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Neuroscience of consciousness: cognition, physics and philosophy of decoding the human brain

Neurociencia de la conciencia: cognición, física y filosofía de la descodificación del cerebro humano

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Abstract

The biophysical roots of consciousness have been the subject of an ongoing debate for centuries. In order to understand the data, create novel experimental methodologies, and increase our ability to investigate this phenomenon of interest, the proposed theories must lead to empirical, repeatable, and testifiable studies. Contemporary theories of consciousness often do not relate to one another, and none of them has been distinguished as complete or proven empirically so far. The aim of this study is an investigation into some of the possible approaches that could merge neuronal brain activity with the laws of physics and some philosophical principles that may be associated with the emergence of consciousness in the first place. As a result, the relationship between consciousness and attention, working memory, access consciousness and phenomenal consciousness is evaluated. The contrast between conscious and unconscious perception, perceived visual inputs and subliminal ones is investigated to facilitate a discussion about the neural correlates of self-awareness. Consciousness as a global broadcast of information to integrated brain modules is being considered, as well as viewing a brain as a parallel information processor linked to attention inputs. Relationship between consciousness and attention is explored, as well as attention without consciousness and vice versa. Implications and shortcomings of the proposed approaches based on brain science, philosophy and quantum physics are also covered to shed some more light on this ever present experience of being conscious that everyone seems to self-witness but no one manages to adequately explain.

Keywords*:* Neuroscience of consciousness; self-awareness; conscious awareness; consciousness; cognition

Resumen

Las raíces biofísicas de la conciencia han sido objeto de un continuo debate durante siglos. Para entender los datos, crear nuevas metodologías experimentales y aumentar nuestra capacidad de investigar este fenómeno de interés, las teorías propuestas deben conducir a estudios empíricos, repetibles y comprobables. Las teorías contemporáneas de la conciencia a menudo no se relacionan entre sí, y ninguna de ellas se ha distinguido como completa o probada empíricamente hasta ahora. El objetivo de este estudio es una investigación sobre algunos de los posibles enfoques que podrían fusionar la actividad cerebral neuronal con las leyes de la física y algunos principios filosóficos que pueden estar asociados con la aparición de la conciencia en primer lugar. Como resultado, se evalúa la relación entre la conciencia y la atención, la memoria operativa, la conciencia de acceso y la conciencia fenoménica. Se investiga el contraste entre la percepción consciente e inconsciente, las entradas visuales percibidas y las subliminales para facilitar una discusión sobre los correlatos neurales de la autoconciencia. Se considera la conciencia como una emisión global de información a los módulos cerebrales integrados, así como la visión del cerebro como un procesador de información paralelo vinculado a las entradas de atención. Se explora la relación entre conciencia y atención, así como la atención sin conciencia y viceversa. También se abordan las implicaciones y deficiencias de los enfoques propuestos basados en la ciencia del cerebro, la filosofía y la física cuántica para arrojar algo más luz sobre esta experiencia siempre presente de ser consciente que todo el mundo parece auto presenciar, pero que nadie consigue explicar adecuadamente.

Palabras clave: Neurociencia de la consciencia; autoconsciencia; consciencia consciente; consciencia; cognición

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Introduction

Exploring the mysteries of the phenomenon of consciousness has not always been a welcome topic in the history of science. The behaviorists in the first half of the 20th century disregarded self-awareness as an unprovable scientific problem and insisted on limiting science to factual, measurable occurrences and testifiable experiments that are within the reach of observation and comprehension. Even the so-called "cognitive revolution," which transformed the field in the latter parts of the 20th century, failed to spark a renewed interest in consciousness. The cognitive approach was to revive the approach of internal representations and mental states rather than the idea of self-awareness itself. However, cognitive scientists developed a number of intellectual milestones and stepping stones in their new information-processing perspective that significantly influenced the cognitive theories of consciousness that followed (Montemayor & Haladjian, 2015). New models of working memory and attention were among these cornerstones, as well as highlighting the contrast between automatic and regulated processes or between peripheral and central processes of how the mind works (Prinz, 2012).

