Rethinking Consciousness: Some Hypothesis on the Role of the Ascending Reticular Activating System in the Global Workspace

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Abstract. Science has always faced the problem of consciousness. Nevertheless, consciousness differs radically from the ordinary objects researched by science: not only because of the complexity of the neural infrastructures which are at its base or because of the subtle connections between these infrastructures and phenomena such as decision making, morals and artistic creativity, but above all because of that which gives life to the qualitative dimension and to the subjectivity of its states. If it is true that consciousness is caused by specific neuronal processes and, therefore, conscious states are causally reducible to neurobiological processes, it is also true that conscious states exist at a higher level than a few bundles of neurons. For this reason it is necessary not only to go beyond a hierarchical idea of levels of consciousness, but also to refute the idea according to which the ‘mental’ sphere is qualitative, subjective, and in the ‘first person’, while the ‘physical’ sphere is quantitative, objective and in the ‘third person’.

Keywords. Consciousness, Phenomenology, Brain imaging, Evolution.

Introduction

Until as recently as a few decades ago, few neuroscientists were willing to assign significant weight to the problem of consciousness despite the obvious interdependence of each and every mental activity on the central nervous system. It is probable that such a position finds its origin in the difficulty of determining ‘objective’ criteria for the exploration of the subjective dimension of consciousness; in the insufficient dependability of introspection as a tool of scientific knowledge; in the artful contrast between the dynamics of consciousness and the unconscious (a contrast which in fact denies the natural unity of the living organism); and finally, in the prejudice concerning the impossibility of understanding consciousness which has made it into a sort of mysterious and inaccessible Holy Grail. On an historic level, circumstances like these have represented a strong impediment to the development of science, which could...
instead face the question of consciousness with the same rigour with which it has succeeded in explaining natural phenomena such as gravity, photosynthesis, the uncertainty principle, the laws of thermodynamics, the drift of the continents and many others. It is because of these same obstacles that the exploration of consciousness (and of subjective experience) has long been the domain of philosophical and literary disciplines, which in turn has made the divide between humanistic culture and scientific culture all the more rigid.

Recently we are presented with a different picture. The development of brain-imaging techniques which explore cerebral functions has not only increased our knowledge on the correlations between mental processes and cerebral structures, but it has also created new hopes for the possibility of facing the age-old and elusive question about the mind-brain relationship with a new way of thinking. These sophisticated technological pieces of equipment are usurping a large part of the traditional applications in image-based diagnostics, with regards to magnetic resonance in its functional application (fMRI), as well as to medical-nuclear (PET and SPECT) and electro-physiological (EEG) methods.

At the same time, the unexpected convergence of disciplines such as genetics, molecular biology, experimental psychology, artificial intelligence, linguistics and still others has caused neuroscientists to focus their attention on the biological basis of knowledge, emotions and behaviour. From this happy hybridization emerged interdisciplinary efforts which have involved the cognitive sciences, basic and clinical neurosciences, in an extraordinary theoretical and empirical undertaking which grants scholars observational and methodological capacities today that were unthinkable at one time. When a balance of the ideas of the last thirty years of the 1900’s is drawn up, it will probably become clear that the most valuable intuitions on the human mind have emerged not from the autonomous acquisitions of the disciplines traditionally interested in the mind (philosophy, psychology or psychoanalysis), but rather from their combination with the biology of the brain. Nevertheless, bio-molecular research is not sufficient in itself. Notwithstanding its extraordinary success, bio-molecular research is not capable, on its own, of penetrating the complexity of neural circuits or of their interactions. One could seek to reduce the knowledge gap between neuron and thought by using a method which clarifies, first of all, the relationship between neural systems and complex cognitive functions. This means, essentially, starting from the basic neural structures and circuits in order to discover the interactions and the regularities which generate coherent representations; grasping the meaning of synaptic conversations; and understanding, finally, the way in which their activity is modulated by attention and awareness.

Just as at the dawning of time physical and chemical elements were transformed into biological structures, so to the natural history of consciousness has characterized itself with a spontaneous tendency towards complexity. That is the reason why research on consciousness must inevitably be multi-disciplinary: destined, that is to say, to concern itself with basic as well as applied bio-chemical research - which in recent years have fuelled a formidable psychopharmacological revolution; with the knowledge of cellular structure and differentiation - whose enormous prospects have grown with the knowledge of embryology (i.e. stem cells) which is opening therapeutic possibilities for some diseases which have a very high human and social cost; with the new integrated and multi-parametrical study techniques of the brain in vivo; with psychiatric disorders and with all of the psychological phenomena characterized by a
strong cultural expressiveness the final horizon of which is a general theory of knowledge in an evolutionary prospective.

