The Brain-Mind as a Networked Entity: A Medical Case Study in Consciousness

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Abstract

Consciousness consists of two principal components: alertness and awareness. The former requires functional integrity of the ascending reticular activating system, while awareness is primarily a function of the cerebral cortex. Consciousness is not unitary but is made up of numerous components working together in a networked fashion. We can understand consciousness to a limited extent by examining the effects of disease states and with the advent of modern neuroscience using modern technology. Higher aspects of consciousness remain elusive, but a multidisciplinary approach should provide further insights and confirmation of the early work of Robert Fludd and John Hughlings Jackson.

Le Cerveau-Mental comme une entité en réseau : une étude de cas médical dans la conscience

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Résumé

La conscience se compose de deux composantes principales : la vigilance et la conscience. La première exige l'intégrité fonctionnelle du système d'activation réticulaire ascendant, tandis que la conscience est principalement une fonction du cortex cérébral. La conscience n'est pas unitaire, mais constituée de nombreux composants travaillant ensemble d'une manière semblable à celle d'un réseau. Nous ne pouvons appréhender la conscience que d'une manière limitée, en examinant les effets des états de la maladie et, avec l'avènement des neurosciences modernes, en utilisant la technologie moderne. Les aspects plus élevés de la conscience restent insaisissables, mais une approche multidisciplinaire devrait fournir d'ultérieures informations et la confirmation des travaux des pionniers Robert Fludd et John Hughlings Jackson.

El Cerebro-Mente como una entidad en red: Estudio de caso médico de la, Conciencia

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Resumen

La conciencia consta de dos componentes principales: alerta y conciencia. El primero requiere integridad funcional del sistema de activación reticular ascendente, mientras que la conciencia es principalmente una función de la corteza cerebral. La conciencia no es unitaria, sino que está formada por numerosos componentes que trabajan juntos en una red. Podemos entender la conciencia en un grado limitado al examinar los efectos de los estados de enfermedad y con el advenimiento de la neurociencia moderna utilizando la tecnología moderna. Los aspectos superiores de la conciencia siguen siendo difíciles de alcanzar, pero un enfoque multidisciplinario debería proporcionar más información y confirmación de los primeros trabajos de Robert Fludd y John Hughlings Jackson.

O Cérebro-Mente como Entidade em Conexão: um Estudo de Caso Clínico sobre Consciência

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Sumário

A consciência consiste em dois componentes principais: atenção e conscientização. O primeiro requer integridade funcional do sistema de ativação reticular ascendente, enquanto a consciência é principalmente uma função do córtex cerebral. A consciência não é unitária, mas é composta de vários componentes que trabalham juntos, como rede de conexão. Podemos entender a consciência de maneira limitada, examinando os efeitos dos estados de doença e com o advento da neurociência moderna usando a tecnologia moderna. Aspectos mais elevados da consciência permanecem indescritíveis, mas uma abordagem multidisciplinar deve fornecer confirmação e informações adicionais do trabalho inicial de Robert Fludd e John Hughlings Jackson.

Gehirn und Geist, eine vernetzte Einheit: eine medizinische Fallstudie des Bewusstseins

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Zusammenfassung

Zwei Hauptkomponenten bestimmen das Bewusstsein: Aufmerksamkeit und Erkenntnis. Die Aufmerksamkeit fordert eine funktionelle Integrität des steigenden retikulären Scharfschaltungssystems, wobei die Erkenntnis primär eine Funktion des zerebralen Kortex ist. Bewusstsein ist nicht unitär sondern ist das Ergebnis vieler Komponenten, die vernetzt mit einander arbeiten. Wenn wir die Auswirkungen der Krankheiten und die aufkommenden modernen Neurowissenschaft mit ihrer modernen Technologie studieren, können wir das Bewusstsein einigermaßen verstehen. Die höheren Aspekte des Bewusstseins sind jedoch schwer zu definieren. Eine multidisziplinäre Annäherung könnte zu weiteren Erkenntnisse führen und das frühe Werk von Robert Fludd und John Hughlings Jackson bestätigen.

Introduction

Consciousness has been variably defined but includes both wakefulness and awareness.[1] Wakefulness and arousal from sleep are characterized by the eyes being open, related to activation of various brain structures comprising the ascending reticular activating system of the brain (discussed later).

Awareness is even more complex and consists not only attending to or being mindful of the environment but to aspects of the self. Awareness depends on integrated brain functions that involve receiving and selectively processing sensory information, connecting this information with other modalities, linking such initial perceptions to memory and emotion, allowing for more complete perception. On the efferent side, response generation is dependent on recognizing the significance of the task to be processed, using judgment, and then triggering motor response systems in the brain and spinal cord. Of course, there is then feedback about the response. Higher cognitive functions that seem to arise spontaneously are less well understood. For example, thought and imagination are so personal and subjective that analysis of their components and processing has largely evaded scholars. Although it is generally accepted that such aspects of consciousness arise from complex actions of the integrated brain regions, the very complexity of the healthy, functioning brain creates difficulty in approaching its holistic function in awareness.