Methodology

The primary type of information used in this study was qualitative data and the author's own reflections grounded on the known laws of physics, philosophy and neuroscience. Qualitative data was more useful for this research than quantitative data, which nearly does not exist in this newly emerging subject of study, except for rare case studies reported that are not unified in their methodological approach and therefore could not be reconciled with each other and taken into account. An ethical review for this particular research process was not required in accordance with the local legislation and institutional requirements. The investigation was conducted in alignment with the Declaration of Helsinki. The study was designed to adhere to the international standards of research and data collection protocols.

Research

Philosophy and Consciousness

Consciousness is viewed as a subjective experience, and philosophers have long debated the nature of it and its relationship to matter. The study of consciousness is an interdisciplinary field that draws on research from psychology, neuroscience, philosophy, physics and other disciplines. There are numerous theories of consciousness, each classified by its stance on the existence of consciousness and the physical world, and how they interact (Blackmore & Troscianko, 2018).

Substance dualism posits that there are two fundamental types of substances in the universe: mental and physical. The mental substance is responsible for consciousness, while the physical substance makes up everything else.

One of the advocates of substance dualism was the French philosopher René Descartes, 1641). One of the key problems in substance dualism is how the two substances can interact.

According to materialists, only the physical world is fundamental and every phenomenon present is explainable in terms of sheer matter. The "hard" problem of consciousness is then one that has long puzzled philosophers and brain scientists (Chalmers, 1996). How can consciousness arise from the physical world? It is "hard" because it seems to defy explanation by science. The "hard" problem of awareness is not an argument against materialism, but merely yet another challenge for materialists to explain.

Emergentism is the view that complex phenomena can arise from simpler components, even if those simpler ones are not themselves complex. For example, life emerged from inanimate matter, even though there was nothing alive about matter itself, initially. In the same way, it could be argued that consciousness emerges from the physical neural networks, even though there is nothing conscious about matter itself. However, emergentism leaves a problem of interactions unsolved and how a non-physical occurrence can emerge from a physical brain. We are still left with the problem of how the mind and body can causally interact with each other.

Epiphenomenalism is a dualistic materialistic theory that holds that consciousness is an emergent side effect of physical processes in the brain. Consciousness plays no causal role in the world and is therefore ultimately viewed as superfluous or redundant.

Eliminative materialism is yet another type of materialistic approach that orthodoxically denies consciousness all together. According to eliminative materialists, our common-sense notions of consciousness are simply wrong. It does not exist in reality; they are merely useful fictions that help us make sense of our behavior.

Idealism holds that consciousness might be the only real phenomenon that exists (Berkeley, 1948). According to idealists, the physical world might be just an illusion created by our minds.

Solipsism is the philosophical idea that only one's own consciousness is sure to exist. All other things, including other people, are only beliefs or assumptions. This means that everything experienced by an individual is only happening in their own mind.

Panpsychism is a type of materialism that holds that consciousness is a fundamental property of all matter (Chalmers, 2015). According to panpsychism, even inanimate objects like rocks and electrons have some form of primitive consciousness.

Functionalism is the belief that consciousness only depends on the mapping of inputs to outputs (Block, 1982). This means that if two systems, for example a brain and a computer, or a brain and a powerful lookup table, have the same input-output map, then they will also have the same consciousness.

There is a distinction between phenomenal self-awareness, leading to subjective sensations and experiences, and access type of consciousness, which refers to the ability to cognitively access information (Block, 1995). Phenomenal consciousness is what allows us to have conscious visual experiences, for example, while access consciousness is necessary for us to be able to report those experiences. The "hard" problem of consciousness deals with phenomenal consciousness. Access consciousness is compatible with functionalism.

A philosophical zombie is a hypothetical being that is indistinguishable from a normal human being in every way, but lacking conscious experience (Chalmers & Chalmers, 1999). In other words, a philosophical zombie would be a perfect imitation of a human being, but without any inner life or consciousness. In particular, a zombie would claim to have conscious experiences even though they actually don't. Chalmers argues that zombies are logically possible, and that the existence of zombies would have profound implications for our understanding of consciousness. Zombies have access type consciousness but not phenomenal consciousness.