1. Unity-Plurality of Consciousness

For ages philosophers and scientists, since Kant, have obstinately clung to the notion of the unitarity and the constancy of consciousness throughout time. Today, a large quantity of evidence shows that it is in fact is a many-sided process which simultaneously contains different contents within itself, each element of which has its own intentionality [1; 2; 3]. This internal plurality requires a clarification of both the system that unifies the different contents, as well as of the biophysical-molecular mechanisms at the origin of the multiple representational contents of unified experience. The model that derives from it has two possible variations: in the first one, consciousness is generated by a single central nervous system, in which information is represented and then carried into consciousness; in the second, consciousness emerges from the co-activation of contents programmed by structures spread out in the brain that, in a unitary process, simultaneously process countless pieces of information. And yet, once the simultaneous plurality of consciousness is accepted, what is the interface and the relationship between cerebral infrastructures and the activity of consciousness? In other words, in what way do the contents of experience – which contribute in multiple ways to instantaneous experience – reach cerebral integration?

This is where the separate strands of a plural model of consciousness and a unified theory of consciousness unite. In fact, if conscious experience is the result of the work of the central nervous system, where informational content must be represented in order to be brought to consciousness; or of a process of unitary consciousness-creation on which the brain simultaneously acts by processing a great quantity of different information, then consciousness is a monodromic phenomenon, which takes place only in the brain. On the contrary, activities with different elements, each one generated by cerebral mechanisms spread out in the brain, produce a plural phenomenology of consciousness. Here, the contents are separate from each other and are exposed to intra-sensory and intersensory influences that, having a reciprocal impact on each other, co-determine the contents of consciousness. In a plural model, in which the mechanisms of consciousness are multiple and localized, these interactions are perfectly constant. Ramachandran (2004) [4] has insisted on the concrete plausibility of a model which integrates visual, auditory, tactile, proprioceptive and other types of experiences. These individual spheres, which are relatively independent, can be altered or marginalized without influencing each other.

Neurologists have for some time drawn attention to the consequences of lesions and ablations to cerebral areas. This evidence shows that it is possible, on the one hand, to lose the ability to visually grasp motion, while conserving the other aspects of the visual experience [5]; and, on the other hand, demonstrating that it is possible to lose the sensation of colour, conserving instead the other aspects of the visual experience (including motion). Studies conducted on the deficits caused by lesions to the degree and type of functional specialization and of cerebral localization have shown that the brain works on a large scale, between modalities and domains that are reflected in specific anatomical regions (primary visual processing in the occipital cortex, auditory processing in the temporal cortex, development of planning and memory in the frontal cortex); while specific functions take place in anatomical regions and areas that are
well-demarcated (for example, that of visual motion in area V5 and that of colour in V4). The zones of the brain that program specific informational content are those in which these contents come into consciousness. For example, different events from a visual scene presented simultaneously are not perceived with the same duration. This multiple asynchrony proves that consciousness is not a unitary faculty, but rather the integrated result of many micro-events [1].

We need to posit the question that if consciousness has this plural nature then why do we have the sensation of being whole, as one individual? And how does the Self emerge from such plurality? A long discussion could certainly be had on the meaning of a unitary subject and on its internal nucleus which we define as the Self. Without venturing into such controversial territory it can be affirmed that the Self emerges when individual events produced by the brain are sufficiently representational, coherent and unified (here representation indicates the way in which the contents of the experience relate to each other). Under normal circumstances, we experience a structured world of distinct objects ordered in space, organized according to regularity and contained within schemas that are meaningful in terms of space and time: extramodal contents (colour, form, etc.) and intramodal contents (proprioceptive, auditory and visual). In reality, representational cohesion is not an invariable characteristic of conscious experience, but rather the result of a selection process through which the brain looks for a path towards its own integration. Therefore, the appearance of the Self has to do with a regulatory activity of consciousness, an activity that develops and supports such a plurality of local contents interacting with each other and generated by conscious experience.