Before proceeding further it is best to try to define "the mind" and how it differs from consciousness. The conscious mind is the product of brain function. The principle of "emergence" allows for something to emerge that is different from the elements that gave rise to it. The mind is immaterial, but arises from the brain and its complex interactions via synapses and neurotransmitters. This is somewhat analogous to how a functioning motorcycle has properties and functions that differ from its various parts. The conscious mind comprises everything of which we are aware at the time. This involves focusing of attention, to perceive sensations, to generate thoughts, speech, and deliberate action. (Much processing goes on without full mindfulness, e.g., the minor adjustments we make while driving, or our avoiding colliding into objects as we walk in a crowded corridor.) Consciousness is more difficult to define, as there are varied concepts, but in general, it deserves a broader, more inclusive definition that involves the immediate mindfulness as well as other mental states other than the more "mundane" aspects of the mind, e.g., psychic phenomena, introspection, the nonverbal "coloring" of emotion and motivation, and the ability to shift one's focus when subliminal stimuli arise.[2]

John Hughlings Jackson, a nineteenth century British neurologist, formulated the concept that "for every mental state there is a correlative nervous state."[3] Hughlings Jackson's concepts were based on careful clinical analysis of cases and were inspired by the evolutionary theory of the philosopher Herbert Spencer.[4]

It is even more remarkable that a Rosicrucian apologist and physician-philosopher, Robert Fludd (1574-1637), had similar concepts.[5,6] (Fludd had also been strongly influenced by the works of Paracelsus [1493/4-1541], a physician-alchemist of the German Renaissance.[7]) The mind-brain relationship was captured in the famous drawing of Robert Fludd, a Rosicrucian, in which he depicts the integrated functions of various brain regions in a hierarchical order, with even the highest functions evolving from brain activity (Figure 1).[8] Note the primary sensory inputs (touch, smell, taste, visual, and auditory inputs), their processing by brain centers, further connections with the mind (*mens*), which lies within the brain, but, with the aid of reason (*Ratio*), either gives rise to or is connected to higher levels of consciousness (*Deus* or God/Cosmic Consciousness). There is input by the "keeper" (*Custos*) perhaps the "keeper/Master Within" (*est enim*). Finally, there is motor output through downward projections through the brainstem and spinal cord after the decision of type of action is made. Thus, the more mundane aspects of experience are depicted along with the ability to access the Cosmic.

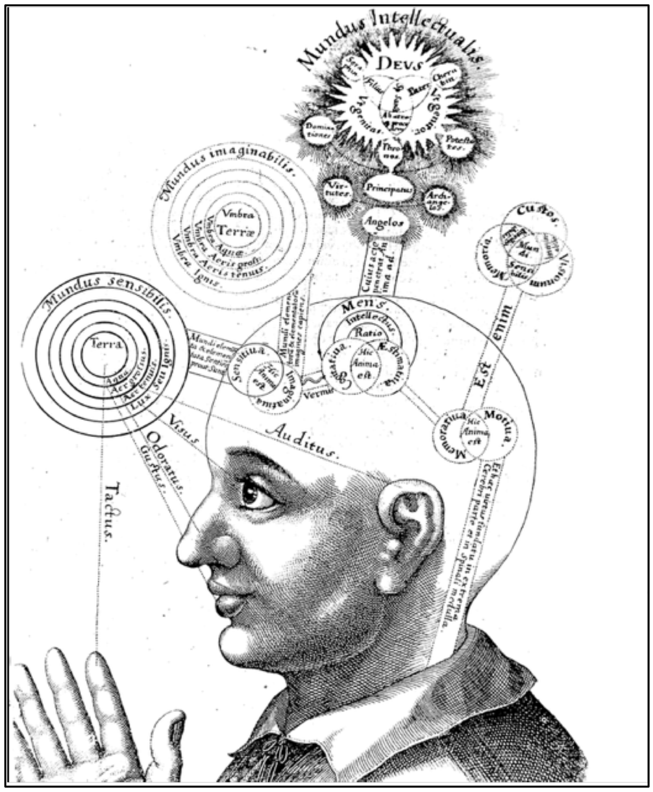

Figure 1

The concept of a hierarchical, interconnected structure and function of the brain, as formulated by Fludd and Hughlings Jackson, was expressed long before advanced neuroimaging techniques and electrophysiological tests were developed, which illustrate and confirm their concepts. Disease states can isolate various components of brain function and structure and can provide insight into consciousness and its components. I have recently encountered a clinical case that provides such an opportunity. Case study is an accepted research methodology that provides an in-depth analysis of a complex issue. As such, the presentation of this case constitutes an "instrumental case study," namely one that "uses a particular case to gain a broader appreciation of an issue or phenomenon."[9] This case is put forward as an illustration of the alteration of mental states from one of a functioning human to a comatose state with only primitive reflexes and back again through various levels of consciousness.

Case Study

A 55-year-old man suffered an out-of-hospital cardiac arrest. He was resuscitated in the emergency room by five direct currents, electrical shocks and intravenous epinephrine to abort the abnormal rhythm of the heart, and ventricular fibrillation to restore his circulation. He was then admitted to the intensive care unit where he was placed on a ventilator and underwent hypothermic treatment using ice packs and cooling blankets designed to keep his core body temperature between 32-34 degrees Celsius for twenty-four hours to provide neuroprotection.[10]

For the first three days he remained deeply comatose with no response to stimuli and made no spontaneous movements. His brainstem reflexes (pupillary responses to light, ocular movements induced by applying cold water to the ear, corneal reflexes in which blinking was induced by stimulating the cornea of each eye, and coughing induced by stimulating the trachea) were intact, but it was not possible clinically to assess his cerebral function (Figure 1). An earlier review of similar patients who were not treated with therapeutic hypothermia suggested that such profound dysfunction indicated a poor prognosis, i.e., no better outcome than complete dependency.[11] However, subsequent reviews of cardiac arrest patients who were treated with hypothermia indicated that motor responses could be delayed for six days or more.[12,13] Hence, one could not say definitively that the patient had a poor prognosis.