There might be no philosophical zombies. In eliminative materialism, everyone is a zombie. Some people might be conscious while others are zombies, as in solipsism being an idea that everyone except oneself is a zombie. One can claim: I am not a zombie and I am pretty sure about that. But how can I be certain? I can only know my own consciousness, so I can't be sure about anyone else's. Maybe everyone else is a zombie and I'm the only one who's conscious. Or maybe I am the zombie and others are conscious.

Consciousness appears to be private. This means that it does not seem possible to compare the consciousness of two different people. For example, it's possible that what one person experiences as the color red is the same thing as what another person experiences as the color blue. This is the so-called inverted spectrum (Shoemaker, 1982).

Neuroscience and Consciousness

Some speculate that consciousness might not be solely produced by the brain, but rather merely correlated with it. They pose questions whether self-awareness could somehow transcend the physical limitations like those of the brain and exist independently from it. This has led to researching neural correlates of self-awareness or consciousness (NCC). Regardless of which theory is ultimately correct, the study of NCCs can help us better understand the complex relationship between the brain and consciousness. In doing so, we may eventually be able to answer some of the most fundamental questions about both self-awareness and the brain.

All contents of consciousness seem to be processed through the senses. Even thoughts and memories may be encoded in terms of sensory information. The conscious perception of emotions appears to be mediated through bodily sensations. The contents of our consciousness can be decoupled from the sensory inputs - for example, when we dream. Even when we're awake, examples of ambiguity, like the well-known images with dual meanings due to shades and perception focus, for example showing both a rabbit and a duck at the same time, show that the contents of our consciousness aren't determined solely by the sensory inputs (Baddeley, 2007).

How much of what we see are we actually conscious of? It might seem like we take in everything within our field of vision, but that's not actually the case. Experiments like change blindness show that we're often only aware of a constantly changing small portion of what's in front of us (Simons & Levin, 1997). If the visual input to the brain changes while the eye is moving (making saccades) or if there's a flash blotting out the change, people can fail to notice significant changes for a long time. However, it could be pointed out that a conscious experience of the changing object during change blindness does exist, but it's just that there's no memory of it.

Our brains are constantly making guesses about what's in our visual field, based on past experiences (Koch & Tsuchiya, 2007). This phenomenon is sometimes called "filling in." One well-known example of filling in is the blind spot. Everyone has a small area in their visual field where the optic nerve connects to the retina. There are no light-sensitive cells in this spot, so we don't see anything there. However, our brains automatically fill in this blank spot with information from the surrounding area. This is why we don't usually notice our blind spots. For instance, the filling in of the blind spot can make a hollow disc look like a full disc.

So what does this mean for our understanding of visual consciousness? It suggests that it isn't as straightforward as we might think. Our awareness is selective, and it's constantly changing based on what our brains deem important.

A popular theory is that we are conscious of objects, which are a binding of features (e.g. color, texture, shape, size and motion) spread all over the brain. However, the nature of binding is still unclear. Some scientists believe that binding occurs when certain features are combined into a single object, while others believe that binding is a more complex process that involves multiple areas of the brain. This could lead to a deduction that the conscious experience of an object is somehow more than the added sum of its individual parts. Instead, it is a unified whole that we can perceive and interact with. If two or more objects are flashed for a split second, the brain might bind features from each object into a single illusory object. This is called an illusory conjunction (Treisman & Schmidt, 1982).

Experiments by Libet et al. (1979) suggest that there is a delay between when an event occurs and an evoked potential arises in the brain, and when we become conscious of it. Although this gap lasts only a fraction of a second, we are not aware of it because our brains backdate the moment of consciousness by less than half a second. This allows us to perceive events as happening in real-time, even though they are actually occurring slightly delayed. This proved duplicatable through various experiments that kept re-confirming the same findings with different variants used. The delay between when we have an evoked potential in the brain, and when we become conscious of it was proven. This delay is called the "consciousness lag."

