in the signal selection process (Nakajima). A 2018 study made a critical finding – the minimum amount of activity needed before the PFC is activated (Van Vugt et al., 2018). Furthermore, that ignition of the PFC led to significant sustained global neuronal activity. In a separate study, Joglekar et al. found that "propagation of neuronal activity from the visual to the frontal cortex benefits from a "balanced amplification" regime, in which the feedback excitation from top-down sources is balanced by local inhibition" (Mashour). Put together, these results would indicate that conscious access of information is reliant on the sustained interactions between "higher cortical areas," which can represent a weak stimulus as sustained activity until intention requires a behavioral response. So, we know that the PFC plays a critical role (as discussed above) in signal selection, and we also know that the PFC is activated after the brain attends to a certain minimum level of activity, thus leading to sustained neuronal interaction across the brain. On top of this, we know that lack of a fully functioning PFC removes the ability to do anything besides react reflexively to stimuli (Mattar). This squares with the theory outlined above – that it is the process of top-down attention modeling that leads to utilization of the GNW. It can then be said that the processes that cause information to be projected into the GNW are the machinations of the attention schema. The model, the GNW, is the filtered version of our attention that we understand as our consciousness. It is the basis of our awareness.

Further Questions - Part 5

Following the theory presented above, further research is required. GNWT describes the nature of the model constructed by the attention schema, but it does not explain how the broadcast of localized processing enables global awareness, only that it happens once the information is in the workspace. AST says the brain attributes awareness in order to judge an attended stimulus, but does not explain the specific chemical processes taking place in the brain. At the moment, it is nothing more than a framework. Understanding the GNW's role in the process as the brain's means of awareness attribution is a step up from AST in terms of a conceptualization of how this occurs, but it does not explain how that actual process happens. The next step would be to utilize that framework in pursuit of a chemical understanding of the process of the brain creating awareness. How does global processing of information based on our top-down model of attention lead to conscious understanding of that information? Once information has entered our neuronal workspace, the theory says, it is broadcast globally and we are aware. What is the chemical essence of this that allows for awareness? Further research is required in this arena. On top of this, research to demonstrate that attentional shifts correlate with the sustained activity found upon ignition of the PFC could provide significant evidence in favor of this hypothesis.

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