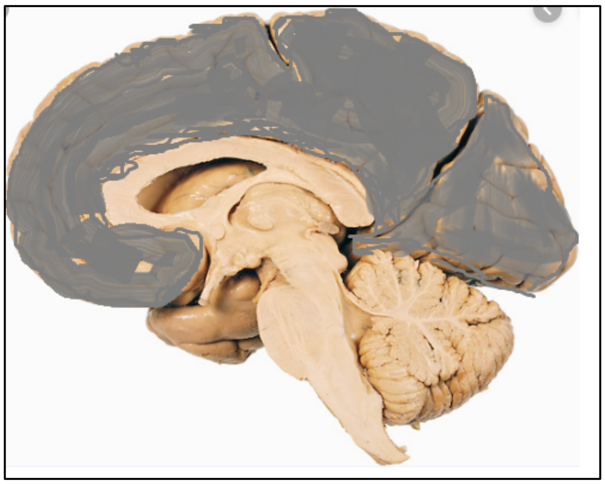

Figure 2

Commonly available tests were then applied to assess the structure and function of the cerebral hemispheres. These included electroencephalography (EEG), somatosensory evoked responses (SSEPs) and Imaging (computed tomography [CT] and magnetic resonance imaging [MRI]). The EEG (Figure 2) showed an abnormal rhythm called alpha-theta pattern coma. This has been shown to be insufficient for prognosis.[14] SSEPs showed a normal initial cortical response (the N20-P23 potential) (set up shown in Figure 3). Although the absence of the N20 response on both sides is almost always associated with a poor outcome, its presence does not necessary imply a good result; in fact, most of such patients still do badly (Cruise et al).[15] Although the CT scan of the brain on Day 2 following the arrest was normal, the MRI on Day 4 showed abnormalities on the diffusion-weighted sequences (Figure 4), indicating that the grey matter of the brain had been partially affected by the temporary lack of circulation. By itself, this was not severe enough to indicate a poor prognosis.[16,17]