The existence of the gap has important implications for our understanding of consciousness. It suggests that consciousness is not simply a product of sensory input, but is instead generated by our brain's interpretation of sensory information. This would mean that consciousness is not an objective reality, but is instead a subjective experience.

If someone wants to create the illusion of light moving around, you can do so by flashing different colors in different locations. Your brain will put the two together and interpret it as a single light moving from one place to another while changing color. This is called the color phi (Kolers & Von Grünau, 1976). It appears to conscious observers that the light changed color before the second flash. However, the brain can only register the color change after the second flash. Subjective retroactive perception is how it's explained.

Subjective backdating is yet another way this effect was called (Li et al., 2002). It occurs when people remember an event as happening at an earlier time than it actually did. This is because our brains fill in the gaps in our memory, based on what we expect to happen. If an event has been predicted accurately in advance by the brain, there's no need for subjective backdating. But if an event is unexpected, it seems to happen a split second later.

There are two interpretations of what happens in consciousness during subjective backdating: the Orwellian interpretation and the Stalinesque interpretation (Dennett & Weiner, 1993). In the Orwellian interpretation, a stationary light with a fixed color briefly enters consciousness, but is immediately forgotten and replaced with the moving color phi. In the Stalinesque interpretation, a stationary light never passes into consciousness at any point. Dennett and Weiner (1993) pointed out that no experiment can ever distinguish between these interpretations, making the distinction meaningless. So, with that angle, there would be no way to objectively determine what the content of consciousness is at any given moment.

Most brain activity is unconscious. Only a small part of it can be accessed and reported (access consciousness). Blindsight is an example of how visual information can influence behavior without the person being conscious of it (Weiskrantz et al., 1974). There are two visual streams: ventral and dorsal (Goodale & Milner, 1992). The ventral stream is associated with consciousness, while the dorsal stream is unconscious and related to action. If someone with blindsight can correctly guess what an object is without being conscious of it, they have access consciousness, but not phenomenal consciousness.

The "Global Workspace Theory" (GWT) by Baars (1993) posits that consciousness is like a theater, with a spotlight that moves between objects. It proposes that when something is conscious, information about it is then broadcasted to different brain regions. In other words, something becomes conscious when there is widespread access to information about it.

The "Global Neuronal Workspace Theory" by Dehaene (2014) is an elaboration of GWT. Dehaene investigated access consciousness and not phenomenal consciousness. If an object is flashed for 40 milliseconds, most people can detect it. However, if the object is immediately followed by another object called a mask, the first object fails to register in consciousness and becomes subliminal. Experiments suggest that it leaves no trace in memory. If the interval is increased to 60 milliseconds, most people will be conscious of the object. At 50 milliseconds, the object is detected about half of the time.

Subliminal stimuli are below the absolute threshold for conscious perception. This means that they are too weak to be consciously perceived, but they can still influence our behavior.

We can adjust the timing of the flashes so that it is consciously seen only half of the time. Then, we can ask the subject whether or not they saw the flash while scanning their brains and measuring their brainwaves. The difference between consciously perceived flashes and subliminal ones are neural correlates of consciousness. This would provide a minimal contrast between conscious and unconscious perception, since the sensory input is the same in both cases.

Conscious perception appears to be an all-or-none phenomenon. This would allow us to isolate the neural correlates of consciousness. If an object is shown to someone subliminally, and then another object is shown to them consciously shortly afterward, they will take slightly less time to recognize the second object if it's the same as the first object and more time if it's different and unrelated. This is called subliminal repetition priming.

Subliminal priming experiments have shown that many parts of the brain, including the ventral visual cortex which is responsible for the early stages of reading, and the amygdala, can activate subliminally (Reddy et al., 2006). For instance, when a primed word is in lowercase, it can speed up recognition of the same word in uppercase even though the visual shapes of the letters are identical. Object binding is also shown to occur subliminally. The letters of the primed words can be shown to be bound together unconsciously because the order of the letters is preserved in the priming even without consciousness of the prime. If the prime is a word with multiple meanings, the subliminal priming activates all possible meanings of the word, regardless of the context. The parts of the brain involved in subliminal processing appear to be those which deal with automatic and acquired or learned processes. Subliminal priming is not just a bottom-up feedforward activity; top-down feedback from attention can also affect whether or not it occurs. It's important to note that subliminal priming is only in effect for a short moment, before it becomes forgotten. For example, if a list of words is flashed subliminally for as many as 20 times, the person will not be able to remember those words after some time has passed.