Perhaps then such a multiple-consciousness model could best explain the birth of the Self, with the Ascending Reticular Activating System (ARAS) at its base, a system that supports both integration and global communication. Consciousness would thus appear as a multiple unity rather than as an undifferentiated unity [6]. It must be said that the unification of consciousness is not a question of unicity, but rather of representational cohesion: a cohesion plausibly created by cortico-cortical circuits and one that would explain how the Self emerges from the multiple representational activities of the brain. All conscious experiences are, in fact, united inside the conscious field [7]. Unity is, therefore, implicit in qualitative subjectivity. But if our awareness is determined by infinite parts, what we see is not one single subject with different conscious states, but many different unified fields of consciousness. In other words, the unitarity of awareness comes with subjectivity and quality, because there is no way of having subjectivity and quality without unity.

It can never be overstated that instantaneous unity is different from the organized unification of conscious sequences that we obtain, for example, from our iconic memory. For non-pathological forms of consciousness and of memory it is essential that the conscious sequence be organized according to a certain order. For example, a sentence is determined by the ability to recall its beginning and by the ability to produce coherent discourse throughout its duration until its end is reached [8]. Now, if instantaneous unity is part of the definition of consciousness, then unity organized through time (the duration) is essential to consciousness, even though it is not necessary for the existence of conscious subjectivity.
While in its evolutionary stages biological life on our planet underwent two main adaptations: initially it imprinted elements into the genetic code that would facilitate the periodic variability to environmental changes such as light, temperature, precipitation and others; and secondly it equipped the animal nervous system with structures that would guarantee the sensory and motor activities developed through time [9]. Compared with higher animals human beings also have an internal representation of time, and this originates in the birth of conscious experience. It is through the conscious perception of time that, over the course of evolution, human beings have been able to achieve enormous adaptive and reproductive advantages.

The cycle of life from past to present to future is an internal representation of reality which we perceive through our own “wiring”. It is always in the cortex that the unification of time takes place, realized through the combination between nervous circuits and our conscious experience, to which we can add through introspection and accounts in the “third person”. Although it is an essential characteristic of consciousness, we know little about time. These notions revolve around the categories of succession and duration [10]. Succession implies the eminently cognitive distinction between the simultaneity and the sequence of a number of events – although not in an absolute sense, because when temporal scales of tens of milliseconds are used the reliability of our judgement becomes more uncertain. Duration instead implies the ability to understand sequential perceptive events as though they were simultaneous, that is to „feel” the interval of time without discontinuity. In Time and Free Will: An Essay on the Immediate Data of Consciousness (1910), Bergson [11] problematizes the spatialized vision of duration of the positive sciences by identifying two dimensions of conscious life: a superficial I, which is built on cognitive issues; and a fundamental I, which is built through the synthesis of consciousness. Before Bergson, it was the Eleatic philosophers and later Saint Augustine (The Confessions) who shed light on the problematic nature of the concept of the Present and who questioned time as the succession of present moments. How short can a moment be, that changing interval that flows from the past to the future and vice versa? According to James (1952) [12]our consciousness of time originates in different speeds, which depend on the number of events or changes that we experience in a certain interval (neuroscientists would speak of a minimum necessary time for the emergence of neural events correlated to a cognitive event). This immaterial structure has been interpreted as the phenomenon of surfaces of a neural integration at wide range, tied to a diffuse synchrony: this being an interpretation that could clarify, through a dynamic reconstruction, both the invariant nature of events and the synchronization process of tangible experience [13].

There is no consensus on how we perceive the passage of time. Generally, the most accredited hypothesis which shows that all is not as it seems, is that the perception of time takes place around the following orders of magnitude: below one hundred milliseconds it is possible to distinguish the beginning and the end of an event, its instantaneity; past five seconds the perception of the duration seems to be cut in half by memory [10]. The “moments” of this deceptive present are believed to oscillate between 100 milliseconds and 5 seconds. Other hypotheses indicate that at the foundation of consciousness is a mechanism of temporal unification of neuronal activities that synchronizes impulses in medium oscillations of 40 Hz [14]. These oscillations are not believed to codify additional information, but they are thought to unify part of the existing information in a coherent perception. Our consciousness, therefore, would not be generated by the action of a specific zone of the brain, but by