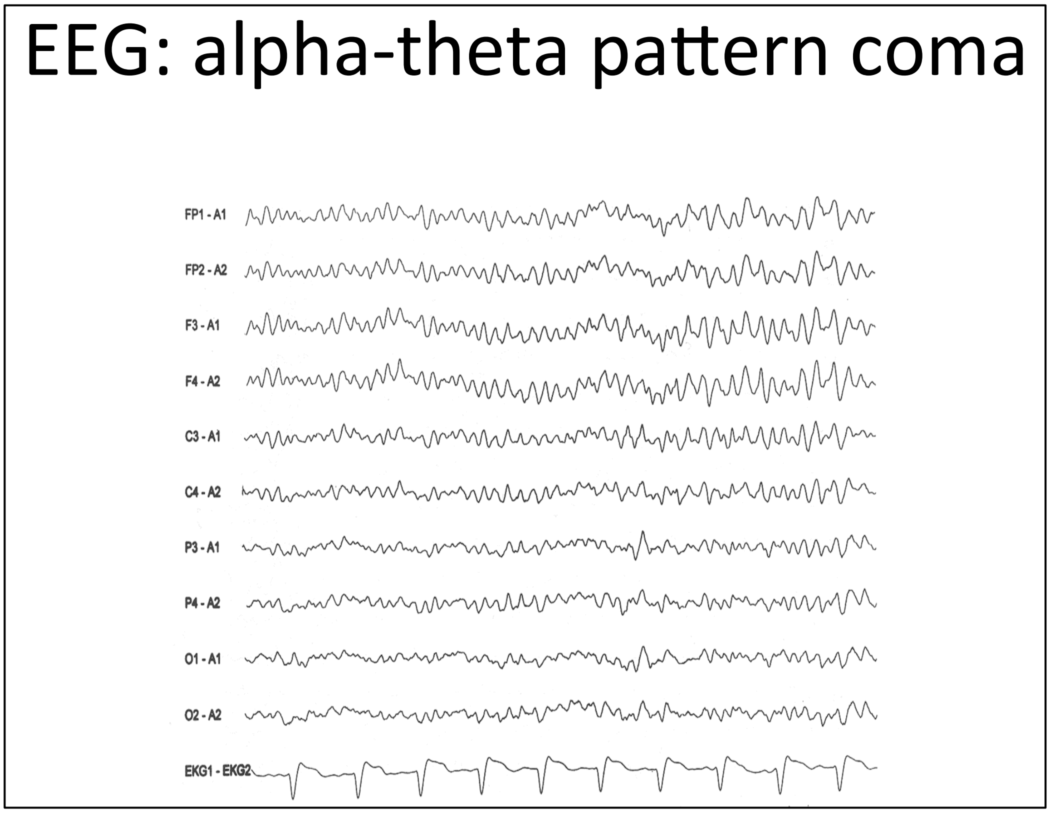

Figure 3

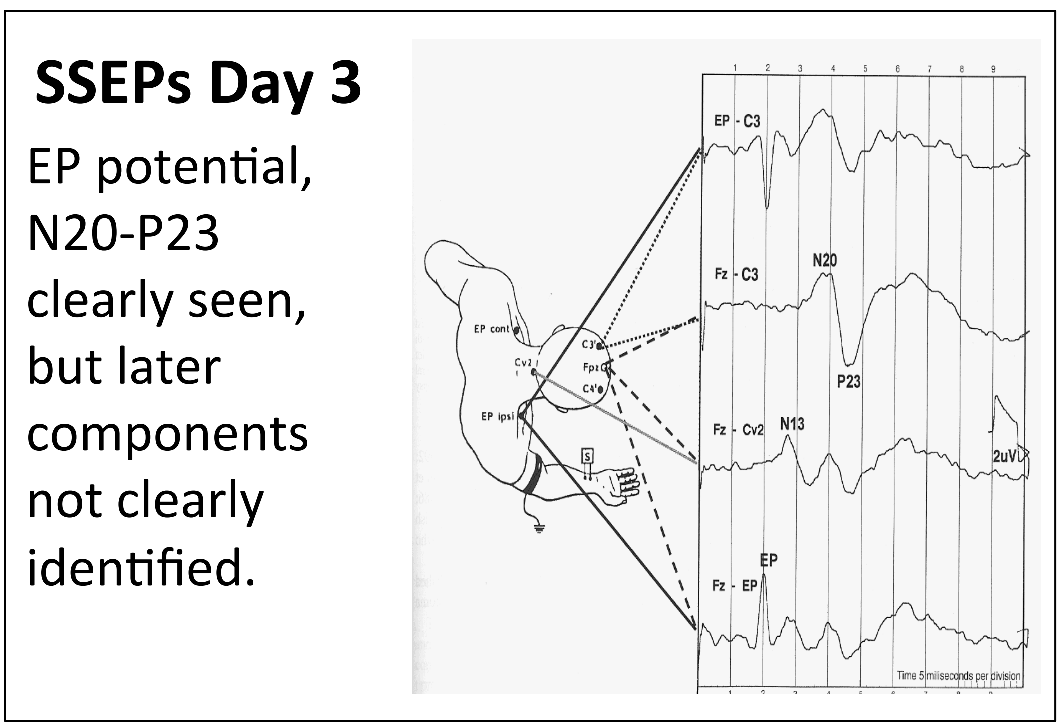

Figure 4

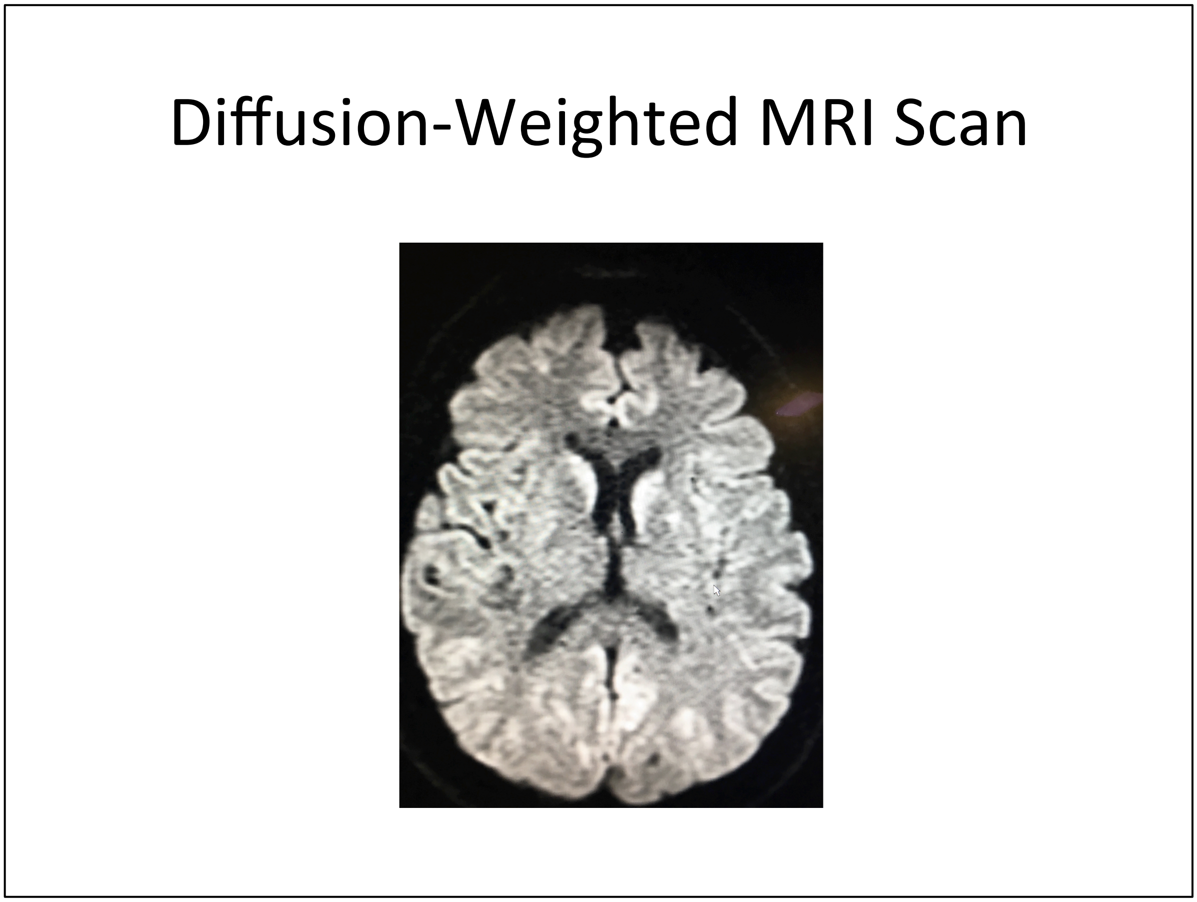

Figure 5

Since the above tests were still not definitive for either a good or poor outcome, functional MRI was used on Day 4. This revealed that the resting-state networks (RSNs) were intact for several networks (Figure 5). Resting state networks, including the default mode network, are brain regions that have a high degree of functional connectivity, as revealed by certain fMRI sequences, without the person being actively engaged in a task.[18] The integrity of the resting state networks can operate without awareness; their presence revealed by scanning merely indicates that the basic interconnections responsible for a given task are intact. We have shown, in a series of patients who were initially comatose after cardiac arrest (Norton et al.) that the default mode network is necessary but not sufficient to allow consciousness to recover.[19] For conscious awareness to occur and for RSNs' operations to be meaningful to the person require further integration with other brain regions. For example, RSN connections are different from the nodes (centers) involved during command-following.