The attentional blink refers to the phenomenon where only one object can be attended to at a time. If one object is being attended to, other objects are blocked from consciousness for a fraction of a second. However, brain scans show that the other objects are still processed in the early stages of visual processing even though they're not conscious. It may seem we are conscious of many objects at the same time, but that's just an illusion caused by the rapid switching of attention from one object to another.

The preconscious refers to brain activity of neurons that are outside the global neuronal workspace, but have strong activations and could enter consciousness if only they are attended to (Dehaene et al., 2006). Subliminal activities are weak activator that can't become conscious even if they are attended to. There are also disconnected circuits in the brain which can't be connected to the global neuronal workspace, no matter how active they are. In minimal contrast experiments using functional magnetic resonance imaging, people who are consciously aware of an event see a strong amplification of that event in the higher visual centers of their brain. Huge regions of the parietal and frontal lobes are also activated. This activation is called a global ignition and happens in synchrony across the brain. This does not happen for events that people are not consciously aware of.

The brainwaves detected during the minimal contrast experiment are the P1, N1, and P3 waves. The P1 wave is positive and peaks around 100 milliseconds after the input. The N1 wave is negative and peaks around 170 milliseconds. Both of these waves occur in both the conscious and subliminal cases. The P3 wave only happens when the event enters consciousness. It is positive and starts around 270 milliseconds and peaks between 350 and 500 milliseconds. The P3 wave is a signature of consciousness. When the brain is processing the P3 wave of an event, the

P3 waves of other events are suppressed. This is the attentional blink. For subliminal signals, unconscious activity is confined to the left temporal lobe, which is responsible for meaning, for about half a second instead of a P3 signal.

Another neuroscientific signature of consciousness could be a significant increase in gamma-band activity around after 300 milliseconds. Yet another one is large-scale synchronization of electromagnetic signals across the cortex after 300 milliseconds at lower brainwave frequencies. During global ignition, only specific neurons are activated, as measured by implanted electrodes, depending on what someone is conscious of. For example, these neurons might respond to specific people, places, and pictures. Thus, by mapping which neurons are activated, we can deduct what the contents of consciousness are. Even merely thinking or imagining an object can cause the relevant neurons to fire. These neurons aren't activated subliminally.

Functional magnetic resonance imaging might also be employed for determining the content of consciousness, by looking at the pattern of brain activation averaged over millions of neurons. In fact, Transcranial Magnetic Stimulation (TMS) can cause neurons in particular brain regions to fire. The conscious perception caused by the firing is then correlated with which brain region was stimulated. Furthermore, TMS can be used to make signals that would otherwise be conscious become unconscious.

The brain ignites nearly all the time while we are awake, even when we are not receiving any sensory input. This corresponds to thinking or daydreaming. If the brain is built by many special-purpose regions, then consciousness in the brain appears to be a global broadcast of information to all these modules. This broadcasting system appears to be composed of neurons with long-distance axons connecting different brain regions in the cortex and the thalamus. If area A projects to area B, then area B also projects back to area A. If area A projects to areas B and C, then area B projects to area C.

For any given content of consciousness, only a few long-distance neurons in the global neuronal workspace fire while the rest are inhibited. They form a huge number of attractor state combinations. The inhibited neurons are responsible for the P3 wave.

A simplified computer simulation by Changeux and Dehaene reproduced the main features of signatures of consciousness (Dehaene, 2014). In the simulation, neurons are partitioned into cortical columns, each of which is tightly interconnected. The thalamocortical column is also included, with timing delays. At the higher levels of the cortical hierarchy, sound and light modalities inhibit each other. Within each column, there are feedforward and feedback connections. In their model, the activation of neurons typically behaves according to either of two patterns: either a huge number of neurons fire in synchrony or almost none of them do.