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the concomitant activation of a series of neurons distributed in the brain. Such oscillations are a necessary but insufficient condition for the production of conscious experience. The phenomena of general neuronal activity as seen by EEG originate in the activation, parallel inhibition and synchronization of multiple neuronal circuits. This is a dynamic balance, in which every event, lasting from 100 to 200 milliseconds, reflects the activation of a distributed and parallel neural network that is translated into the contents of consciousness, such as an abstract thought or a visual image [15]. In certain conditions, there are areas in which neuronal oscillations play a crucial role. In addition, certain states of consciousness (alertness, falling asleep, waking, etc.) and pathologies such as depression, epilepsy, and Parkinson’s disease cause different registrations of thalamic-cortical rhythms [16], whose duration varies with the variation of clinical populations. For example, in paranoid schizophrenics they are shorter, whereas in manic patients the rhythms show continuous changes [17] and so on. It is not implausible to maintain that these neuronal harmonies and discord give way to the emerging phenomena that make subjective experience possible. A thus-constructed model would allow us to do without metaphysical entities such as the central theatre of Baars (1997) [18], the homunculus of Dennett (2005) [19] or any other metaphysical entity, letting the I of neuronal organization emerge and, therefore, the subjectivity of the physical brain. Careful reflection on the concept of temporality encourages the reconsideration of some aspects of consciousness that seem obvious. The first aspect to be reconsidered is the unity of conscious experience, which disappears as soon as it is considered on the basis of time scales of milliseconds [20]; the second is immediacy, a phenomenon sometimes too quickly attributed to consciousness. We have already seen previously how continuous visual information is connected to different processes that require certain intervals of time. Furthermore, the milliseconds relating to the duration of these processes are irrelevant [21] and no piece of information can reach consciousness until at least half a second has passed after its arrival in the cerebral cortex.

In reality, experimental research has not yet advanced convincing solutions for the problem of the experience of time. This is perhaps because this disconcerting enigma is different from the one relating to the cerebral areas and structures that are at the origin of phenomena and experiences, which can be studied today through brain imaging methods [22]. As the origin and structure of consciousness, temporality joins together the different levels of neurophysiological and phenomenological reflection. An efficient research method is composed of cerebral activation studies (PET, fMRI, MEG, event-related potentials) which allow for the exploration of the central nervous system before and after an adequate stimulus: the presentation of ambiguous visual stimuli, the transition from general anaesthesia to reawakening, the passage from a vegetative state to a minimally conscious one and still others. For example, the rekindling of the activity of the re-entering thalamic-cortical circuits, in a patient who was first “vegetative” and then “minimally conscious”, shows the importance of the role of the connections between the intralaminar nuclei of the thalamus and the frontal and parietal associative cortices in the maintaining of consciousness. Here, a fundamental task is performed by the Ascending Reticular Activating System (ARAS) – a system composed of the reticular formation, the thalamus and the thalamic-cortical projection system – which presides over the diffuse activation of the cerebral cortex in states of wakefulness and alertness, states necessary for the formulation of the contents of consciousness [23]. This is a distributed system, not circumscribable to the reticular nuclei of the encephalic trunk [24] that projects itself in a descending direction towards
the spinal cord and, in an ascending direction, towards the cerebral hemispheres. Each one of its constituent nuclei has particular anatomic, physiological and biochemical characteristics: those that modulate the functioning of the cortex reside in the upper two thirds of the pontine tegmentum, others in the lower third of the pons and in the bulb – that is why, in stroke patients, isolated lesions of the pons can cause a coma even in the absence of mesencephalic damages [25]. It is not without significance, moreover, that some nuclei of the cerebral trunk surpass the thalamus in order to connect directly with the frontal-basal cortex, from which the bilateral projections diffused to the cerebral cortex originate; or that other nuclei go beyond both the thalamus and the frontal-basal cortex to reach wide areas of the cerebral cortex; or that, finally, other nuclei are connected with the reticular nucleus of the thalamus and not with the intralaminar nuclei.

This unique system of neuronal mapping lets us consider the functions of the ARAS as being much more wide-ranging and complex than those linked to the simple “desynchronization” of the cerebral cortex [26], also essential to the state of wakefulness and attention. Then there are the non-specific thalamic-cortical projections, such as the activation of the thalamic-cortical circuit at a high oscillatory frequency, projections fundamental to the essential functions of consciousness. Studies on cerebral activation [27] have demonstrated that, in patients in a vegetative state (a state of wakefulness without content), the connectivity between cerebral areas that are normally connected is lost: in particular, between the primary cortical areas and the associative multimodal ones (the prefrontal, premotor, and parietal-temporal areas, the cortex of the posterior and precuneous gyrus cingulate) or between these cortical areas and the thalamus. This leads one to wonder whether the exclusive role of ARAS in determining consciousness should not be reconsidered, rethinking consciousness as the effect of the interaction of an enormous variety of qualia and of distinct perceptions implied in the distributed and dynamic activity of the thalamic-cortical nucleus.

References