[20] In such tasks, the patient is given a verbal command for either a motor task, such as playing tennis or swimming, or a mental-imaging task, such as pretending to walk through the rooms of one's house. If the patient, even while behaviourally unresponsive, obeys the motor task, a motor brain region (the supplementary motor area) becomes more active. With the latter task, regions associated with visual processing show connected activity. In this way the researcher can detect that the patient understood the command and activated appropriate brain regions for the task.[21]

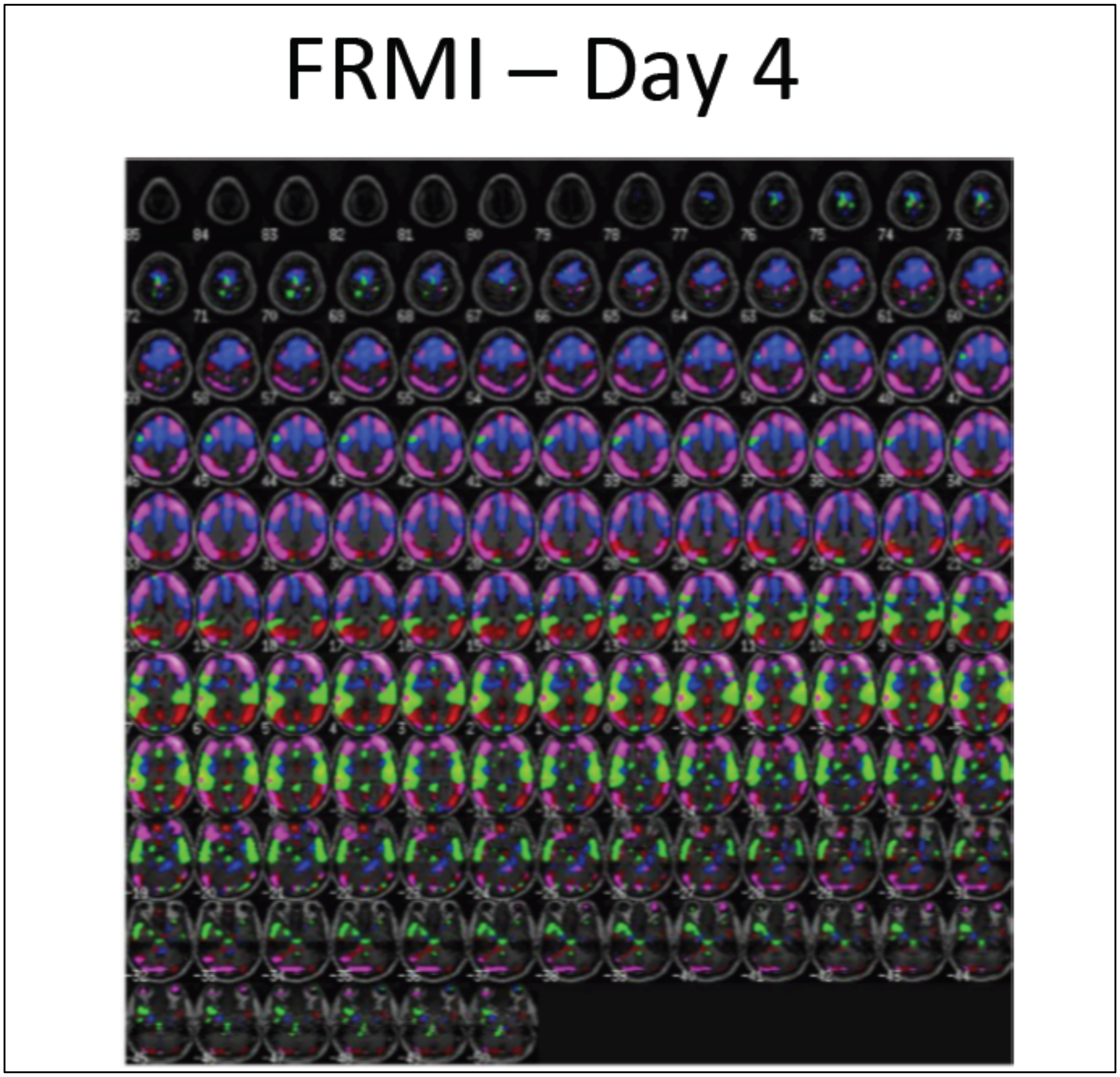

Figure 6

On Day 5 the patient showed spontaneous eye opening but did not fixate or follow moving objects or persons with his eyes. He also showed spontaneous movements of right upper and lower limbs. He showed some visual fixation and following with his eyes by Day 7. By Day 13 he was obeying simple commands. After a short stay on the medical floor, where he exhibited a delirium or acute confusional state, he was transferred to a rehabilitation unit where he made further progress, ultimately returning home and then to work.