A local-global test can be used to detect if someone is conscious. If a person is conscious, they will generate a P3 wave in their brain when they detect novelty. However, if a person will also generate an unconscious mismatch negativity (MMN) response in their brain after 100 milliseconds whether or not they are conscious. For example, if a couple of beep, beep, beep, beep, boop sequences are played, followed by a beep, beep, beep, beep, beep sequence, the MMN will occur after a boop is played, but not when a beep is played. However, the consciously detected novelty, which is more sophisticated, occurs for the last beep of the last sequence because the brain is expecting a boop.

Physics and Consciousness

When it comes to the measurement problem in quantum mechanics, consciousness plays an interesting role. This was illustrated by the Wigner's friend thought experiment (Wigner, 1995). In this scenario, there is an observer (Wigner's friend) who performs a measurement on a particle. However, until the observer reports the results of the measurement, some interpretations suggest that they remain in a superposition of states - that is, they kind of exist in all possible states simultaneously. Can consciousness exist in a superposition, or must the contents of consciousness always be definite? It's not clear what a superposition of consciousness would be. However, if consciousness can never be in a superposition, then the wavefunction must collapse before information reaches consciousness. Some theories suggest that consciousness is what causes the wave function to collapse (Goswami, 1995).

Wigner's friend can either be conscious or a zombie, in the context of the philosophical experiment presented earlier in this paper. The idea that consciousness causes the collapse of the wavefunction means that if Wigner's friend is conscious, they are in a definite state. If they are a non-conscious zombie, they are in a superposition. The timing in milliseconds of when the result of measuring the particle enters the consciousness of Wigner's friend determines the moment the wavefunction collapses.

However, just like there is no physical distinction between Orwellian and Stalinesque interpretations of the color phi, the moment the wavefunction collapses is also unphysical. If we present the results of a measurement to Wigner's friend subliminally followed by a mask, what happens? In the Orwellian interpretation, the wavefunction first collapses, then uncollapses. In the Stalinesque interpretation, it never collapses.

Goswami (1995) believes that there is only one conscious observer in the universe, and that this observer is the union of all conscious observers. Anthropic principle gives consciousness a role in cosmology (Carr & Rees, 1979). It notes the universe as fine-tuned for the sentient observers and intelligent life forms. It theorizes that if any of the biophysical constants were not as they are, the known life to observe would not be there. Therefore, it makes sense in that context that consciousness is seen as necessary for the universe to exist as we know it. In one version of the anthropic principle, the necessary existence of consciousness has a backward causation effect, causing the early universe to be fine-tuned.

Discussion

One of the key mysteries in contemporary neuroscience is comprehending the neural underpinnings of consciousness. Using concepts from philosophy, psychology, computer science, and neuroscience, a variety of complex models and hypotheses have made an effort to codify how the brain implements or produces consciousness. These include the integrated information theory and the global neuronal workspace theory, two important and perhaps competing theories that differ primarily in their degree of conceptual abstraction and anatomical specificity. Increasing our understanding of the phenomenon of self-awareness states may have important implications for anesthesia awareness and improving current neuroimaging techniques for more precise detection of consciousness in the locked-in syndrome in vegetative patients, or those suffering from other disorders of consciousness.

Conclusions

A sizable body of experimental data has accumulated in recent years in an effort to establish a causal link between objective and subjective data on conscious processing as a result of the development of experimental tools to study conscious and subliminal processes of the brain. Experimental studies that have used behavioral, PET, fMRI, ERP, and MEG imaging, as well as single-cell electrophysiology, to identify the physiological characteristics of conscious sensory perception by contrasting it with subliminal processing. The applicability of these findings to disorders of consciousness in coma and vegetative states is apparent. The distinctions between conscious and non-conscious processing have been the topic yielding many recent experimental evidence, but deepening our understanding is still required to close the neuro-psychological gap and build a linkage between unbiased, objectively measured neurophysiological data and one's subjective experience of self-awareness.

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Conflict of interests

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