Discussion

The case is illustrative of several levels of consciousness and of the remarkable recuperative ability and plasticity of the brain. In the initial post-cardiac arrest state he was in coma, an unarousable unconscious state, where there was neither wakefulness nor awareness. In our patient the “devolution” into coma from wakefulness was collapsed in time to be almost instantaneous. The “evolution” from coma to wakefulness and conscious awareness occurred more gradually.

Wakefulness is a state in which the person can be aroused to an eyes-open state, while awareness indicates cognitive function, in which one can perceive information as evidenced by appropriate responses. Wakefulness requires functioning of the ascending reticular activating system (ARAS).[22] This is a network that originates in the brainstem and projects via multiple synaptic relays through the brainstem, the thalamus, and ultimately to the cerebral cortex (see Figure 6). There are several neurotransmitters involved in wakefulness, namely acetylcholine, dopamine, serotonin, norepinephrine, histamine, and others.

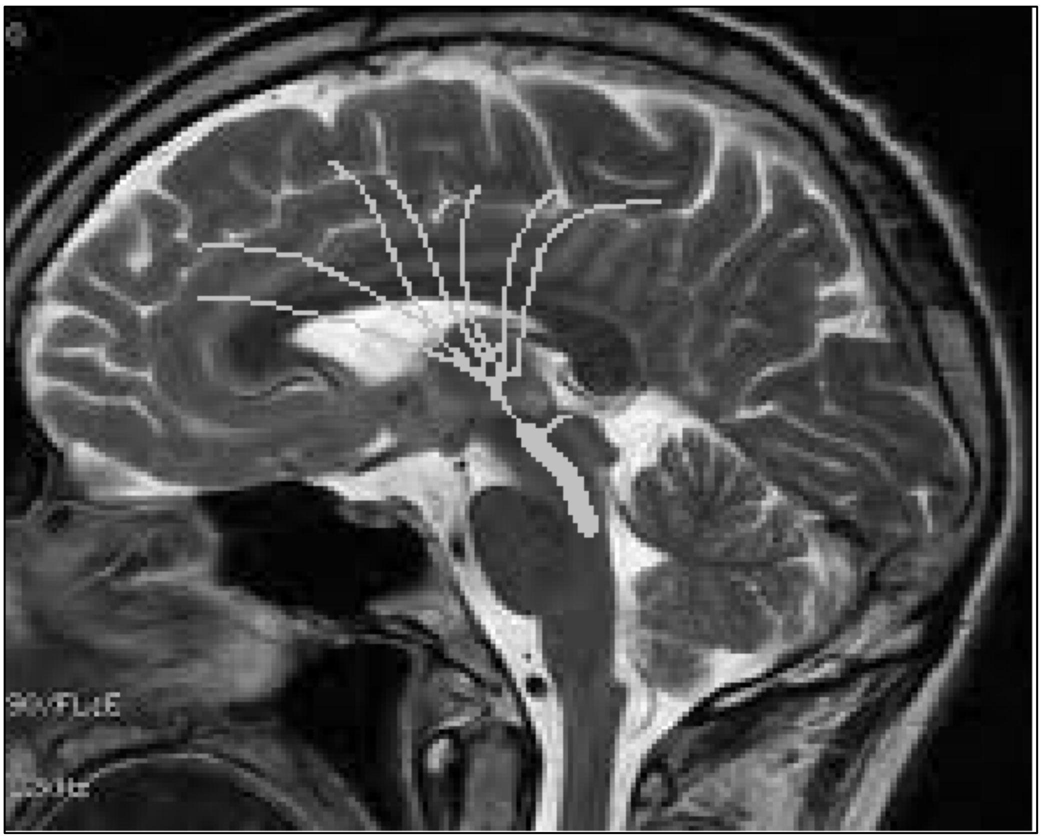

Figure 7

Awareness requires the functional integrity of the ARAS[22] but is also dependent on highly integrated networks involving various cerebral cortical and subcortical regions. For example, the selection of which stimuli to attend to depends on the anterior cingulate region and medial frontal regions (Figure 7)[23], which are connected to other regions allowing recognition (memory centers) or visual, auditory, language, or somatosensory processing regions. The generation of a response requires action of the frontal motor areas, including the supplementary motor areas and connections with the primary motor cortex. This is overly simplified, but it gives the idea that conscious awareness requires the highly integrated action of various regions or brain networks.[24]

As Ralph M. Lewis concisely stated, cognitive processes such as conception of ideas are "*dependent* upon consciousness".[14] This includes both objective and subjective consciousness.[25]

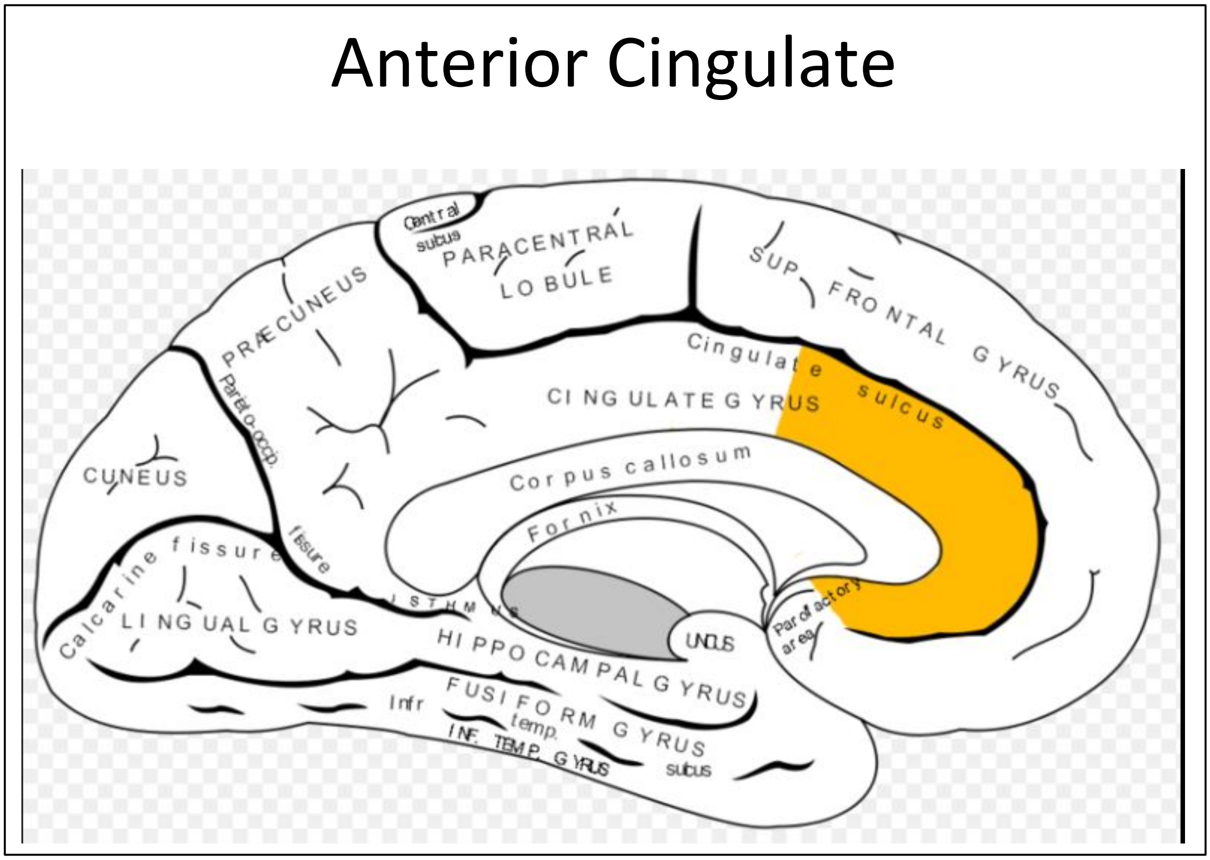

Figure 8

The presence of wakefulness without awareness has been referred to as the persistent vegetative state (PVS)[26], features of which are given in Table 1. (The term "vegetative" refers to preservation of basic "vegetative functions" such as maintaining blood pressure, temperature, endocrine function, breathing and other basic bodily functions.) Wakefulness implies the functional integrity of the major subcortical regions of the ASAS, but PVS indicates dysfunction of the integrated networks of the cerebral hemispheres. (It should be noted, however, that about 17 percent of patients who are behaviorally unresponsive still show evidence of awareness by command-following paradigms in which various brain networks are activated by different tasks. Thus, the term "unresponsive wakefulness syndrome" [UWS] is a more accurate term to include both patients who are truly vegetative and those who show evidence of awareness.) The recovery of awareness can be gradual, as in this patient. He could obey some simple verbal commands but could not recognize relatives, nor could he retain information in memory or demonstrate orientation in time or place. He later regained these aspects of cognition. The early transition to some aspects of awareness has been referred to as the minimally conscious state (MCS),[27] the main features of which are given in Table 2. Delirium, which was also present for a time as our patient recovered, is a state in which there is diminished ability to sustain attention, along with disorientation and impaired memory.[28] This is usually transient, with degrees of awareness fluctuating from hour-to-hour or day-to-day. Patients can be agitated (hyperactive), hypoactive (drowsy and inactive), or show a mixture of both agitated and hypoactive features.

A normal mental state, with alertness and awareness intact, has been considered an essential quality for "personhood," the state of being a person. This has been a subject of philosophical debate, but it is reflected in our social and medical value systems in Western societies. Descartes's famous quote "Cogito, ergo sum," or "I think, therefore I am" captures this concept.[29]

Although Descartes perceived that the mind and the body were separate entities, it became obvious that when the brain was not working properly, neither was the mind. This is reflected in the recovery of our patient from a state of coma, through the minimally conscious state, delirium, and finally full consciousness. The dualistic concept of mind and brain being separate is still with us, but it seems to be losing ground. Research on brain functions has shown that consciousness is not an all-or-none entity and that there are different aspects and levels of consciousness. The highest level of consciousness is cognition and metacognition. These are, like other mental states, immaterial. The issue is whether such immaterial phenomena are due to something ethereal or whether consciousness emerges from the complex actions of the brain. Although we only understand some of the components of brain processing, the progressive complexity, and reduced modularity, of dynamic brain networks parallels the levels of consciousness.[30]

Functional magnetic resonance imaging has been very instrumental in exploring disorders of consciousness and understanding full consciousness with awareness. In comparing patients with the "vegetative state," minimally conscious state and the awake and aware state (normal volunteers) there is a progressive increase in complexity and interregional connectivity, with the latter group showing brain-wide coordination.[31] The connections involved in thought and self-awareness, e.g. that "I perceive," are undoubtedly more complex, at a higher level of cognition.

The "network theory of consciousness" holds that conscious awareness arises from widespread communication across widespread regions of the cerebral hemispheres. Indeed, this is compatible with the concepts of Fludd, as in his diagram, all aspects of brain processing, thought, and metacognition (the awareness of one's own though processes) and even spirituality are dependent on brain function (see Figure 1). It is also congruent with concepts of Hughlings Jackson, who conceived as the brain processing information at increasing levels of complexity and generating responses, compatible with current neuroscience. He also proposed the principle of concomitance, that there is no need to propose supernatural phenomena to explain natural phenomena.

The increasingly obvious fact that brain function underlies cognition should be extended to include spiritual and metaphysical experiences. This requires further research that will likely involve various disciplines, e.g., neuroscience, psychology, neurology, and philosophy, working together. Inputs into primary sensory areas communicate with association areas for further processing and these are linked in regions that combine various already processed sensory modalities. There is linkage then with areas for memory, emotion, and with regions of motor output. Serial and parallel processing in the brain has been well studied. However, the concepts of self-awareness, introspection, control of thought and action, metacognition and perception of phenomena not captured by our various sense organs require further exploration. A blending of disciplines, e.g., philosophy, psychology, cognitive science, neuroscience, network neuroscience, linguistics, artificial intelligence, and robotics is needed. Some progress in being made, e.g., a controlled psychiatric study of metacognition in depression[32] and theory of mind (the ability to understand the mental state of others),[33] the study of brain networks involved in meditation[34] and functional brain connectivity for out-of-body and near death experiences.[35,36]

To state that the brain function is essential for transcendent experiences does not mean it is sufficient for them, i.e., that materialism/reductionism wins out over an intelligent Universe or Universal Soul with which we can communicate. Fludd and other great scientists, mathematicians, and philosophers, e.g. Isaac Newton, Francis Bacon, Gottfried Leibniz, Giordano Bruno, Robert Boyle, and John Locke, who were also mystics supported the concept of Cosmic Soul and its interconnectedness with everything, including the human mind. There are current hypotheses, especially invoking quantum mechanics, that relate the interaction of the human mind and the external behaviour of matter and energy (Francini, 2008; Carroll, 2019).[37,38] The "observer" is part of the "outside world" in an intimate interconnection and each affects the other. This moves us closer to understanding the interaction and merging of the human mind and the Universe/Cosmic.

It seems reasonable to suggest that the highly complex, interconnected brain-mind is a microcosm and yet part of the Universe, which is also extensively interconnected ("as above, so below").

Conflict of Interest

The author declares no conflict of interest.

Table 1: Criteria for the Persistent Vegetative State

From the Multi-Society Task Force on PVS, 1993

1. No evidence of awareness of themselves or their environment; they are incapable of interacting with others.
2. No evidence of sustained, reproducible, purposeful, or voluntary behavioral responses to visual, auditory, tactile, or noxious stimuli.
3. No evidence of language comprehension or expression.
4. Intermittent wakefulness manifested by the presence of wake-sleep cycles.
5. Sufficiently preserved hypothalamic and brainstem autonomic functions to survive if given medical and nursing care.
6. Bowel and bladder incontinence.
7. Variably preserved cranial nerve (pupillary, oculocephalic, corneal, vestibule-ocular, and gag) and spinal reflexes.

Table 2. Criteria for a Minimally Conscious State
(from Giacino et al., 2002)

To diagnose a minimally conscious state, limited but clearly discernable evidence of self-or environmental awareness must be demonstrated on a reproducible basis by 1 or more of the following behaviors:

1. Follows simple commands.
2. Gestural or verbal yes/no responses (regardless of accuracy).
3. Intelligible verbalization.
4. Purposeful behavior, including movements or affective behaviors that occur in contingent relationship to relevant environmental stimuli and are not due to reflexive activity.

Appendix 1: Legends for Figures

Figure 1. The figure is taken from Robert Fludd's *magnum opus*, *Utriusque Cosmi*. The "microcosm" diagram of the mind shows various functions of the brain in hierarchical order. The explanation is given in the text.

Figure 2. The cerebral hemispheres are indicated in grey color. The lower structures (unstained) are the brainstem and cerebellum.

Figure 3. The EEG shows an invariant pattern of waves in the alpha (8-13 Hz) and theta (>4 but <8 Hz) range. This is a very abnormal rhythm that is present throughout the cortex and does not respond to stimulation or opening and closing the eyes, which normally would alter such rhythms.

Figure 4. The sequential responses to electrical stimulation of the median nerve at the wrist are shown. The vertical bars are separated by 5 milliseconds. The EP (Erb's point) potential is generated by the brachial plexus in the shoulder region. The N13 response comes from the upper spinal cord. The N20-P23 complex is from the primary sensory cortex of the cerebral cortex.

Figure 5. The diffusion-weighted sequence of the MRI scan shows patchy areas of abnormal (white) signal in the frontal and occipital cortices and the caudate nuclei, indicating these regions were affected by ischemia (the lack of perfusion by blood) during the period of cardiac arrest.

Figure 6. The functional MRI (fMRI) scan shows that multiple resting state networks (RSNs) are intact. The frontal RSN is in purple; the somatosensory RSN is in blue; the default mode network is in red and the auditory RSN is in green.

Figure 7. The ascending reticular activating system begins in the brainstem and ascends through the thalamus to the cerebral cortex. Simple arousal and wake and sleep cycles do not require the cerebral cortical component.

Figure 8. The anterior cingulate (in color) and medial frontal regions (surrounding the anterior cingulate) are shown in this sagittal (front-to-back view from the center of the forehead to the midline of the back of the head) perspective of the brain after the hemispheres have been separated from each other.

Endnotes

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